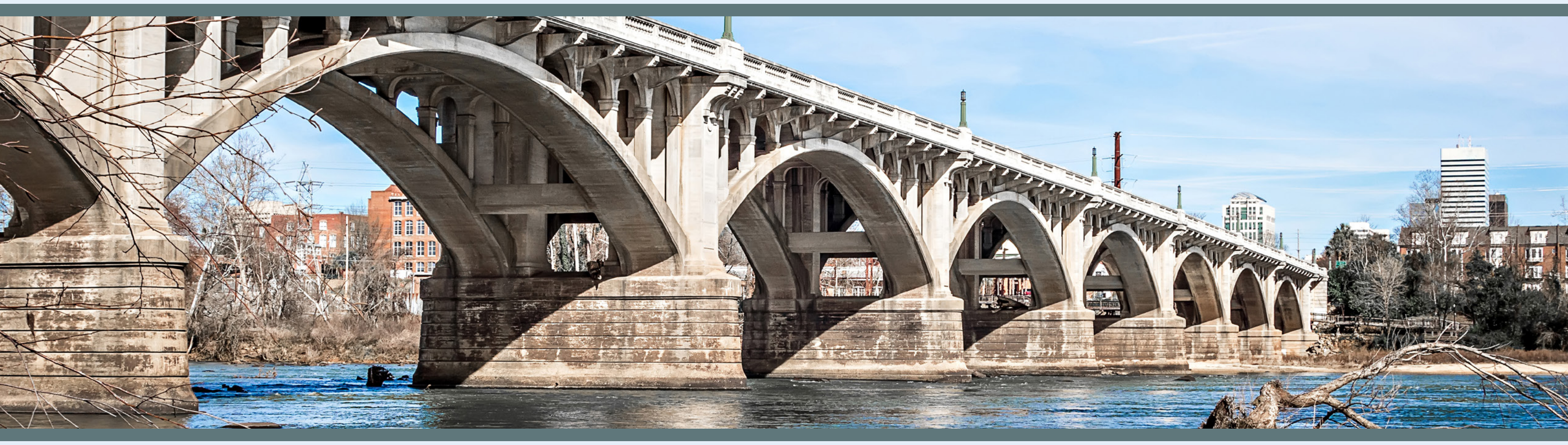
Bridge Design Manual

June 2006



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Welcome To The SCDOT Bridge Design Manual

SCDOT

Chapter 1

BRIDGE DESIGN SECTION ORGANIZATION

SCDOT BRIDGE DESIGN MANUAL

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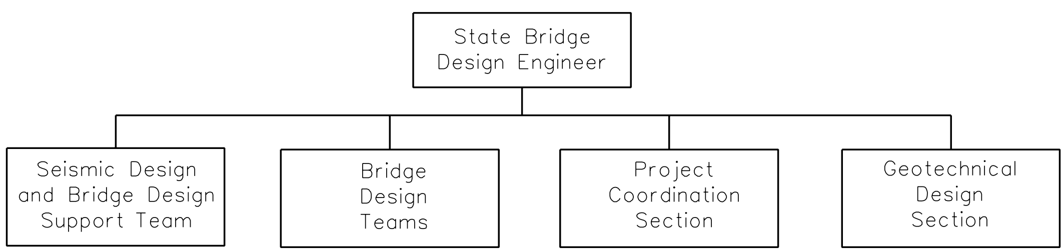
CHAPTER 1

BRIDGE DESIGN SECTION ORGANIZATION

This Chapter presents the organization of the Bridge Design Section and discusses the responsibilities of the functional units within the Section.

1.1 BRIDGE DESIGN SECTION

In general, as part of the Preconstruction Division, the Bridge Design Section is responsible for the design and project coordination for new bridges, bridge widenings and, occasionally, bridge rehabilitation projects. Figure 1.1-1 illustrates the functional organization of the Bridge Design Section. The following discusses the responsibilities of each functional unit within the Bridge Design Section.



SCDOT BRIDGE DESIGN SECTION

Figure 1.1-1

1.1.1 <u>State Bridge Design Engineer</u>

The State Bridge Design Engineer is responsible for the overall engineering, administrative, and management activities of the Bridge Design Section. The State Bridge Design Engineer establishes overall Department structural policies and determines the Section's coordination with units outside of the Bridge Design Section. The functional responsibilities of the State Bridge Design Engineer are to:

- lead the administrative and management activities for the Bridge Design Section (e.g., develop budgets, manpower management, schedule meetings);
- develop work programs for bridge projects for inclusion in the Department's annual and 5-year program of projects;

- participate in professional organizations related to bridge design (AASHTO, TRB, AWS, etc.) to represent the Department's interests and concerns;
- oversee the development of:
  + new and revised sheets for structural designs in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website;
  + revisions to the *SCDOT Bridge Design Manual*;
  + structural specifications (in a participation role) for the *SCDOT Standard Specifications for Highway Construction*; and
  + the structural design criteria used by the Bridge Design Section;
- determine the Bridge Design Section's appropriate participation in public hearings and public informational meetings for projects where the Bridge Design Section is the lead unit;
- remain abreast of the key issues on individual bridge projects;
- determine the Bridge Design Section's course of action for any special studies, reports, etc., upon request from the State Highway Engineer, FHWA, etc;
- serve as the Section's focal point for coordination with FHWA, other SCDOT units, etc.;
- provide final approval to all structural plans;
- ensure that work is implemented according to the Bridge Design Section's policies and that it complies with the appropriate design standards and criteria; and
- ensure that the project design and construction plans are completed on schedule.

1.1.2 Seismic Design and Bridge Design Support Team

The Seismic Design and Bridge Design Support Team is responsible for seismic training and for maintaining the *SCDOT Seismic Design Specifications for Highway Bridges* and its compliance and updates. The Seismic Design and Bridge Design Support Team supports the Bridge Design Teams with any seismic-related issues from the preliminary stages of the bridge projects until the structural design is complete. The Seismic Design and Bridge Design Support Team also works closely with the Geotechnical Design Section to ensure consistency between the structural and geotechnical seismic-related elements of the design.

The Seismic Design and Bridge Design Support Team is responsible for the following:

- reviews preliminary and 95% bridge plans and provides comments to ensure compliance with the Department's seismic requirements;

- monitors the latest developments in seismic design of bridges by active participation in committees and workshops;
- overviews seismic research projects (e.g., the SCDOT Seismic Hazard Maps);
- works with FHWA in special studies (e.g., Lifelines) and related transportation networks and the Forensic Engineering Implementation Response Plan; and
- provides support to the Bridge Construction Office and the Office of Materials and Research.

1.1.3 Bridge Design Teams

The Bridge Design Teams are the Bridge Design Section's focal point for the preparation of all in-house structural designs. The Bridge Design Teams have the day-to-day responsibility to develop structural plans from project inception to letting.

The Bridge Design Teams perform the designs, conduct structural analyses of the proposed structures, prepare the bridge plans, and compute bid quantities for bridge projects. The Teams are responsible for reviewing and checking the plans for completeness and accuracy.

The specific functional responsibilities of the Bridge Design Teams are to prepare in-house structural designs for all types of highway bridges, including:

- the determination of applicable loads to the bridge;
- the design of flat slabs (structural analysis, reinforcement, etc.);
- the design of prestressed concrete superstructures (structural analysis, flexural strength, shear, bearings, etc.);
- the design of structural steel superstructures (structural analysis, splices, diaphragms, fasteners, girder design, etc.);
- the design of substructures and foundations (bents, piles, footings, drilled shafts, etc.);
- the design of all structural elements to meet the Department's seismic performance criteria;
- coordinating with the Road Design Section to develop the geometric design of the structure (bridge widths, vertical clearances, etc.);
- the design of bridge appurtenances (bridge rails, sidewalks, fencing, etc.);
- the rehabilitation of existing bridges;
- attending field reviews;

- attending project meetings;
- meeting the project schedule and man-hour estimates;
- assisting in the preparation of the contract documents for structural items, including construction plans, Special Provisions, construction quantities, and engineering cost estimates;
- remaining abreast of state-of-the-art-technology in bridge design through review of AASHTO, TRB, FHWA, etc., publications, and investigating the use of new bridge design techniques;
- as directed by the State Bridge Design Engineer, investigating and implementing revisions to the:
  + *SCDOT Bridge Design Manual*, and
  + *SCDOT Bridge Drawings and Details*, available at the SCDOT website;
- providing technical support for structural designs for bridge projects on non-State facilities that are funded by State and/or Federal dollars;
- serving as a technical resource in structural designs for county and city government bridge projects;
- in coordination with the Construction Division, reviewing and approving construction shop plans, shop drawings, working drawings, and working plans;
- in coordination with the Construction Division, reviewing Value Engineering proposals from Contractors; and
- reviewing and commenting on construction change orders when requested by the Construction Division.

The Bridge Design Section staff that develops cost estimates is responsible for the following for in-house projects:

- developing Supplemental Specifications and Special Provisions;
- working with the Construction Division on revisions and updates to the *SCDOT Standard Specifications for Highway Construction*;
- monitoring unit bid prices for construction;
- preparing the Engineer's Estimate for structural design projects;
- performing a cost analysis for each bridge construction contract; and
- reviewing the Construction Cost Estimates.

1.1.4 Project Coordination Section

The Project Coordination Section is responsible for all projects funded through the FHWA Highway Bridge Program (HBP) for which the Bridge Design Section is the lead unit. This applies to HBP projects that are either designed in-house or with a design consultant. The basic responsibility of the Project Coordination Section is to handle the management and administration of HBP projects to ensure that these projects are developed on schedule and within budget and that project development meets all SCDOT requirements and complies with all applicable laws, regulations, policies, etc. More specifically, the Project Coordination Section is responsible for:

- coordinating with other units (internal and external to SCDOT) for all activities necessary for project design (e.g., environmental evaluation, right-of-way, hydraulics, permits, roadway design);
- initiating the consultant selection process;
- preparing man-hour and cost estimates for in-house and Consultant designs; and
- managing and administering HBP projects designed by a Consultant.

1.1.5 Geotechnical Design Section

The Geotechnical Design Section is responsible for all geotechnical requirements of the Department for both roadway and bridge projects. For bridge projects, the Section's responsibilities include:

- developing a soil exploration plan;
- preparing the Preliminary Geotechnical Report (PGR) to assist in the selection of a bridge foundation type and to perform a preliminary seismic analysis/evaluation;
- identifying the proposed boring locations and anticipated foundation type;
- requesting the field exploration to gather the geotechnical data;
- preparing the Bridge Geotechnical Report (BGR) (based on the geotechnical subsurface exploration data, preliminary bridge plans, and loads computed by the Bridge Design Team), which provides the necessary geotechnical parameters for the Bridge Design Teams to perform the detailed foundation design;
- assisting the Construction Division by preparing pile driving criteria;
- assisting the Construction Division in reviewing pile and drill shaft installation plans;
- assisting the Construction Division and bridge designer in determining acceptance of as-built drilled shafts and piles; and

- assisting the Construction Division and bridge designer in determining drilled shaft and pile production lengths based on field load tests.

For roadway projects, the Geotechnical Design Section's responsibilities include:

- performing site surveys as needed in the project area;
- requesting field investigations (i.e., in-situ field tests, gathering samples for laboratory analysis);
- identifying geotechnical properties and parameters for embankment design;
- recommending subgrade treatments for pavement section support;
- gathering geotechnical data to determine the stability of fill and cut earth slopes and of rock cuts;
- recommending slope stabilization methods;
- conducting external stability analyses for retaining walls; and
- working with the Construction Division to address geotechnical issues that arise during construction.

Chapter 2

BRIDGE REPLACEMENT PROJECT DEVELOPMENT PROCESS

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CHAPTER 2

BRIDGE REPLACEMENT PROJECT DEVELOPMENT PROCESS

This Chapter outlines the basic approach used by SCDOT in its project development process for bridge replacement projects. The Chapter presents the process graphically to illustrate the development of a typical bridge design project, and it identifies the significant tasks necessary to develop a set of bridge construction plans.

2.1 GENERAL

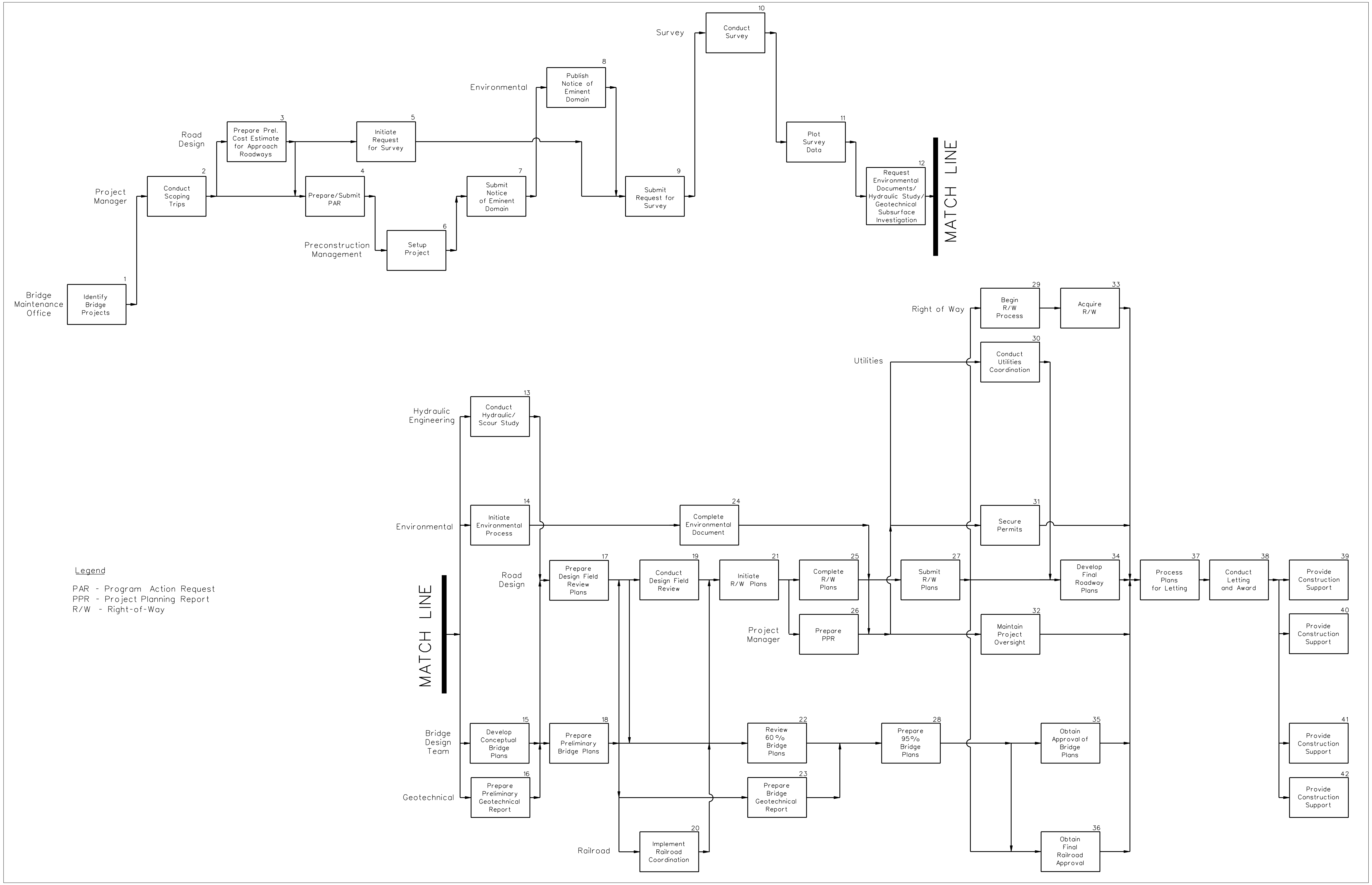
Figure 2.1-1 presents a network or flowchart that graphically illustrates the general project development process. Following the Figure is a brief description of each task within the network. When using this network, consider the following:

1. Precedence Task Network. The network (or flowchart) is a precedence task network. A "task" occurs when a significant, discrete event occurs or when the responsibility for the project (task) is transferred from one Unit to another. The "precedence" nature of the network implies that a new task cannot occur until all tasks preceding this new task have been completed. However, the user must be aware that some flexibility is necessary to apply this network to project development.

2. Project Application. Figure 2.1-1 represents an approximate process for a typical bridge design project. Not every activity will be applicable to every project (i.e., some activities will represent "zero" time on relatively minor projects). The network illustrates a project that is designed in-house. The process for a Consultant-designed project will be similar, except that communication lines will also exist between SCDOT and the Consultant for SCDOT review. For additional guidance on Consultant project procedures, see Section 5.3.

3. Lines of Communication. Each project is different, and changes or modifications to the network can be made to accommodate each project on a case-by-case basis. Communication between Units must be continuous.

4. Other *Manual* Chapters. The *SCDOT Bridge Design Manual* contains several other Chapters that provide complementary information to Chapter 2. In particular, Chapter 2 should be used in conjunction with Chapter 3 "Procedures for Plan Preparation," Chapter 4 "Coordination of Bridge Replacement Projects," and Chapter 5 "Administrative Policies and Procedures."



BRIDGE REPLACEMENT PROJECT DEVELOPMENT NETWORK

Figure 2.1-1

PROJECT TASK

Task Title: Identify Bridge Projects

Task No.: 1

Responsible Unit: Bridge Maintenance Office

Task Description:

The Bridge Maintenance Office develops and forwards the Programming List to the Bridge Design Section, based on a Statewide assessment of highway improvement needs and available funds. Once the bridge projects are selected, the Project Managers prepare for a Scoping Trip (see Task 2).

PROJECT TASK

Task Title: Conduct Scoping Trips

Task No.: 2

Responsible Unit: Project Manager

Task Description:

After each Project Manager receives the Programming List from the Bridge Maintenance Office and the proposed bridge projects for the fiscal year are chosen (Task 1), Scoping Trips are conducted. The Scoping Trips are arranged by the Project Manager and are based on geographic area. The purpose of the Scoping Trip is to identify site characteristics, design features, project-related issues, and any potential problems or conflicts.

To prepare for the Scoping Trip, the Project Manager accumulates and reviews all available information. As appropriate, the information may include, but is not limited to:

- planning reports or studies;
- existing plans;
- history of structure (e.g., maintenance, repair, NBI data, flooding);
- crash data;
- traffic data;
- original surveys;
- aerial photos;
- route management data (condition of other bridges along the route); and
- conditions of roads and bridges for potential detour routes.

Depending on the project, representatives from the following Units may be included in the Scoping Trip:

- Bridge Design Section;
- Road Design Section;
- Hydraulic Engineering Section;
- Geotechnical Design Section;
- District Construction Engineer;
- District Maintenance Engineer,
- FHWA, where applicable; and
- others, as applicable (e.g., Environmental Management Office, Right of Way Office, Utilities Office).

PROJECT TASK

Task Title: Prepare Preliminary Cost Estimate for Approach Roadways

Task No.: 3

Responsible Unit: Road Design Section

Task Description:

At the completion of Task 3, the Bridge Project Facilitator within the Road Design Section is responsible for providing the Bridge Design Section with the following:

- an approximate length of the approach roadways, and
- a preliminary cost estimate for the approach roadways.

If warranted, any possible alternatives to the proposed project design should be presented at this stage of project development.

PROJECT TASK

Task Title: Prepare/Submit Program Action Request (PAR)

Task No.: 4

Responsible Unit: Project Manager

Task Description:

Once the Preliminary Design Group completes the preliminary cost estimate and approximate length for the approach roadways (Task 3), the Project Manager will prepare and submit a Program Action Request (PAR). The PAR serves as a request for project approval for the candidate bridge project. Detailed project information (e.g., date of request, road and route number, county name, city/town name, project length, project location) should be included in the PAR. For a detailed description on the PAR and its contents, see Section 5.5.

Once the PAR is completed, the Project Manager forwards it to the Director of Preconstruction for approval. The Director of Preconstruction reviews and signs (authorizes) the PAR.

If the project involves Federal-aid, the Federal-aid Unit is responsible for forwarding the PAR to FHWA for approval.

After the approval process is completed, the Federal-aid Unit will setup the project (see Task 6).

PROJECT TASK

Task Title: Initiate Request for Survey

Task No.: 5

Responsible Unit: Road Design Section

Task Description:

When the existing alignment is used, the Road Design Bridge Project Facilitator "red-lines" the existing plans according to the proposed project's needs. The Bridge Project Facilitator will use any applicable information obtained from the Scoping Trip (Task 2) in preparing the survey request.

When the existing alignment is not used, the Preliminary Design Group within the Road Design Section is responsible for determining the new alignment. If necessary, the Bridge Design Section will provide a minimum offset dimension. The Preliminary Design Group will provide the new alignment to the Bridge Project Facilitator. The Facilitator will use the alignment information to prepare the survey request.

The Project Manager will coordinate with the Road Design Section and determine the type of necessary survey information (see Task 10). The survey information may include, but is not limited to:

- a "red-lined" survey;
- existing field conditions (e.g., topography, vegetation, existing structure features, existing road features, delineated wetlands);
- drainage features (e.g., bodies of water, open channels, channel slopes, channel cross sections, existing drainage appurtenances);
- for highway bridges over railroads, profile and cross sections through the tracks, appropriate ties to railroad stationing (nearest railroad mile marker), the number of tracks, and existing off-track equipment roads;
- existing landmarks;
- existing above and below ground utilities;
- existing right-of-way markers and property lines; and
- alignment and cross section of any existing intersecting roads and driveways near the bridge.

The Road Design Bridge Project Facilitator will provide the survey request to the Project Manager.

For additional information on survey requests, see Section 5.5.

PROJECT TASK

Task Title: Setup Project

Task No.: 6

Responsible Unit: Preconstruction Management Section

Task Description:

After receiving approval from the Director of Preconstruction for the PAR (Task 4), the Project Manager should ensure that the Preconstruction Management Section has the appropriate project information to setup the project in the Department's Preconstruction Project Management System (PPMS). During project setup, the Preconstruction Management Section will verify that the project is in the Department's State Transportation Improvement Program (STIP) and setup the following project identifiers:

- project identification number (PIN),
- funding program, and
- file number.

Based on a Statewide assessment of highway improvement needs and available funds, the Preconstruction Management Section will determine the appropriate funding category for the project. This may be Federal funds and/or State funds. If Federal funds are used, the Federal-aid Unit will request FHWA approval for the project (Task 4).

Once funding for preliminary engineering has been approved, this establishes the proposed project as an active project for further development.

PROJECT TASK

Task Title: Submit Notice of Eminent Domain

Task No.: 7

Responsible Unit: Project Manager

Task Description:

The Project Manager is responsible for preparing a Notice of Eminent Domain, which includes a description of the project, and forwarding it to the Environmental Management Office. The Environmental Management Office is responsible for publishing the Notice (see Task 8) in the appropriate local newspaper for the proposed bridge project. The Notice informs the public of the proposed project prior to the entry of real property of any affected property owners and/or any future temporary traffic control (e.g., possible detours, closed roads).

PROJECT TASK

Task Title: Publish Notice of Eminent Domain

Task No.: 8

Responsible Unit: Environmental Management Office

Task Description:

The Environmental Management Office is responsible for publishing the Notice of Eminent Domain by letter and transmitting a copy of the advertisement to the local newspapers or other public notice media. Once the Notice is published, the Environmental Management Office will notify the Project Manager. See Section 5.5 for a description of a Notice of Eminent Domain. See Section 5.2 for information on public notification of bridge replacement projects.

The Notice of Eminent Domain must be published before the Request for Survey's submittal (see Task 9).

PROJECT TASK

Task Title: Submit Request for Survey

Task No.: 9

Responsible Unit: Project Manager

Task Description:

When the Project Manager receives notification from the Environmental Management Office that the Notice of Eminent Domain has been published (Task 8), the Project Manager will submit the Request for Survey (Task 5) to the Surveys Office.

PROJECT TASK

Task Title: Conduct Survey

Task No.: 10

Responsible Unit: Surveys Office

Task Description:

The work associated with the survey begins when the Surveys Office receives the Request for Survey (Task 9). The Surveys Office conducts the survey and prepares the survey data for existing field conditions, drainage systems, utility lines, and right-of-way.

The Surveys Office converts the survey information into CADD format and places it on the Department's network for use by the Bridge and Road Design Sections. The following describes some of the information provided by a field survey:

1. Existing Field Conditions. The Survey Crew records any topographic feature that will influence or be influenced by the project design. This would include existing structures, barriers, highway facilities, vegetation, wetlands, and concrete work.

2. Drainage Systems. The drainage considerations include any bodies of water, open channels, or pipe systems.

3. Utilities. The utility information consists of the location and ownership of all railroads, power lines, substations, pipelines, etc., above and below ground.

4. Right-of-Way. The Survey Crew researches and documents ownership of property, existing right-of-way, property boundaries, property ownership, and entrances to property.

As the project design evolves, additional surveys may be required.

PROJECT TASK

Task Title: Plot Survey Data

Task No.: 11

Responsible Unit: Road Design Section

Task Description:

The Road Design Section will prepare the plan, profile, and cross-section sheets based on the survey information (Task 10). As appropriate for the project, the plan sheets include:

- all topographical data from the survey;
- all relevant existing on-the-ground survey information;
- plan views of underground utilities;
- crossing elevations of underground utilities (profile view);
- existing elevations at the centerline of the roadway; and
- new horizontal alignment of roadway.

PROJECT TASK

Task Title: Request Environmental Documents/Hydraulic Study/Geotechnical Subsurface Investigation

Task No.: 12

Responsible Unit: Project Manager

Task Description:

Based on the information gathered from the Scoping Trip (Task 2), the Project Manager initiates the Hydraulic/Scour Study (see Task 13), the Environmental Process (see Task 14), and the Geotechnical Subsurface Investigation (see Task 16) by submitting a request to the Hydraulic Engineering Section, the Environmental Management Office, and the Geotechnical Design Section, respectively.

PROJECT TASK

Task Title: Conduct Hydraulic/Scour Study

Task No.: 13

Responsible Unit: Hydraulic Engineering Section

Task Description:

This Task is concerned with 1) the disposal of water collecting on the approach roadways or adjacent areas, and 2) drainage flowing across the right-of-way.

The Hydraulic Engineering Section will research the area's hydrology, assemble the hydrologic data, and perform a hydraulic/scour study for the proposed bridge. The study determines the following information:

- water surface elevations at various flood frequencies;
- the required size of the waterway opening to accommodate the design flood and to satisfy the backwater allowances;
- debris impacts;
- impacts on floodplains based on FEMA regulations;
- hydraulic scour (e.g., contraction scour, local scour) to assist in determining the proper foundation design; and
- any permanent erosion protection recommendations for the embankments beneath the bridge.

The hydraulic designer documents the findings in a Hydraulic Report/Scour Report and forwards the Report to the Bridge and Road Design Sections. For more information on the Report, see Section 5.5.

PROJECT TASK

Task Title: Initiate Environmental Process

Task No.: 14

Responsible Unit: Environmental Management Office

Task Description:

The Project Manager initiates the environmental process by submitting an Initial Studies Request to the Environmental Management Office (Task 12). The Environmental Management Office performs the preliminary work to evaluate the environmental impacts of the proposed project.

The following are the three possible types of environmental action:

- Categorical Exclusion (CE),
- Environmental Assessment (EA), and
- Environmental Impact Statement (EIS).

The level of action necessary is based on how (and to what extent) a project will impact the social, economic, and environmental aspects of a region; the location of the proposed project; and how the proposed project will change the layout or function of connecting roads or streets. For further information on environmental procedures, see Chapter 27 of the *SCDOT Highway Design Manual*.

At this stage, the Environmental Management Office begins the following activities:

- evaluating the data in the Initial Studies Request and determining any project impacts;
- determining the type of environmental action required for the project;
- notifying the appropriate SCDOT Sections/Offices of the type of environmental action for the project;
- coordinating with appropriate agencies;
- preparing the draft environmental document; and
- in coordination with the Project Manager, arranging and conducting a public information meeting and/or a public hearing, if necessary.

PROJECT TASK

Task Title: Develop Conceptual Bridge Plans

Task No.: 15

Responsible Unit: Bridge Design Section

Task Description:

The basic objective of the Conceptual Bridge Plans is to determine what appears to be the most appropriate superstructure, substructure, and foundation type and configuration for the given or anticipated site conditions. See Section 3.2 for more information. The Conceptual Bridge Plans are based on the evaluation of many factors, including site conditions and bridge geometry, hydraulic analysis and scour, structural loads, anticipated foundation conditions, seismic loading, environmental and right-of-way impacts, aesthetics, and construction costs. See Chapter 12 for a discussion on structure type selection and dimensions.

The Bridge Design Section will prepare the general layout of the bridge, which will present the following:

- a plan and profile of the bridge showing the proposed type of superstructure, substructure, and foundation;
- bridge end elevations;
- location of expansion and fixed bearings;
- channel profiles and interior bent locations;
- design loads, specifications, and other structural criteria; and
- minimum horizontal and vertical clearances.

PROJECT TASK

Task Title: Prepare Preliminary Geotechnical Report

Task No.: 16

Responsible Unit: Geotechnical Design Section

Task Description:

Based on the Scoping Trip (Task 2) and Survey Information (Task 10), the Geotechnical Design Section will conduct a preliminary field review of the bridge site to investigate its geotechnical characteristics. The nature and depth of the investigation will be determined on a project-by-project basis. A copy of any reports or memoranda summarizing the findings of this investigation (i.e., Preliminary Geotechnical Report) should be sent to the Bridge Design Section (see Task 23). The Preliminary Geotechnical Report may include:

- a summary of field reconnaissance of the surface indications of subsurface properties (e.g., surface soils, rock exposures, stream-deposited soils, gullies, stream banks, water surface flows, existing structures in the area, topography, vegetation);
- the initial evaluation of a boring plan and the physical characteristics of the site for the setting up of its drill rigs for the boring logs;
- a description of the necessary in-situ field testing and the necessary boring samples for laboratory testing;
- an evaluation of the embankment stability;
- for proposed cuts, a determination of the slope stability characteristics and the need for any special treatments (e.g., benching);
- an evaluation of any erosion potential within the project limits;
- anticipated foundation types and estimated fixity depths; and
- a geotechnical seismic report.

PROJECT TASK

Task Title: Prepare Design Field Review Plans

Task No.: 17

Responsible Unit: Road Design Section

Task Description:

After receiving the survey information (Task 10) and the proposed bridge length and minimum finished grade elevation (Task 13), the Road Design Section will perform the following:

- plot the existing topography and determine the plan sheet layout;
- prepare the preliminary Typical Section Sheets;
- when applicable, submit the pavement design request to the Pavement Design Engineer in the Office of Materials and Research;
- provide the Bridge Design Section with the proposed grades; and
- continue to gather and assemble project data.

The Project Manager will review the project for inclusion of bicycle and pedestrian accommodations.

Note: For grade separation projects, the Bridge Design Section will provide the proposed bridge length and minimum finished grade elevations.

PROJECT TASK

Task Title: Prepare Preliminary Bridge Plans

Task No.: 18

Responsible Unit: Bridge Design Section

Task Description:

Once the Road Design Section determines the roadway alignment (Task 17) and the Conceptual Bridge Plans are completed (Task 15), the Bridge Design Section can begin preparing the Preliminary Bridge Plans. When these plans are prepared, the project is considered 20% completed, and they are used to develop the detailed bridge plans. Preliminary Bridge Plans will present the following:

- plan and profile of the bridge showing the proposed type of superstructure, substructure, foundation, bridge end elevations, location of expansion and fixed bearings, and roadway approaches;
- superstructure cross section showing pertinent structural details (e.g., number of beams, depth and width of bridge deck);
- bridge barrier or sidewalks and bridge railing;
- design loadings, material strengths, specifications, and other structural criteria;
- minimum horizontal and vertical clearances;
- hydraulic data, high-water and low-water elevations, etc.; and
- Title Sheet.

For additional information on the contents of Preliminary Bridge Plans, see Chapter 3.

The Bridge Design Section forwards this information to the Construction Division for review and to the Road Design Section for incorporation into the Right-of-Way Plans (see Task 21).

Also, at this stage, the Bridge Design Team will conduct the following:

- for projects over railroads, include railroad cross sections from the Road Design Section;
- begin coordinating any construction staging phases with the Traffic Engineering Division as the project requires;
- initiate the involvement of the Seismic Design and Bridge Design Support Team; and
- request that borings be obtained from the Geotechnical Design Section (see Task 23).

PROJECT TASK

Task Title: Conduct Design Field Review

Task No.: 19

Responsible Unit: Road Design Section

Task Description:

Once the Design Field Review Plans are completed (Task 17), the Road Design Section, with input from the Project Manager, selects the personnel involved in the field review based on the characteristics of the project, funding, and location. Participants in the field review include the Project Manager and may include representatives from:

- Bridge Design Section,
- Geotechnical Design Section;
- Traffic Engineering Division,
- Preliminary Design Group,
- Environmental Management Office,
- Right of Way Office,
- Hydraulic Engineering Section,
- Surveys/Utilities Office,
- District Office,
- Construction Division, and/or
- FHWA.

The Design Field Review is an evaluation of the design in terms of traffic patterns, drainage conditions, right-of-way, utilities, and topography. At this point in the project development, the completeness of the plans is evaluated, and any known design features that must be adjusted are identified.

In addition, the Road Design Section, with input from the Project Manager, will decide whether or not to require right-of-way or slope permission from the construction limits. When establishing these limits, a method of construction access shall be determined and, if applicable, Special Provisions for the access shall be included in the permit application.

The Road Design Section will incorporate revisions to the Design Field Review Plans based on the results of the review, and the Bridge Design Section will incorporate revisions to the Preliminary Bridge Plans.

The Road Design Section will complete and provide copies of the revised Design Field Review Plans to the Project Manager and to the Hydraulic Engineering Section. The Hydraulic Engineering Section will use the revised plans to prepare the roadway hydrology and erosion control design.

PROJECT TASK

Task Title: Implement Railroad Coordination

Task No.: 20

Responsible Unit: Utilities Office

Task Description:

Railroad facilities impacted by the project are identified during the early stages of project development and are shown in the Design Field Review Plans. The Utilities Office will submit a letter and the plans to the affected railroads. The complexity of work required will depend on the location of the proposed project on or adjacent to railroad right-of-way.

After receiving the preliminary plans, the Utilities Office coordinates with the railroad companies to prepare any necessary agreements for the proposed work. For information on Agreements, see Section 5.1.

The Utilities Office will also work with the railroad companies to resolve any issues during the railroad approval process.

The Utilities Office assists in the preparation of any Special Provisions that will be included in the final contract. The Special Provisions should list all of the involved railroad companies, unusual construction methods, and any critical information or special considerations for the Contractor. These are forwarded to the Road Design Section for incorporation into the Final Roadway Plans (see Task 34).

Early coordination with the railroad company is essential to accommodate the railroad approval process.

For further information on railroad coordination, see Chapter 6 of the *SCDOT Highway Design Manual* and Chapter 22 of the *SCDOT Bridge Design Manual*.

PROJECT TASK

Task Title: Initiate Right-of-Way Plans

Task No.: 21

Responsible Unit: Road Design Section

Task Description:

Based on the results of the Design Field Review (Task 19) and any revisions to the preliminary road and bridge design, the Road Design Section will begin the preparation of the Right-of-Way Plans. The Road Design Section will incorporate the hydrologic and erosion control plans and address roadside safety issues. See the *SCDOT Highway Design Manual* for additional information.

PROJECT TASK

Task Title: Review 60% Bridge Plans

Task No.: 22

Responsible Unit: Bridge Design Section

Task Description:

This stage of project development is a review of the bridge plans and other necessary design documents to:

- verify alignment and grade information from the Road Design Section,
- review the proposed structure,
- discuss the foundation,
- compile a list of information to be provided to or required from other Units, and/or
- address any other special features.

See Section 3.4 for further information.

PROJECT TASK

Task Title: Prepare Bridge Geotechnical Report

Task No.: 23

Responsible Unit: Geotechnical Design Section

Task Description:

Based on the final geotechnical field investigation and the analysis of the boring logs, the Geotechnical Design Section will document its findings and recommendations to the Bridge Design Section in the Bridge Geotechnical Report. The Report will present:

- the native soil and rock types;
- bearing capacities;
- discussions on the recommended foundation type;
- for the selected foundation type, pertinent loading information, allowable bearing capacity for spread footings, depth and diameter of piles/drilled shafts, estimated pile/shaft tip elevations, minimum pile/shaft tip elevations to maintain lateral stability;
- geotechnical-related specifications; and
- construction-related notes.

The Bridge Geotechnical Report will also transmit the necessary boring log information to allow the bridge designer to directly incorporate the information onto the Boring Log Sheet.

PROJECT TASK

Task Title: Complete Environmental Document

Task No.: 24

Responsible Unit: Environmental Management Office

Task Description:

At this stage of project development, the Environmental Management Office should conduct the following activities:

- submit a copy of the Project Planning Report to the State Energy Office and FHWA, as appropriate;
- distribute the draft environmental document for review and comment;
- submit the draft environmental document for approval;
- revise the final environmental document, as necessary; and/or
- submit and obtain approval for the final environmental document.

Based on the characteristics of the project and any public input, the Environmental Management Office will prepare the final environmental document. The possible outcomes of the Task are:

1. Categorical Exclusion (CE). If the project was classified as a CE project, then the environmental process will have been completed at the end of Task 14.
2. Environmental Assessment (EA). If the EA classification leads to the determination that the project will have no significant impact on the environment, the EA document will state this conclusion. As a result, the purpose of this task will be to prepare a Finding of No Significant Impact (FONSI).
3. Environmental Impact Statement (EIS). If a Draft EIS was prepared for the project, then the purpose of this Task is to prepare the Final EIS to reflect any comments from the review process and to document the final decision on project alternatives (i.e., the Record of Decision (ROD)).

The Project Manager is responsible for overseeing the incorporation of the necessary features into the road and bridge plans to reflect the mitigation measures described in the environmental document.

PROJECT TASK

Task Title: Complete Right-of-Way Plans

Task No.: 25

Responsible Unit: Road Design Section

Task Description:

The purpose of a complete set of Right-of-Way Plans is to clearly reflect adjustments in the construction limits of the project and to allow the following activities to occur:

- the Traffic Engineering Division will develop traffic control, pavement marking, and signing plans;
- the Right of Way Office will acquire the necessary properties and easements (Tasks 29 and 33), and
- the Utilities Office will begin finalizing relocation plans and agreements with the affected utility and railroad companies (Task 30).

See the *SCDOT Highway Design Manual* for information on the content of the Right-of-Way Plans.

PROJECT TASK

Task Title: Prepare Project Planning Report (PPR)

Task No.: 26

Responsible Unit: Project Manager

Task Description:

At this stage of project development, the Project Manager will prepare and submit the Project Planning Report (PPR). The PPR will document all major design features for the proposed bridge project. Unless opposition is received, the PPR will form the basis for all detailed engineering work required for the project, including road design, structural design, right-of-way design, and utility adjustments. The Project Manager will prepare and distribute the PPR as discussed in Section 5.5. Once the PPR is prepared, the following activities will occur:

- the Utilities Office will begin finalizing relocation plans and agreements with the affected utility companies (Task 30), and
- the Environmental Management Office will secure the necessary environmental permits (Task 31).

PROJECT TASK

Task Title: Submit Right-of-Way Plans

Task No.: 27

Responsible Unit: Road Design Section

Task Description:

Once the Right-of-Way Plans have been completed, the Road Design Section will route them to the Hydraulic Engineer and the Project Manager for approval. Once approval is obtained, the Road Design Engineer signs and seals the Right-of-Way Plans and forwards them to the applicable Department Units (e.g., Right of Way Office, Utilities Office, Environmental Management Office, Traffic Engineering Division).

PROJECT TASK

Task Title: Prepare 95% Bridge Plans

Task No.: 28

Responsible Unit: Bridge Design Section

Task Description:

At this stage of project development, the Bridge Design Section will be able to incorporate the necessary resources into the detailed bridge design to complete the 95% Bridge Plans.

Part II of the *Bridge Design Manual* presents SCDOT criteria, policies, and practices for the detailed structural design. Working from the Preliminary Bridge Plans (Task 18), the bridge designer can now perform the following work as needed for the specific project:

- any necessary structural analyses as discussed in Chapter 14;
- the design of the superstructure for concrete (Chapter 15) or for steel (Chapter 16);
- the design of the bridge deck and its appurtenances (e.g., bridge rails, utilities, fencing) (Chapter 17);
- the bridge deck drainage design (Chapter 18);
- the design of the foundation (Chapter 19) and substructure (Chapter 20);
- the selection and design of joints and bearings (Chapter 21);
- the geometric design to accommodate any railroads passing beneath a highway bridge (Chapter 22); and
- determine bid items and calculate quantities.

In addition, Chapters 3 and 6 provide guidance on the contents of the 95% Bridge Plans and on the procedures and drafting conventions for plan preparation.

PROJECT TASK

Task Title: Begin Right-of-Way Process

Task No.: 29

Responsible Unit: Right of Way Office

Task Description:

After the Right of Way Office receives the sealed Right-of-Way Plans, the Right of Way Office will initiate the right-of-way process. The Right of Way Office conducts the title search and prepares the property appraisal.

The objective of this Task is to perform the background work necessary to prepare for the preparation of acquiring the necessary right-of-way (Task 33).

PROJECT TASK

Task Title: Conduct Utilities Coordination

Task No.: 30

Responsible Unit: Utilities Office

Task Description:

After receiving the Project Planning Report (Task 26), the Utilities Office continues to coordinate with the utility companies. The Utilities Office requests that the utility company perform the following:

- review the Right-of-Way Plans,
- prepare a tentative Utility Agreement, and/or
- prepare relocation sketches.

The content of the Utility Agreement should include the following:

- prior rights information,
- description of relocation work,
- a cost estimate,
- relocation sketches (showing existing and proposed facilities), and
- any Special Provisions that must be addressed.

The utility company prepares the Agreement and/or relocation sketches and forwards them to the Utilities Office, through the Resident Construction Engineer and District Engineering Administrator, for approval. The Utilities Office reviews the Utility Agreement and/or relocation sketches and coordinates any necessary revisions. For projects with Interstate funds or Federal-aid projects over $50 million, Utility Agreements and/or relocation sketches are forwarded to FHWA for its approval.

If the utility work will be completed by an SCDOT Contractor, the Utilities Office will coordinate the preparation of the utility relocation plans and any necessary Special Provisions. These items are forwarded to the Road Design Section for incorporation into the Final Roadway Plans (see Task 34).

For further information on Utility Agreements, see Section 5.1.

PROJECT TASK

Task Title: Secure Permits

Task No.: 31

Responsible Unit: Environmental Management Office

Task Description:

After receiving the Project Planning Report (Task 26), the Environmental Management Office may complete the process of acquiring the necessary environmental permits. Preliminary work for obtaining permits should begin as soon as possible in the project development process due to the long lead times necessary for approval.

Permits are used as a means of controlling activities that impact an area of particular concern. The areas of interest for the Department include wetlands, coastal zones, navigable waterways, and power-generating facilities. Consideration is also given to the impact of proposed improvements on the water quality of streams, rivers, and wetlands. The permit authorizes or confers the right on the permittee to perform the work required within the requirements established by the permit. Types of requirements include monitoring programs, special construction methods, and reclamation standards.

The Environmental Management Office coordinates with the permit-issuing agency to ensure that any problems can be resolved and that all conditions are satisfactory to the permit-issuing agency.

For more information on permits, see Section 27.5 of the *SCDOT Highway Design Manual*.

PROJECT TASK

Task Title: Maintain Project Oversight

Task No.: 32

Responsible Unit: Project Manager

Task Description:

The Project Manager must continuously monitor the project to ensure all Department Sections and Units are proceeding on schedule. This will require the Project Manager to continuously communicate with the applicable Sections/Units to ensure that the:

- Right of Way Office is purchasing the necessary properties or obtaining the necessary easements;
- Utilities Office is working to obtain the necessary Agreements with the utility and railroad companies;
- Environmental Management Office is securing the necessary permits;
- Road Design Section is developing the final roadway plans, specifications, and cost estimates;
- Bridge Design Section is proceeding in a timely manner to complete the final bridge plans, specifications, and cost estimates; and
- other Sections/Units are proceeding in a timely manner to maintain the project schedule, as necessary.

PROJECT TASK

Task Title: Acquire Right-of-Way

Task No.: 33

Responsible Unit: Right of Way Office

Task Description:

The Right of Way Office must complete the right-of-way acquisition and have all Participation Agreements signed and approved before the plans can be processed for letting.

For right-of-way acquisition, the Right of Way Office must have certification formally acknowledging that the Department holds title or that right-of-entry is available to all properties within the project right-of-way and that all property has been vacated.

The Participation Agreements must be signed by the local government and accepted by the Department.

See Section 5.1 for detailed information on Participation Agreements.

PROJECT TASK

Task Title: Develop Final Roadway Plans

Task No.: 34

Responsible Unit: Road Design Section

Task Description:

At this stage in the project development process, the Road Design Section should finalize the plans for the roadway approaches. As applicable to the bridge project, this includes the following:

- generating the detailed cross sections, including any utilities potentially in conflict with the roadway design;
- performing the earthwork calculations to achieve an earthwork balance, where practical;
- presenting the necessary details on the Title Sheet (e.g., project numbers, project length, traffic data, location);
- presenting the necessary details on the Typical Sections (e.g., guardrail, ditch sections);
- presenting the necessary details on the Plan and Profile Sheets (e.g., grade percents, vertical and horizontal curvature data, stationing);
- developing details for special design elements (e.g., ADA requirements, fencing);
- determining bid items and calculating quantities;
- preparing Special Provisions for road design items; and
- incorporating traffic control requirements for the roadway portion of the project.

See Section 37.1 of the *SCDOT Highway Design Manual* for information on the review and approval process for roadway plans.

The Road Design Group will review the following materials and is responsible for identifying and incorporating the necessary information directly into the Construction Plans, including all quantities and plan sheets prepared by others. This Task requires that the plans and specifications from other SCDOT Units be completed and approved and forwarded to the Road Design Section. This includes:

- right-of-way plan revisions and commitments from the Right of Way Office;
- traffic engineering plans, quantities, Special Provisions, and cost estimates from the Traffic Engineering Division;
- where necessary, relocation plans, quantities, Special Provisions, and cost estimates from the Utilities Office; and
- completed roadway structures plans, quantities, Special Provisions, and cost estimates from the Roadway Structures Group.

PROJECT TASK

Task Title: Obtain Approval of Bridge Plans

Task No.: 35

Responsible Unit: Bridge Design Section

Task Description:

After the Bridge Design Section has completed the 95% Bridge Plans, the following activities will occur:

1. Quantities. The Project Manager is responsible for ensuring that all of the applicable quantities are provided to the Cost Estimate Coordinator in the Bridge Design Section. The Cost Estimate Coordinator is responsible for developing the cost estimate.

2. Constructibility Review. The Project Manager is responsible for forwarding a set of bridge plans to the Construction Division for a review of constructibility and for a construction time estimate.

3. Plan Review and Signatures. The following individuals are responsible for reviewing and signing the plans:

   - Bridge Design Team Leader,
   - appropriate Assistant State Bridge Design Engineer,
   - Project Manager,
   - State Geotechnical Design Engineer, and
   - State Bridge Design Engineer.

See Section 9.1 for a description of the bridge plan approval process.

PROJECT TASK

Task Title: Obtain Final Railroad Approval

Task No.: 36

Responsible Unit: Utilities Office

Task Description:

Based on the railroad company's review of the Preliminary Bridge Plans and Right-of-Way Plans, the Utilities Office must provide the Project Manager an Agreement from the railroad company before processing the plans for letting. The Utilities Office is responsible for ensuring that all Railroad Agreements are signed and included in the project file.

PROJECT TASK

Task Title: Process Plans for Letting

Task No.: 37

Responsible Unit: Road Design Section

Task Description:

The Letting Preparation Group in the Road Design Section is responsible for preparing the Bid Package. For additional information on preparing the Bid Package, see Section 9.1.

After the Package is assembled (i.e., plans and bid proposal documents), the Letting Preparation Group forwards the Bid Package to the Engineering Reproduction Services for printing. After the printing has been completed, the bid documents are forwarded to the Engineering Publications Customer Service Center within the Construction Division.

PROJECT TASK

Task Title: Conduct Letting and Award

Task No.: 38

Responsible Unit: Contracts Administration Office

Task Description:

In conducting the letting and award, the Contracts Administration Office is responsible for the following activities:

- advertising,
- conducting bid opening,
- reviewing the bids, and
- awarding the project.

A description of the activities is provided in Section 9.1.

Once the contract has been awarded, and the notice-to-proceed has been issued, the Contractor can begin construction on the project.

PROJECT TASK

Task Title: Provide Construction Support

Task No.: 39

Responsible Unit: Road Design Section

Task Description:

At this stage, the Road Design Section may be requested by the Contractor (through the Construction Division) to clarify the construction plans, offer guidance, etc.

PROJECT TASK

Task Title: Provide Construction Support

Task No.: 40

Responsible Unit: Project Manager

Task Description:

At this stage, the Project Manager may be requested by the Contractor (through the Construction Division) to clarify the construction plans, offer guidance, etc. See Chapter 24 for a discussion on the involvement of the Bridge Design Section in the construction of structural elements.

PROJECT TASK

Task Title: Provide Construction Support

Task No.: 41

Responsible Unit: Bridge Design Section

Task Description:

At this stage, the Bridge Design Section may be requested by the Contractor (through the Construction Division) to clarify the construction plans, offer guidance, review shop plans, etc. See Chapter 24 for a discussion on the involvement of the Bridge Design Section in the construction of structural elements.

PROJECT TASK

Task Title: Provide Construction Support

Task No.: 42

Responsible Unit: Geotechnical Design Section

Task Description:

At this stage, the Geotechnical Design Section may be requested by the Contractor (through the Construction Division) to clarify the construction plans, offer guidance, review foundation installation plans, etc.

Chapter 3

PROCEDURES FOR PLAN PREPARATION

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 3

PROCEDURES FOR PLAN PREPARATION

This Chapter provides an overview of the policies and procedures for the development of SCDOT's bridge plans with respect to content, reviews, and responsibilities. Chapter 2 provides information on the bridge replacement project development process, and Chapter 6 provides information on the preparation of bridge plans.

3.1 DESIGN STAGES

At designated stages of a bridge project, the designer is required to submit a draft set of bridge plans for review by others to ensure that the project is on schedule, the design is appropriate for the location, and the plans have addressed the appropriate design details. For all interim review submittals, label the Title Sheet with the date and type of submittal (i.e., Conceptual, Preliminary, 60%, 95%). Bridge plans are typically submitted for review at the following design stages:

1. Conceptual Bridge Plans. These plans are submitted for projects where permanent retaining structures are proposed at the bridge ends (e.g., MSE walls, permanent sheet pile walls), for bridges over railroads, or when required by the Bridge Project Manager. See Section 3.2 for information on Conceptual Bridge Plans.

2. Preliminary Bridge Plans. For typical bridge projects, the bridge designer receives approval for the design of the bridge at this stage. See Section 3.3 for information on Preliminary Bridge Plans.

3. 60% Bridge Plans. These plans are only submitted when required by the Bridge Project Manager. See Section 3.4 for information on 60% Bridge Plans.

4. 95% Bridge Plans. This stage is reached when the bridge designer has completed the structural design and drafting of all plan sheets that are within the Bridge Design Section's control. The bridge plans are then submitted for review. See Section 3.5 for information on 95% Bridge Plans.

5. Submission of Final Bridge Plans for Letting. At this stage, the bridge plans are completed and all signatures have been obtained. The plans are submitted to the Assistant State Bridge Design Engineer – Specifications for processing. After processing, the Final Bridge Plans are forwarded to the Engineering Reproduction Services for printing. See Section 3.6 for information on the Final Bridge Plans submittal.

6. Construction Phase. Chapter 24 discusses the procedures for plan revisions and construction changes after the bridge plans have been submitted to the Engineering Reproduction Manager.

3.2 CONCEPTUAL BRIDGE PLANS

3.2.1 Purpose

Conceptual Bridge Plans are generally only completed for large or complex bridge projects, for projects where permanent retaining structures are proposed at the bridge ends (e.g., MSE walls, permanent sheet pile walls), and for bridges over railroads. For smaller and less complex structures, no formal set of plans is prepared for this design stage.

The basic objective of the Conceptual Bridge Plans is to determine the most appropriate superstructure, substructure, and foundation type and configuration for the given or anticipated site conditions. The conceptual bridge layout is based on the evaluation of many factors, including geometry, site conditions, hydraulic conditions, structural loads, anticipated foundation conditions, seismic criteria, environmental and right-of-way impacts, aesthetics, and construction costs. See Chapter 12 for a discussion on structure-type selection and dimensions.

3.2.2 Coordination

If the existing roadway alignment is not used, the Preliminary Design Group within the Road Design Section will determine the relocated roadway alignment. The Road Design Group will prepare the Lines and Grades Plan Sheets. The Road Design Section will then forward this information to the Project Manager. The Project Manager then submits this information to the Hydraulic Engineering Section, Environmental Management Office, and Geotechnical Design Section.

As the Hydraulic Engineering Section conducts the Hydraulic/Scour Study, this Section will coordinate with the Project Manager, bridge designer, Geotechnical Design Section, and others as deemed necessary to determine the appropriate superstructure, substructure, and foundation type and configuration.

See Chapter 4 for information on bridge design coordination.

3.2.3 Conceptual Plan Content

The Conceptual Bridge Plans should include the following information:

- Title Sheet;
- plan and profile of the bridge showing the proposed type of superstructure (e.g., prestressed concrete, steel, flat slab) and substructures (e.g., drilled shafts, piles, footings), and existing ground profiles at the bridge site;
- permanent retaining walls and temporary shoring;

- superstructure cross section showing pertinent structural elements (e.g., number and type of beams, width of bridge deck, superstructure depth);
- bridge rails, sidewalks, and/or shoulders;
- horizontal and vertical clearances;
- preliminary geotechnical subsurface information, if available;
- channel section and bent locations; and
- existing high-water elevation, if available.

The Assistant State Bridge Design Engineer will review the Conceptual Bridge Plans before the Project Manager forwards this information to the Road Design Section. These plans are then used to develop the Preliminary Bridge Plans.

3.3 PRELIMINARY BRIDGE PLANS

3.3.1 Purpose

Preliminary Bridge Plans are intended to define the type of proposed structure and general layout. Once the Road Design Section determines the roadway alignment and the conceptual bridge layout is completed, the Bridge Design Section begins the preparation of the Preliminary Bridge Plans. A review of the plans is generally conducted when the detailing of bridge plan sheets is approximately 20% complete. The foundation design is not complete at this stage, but should show the anticipated size and type based on the Preliminary Geotechnical Report.

If a formal set of Conceptual Bridge Plans was prepared, the bridge designer should address all comments received from the review of the Conceptual Bridge Plans. If no formal Conceptual Bridge Plans were submitted, the designer should address all items as described in Section 3.2 in the preparation of the Preliminary Bridge Plans.

3.3.2 Preliminary Plan Sheets Content

At this stage, the bridge designer will begin preparing the plan sheets that ultimately will be part of the Final Bridge Plans. The following lists the sheets and the information that should be included on the sheets for the Preliminary Bridge Plans:

1. Title Sheet. The Title Sheet should be completed as outlined in Section 6.3 except for the following information:

    a. Index of Sheets. Include an Index of Sheets for the plan sheets that are actually included in the Preliminary Bridge Plans.

    b. Signature Blocks. Signatures are not required at this stage of plan development.

2. General Notes. Include the General Notes as shown in Section 6.3.

3. Roadway Typical Section Sheet. The bridge designer should obtain the latest Roadway Typical Section Sheet from the Road Design Section. If the proposed bridge is over a roadway, also include a typical section of the lower roadway.

4. Roadway Plan and Profile Sheet. The bridge designer should obtain the latest Roadway Plan and Profile Sheets from the Road Design Section. If the proposed bridge is over a roadway, also include the Plan and Profile Sheets of the lower roadway at the proposed bridge location.

5. Bridge Plan and Profile Sheet. This Sheet should include all of the information discussed in Section 6.3 that is available at the time of the submission, including all applicable horizontal and vertical clearances at the bridge. In addition, show the proposed locations for deck drainage, retaining walls, and/or temporary shoring.

If the bridge is over a roadway, also show the horizontal alignment of the crossroad in the Plan View and a cross section of the crossroad in the Profile View.

If the bridge is over a railroad, also show the horizontal alignment of the railroad in the Plan View and a cross section of the railroad in the Profile View. The distance to the nearest railroad milepost should be shown in the Plan View, and a table of top-of-rail elevations should be shown in the Profile View.

6. Bent Sheets. Provide a typical section for each bent showing the anticipated dimensions. Where two or more bents are essentially the same, they can be combined onto one sheet. For information on dimensioning Bent Sheets, see Section 6.3.

7. Superstructure Details Sheets. The bridge designer should provide a Typical Section of the superstructure as discussed in Section 6.3. Note that the reinforcing details, stud locations, and special pouring locations discussed in Section 6.3 are not required at this design stage.

8. Special Details. The bridge designer should include all necessary details for any designs that are typically not used on SCDOT projects. If any part of the proposed structure will use post-tensioning, provide a preliminary detail showing the proposed design for post-tensioning.

9. Staged Construction Sheet. If applicable, include the Staged Construction Sheet(s). Although the temporary traffic design may be incomplete, all construction sequencing should be shown.

10. Railroad Cross Section Sheets. The Road Design Section will plot the railroad cross sections of the railroad alignment and provide these sections to the bridge designer for inclusion in the Preliminary Bridge Plans. Note that these Sheets are not included in the later sets of design plans. The cross sections should be shown at 25-ft intervals for 100-ft on each side of the centerline of the bridge. The new end fill slopes should be plotted on the cross sections.

3.4 60% BRIDGE PLANS

3.4.1 Purpose

For typical bridge structures, no formal set of plans are submitted at this design stage. 60% Bridge Plans are generally only completed for large, complex, or unique bridge projects.

The 60% Bridge Plans will verify that the bridge design and plans are appropriate. The bridge design should be 90% complete and detailing of the plans 60% complete. The bridge designer should have received the Bridge Geotechnical Report by this time. The plan sheets will include all data previously submitted with the Preliminary Bridge Plans and should address the comments received from the Preliminary Bridge Plans review. All member sizes should be finalized and concrete outlines shown. Reinforcing steel schedules may not yet be completely detailed. Plans will be presented in a "stop-print" format to avoid clean-up just for this submittal.

3.4.2 60% Bridge Plans Sheets Content

In addition to the sheet content discussed in Section 3.3, the Bridge Plans should also address the following information:

1. Title Sheet. At this stage, the Index of Sheets should be updated to list all proposed sheets for the project. However, not all plan sheets will be completed nor are signatures required at this stage. For additional information on the Index of Sheets, see Section 6.3.

2. Summary of Estimated Quantities Sheet. The Tabulation of Estimated Quantities and Summary of Estimated Quantities Table should be provided on this Sheet. Both tables should include a list of pay items that will be used on the project; however, the final quantities may not yet be known at this stage. The Tabulation of Estimated Quantities should list the bid items according to each structure element, number of structure element, construction phases, etc. For additional information on tabulating quantities, see Section 6.3.

3. General Details Sheet. The General Details Sheet should be completed as discussed in Section 6.3.

4. Roadway Typical Section Sheet. The bridge designer should obtain the latest Roadway Typical Section Sheet from the Road Design Section.

5. Roadway Plan and Profile Sheet. The bridge designer should obtain the latest Roadway Plan and Profile Sheet from the Road Design Section.

6. Staged Construction Sheet. If applicable, include the Staged Construction Sheet. Any revisions or updates provided by the Traffic Engineering Division should be incorporated. Section 6.3 provides information on the Staged Construction Sheet.

7. Bridge Plan and Profile Sheet. Except for minor editing or minor design corrections, the Bridge Plan and Profile Sheet should be essentially complete.

8. Boring Locations and Boring Logs Sheet. If the Geotechnical Design Section has received the final Boring Log information from the Office of Materials and Research, include this information at this stage. Otherwise, this information will be presented in the 95% Bridge Plans.

9. Foundation Layout Sheet. To the maximum extent practical, the Foundation Layout Sheet should be completed at this stage. For information on the Foundation Layout Sheet, see Section 6.3.

10. Bent Sheets. Show the basic outline and dimensions of all bents. See Section 6.3 for detailing information and dimensions that are required on Bent and Bent Details Sheets. Note that the reinforcing details, reinforcing steel schedule table, and table of quantities are generally incomplete at this design stage.

11. Superstructure Plan Sheet. The Superstructure Plan Sheet, as discussed in Section 6.3, should be essentially complete except that the reinforcing details, reinforcing steel schedule table, table of quantities, and slab pouring sequence are generally incomplete at this design stage.

12. Superstructure Sheets. In addition to the Superstructure Plan Sheet, the following other Superstructure Sheets, as applicable, should essentially be completed:

    a. Framing Plan Sheet. The Framing Plan Sheet should be prepared as discussed in Section 6.3.

    b. Concrete Beam Details Sheet. For information on concrete beam details, see Section 6.3.

    c. Structural Steel Details Sheet. For detailing structural steel details, see Section 6.3 and Chapter 16.

    d. Girder Details Sheet. For detailing girder details, see Section 6.3 and Chapter 16.

    e. Camber/Blocking Diagram Sheet. See Section 6.3 for information on preparing a camber/blocking diagram.

    f. Bearing Details Sheet. Provide a separate sheet detailing the bearing details after the Camber/Blocking Diagram Sheet. Sections 6.3 and 21.2 provide information on detailing bearings.

    g. Joint Details Sheet. Include the necessary details as discussed in Section 6.3.

    h. Seismic Restrainer Details Sheets. Include these Sheets for projects that require seismic restrainers; see Section 6.3.

i. Top of Slab Elevations Sheet. Where applicable, provide a Top of Slab Elevations Sheet as described in Section 6.3.

j. Sidewalk and Railing Details Sheet. Where applicable, add details for sidewalks and railings. For information, see Section 6.3.

13. Approach Slab Sheet. See Section 6.3 for the appropriate design details that should be incorporated.

14. Sheet Pile Wall/MSE Wall Sheet. The basic outline and dimensions should be provided at this design stage.

15. Special Designs. The bridge designer should include all necessary details for any designs that are typically not used on SCDOT projects. All post-tensioned designs must be finalized and detailed.

16. Special Provisions. In addition to the plan sheets, the bridge designer should include a list of anticipated Special Provisions plus a brief description of the item and work that will be required in the Special Provisions. Results of any rock core compressive strength testing should be provided for inclusion in the Special Provisions.

3.5 95% BRIDGE PLANS

The 95% Bridge Plans are used for final review by the Department (e.g., District, Hydraulic Engineering Section, Utilities Office). Consultant plans should have been through a formal QA/QC process before submittal to SCDOT. All comments from the 60% Bridge Plans should have been addressed. The type and extent of work proposed dictates the disciplines involved in this review process.

At the end of this task, all plan sheets, quantities, specifications, cost estimates, and a construction time estimate should be complete. Chapter 6 provides the layout requirements and format of each individual sheet in the 95% Bridge Plans. Chapter 9 discusses the procedures for entering the quantities into the Department's Proposal and Estimates System (i.e., Trns•port), reviewing the bridge plans, and signing the bridge plans.

3.6 SUBMIT FINAL BRIDGE PLANS

The Final Bridge Plans should incorporate all amendments or revisions evolving from the 95% Bridge Plans review.

After the bridge plans have been signed by the applicable individuals, the Project Manager will forward them to the Assistant State Bridge Design Engineer – Specifications for processing. The Assistant State Bridge Design Engineer – Specifications will then forward the Final Bridge Plans to the Engineering Reproduction Services for printing. Chapter 9 provides the procedures for preparing the Final Bridge Plans for letting.

Chapter 4

COORDINATION OF BRIDGE REPLACEMENT PROJECTS

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CHAPTER 4

COORDINATION OF BRIDGE REPLACEMENT PROJECTS

During the development of a bridge replacement project, the bridge designer must coordinate with many units internal and external to the Bridge Design Section. Chapter 1 describes the functional responsibilities of units within the Bridge Design Section. Chapter 2 presents a network that describes the project development sequence for the bridge replacement process. Chapter 4 discusses specific coordination responsibilities between the bridge designer and other Units. Together, these three Chapters will provide an understanding of the necessary interaction among the various Units in project development.

4.1 SCDOT UNITS EXTERNAL TO PRECONSTRUCTION DIVISION

The following discusses the specific coordination responsibilities between the bridge designer and selected SCDOT Units external to the Preconstruction Division.

4.1.1 Traffic Engineering Division

The Traffic Engineering Division provides a variety of traffic engineering services to other Departmental Units (e.g., selection and design of traffic control devices, highway capacity analyses, traffic engineering studies). The Traffic Engineering Division will be invited to field reviews on an as-needed basis and will receive appropriate project-related correspondence (i.e., Project Planning Report, Design Field Review Plans, Preliminary Bridge Plans, 95% Bridge Plans).

Where a bridge project involves the removal of an existing structure in a specific sequence during construction, the Bridge Design Team will provide a proposed staging plan to the Traffic Engineering Division for the development of the proposed Work Zone Traffic Control Plans. The Traffic Engineering Division provides the Road Design Section with the Work Zone Traffic Control Plans.

The Traffic Engineering Division is responsible for the following:

1. Work Zone Traffic Control. The Traffic Engineering Division is responsible for developing a plan for the maintenance and protection of traffic during construction within the project limits. This may include, for example, providing one lane of traffic across a 2-lane, 2-way bridge, providing a detour around the bridge or, on a multilane facility, providing a crossover between the two roadways. The Work Zone Traffic Control Plan should include any necessary temporary signing or pavement markings.

2. Permanent Signing And Pavement Markings. The Traffic Engineering Division is responsible for developing the Signing and Pavement Marking Plans for the placement of permanent signs and pavement markings. Typically, permanent signing is included only on major bridges.

3. Traffic Signals and Highway Lighting. The Traffic Engineering Division is responsible for developing a plan for the placement of traffic signals and highway lighting on SCDOT bridge projects.

4. Traffic Data. The Traffic Engineering Division maintains current traffic data (e.g., ADT, ADTT) and will provide such data upon request.

4.1.2 Environmental Management Office

The Environmental Management Office is within the Planning, Finance, and Administration Division and is responsible for a variety of activities related to environmental impacts and procedures. This includes air, noise, and water quality analyses; biological, archeological, and historical impacts; preparation of environmental documents for SCDOT projects; evaluation and mitigation of hazardous waste sites; and public involvement. In particular, the Environmental Management Office coordinates with the applicable Federal and/or State agencies for processing the permit information and obtaining the agency approvals.

The following summarizes the coordination between the Project Manager and the Environmental Management Office:

1. Notice of Eminent Domain. The Project Manager provides the Environmental Management Office with a draft Notice of Eminent Domain. The Environmental Management Office is responsible for advertising the proposed project (i.e., publishing the letter/notice in the local and/or regional newspapers).

2. Permits/Approvals. Typically, the Project Manager will provide an Initial Studies Request for Environmental Documents when the Hydraulics Request is submitted. At this time, the Environmental Management Office is responsible for reviewing the project and obtaining the necessary permits and/or approvals. The Environmental Management Office will provide the Project Manager with the permit and/or approval once obtained. The following provides examples of some of the required permits and approvals:

   a. US Army Corps of Engineers (USACE) Section 404 permit. All State highway projects involving possible discharges of dredge and fill material into waters of the United States, including wetlands, require a permit from the Corps as required by Section 404 of the *Clean Water Act*.

   b. US Army Corps of Engineers (USACE) Section 10 Permit. Pursuant to Section 10 of the *Rivers and Harbors Act of 1899*, an individual Section 10 permit is required for structures and/or work affecting any navigable water of the United

States. Navigable waters of the US are those waters that are presently used, or have been used, or may be used to transport Interstate or foreign commerce.

c. US Coast Guard (USCG) Section 9 Permit. A USCG Section 9 permit is required for the construction of bridges or causeways over navigable waters of the United States.

d. Section 4(f). A Section 4(f) approval is required if a project will impact publicly owned land (e.g., public park, recreational area, wildlife/waterfowl refuge, historic/archeological site). An approval will be granted only if there is no feasible and prudent alternative.

e. Section 6(f). Federal law places restrictions on the use of land acquired with funds authorized by the *Land and Water Conservation Act* of 1965 as administered by the US Department of Interior (Section 6(f) of the LWCF). The Environmental Management Office secures approval where required.

f. Section 106. For all Federally funded projects, SCDOT must identify archeological and historic sites in the vicinity of the project. The identified sites must be evaluated to determine if they are eligible for the National Register of Historic Places (NRHP). SCDOT submits recommendations for eligibility to the State Historic Preservation Officer (SHPO) for its concurrence. If a site is considered eligible for the NRHP and, if the project will impact the site, the Department is mandated to mitigate the adverse effects. The Environmental Management Office and the Project Manager coordinate with one another to satisfy the Section 106 procedures.

g. US Fish and Wildlife Permits/Approvals. Where threatened and endangered species may be affected by a bridge project, the Environmental Management Office must obtain a permit and/or approval from the US Fish and Wildlife Service.

3. <u>NEPA Requirements</u>. The Environmental Management Office is responsible for ensuring that the project meets the Department's environmental and public input criteria pursuant to the *National Environmental Policy Act* of 1969. This includes project documentation (i.e., Categorical Exclusion, Environmental Assessment, Environmental Impact Statement), water quality impacts, biological impacts, historical impacts, archeological impacts, and the need for public hearings. In general, the Environmental Management Office makes its determination of impacts based on the input from the Project Manager.

4. <u>Wetland Mitigation</u>. For wetland mitigation sites, the Environmental Management Office will determine the location, size, and type of wetlands at the site; review the hydrology with the Hydraulic Engineering Section to ensure an adequate water supply; and provide a conceptual plan of the site. The Road Design Group is responsible for the preparation

of plans, cross sections, and summaries of quantities, and for providing any Special Provisions that may apply to construction items.

5. State Agency Coordination. The Environmental Management Office determines the need for early coordination on environmental issues with other State (e.g., Department of Natural Resources, Department of Environmental Health and Control, Coastal Council) and Federal (e.g., FHWA, EPA, USACE) entities and initiates all direct contact.

4.1.3 Construction Division

The Construction Division, in coordination with the District Offices, is responsible for all construction activities on all State-administered projects. This includes construction specifications, construction inspections, construction staffing, and approval of construction change orders. The following summarizes the coordination between the Bridge Design Section and the Construction Division:

1. Office of Materials and Research. The Bridge Design Section submits a request for subsurface field investigations and asbestos/lead-based paint investigations to the Office of Materials and Research.

2. Reports. The Bridge Construction Engineer receives copies of the Project Planning Report and the 95% Bridge Plans. The Bridge Construction Engineer reviews the plans and provides recommendations for changes to the Project Manager.

3. Constructibility Reviews. Selected projects may undergo a Constructibility Review to ensure that a project is buildable, cost effective, biddable, and maintainable. A representative from the Construction Office is the designated Team Leader during all Constructibility Reviews; however, the Project Manager is responsible for the organization of the Review. See Section 4.1.6.

4. Bid Proposal. After the Final Construction Plans are completed and all reviews/ approvals/signatures are obtained, the Letting Preparation Group will transmit the Bid Proposal Package to the Contract Administration Office within the Construction Division for letting. See Section 9.1 for a list of documents to be included in the Bid Proposal Package.

5. Shop Plans. Contractors are responsible for submitting the required Shop Plans (e.g., structural steel, prestressed concrete beams) to the Department or Design Consultant for review. See the *SCDOT Standard Specifications*, Section 725 of the *SCDOT Construction Manual* and Section 24.1 for more information on Shop Plans.

6. Change Orders. See Section 24.3 for information on change orders.

7. Value Engineering Proposals. See Section 24.3 for information on Value Engineering Proposals.

4.1.4 District Offices

The Department's seven District Offices provide field services within each geographic area. Their responsibilities include maintenance of the State highway system, construction inspection services, contacts with county and city governments, and traffic-related activities (e.g., encroachment permits).

In general, for all projects, the Project Manager will maintain continual contact with the District Office. The District Office will be invited to the Scoping Meeting and all Design Field Reviews, and receive appropriate project-related correspondence. For projects where traffic is detoured during construction of the replacement bridge, the Project Manager should coordinate the detour route with the District Traffic Engineer.

4.1.5 Bridge Maintenance Office

The Bridge Maintenance Office is within the Maintenance Division. This Office has the responsibility to inspect all in-service bridges and to maintain all State-owned, in-service bridges. The Bridge Maintenance Office is responsible for administering the SCDOT Bridge Management System (BMS). The BMS uses the National Bridge Inventory (NBI) data, additional bridge data, input from Department management, and input from the District Offices to develop an optimum bridge program for:

- preservation,
- rehabilitation, and
- replacement.

Specifically for bridge rehabilitation projects, the Bridge Maintenance Office and Bridge Design Section coordinate to determine which Unit performs bridge rehabilitation work depending on the workload of each Unit. For bridge widening projects, the bridge designer should consult with the Bridge Maintenance Office on the condition and load capacity of the existing structure. See Chapter 23 for more discussion on bridge widening and bridge rehabilitation projects.

4.1.6 Constructibility Review Team

The Project Manager is responsible for organizing a Constructibility Review for projects with estimated construction costs of 25 million dollars or greater. This responsibility includes establishing a Constructibility Review Team early in the design stage (i.e., prior to the Design Field Review Meeting) that is comprised of representatives from the various Units of the Department as well as representatives external to SCDOT (e.g., Bridge Design, Construction, District, FHWA, Contractors). The Project Manager should coordinate with the Director of Construction in selecting the appropriate participants. The Construction Office representative will act as the Team Leader during the actual review meetings. A final report will be prepared by the Review Team and submitted to the Project Manager for review and approval. The Project Manager is responsible for ensuring that the accepted recommendations of the team are incorporated into the project documents. For more information on Constructibility Reviews, see Section 101.3 of the *SCDOT Construction Manual*.

4.1.7 Contract Audit Services

Contract Audit Services is housed within the Planning, Finance, and Administration Division and is responsible for the pre-award audit for Consultants, any Bi-State agreements, and any Participation Agreements. The following applies:

1. Pre-award Audit. Consultants for the Department are required to undergo a pre-award audit before working for SCDOT. The Project Manager is responsible for requesting that Contract Audit Services performs the pre-award audit.

2. Bi-State Agreements. Where a bridge project crosses the State line, the Project Manager is responsible for notifying Contract Audit Services to initiate a Bi-State agreement. See Section 5.1 for information on Bi-State Agreements.

3. Participation Agreements. Any local bridge construction or maintenance project that receives Federal funding through the State must be supervised and approved by the Department and requires an Agreement. The Project Manager is responsible for notifying Contract Audit Services to initiate a Participation Agreement. See Section 5.1 for information on Participation Agreements.

4.2 PRECONSTRUCTION DIVISION

4.2.1 Road Design Section

The following describes the coordination between the Bridge Design Section and the Road Design Section:

1. Preliminary Design. A scoping field review is held for all bridge replacement projects. The roadway representative on these scoping meetings is the Road Design Bridge Project Facilitator. After the field review, the Road Design Bridge Project Facilitator will proceed with the preparation of the Survey Request, if the existing alignment will be retained. If a new alignment is recommended, the Road Design Bridge Project Facilitator will forward the information to the Preliminary Design Engineer. Once the Preliminary Design Engineer sets a new alignment, the alignment is sent to the Road Design Bridge Project Facilitator for preparation of the Survey Request.

   The Road Design Bridge Project Facilitator sends the Survey Request to the Project Manager for review and submittal and to the Hydraulic Engineering Section and the Traffic Engineering Division for review. While the Survey Request is being reviewed, the Road Design Bridge Project Facilitator will prepare and provide a roadway cost estimate to the Project Manager. After all reviews are completed, the Project Manager submits the Survey Request to the Surveys Office. Once the survey is completed, it is forwarded to the Road Design Section where a Design Group is assigned for plan development.

2. Approach Roadway. The Road Design Group is responsible for all roadway approach work. The Road Design Group coordinates embankment designs with the State Geotechnical Design Engineer, as necessary.

3. Roadside Safety Appurtenances. The Project Manager will select the type and design of the bridge rail. The Road Design Group will determine the type and design of the approaching guardrail transition into the bridge rail.

4. Sidewalks. The Project Manager will determine sidewalk requirements on bridges and will forward the decision to the Road Design Group.

5. Plan Preparation. The Bridge Design Section prepares all necessary bridge design plan sheets. The Bridge Design Section forwards the plans to the Engineering Reproduction Services for printing.

6. Bid Proposal. The Bridge Design Section provides any Special Provisions to the Letting Preparation Group to prepare the proposal.

4.2.2 Program Development Section (East and West)

For designated projects, the Program Development Section manages bridge replacement projects. For these projects, the Program Manager serves as the bridge replacement Project Manager. For all bridge replacement projects, the Bridge Design Section and Program Managers maintain contact throughout the development process.

4.2.3 Right of Way Office

4.2.3.1 Coordination

The Right of Way Office is responsible for all activities related to the right-of-way for the State highway system. This includes appraisals, acquisitions, relocation, and property management. The Road Design Section is responsible for developing, signing, and sealing the right-of-way plans; however, the Project Manager must review and approve the plans. The following summarizes the coordination between the Road Design Section and the Right of Way Office with oversight by the Project Manager:

1. Coordination. The Road Design Section provides the Right of Way Office with the needed design information to determine the right-of-way impacts.

2. Plan Preparation. The Road Design Section provides the Right of Way Office with the Right-of-Way Plans. The Right of Way Office requests modifications to the Right-of-Way Plans from the Project Manager based on contacts and negotiations with landowners and the search of public records to determine ownership.

3. Acquisition. The Right of Way Office performs all right-of-way work and procures all properties needed for the project. The Right of Way Office notifies the Project Manager of any design considerations resulting from negotiations with the property owners.

4.2.3.2 Right-of-Way Plans

The following procedures apply to the coordination between the Road Design Section and the Project Manager for sending and receiving prints for obtaining new right-of-way and right-of-way revisions, and verifying existing right-of-way:

1. Plans. After the Right-of-Way Plans have been checked and all necessary signatures obtained, the proper number of prints will be sent to the Right of Way Office by the Letting Preparation Group's Coordinator. Bridge replacement project plans that are not complete for construction at this time will be maintained by the Road Design Section until completion of the Final Construction Plans and will be available from the Road Design Group. Right-of-Way Plans must be approved by the Project Manager.

   The Right of Way Office obtains CADD files from the Road Design Group by informing the Road Design Group Leader of the needed files. The Road Design Group should provide the files to the Right of Way Office for its use. Files should then be sent back to the Road Design Group Leaders as soon as practical. The Road Design Group should coordinate with the Project Manager for any input needed.

2. Revisions. Any plan revisions made after the Right-of-Way Plans are submitted must be approved by the Project Manager and detailed by placing a revision note on the appropriate plan sheet. Include in the revision note any tract numbers affected by the changes. All plan revisions should be routed to the Right of Way Office in the normal manner so that the Right-of-Way Agent has the correct information to provide to the affected landowners.

3. Existing Right-of-Way. The Road Design Group, using old plans, verifies the existing right-of-way. If the old plans contain recorded deeded information, then it is accepted as being verified and initialed by the Road Design Group individual verifying the present right-of-way. If present right-of-way is shown on the plans, but does not have recorded right-of-way data, then the plans are transferred to the Right of Way Office for verification. Deed or plat book and page number must be used to verify any dedicated right-of-way. The Surveys Office or the Right of Way Office supplies this information to the Road Design Group.

4.2.4 Hydraulic Engineering Section

The Hydraulic Engineering Section is responsible for performing and/or reviewing hydrologic and hydraulic analyses on all projects for both roadway drainage appurtenances and bridge waterway openings. For hydrologic/hydraulic analyses, the responsibilities of the Bridge Design Section and the Hydraulic Engineering Section are as follows:

1. Request for Survey. The Project Manager is responsible for forwarding the Request for Survey to the Hydraulic Engineering Section for review and approval.

2. Hydraulic Report/Scour Report. Typically, any structures over a waterway require a Hydraulic Report/Scour Study. Once the general bridge location is known, the Project Manager will prepare a Hydraulic Study request for the Hydraulics Engineer to conduct the necessary studies and prepare the applicable reports. Based on the hydrologic data collected, the preliminary alignment, and input received from the Project Manager, bridge designer, and Geotechnical Design Section, the Hydraulic Engineering Section will perform the detailed hydraulic analysis for a bridge. See Section 5.5 for more details on the content of the Hydraulic Report/Scour Report. The Report will provide the following information to the Road Design Group and Bridge Design Team:

   - beginning and ending stations (i.e., bridge length);
   - the water surface elevation for the design-year flood;
   - a minimum low-chord elevation;

- the proposed number of spans and span arrangement;
- riprap requirements;
- the necessary bridge waterway channel bottom width, side slopes, skew angle, and channel centerline station; and
- the results of the hydraulic scour analysis.

In addition, as needed, the Bridge Design Section and Hydraulic Engineering Section coordinate on the design for bridge deck drainage. See Chapter 18 for a discussion on this coordination.

4.2.5 Surveys Office

The Surveys Office is responsible for conducting aerial and field surveys for all Department projects. The following summarizes the coordination with the Bridge Design Team:

1. Field Survey. If, during the bridge scoping trip, the decision is made that a field survey is needed, the Road Design Section prepares a Request for Survey. The survey request is submitted to the Surveys Office by the Project Manager and assigned to the appropriate Regional Survey Group. Upon completion of the survey, the planimetric data of the site is plotted into a 2-D MicroStation design file along with all alignment and property information. All cross section data is mapped into a 3-D MicroStation design file in the form of a digital terrain model or provided in ASCII files that are compatible for processing with the Department's design software. All files associated with the project are then placed on the network, and the appropriate personnel are notified that the survey information is available.

2. Aerial Survey. A Survey Request is submitted to the Surveys Office, which includes a proposed alignment outlined on a 7½-in USGS quadrangle map. That information is then forwarded to an on-call Aerial Consultant. The Surveys Office, in most cases, will provide all ground surveys needed for an aerial project including the setting of panel points, traverses, drainage surveys, and any additional data that might be required. The Aerial Consultant will provide all planimetric mapping in a 2-D MicroStation design file and all Digital Terrain Models mapped in a 3-D MicroStation design file as breaklines and spot elevations. All files associated with the project are then placed on the network, and the appropriate personnel are notified that the survey information is available.

3. Control Traverse. The Surveys Office ensures that all horizontal and vertical control is set for the project and provides the information to the Road Design Section. The Road Design Section is responsible for placing this information on the plans in a form that can be easily found and understood by those charged with the task of constructing the project. The Road Design Section coordinates with the Project Manager to complete the plans.

4.2.6 Utilities Office

The Utilities Office is responsible for coordinating with utility and railroad companies impacted by bridge replacement projects.

After the Right-of-Way Plans are completed and approved, the Road Design Section provides the Utilities Office with a set of plans with the existing utilities plotted as determined by the survey. The Road Design Group will list the utility conflicts by station and offset from the centerline and place the subsurface utility locations on the cross sections. The Utilities Office will work with any impacted utility companies to implement the utility coordination process. See Section 5.1 for a discussion on Utility Agreements.

Railroad coordination must occur as early as practical in the project development process. See Chapter 2. The Project Manager should implement railroad coordination through the Utilities Office. The Utilities Office will work with both the Road Design Group and the Bridge Design Team, and other Department Units, as necessary to incorporate the railroad requirements and criteria that are acceptable to all parties.

4.3 EXTERNAL AGENCIES

In general, the Project Manager is responsible for coordinating with all agencies external to SCDOT. This Section discusses the typical coordination activities between the Project Manager and selected major units external to SCDOT.

4.3.1 Federal Agencies

4.3.1.1 Federal Highway Administration (FHWA)

FHWA administers the Federal-aid program, which funds eligible highway improvements nationwide. Its basic responsibility is to ensure that the State DOTs comply with all applicable Federal laws in their expenditure of Federal funds and to ensure that the State DOTs meet the applicable engineering requirements for their proposed highway projects. FHWA maintains a Division Office within each State, and this Office is the primary point of contact for a State DOT.

4.3.1.2 United States Forest Service (USFS)

USFS is responsible for the management of all national forests. If a proposed bridge replacement project will impact a national forest, the Project Manager must coordinate the project development with USFS. USFS will, for example, be invited to any field reviews and receive copies of major project reports (e.g., Project Planning Report). In some cases, project actions will require USFS approval (e.g., right-of-way acquisition).

4.3.1.3 Federal Aviation Administration (FAA)

Coordination may be necessary with FAA when projects are located in the vicinity of airports. The anticipated development of the airport and existing traffic patterns that involve the airport should be considered during the design process.

4.3.1.4 National Park Service (NPS)

Coordination with NPS will be necessary where highway projects are in the vicinity of land under the jurisdiction of NPS. The coordination on these projects will be similar to that between SCDOT and USFS.

4.3.1.5 US Coast Guard (USCG) Homeland Security Command Center

The Project Manager is responsible for notifying the USCG Homeland Security Command Center when planning to visit a bridge located over navigable waters of the United States.

4.3.1.6 US Geological Survey (USGS)

The Project Manager and the Hydraulic Engineering Section will coordinate with USGS on the resetting of survey markers and gage stations.

4.3.2 State Government

4.3.2.1 South Carolina Department of Natural Resources (SCDNR)

Where a project involves a boat ramp, the Project Manager is responsible for coordinating with SCDNR.

4.3.2.2 South Carolina Office of Coastal Resource Management (OCRM)

The Project Manager, in conjunction with the Environmental Management Office, will coordinate with OCRM for projects located in coastal counties.

4.3.3 Local Government

4.3.3.1 City and County Government

The following describes the coordination between the Project Manager and city and county government agencies:

1. Design. The Project Manager is responsible for soliciting input from the city and county government on projects in that locality and, in general, keeping the local government up-to-date on any current or planned activities. SCDOT has the exclusive authority to establish design criteria on State roads and bridges pursuant to the South Carolina Code, Section 57-3-110(1); however, larger municipalities may have their own design criteria, which may be considered during the design process. The Project Manager will keep the Bridge Design Team and Road Design Group apprised of all local requirements.

2. Coordination. The Project Manager typically invites the local government to any public meetings.

3. Assistance. The Project Manager provides technical assistance to city and county governments upon request and responds to any verbal or written inquiries.

4.3.3.2 Local Planning Agencies

All local governments conduct planning activities (e.g., land use, zoning). The Department coordinates with the local planning agencies, Metropolitan Planning Organizations (MPO), and Councils of Government (COG) to ensure that the projects are consistent with local planning activities. Figure 4.3-1 provides a list of MPOs in South Carolina. Figure 4.3-2 provides a list of the COGs in South Carolina.

Abbreviation	Full Name
ANATS	Anderson Area Transportation Study
ARTS	Aiken/North Augusta Area Transportation Study
CHATS	Charleston Area Transportation Study
COATS	Columbia Area Transportation Study
FLATS	Florence Area Transportation Study
GRATS	Greenville Area Transportation Study
GSATS	Grand Strand Area Transportation Study
RFATS	Rock Hill/Fort Mill Area Transportation Study
SPATS	Spartanburg Area Transportation Study
SUATS	Sumter Area Transportation Study

METROPOLITIAN PLANNING ORGANIZATIONS (MPO)

Figure 4.3-1

Name	Location
South Carolina Appalachian Council of Government	Anderson, Cherokee, Greenville, Oconee, Pickens, and Spartanburg Counties
Upper Savannah Council of Government	Abbeville, Edgefield, Greenwood, Laurens, McCormick, and Saluda Counties
Catawba Regional Council of Government	Chester, Lancaster, York, and Union Counties
Lower Savannah Council of Government	Aiken, Allendale, Bamberg, Barnwell, Calhoun, and Orangeburg Counties
Santee-Lynches Council of Government	Clarendon, Kershaw, Lee, and Sumter Counties
Pee Dee Regional Council of Government	Chesterfield, Darlington, Dillon, Florence, Marion, and Marlboro Counties
Central Midlands Council of Government	Fairfield, Lexington, Newberry, and Richland Counties
Waccamaw Regional Planning and Development Council	Georgetown, Horry, and Williamsburg Counties
Berkeley-Charleston-Dorchester Council of Government	Berkeley, Charleston, and Dorchester Counties
Lowcountry Council of Government	Beaufort, Colleton, Hampton, and Jasper Counties

COUNCILS OF GOVERNMENT (COG)

Figure 4.3-2

Chapter 5

ADMINISTRATIVE POLICIES AND PROCEDURES

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 5

ADMINISTRATIVE POLICIES AND PROCEDURES

Chapter 2 outlines the basic approach used by SCDOT in its project development process for bridge replacement projects. Chapter 5 discusses items related to the operational practices of the SCDOT Bridge Design Section during the project development process.

5.1 AGREEMENTS

5.1.1 <u>Participation Agreement</u>

5.1.1.1 Purpose

Generally, the Department will manage bridge construction or maintenance activities on the State Highway System. However, counties, municipalities, or other agencies acting on behalf of a County Transportation Committee may enter into agreements with the Department to construct and/or maintain State bridges if SCDOT has given explicit authority to do so. In this case, the local agency must demonstrate that it has the equipment, staff, and financing to satisfy the Department's requirements.

Conversely, bridge construction projects on the State Highway System that are funded entirely by the local agency (i.e., those that do not receive any State or Federal financing) may be performed under the supervision and approval of SCDOT, if requested by the local agency, and provided that an agreement can be reached.

Any local bridge construction or maintenance project that receives Federal funding through the State must be supervised and approved by the Department and requires an agreement.

Typically, the Contract Audit Services and Legal Services Office are responsible for writing and/or reviewing these agreements with the Project Manager's input, as appropriate. Prior to the submittal for SCDOT management execution, the originating Unit must affix its authorized signature as "Reviewed by" or "Developed by." Topics that are generally addressed in a Participation Agreement include:

- design criteria (e.g., enhancements, sidewalks, lighting, structures, approach roadway, signing, bicycle paths);
- financial obligations;
- individual party responsibilities;
- right-of-way;

- quality assurance/quality control;
- dispute resolution; and
- utilities.

For information on Participation Agreements involving the exchange of funds, see SCDOT Departmental Directive Number 30.

5.1.1.2 Application

A Participation Agreement is required when local funds are involved in projects financed in part with State and/or Federal funds, and when one or more of the following conditions apply:

- improvements on a local bridge for which construction, engineering, utility relocation, and/or right-of-way acquisition is paid totally, or in part, with State or Federal funds;
- improvements on a State bridge in which the local agency is participating in the cost and/or any subsequent maintenance on any phase of the improvement, or in utility and/or maintenance costs;
- improvements on a State or local bridge involving a jurisdictional transfer between the State and the local agency;
- any highway authority proposing to transfer jurisdiction of a bridge to another highway authority;
- any highway authority proposing to use "C" funds for participation in a joint improvement with another highway authority;
- any highway authority proposing to use "C" funds to pay another highway authority to perform maintenance on a bridge that is the responsibility of the first highway authority; and
- when there are agreements with private entities (e.g., developers, corporations).

5.1.1.3 Content

Agreements between the Department and a local agency are typically provided for maintenance and construction. SCDOT and the local agency must enter into an agreement that ensures funds are expended in accordance with State and Federal laws. The agreement should, where applicable, include the following:

- that the Department will make periodic inspections of the project, as it deems necessary, to determine that the work is being performed in compliance with the plans, specifications, and SCDOT policies and procedures;

- that the agreement indicates any provisions that do not apply to any Federal-funded or State-funded projects that are not administered under the "C" Program's policies and procedures;
- that the agreement may be terminated at the discretion of either party; and
- that the use of "C" funds, other than specified in the agreement, will require approval by the Department.

5.1.2 Utility Agreement

If it is found that a utility will be impacted by a SCDOT bridge project and the utility company has prior rights, a Utility Agreement is required. The utility company must prepare and submit SCDOT Form 3068A — Utility Agreement, with a detailed cost estimate and plans for the utility work. Upon receipt, the Resident Construction Engineer will review the submittal for completeness and prepare and forward recommendations through the District Engineering Administrator for review and approval by the Utilities Office. The Utilities Office will coordinate any needed review by FHWA. The Utility Agreement should include the following:

1. Utility Plans. Utility plans must include the following information:

   - legend;
   - location of facilities to be relocated or adjusted in relation to centerline stationing;
   - utility facilities that are occupying public lands;
   - vertical and horizontal clearances; and
   - location, type, size, and class of major items of material for:

     + existing facilities to be adjusted,
     + temporary facilities to be installed,
     + permanent facilities to be installed, and
     + facilities to be abandoned.

2. Cost Estimates. Cost estimates for utility work must include the following information:

   - items of work to be performed;
   - detailed costs for the utility work, including:

     + labor costs,
     + construction overhead charges,
     + costs for materials and supplies,
     + handling charges,
     + transportation and equipment charges,
     + right-of-way costs,
     + preliminary engineering costs, and
     + construction engineering costs;

- items of material representing major components;
- factors included in construction overhead charges;
- betterment and extended-service-life credits due, including calculations; and
- itemized salvage credit due.

5.1.3 Railroad Agreement

All work over, under, or within the railroad right-of-way requires the Utilities Office to acquire the approval of and process an agreement with the railroad company. Because the processing of agreements with railroad companies may require significant time to obtain, early coordination with the Utilities Office is necessary to minimize potential delays to the project.

The Project Manager will ensure that the Utilities Office is involved in the early stages of project development and that the Utilities Office remains informed of any changes in the project and any pertinent correspondence. If required, the Utilities Office will inform the railroad company of the proposed project and obtain its comments. These comments may affect the location and/or subsequent design of the project; therefore, designers need to recognize the design requirement of the railroad companies and provide the necessary design controls to accommodate the operational requirements of both the bridge and the railroad. For grade-separation structures, the Bridge Design Section has the responsibility for structure design to meet the criteria required by the railroad company and to provide the preliminary and final design plans to the Utilities Office. See Chapter 22 for more information on highway bridges over railroads.

5.1.4 Bi-State Agreement

Where a bridge project crosses the State line, a Bi-State Agreement is required. Where this occurs, SCDOT and the bordering State must enter into an Agreement that designates the responsibilities and obligations of the bridge project between both parties. The Project Manager should notify Contract Audit Services to initiate a Bi-State Agreement. The Agreement, where applicable, should designate the following activities for each involved party:

- coordination responsibilities;
- project location;
- production of plans, specifications, and quantities;
- approval of plans, specifications, and quantities;
- right-of-way responsibilities;
- construction responsibilities;
- construction supervision and inspection;
- related costs and reimbursement schedules for the project; and
- maintenance responsibilities after the project is completed.

5.2 PUBLIC INVOLVEMENT

5.2.1 Introduction

The procedures in this Section are intended to provide an overview of effective public participation and consideration for bridge location and design proposals. In general, the procedures provide for a candid and open discussion of project alternatives to encourage early resolution of controversial issues. The procedures also reflect coordination with other public agencies, private organizations, and individuals. The public involvement process ensures that potential adverse social, economic, and environmental effects are fully considered in project development. This participation process should result in final decisions that reflect the best overall public interest in providing safe, economic, and efficient transportation with minimal adverse affects.

When a project or series of projects will be initiated in a general locality, providing advance notice can avert much of the controversy and provide a public forum for the community to receive information on the projects and to comment where appropriate. An effective public involvement program can consolidate overall public support and contribute significantly to the successful completion of projects.

5.2.2 Public Involvement Team

A Public Involvement Team (PI Team) will be established for significant or major projects. Significant or major projects are projects with significant right-of-way takings; changes in layout or function; significant social, economic, and environmental effects; and general public interest. The Project Manager will establish a PI Team prior to obligating funds for project design work. The PI Team should include representatives from the Planning Office, Environmental Management Office, Office of Right of Way, Road Design Section, District, MPO/COG, and FHWA, as needed. The PI Team may also include representatives from the legislative delegation, Chamber of Commerce, affected businesses, neighborhood associations, or other groups affected by the project. New members may be added to the PI Team at any time during the project as new issues or affected groups are identified. The PI Team should be used as follows:

1. The PI Team will assist in identifying those persons or groups affected by a project and assist in developing a plan to effectively communicate with those affected at various stages of project development.

2. The PI Team members may work with these affected/interested groups to determine an appropriate level of coordination and involvement. These groups may also be used as a resource to assist the Department with the flow of project information throughout the life of the project.

5.2.3 Public Involvement Plan

The Project Manager should work with the Environmental Manager to develop a Public Involvement Plan for each project as necessary. The Public Involvement Plan should outline the individuals to be on the PI Team, affected/interested groups, issues and concerns, the type of public meeting desired, and other outreach tools.

The Project Manager should submit the Public Involvement Plan to the Program Development Engineer or State Bridge Design Engineer for approval. A copy of the approved plan should be distributed to the Environmental Management Office, the Director of Preconstruction, District, FHWA, and others as necessary.

The Public Involvement Plan should be reviewed and adjusted as the project development process advances.

5.2.4 Types of Public Involvement

5.2.4.1 General

Public involvement activities may use a number of formats in providing information to the public and receiving public input. By varying the format, the public may be involved individually in an informal atmosphere, in listening to formal presentations of information, or in making comments for the record at a public hearing. Some of the formats provide for more than one of these relationships. The Project Manager should select the format for an activity according to the situation. Many people from the public sector prefer an individual contact that will not require them to speak before large groups.

The types of public involvement include:

- public hearings,
- informal public hearings,
- informational meetings, and
- workshops.

Offers for public hearings and/or public hearings are required by law for certain types of projects, whereas informational meetings and workshops are conducted on a case-by-case basis. The following Sections provide brief descriptions of these types of public involvement activities.

5.2.4.2 Public Hearings

In accordance with the FHWA *Regulations on Environmental and Related Procedures* (23 CFR 771), SCDOT will hold one or more public hearings, or offer the opportunity for a public hearing to be held at a convenient time and place for any Federal-aid project that:

- requires significant amounts of right-of-way;
- substantially changes the layout or function of connecting roadways, or of the facility being improved;
- has a substantial adverse impact on adjacent property;
- has a significant social, economic, environmental, or other impact; or
- has other valid public interest.

For other projects, an opportunity for a public hearing may be advertised to determine if there is sufficient interest to warrant a public hearing. Projects for which an opportunity for a public hearing may be advertised are those projects requiring limited right-of-way and minimal environmental impacts.

The Project Manager will conduct a Public Hearing in coordination with the Environmental Management Office and FHWA. The PI Team should be involved in the meeting by requesting the Team members to assist in notifying any affected/interested groups that have been previously identified. Project location and project design are usually the primary subjects of public hearings. The location and design may be the focus of one or more public hearings as follows:

1. <u>Combined Location and Design Public Hearing</u>. This method is used for those projects that are improvements to existing transportation facilities and the location is generally established by the existing facility.

2. <u>Location Public Hearing and Design Public Hearing</u>. This method may be used for projects on new location to establish the location prior to proceeding with the design efforts. A separate hearing is held to review and discuss the project features and design with the public.

Department policy is to provide all interested persons an opportunity to become acquainted with highway proposals of concern to them and to express their views at those stages of a proposed project when the flexibility to respond to those views still exists. Accordingly, SCDOT may require public involvement activities in addition to the holding or offering of public hearings on Federal-aid projects.

5.2.4.3 Informal Public Hearing

The informal public hearing format provides for a continuous flow of visitors over a period of hours in contrast to a formal public hearing that attracts a large number of people at a fixed time. It is necessary to have appropriate Department representatives to provide explanatory project information, provide for the receipt of oral and written statements, and prepare a summary of the proceedings. The smaller number of visitors present at any given time at an informal public hearing allows personalized service through staff discussions with individuals. Surveys of participants in public activities for SCDOT highway projects have indicated that the informal public hearing format is generally viewed more favorably than the formal public hearing format. The informal hearing format is less intimidating to participants and offers a more workable option for conducting hearings for very large audiences. FHWA has recognized the benefits of this format and encourages its use as an effective public involvement method that meets the hearing requirements of the *US Code of Federal Regulations*.

5.2.4.4 Informational Meetings

Informational meetings are informal public gatherings that blend the individual discussions of open houses with the group interaction of public hearings and are used to disseminate information on projects in which the public may have a significant interest. Generally, a transcript of an informational meeting is not recorded.

Informational meetings provide an opportunity to assemble a large group at one time to discuss the status of the project, the decisions made to date, the options yet to be decided, and the criteria considered critical for the remaining decisions.

There are two types of informational meetings that may be used, as deemed appropriate. They are as follows:

1. Early Information Meeting. Early Information Meetings are not typically held. The Planning Office may conduct, in coordination with the Project Manager, an Early Information Meeting prior to the obligation of design funds for proposed projects. The previously established PI Team will be invited to attend the Early Information Meeting and asked to encourage others affected by or interested in the project to attend. The Planning Office will include information gathered at this meeting in the Advance Project Planning Report.

2. Public Information Meeting. The Project Manager may conduct a Public Information Meeting in coordination with the Environmental Management Office and FHWA. The PI Team, if applicable, may be requested to assist in the meeting.

5.2.4.5 Workshops

Workshops are meetings where participants are given basic transportation requirements, economic and design constraints, and anticipated social, economic, and environmental impacts related to a proposed project or project problem. In a workshop format, participants are requested to analyze the provided information, identify impacts that may have been overlooked, work with other participants, and offer solutions.

Workshops provide an opportunity for the public to experience the complexities and problems that confront Department personnel during project development. This experience enhances public understanding and appreciation of the Department effort. Because the public will be analyzing pertinent information, suggesting solutions to problems, and/or indicating preferences among impacts and tradeoffs, a sense of community participation may be gained.

5.2.5 Coordination

5.2.5.1 General

During the development of a proposed bridge project, the Department often must coordinate with a variety of resource agencies. Many of these contacts are informal and are only intended to discuss certain aspects of upcoming projects (e.g., potential effects of the project on specific resources, cost participation by local agencies associated with a State bridge project that affects local-system facilities). Notices of upcoming public involvement activities afford another mechanism for agencies to obtain information on proposed projects. All of these actions contribute to interagency coordination.

5.2.5.2 Project Coordination Meetings

The Project Manager conducts periodic coordination meetings that may involve personnel from the Department, FHWA, and other appropriate agencies. The goal is to coordinate planning; identify social, economic, and environmental impacts; minimize these impacts through mitigation; and develop the best overall solution to satisfy the transportation needs.

5.2.6 Meeting and Hearing Format

Public involvement meetings and public hearings should be conducted in accordance with the following:

1. Format. Select the most appropriate meeting format; see Section 5.2.4. Desirably, use the informal public hearing format, which allows the public to drop-in and individually discuss the project. Formats may be varied to accommodate specific needs.

2. Time and Location. Hold the meetings and hearings at a convenient time. Desirably, the meetings would occur on Monday, Tuesday, or Thursday evenings between 4:00 p.m. and 7:00 p.m. The location should be convenient and as close to the project as practical.

3. Attendees. Staff members from the Bridge Design Section, Program Development Section, Office of Right of Way, and the Environmental Management Office should participate in the meetings or hearings. FHWA must be invited to all meetings and hearings for Federal-aid projects. Invite the PI Team to attend as well as District or Construction staff.

4. Information. Large plans and displays for the proposed project should be available for viewing. For hearings, handouts explaining the project's purpose and need; consistency with local planning; social, economic, and environmental impacts; relocation assistance;

and the right-of-way acquisition process must be available. Comment forms must be provided at hearings and should be provided at public meetings.

5. Roles and Responsibilities. Staff must be available for explaining the project, answering questions, and encouraging individuals to comment on the project. The Project Manager will reply to all comments received at hearings and may respond to comments received at the meeting. The Environmental Management Office is responsible for transcribing verbal comments and certifying hearings to FHWA.

5.2.7 Notice of Meetings and Hearings

Advertise Notices of Public Meetings and Hearings in general circulation newspapers serving the project area. The advertisement should be in the form of a display ad in the local/community section of the newspaper. Public meetings should be advertised 15 days prior to the meeting. For public meetings, public notice signing may be used if desired by the Project Manager. Public hearings must be advertised a minimum of 15 days, but not more than 30 days, prior to the hearing. For public hearings, public notice signing should be provided at the location of the project. A Notice of Opportunity for Public Hearings must be advertised once in a local newspaper and a 21-day response period allowed for hearing requests.

5.2.8 Public Notification of Bridge Replacement Projects

5.2.8.1 Purpose

This Section provides a discussion on the specific policies and procedures for notifying the public of bridge closings and replacements.

On NHS routes and other roads with high traffic volumes or bridges with lengthy detours, closing a road to replace a bridge is only done after exhausting all other alternatives. Circumstances that may dictate road closure are environmental impacts including wetland and tree removal, right-of-way acquisition, costs, and road alignment. The Project Manager is responsible for weighing all options carefully before making the decision to close an existing road to replace a bridge. This will be done only after consultation with District personnel.

Various methods to accelerate construction should be used on bridges that are closed (e.g., “A+B” bidding with higher liquidated damages, incentive/disincentive specifications, flex time allowing the Contractor to only close the bridge for a short time, duration of road closure). To shorten construction duration, give consideration to using innovative bridge designs.

5.2.8.2 Notifications

To inform legislators and other local officials of pending bridge replacements, send out notifications at various times during the preconstruction process. Very early in the programming process, the Project Manager will prepare a letter to these interested officials for the Executive Director's signature.

Include the following items in the letter to the interested parties:

- county name, route number, and crossing information;
- local road name and/or bridge name;
- tentative decision on whether the bridge will be closed or if traffic will be maintained during construction (explain if traffic will be maintained by new alignment, detour bridge, or staging). Also, advise that this is preliminary only and is subject to change; and
- approximate timing of letting. Indicate that this is preliminary only and is subject to change.

The Project Manager will blind copy the Office of Communications and the District Engineering Administrator.

The Office of Communications should issue a news release that includes the following information:

- county name, route number, and crossing information;
- local road name and/or bridge name;
- whether the bridge will be closed or if traffic will be maintained during construction (explain if traffic will be maintained due to new alignment, detour bridge, or staging);
- approximate date of expected closure, if determined; and
- approximate length of closure and/or completion date.

Approximately two to three months prior to letting, the Project Manager will prepare a letter for the Executive Director's signature, similar to the first communication.

5.3 CONSULTANT MONITORING

5.3.1 Construction and Resource Management Program

The Construction and Resource Management (CRM) Program was a public-private partnership aimed at completing 27 years worth of road and bridge work in seven years as part of SCDOT's accelerated construction program.

5.3.2 Consultant Services

5.3.2.1 General

Consultants are used to assist in the development of projects for different divisions of SCDOT. Each SCDOT division is responsible for all administrative aspects of Consultant-designed projects, including those under a term contract. These responsibilities include:

- advertising for Consultant services,
- preparing the Request for Proposals,
- administering the Consultant evaluation and selection process,
- conducting contract negotiations with the selected Consultant,
- processing and executing the agreement,
- preparing the Notice to Proceed,
- monitoring project progress,
- processing Consultant payments,
- conducting Department reviews,
- processing contract modifications,
- resolving disputes, and
- closing out the agreement.

The following Sections discuss the typical activities that occur during the implementation of Consultant-designed projects.

5.3.2.2 Advertise for Consultant

The following procedures are required when advertising for a Consultant:

1. Request. Prior to advertising for a Consultant, the Director of Preconstruction will request Commission approval to contact or advertise for the selection of an entity to provide professional services. Requests for engineering services shall be submitted through the State Highway Engineer and Executive Director.

2. Announcement. After the request has been approved, the Project Manager will prepare an announcement requesting a Letter of Interest and Qualification from Consultants. The contents of the announcement should include the following information:

a. Purpose. The announcement should identify that the South Carolina Department of Transportation is requesting a Consultant to work on a bridge project or other projects for the Bridge Design Section.

b. Description. The announcement must contain a description of the work required by the Consultant. Ensure that enough information is provided so that the Consultant can easily determine whether or not it is qualified.

c. Selection Criteria. Evaluation of each firm's proposal will be based on the selection criteria and relative importance as published in the announcement. Include the following selection criteria in the announcement and the proposed weight (percentage) for each factor:

- experience, qualifications, and technical competence of the firm, including past performance on similar projects;
- qualifications of the staff, specifically the Project Administrator and other key staff, to be used on the project;
- proposed methodology for the project, ability to perform all aspects of service, quality assurance procedures, and responsiveness to the Department;
- present and projected workload;
- volume/value of SCDOT work awarded to the Consultant in past two years;
- Disadvantaged Business Enterprise (DBE) contract goal or, if a DBE goal is not provided, the Consultant's proposed DBE utilization plan; and
- other factors that may be pertinent to the project.

d. Additional Documents. The announcement must state that the Consultant will need to provide resumes for key personnel that are proposed to work on the project, and Federal Standard Form (SF) 254 "Architect-Engineer and Related Services Questionnaire" and SF 255 "Architect-Engineer and Related Services Questionnaire for Specific Project" for both the primary firm and any subconsultants.

e. Additional Information. The announcement should also note the following:

- proposed method of payment for the project;
- date and time the Letter of Interest is required to be submitted;
- the maximum page limit for the Letter of Interest;

- maximum allowable hourly rate for the Consultant's employees;
- the Department's contact person, including telephone number and email address, who may be contacted for inquiries and questions on the proposal; and
- name and address of the person to whom the proposal should be submitted.

3. Announcement Approval. The final draft of the announcement will be submitted to the Department's Selection Board for approval. This submission must be coordinated with the Director of Contract Audit Services. Upon approval by the Selection Board, the Director of Contract Audit Services will arrange for the announcement to be advertised in the *South Carolina Business Opportunities* or other means as determined appropriate by the Selection Board.

4. Selection of the Firm. The Director of Contract Audit Services will record the name, date, and time of all Consultant Letters of Interest received. The Director of Contract Audit Services will review all submittals for compliance with the announcement and will record any areas of non-compliance for discussion and action with the Selection Board. The Director of Contract Audit Services will notify Consultant firms if their Letters of Interest are determined to be non-responsive by the Selection Board.

   The Selection Board, or its designated selection committee, will evaluate firms responding to the announcement against the selection criteria and relative importance and rank them in order of qualifications. The Board will also consider the results of the "Consultant Performance Evaluations" in the past performance criteria. Special attention will be given to cost overruns, completing work on schedule, quality of work, errors and omissions, etc. The Selection Board may short-list top rated firms for the submission of additional information or interviews. The Selection Board will recommend the final ranking of order of negotiation for the State Highway Engineer's approval.

   The State Highway Engineer will notify the Director of Contract Audit Services and the Director of Preconstruction of the approved order for negotiation. The Director of Contract Audit Services will notify all firms of their selection status and all responsive Consultants of the selected firm. The selected Consultant will be documented in the announcement file.

5.3.2.3 Scoping of Services

The Project Manager will arrange for a meeting with the Consultant for the purpose of negotiating and refining the scope of services (SOS) and the project schedule (PS), and to provide information to the Consultant regarding the negotiation process. As part of this process, generally the following will occur:

1. Existing Material. The Project Manager will furnish the Consultant any preliminary data previously assembled for the project (e.g., location and design reports, aerial photography, mapping, studies, traffic data, other items currently in the possession of the Department).

2. Consultant. The Project Manager will direct the Consultant to prepare a general scope of services and a project schedule, and to bring six copies of these Forms to the meeting. The Consultant will prepare the scope of services and project schedule independent of the Department based on the preliminary scope, any preliminary data, and the Consultant's understanding of the project. The schedule will be in sufficient detail to determine any assumptions related to Department review and approval timeframes for project components, and other items requiring approval from the Department or other regulatory agencies.

3. Department. The Project Manager will develop a general scope of services and project schedule, making any necessary revisions as may be required by the particular project. This scope of services and project schedule will be prepared independent of the scope of services and project schedule prepared by the Consultant. The Project Manager will seek assistance from various units within the Department for specialized areas of work (e.g., hydrology, environmental, right-of-way, bridge design, construction). The Project Manager may hold an internal scoping meeting of Department personnel for large or unusual projects.

4. Scoping Meeting (Department/Firms). A review and comparison of the scopes and services prepared by the Department and the Consultant will ensue. Differences will be discussed for the purpose of refinement and mutual agreement. When general agreement of the scope of services and project schedule is reached, the Project Manager will request the Consultant to revise and resubmit the SOS and PS, if necessary. Final scope details that are generally minor in nature may be finalized at a subsequent meeting to negotiate man-hours and cost.

5. Documentation. The Project Manager will be responsible for maintaining documentation of the modified scope of services and project schedule, and will furnish to the Director of Contract Audit Services the original scope of services and project schedules prepared by the Department and the Consultant, along with the revised scope of services and project schedules. The Director of Contract Audit Services will maintain on file all documentation related to the determination of the scope of services and negotiation process.

5.3.2.4 Negotiations

The negotiations are a critical phase of the process leading to execution of an agreement and authorization to proceed with the work. The Project Manager will furnish the selected Consultant with copies of the following data and forms:

- Standard Agreement for Consultant Services,
- manpower requirement forms, and
- cost estimate forms.

The Project Manager will be responsible for negotiating the scope of services, project schedule, man-hours, job classifications, hourly rates, direct non-salary costs, and fixed fee (profit). Resources to be used in the negotiations may include but not be limited to the scope of services, cost estimates, and the audit opinion issued resulting from a pre-award audit.

The steps to be followed in the negotiation process are as follows:

1. <u>Consultant Man-Hours and Cost</u>. The Director of Contract Audit Services will direct the Consultant to prepare and submit man-hour requirements and a cost estimate after an agreement of the scope of services and project schedule have been reached.

2. <u>Department Review</u>. The Project Manager will prepare an independent estimate of the man-hours and cost based upon the agreed and approved scope of services and project schedule. The Department's man-hours and cost estimate are confidential and are not to be shared with the Consultant before the negotiation meeting.

   After preparation of the Department's estimate, the Project Manager will review the Consultant's man-hour requirements and cost estimate. If the Project Manager finds the cost estimate and scope to be appropriate, the contract can be recommended for approval. If not, the Project Manager will arrange for a negotiation meeting with the Consultant. The purpose of the meeting is to reach agreement on the total scope of services, man-hours, direct non-salary costs, and fixed fee by negotiation. In the event the project will use a lump-sum contract, the Project Manager will review the scope of services, project schedule, and fee structure for the project, and follow the above process for recommendation or arrangement for a negotiation meeting with the Consultant.

3. <u>Negotiation Meeting</u>. The Project Manager will compare the man-hours, job classifications, and hourly rates proposed for each task of work for the purpose of ascertaining the appropriateness of these numbers and will discuss with the Consultant at the meeting those items that are unacceptable or in question. Acceptance will be by mutual agreement of the Project Manager and the Consultant. It is anticipated that the approved scope will be refined as a result of these discussions and minor revisions may be made. The Department may terminate negotiations if an agreement cannot be reached.

   The Project Manager will also compare direct non-salary costs on a task-by-task basis and make any revisions as agreed upon by negotiation. Subconsultant fees will be negotiated based on Department experience on other projects, with consideration given to those items listed in the next paragraph for negotiation of fixed fee (profit).

   After agreement on other costs, the Project Manager will negotiate the fixed fee (profit) with consideration of the financial and professional investment required, the extent, scope of services, complexity, character, and duration of services, the degree of responsibility to be assumed by the Consultant, the pre-award audit opinion, and other factors as may be considered at the time of negotiation.

4. Documentation of the Negotiations. The Project Manager will be responsible for documenting the negotiations including preparation of the Record of Negotiation (RN) Form. The Project Manager will record who attended the Man-hour and Cost Estimate Meeting, distribute information, and request the Consultant to take minutes and to provide all participants a copy of the minutes.

5. Submission to Contract Audit Services. The Project Manager will provide the Director of Preconstruction with copies of the Department and Consultant prepared man-hour requirements and cost estimates with notes and comments from all Department units involved in the review process, along with all comments and revisions made during the Department's internal negotiation meeting. The Director will review this information and provide it to the Director of Contract Audit Services. The Director will also furnish the Director of Contract Audit Services a copy of the mutually agreed on man-hour requirements and cost estimate, along with the agreed upon scope of services with any revisions resulting from the Man-hour and Cost Estimate Meeting.

6. Agreement. The Director of Contract Audit Services will prepare an agreement for consultant services to include the mutually agreed decisions resulting from the negotiations.

7. Non-Agreement. If the Consultant and the Department cannot reach agreement on the scope of services, man-hour requirements, cost estimate, etc., the Director of Preconstruction will prepare a recommendation to terminate negotiations with the selected Consultant for the Selection Board's approval. The Department may begin the negotiation process with the next firm in the order of negotiation after the Selection Board's approval.

5.3.2.5 Execution of Contract

Generally, SCDOT's goal is to prepare contracts for projects for which logical and easily identifiable beginning and ending points can be established in their entirety. However, this may not always be practical or fiscally efficient. For multiple-phase projects, the following will apply:

- For fiscal efficiency, the Department may elect to negotiate individually each phase of a multiple-phase contract. An agreement for a project with multiple phases may be executed based on the initial phase. Agreements for projects with multiple phases will clearly state that the agreement is for the total project, and the negotiations for the remaining phases will be conducted during the course of the agreement. The agreement will also state that the Department reserves the right to discontinue the agreement at the end of any phase at the sole discretion of the Department. Before beginning negotiations for each subsequent phase within a contract, a request to negotiate the next phase of work including a justification for continuing with the contract must be prepared. The justification should consider the general scope of services for the next phase, estimated cost, project schedule, coordination of work with other phases, benefits, and/or detriments of continuing with the original agreement including the effects of a new consultant selection process. This justification is forwarded to the Selection Board for approval prior to proceeding with negotiations for the next phase.

- Negotiations for individual phases of work will be conducted in accordance with Section 5.3.2.4 and will be conducted during the course of the agreement. Work cannot begin on the next phase until negotiations for that phase are concluded and approved.
- When the agreement includes both the preparation of an environmental document and subsequent final engineering and design, the Project Manager will conduct a review that addresses the objectivity of the environmental document. The review will be submitted to the FHWA Division Administrator before authorizing the Consultant to perform the final engineering and design.
- Failure to obtain approval to negotiate a phase or approval of the negotiated phase will require that the work of the phase be accomplished by Department staff or a new Consultant selection process be held.
- Projects on new locations, on significant realignments, or which are unusually large or are of an unusual nature such that there is insufficient information to define the overall scope should be contracted by individual phases. Under normal circumstances, a new selection will be held and a new contract written for each phase of work. Any circumstances that require a change in these procedures will require justification and the approval of the State Highway Engineer and the FHWA Division Administrator.

5.3.2.6 Notice to Proceed

Once the Consultant contract has been signed by both parties, the Department will provide the Consultant with a Notice to Proceed.

5.3.2.7 Project Execution

During the execution of the project, the Consultant will be required to conduct the following:

1. Invoices. The following monetary values should be shown on all invoices:

    - Total Contract Amount,
    - Work This Period,
    - Previous Period,
    - Complete to Date, and
    - Distribution of Fees List.

Also, each invoice should be accompanied by a summary of work completed for the period in which payment is requested. For cost-plus contracts, a breakdown of man-hours for each task listed in the contract man-hour requirements should be included.

2. Department Reviews. The Consultant is responsible for the accuracy and quality control of its work products. The Consultant will submit all work products to the Department for review and comment. On an as-needed basis, periodic review meetings will be scheduled with the Consultant. The objectives of the meetings may include answering SCDOT questions, resolving Department comments, assessing project progress, etc. After the meeting, the Consultant will be responsible for preparing minutes to document the key decisions made during the meeting. Chapters 3 and 6 provide a list of items the Consultant must provide to the Department for review when preparing bridge plans.

3. Contract Modifications. When significant changes occur in the scope, character, or complexity of the project, a contract modification may be negotiated if it is mutually agreed that changes are necessary. The Consultant will document the revised scope of services and prepare a cost estimate for review and approval by the Department. If the change in scope is approved, a contract modification will be processed.

4. Final Invoice. After the Consultant has completed all services required by the contract, a final invoice is submitted to the Department. This invoice should be noted by the Consultant that it is the final invoice. A paid final invoice is considered to be the final acceptance of work performed by the Consultant.

5.4 VALUE ENGINEERING

5.4.1 Purpose

Designers should acquaint themselves with value engineering (VE) objectives and methods, because savings can be achieved in the design phase by using VE techniques. The basic principle of VE encourages the design of cost-effective projects and may include the substitution of alternative designs, materials, and/or innovative construction methods. The following are elements of a VE program:

- a commitment of resources and support by management;
- all levels of management must understand and support the concept of VE;
- a policy directive describing details of a State VE program;
- a VE training program for all levels of management;
- a VE coordinator position that administers and monitors the State's VE program;
- a VE program should be administered:
  + early in the planning/design process to maximize the potential product improvement and cost savings,
  + on high-cost and complex projects, and
  + by a multidisciplinary team of professionals trained in VE techniques;
- all recommendations must be fairly evaluated for implementation; and
- the VE programs within the State organization should be closely monitored, evaluated, and modified to ensure the program's effectiveness.

Typically, SCDOT performs informal value engineering for all projects at various intervals during the project development process. Comments and recommendations are usually made during the initial field review, at the Design Field Review, and other meetings, as needed.

SCDOT also encourages value engineering during construction. Incentives are provided to Contractors to perform value engineering on a project beyond the preconstruction stage. This allows the Department to benefit from a Contractor's design and construction ingenuity, experience, and ability to work through or around restrictions.

5.4.2 Value Engineering Team

For projects that are implemented with Federal-aid funds estimated to exceed $25 million, the Director of Preconstruction should ensure that a multidisciplinary team reviews the proposed project prior to completion of the Project Planning Report (see Section 5.5) to perform a value engineering study. The Value Engineering Team may include the following representatives:

- Bridge Design (Project Manager),
- Preliminary Design,
- Road Design,
- Traffic Engineering,
- Planning,
- Environmental,
- Construction,
- Materials and Research,
- Right of Way,
- Hydraulics,
- District Engineering,
- AGC,
- Consultant,
- FHWA, and
- others as required.

The Value Engineering Team will perform a systematic review and analysis of a project to identify opportunities for reducing the total cost of the project and still provide a project of equal or better quality. Recommendations may include time considerations, traffic control, ease of construction, and maintenance. Other suggestions may include combining or eliminating otherwise inefficient or expensive parts of the original proposed design for the project or a total redesign of the proposed project using different technologies, materials, or methods and yet accomplish the original purpose of the project.

Once the Value Engineering Study Approval Committee approves the Value Engineering Team's recommendation(s), the Project Manager may complete the Project Planning Report. If significant changes are required during the subsequent development of the Project, the Director of Preconstruction may reconvene the Value Engineering Team to consider changes in the scope of the project and offer additional recommendations.

5.5 PROJECT REPORTS/REQUESTS

This Section provides information on how to prepare Department reports for bridge projects including the Program Action Request; Project Planning Report; Bridge Type, Size, and Location Study for Conceptual Bridge Plans; and other reports/requests. When used as described, this information will provide consistent, accurate, and appropriate project reports and requests.

5.5.1 Bridge Replacement Site Information Sheet

For bridge replacement projects, the Project Manager is responsible for completing the Bridge Replacement Site Information Sheet. This Sheet provides information to the designer regarding the location and condition of the existing bridge, utilities, and hydraulics. It also provides recommendations to the bridge designer on the design of the structure.

The Project Manager will forward the Sheet to the Bridge Design Teams, who will retain it in the project file. The Project Manager also includes a site location map and summary report from the National Bridge Inventory (NBI) database.

The Bridge Replacement Site Information Sheet should include the following information:

1. Heading. Include the date of preparation and whether the proposed project is fast-tracked, FEMA, or normal.

2. Existing Bridge. Identify the following existing bridge information:

   - county name,
   - road/route name and number,
   - local road and/or bridge name,
   - structure number,
   - type of crossing,
   - structure location,
   - structure length,
   - structure width,
   - traffic data, and
   - length of detour (if applicable).

   Ensure that the structure number matches the information provided in the NBI database. Also, include the posted weight limit, if applicable, superstructure and substructure type, distance from the finished grade to the existing ground, and the type of existing pavement.

3. Utilities. Indicate if utilities exist and whether they are attached, overhead, or underground. Include a description (e.g., 10-in waterline, phone, fiber optic).

4. Hydraulics. Include the distance of the finished grade to the water, water depth, and any other observations regarding the channel (e.g., observed scour, observed debris, exposed rock).

5. Recommendations. Provide design recommendations, as appropriate. Some of the recommendations should include the following:

   - type of structure,
   - approach slab requirements,
   - required permits,
   - skew angle,
   - opportunity for public hearing,
   - pavement width,
   - shoulder width,
   - design speed,
   - bridge length,
   - bridge width,
   - number and length of spans,
   - whether or not to raise the grade, and
   - existing and proposed right-of-way requirements.

6. Comments. Include any other information that is necessary to clarify the details on the existing and/or proposed structure.

7. Sketch. Include a sketch of the existing site conditions and proposed replacement options.

8. Attachments. Include a site location map and the latest Structure Inventory and Appraisal (SI&A) Sheets.

5.5.2 Program Action Request (PAR)

A proposed project can originate from a variety of sources, including local officials, county transportation commissions, councils of government (COG), or metropolitan planning organizations (MPO) (community-based need); directly from the SCDOT District Office (district-based need); from a Section/Division within the Headquarters (e.g., Preconstruction, Traffic Engineering Division, Planning Division); or from SCDOT management systems (e.g., Traffic Safety, Bridge Replacement Program) targeting a special or Statewide need. Once the review and recommendations are completed, the Project Manager prepares and submits a PAR to the Director of Preconstruction for approval. The following information is included in the PAR:

- date of request,
- road/route number and local name,
- county name,
- city/town,

- MPO area,
- COG area,
- Congressional District,
- project length,
- number of lanes,
- project location,
- general description of road and/or bridge work,
- bridge structure number,
- nature of request,
- proposed improvement type,
- type of highway and its functional class,
- proposed funding source,
- obligation schedule and cost estimate,
- an attached site location map,
- an attached Structure Inventory and Appraisal Sheet (SI&A), and
- an attached PPM Project Characteristics Form.

For Federally funded projects, the Federal-aid Unit will forward the PAR to FHWA for its approval.

5.5.3 Notice of Eminent Domain

Established procedures from the *Code of Laws of South Carolina* specify that reasonable notice must be given to landowners prior to entry upon the real property for the purpose of making a survey, determining the location of proposed improvements, or making an appraisal. Prior to the Request for Survey, the Project Manager is responsible for providing a description of the project to the Legal Advertising Coordinator in the Environmental Management Office, which will publish a legal notice in the appropriate local newspaper. The Notice of Eminent Domain will include the following information:

- a legal description of the *Eminent Domain Procedure Act* (prepared by the Advertising Coordinator),
- a contact number for more specific project information (prepared by the Advertising Coordinator), and
- the location and a brief description of the proposed project (prepared by the Project Manager).

The Survey will not be initiated until the Notice of Eminent Domain has been advertised.

5.5.4 Request for Survey

5.5.4.1 General Survey

When the existing alignment is used, Road Design's Bridge Project Facilitator "redlines" the existing plans according to the proposed project's needs. The Bridge Project Facilitator will use any applicable information obtained from the Scoping Trip in preparing the survey request.

When the existing alignment is not used, the Preliminary Design Group within the Road Design Section is responsible for determining the new alignment. If necessary, the Bridge Design Section will provide a minimum offset dimension. The Preliminary Design Group will provide the new alignment to the Bridge Project Facilitator. The Facilitator will use the alignment information to prepare the survey request. The following procedures will occur:

1. Road Design Section. The Road Design Section will initiate the Request by editing (i.e., red-lining) a set of old plans or maps and forwarding them to the Bridge Design Section.

2. Checklist. The Project Manager will review the marked-up plans and/or maps. The Bridge Project Facilitator will then complete a checklist and forward it through the Project Manager to the Hydraulic Engineer for review.

3. Hydraulic Review. After the Hydraulic Engineering Section has completed its review, the Hydraulic Engineer will sign and date the Request. The Request is returned back to the Project Manager.

4. Submission. After all reviews and signatures are obtained, the Project Manager will forward the request, marked-up plans, and/or maps to the Surveys Office.

5. Surveys Office. Once the Surveys Office receives the Request, it will conduct the field survey and prepare all necessary notes, drawings, and recommendations for existing field conditions, drainage systems, utility lines and right-of-way, and their relative positions and elevations. The Surveys Office will select and contract with a Subsurface Utility Engineering (SUE) Consultant, when requested. The Surveys Office places the survey information into CADD for the Bridge Design Team's use.

5.5.4.2 Surveys/Subsurface Utility Engineering

The standard survey practice of accurately finding the location and elevation of all aboveground utility topography is typically used for most projects. For other projects, where the location of underground utilities is considered critical to the design process, the use of a Subsurface Utility Engineering (SUE) service will be required.

SUE is a method for identifying the location of subsurface utilities at various levels of quality. Each quality level is defined by the thoroughness, accuracy, and methods used in gathering the subsurface utility information.

A representative of the Surveys/Utilities Office working with the SUE firm, as well as the Project Development Team, will determine the extent of utility delineation and the appropriate levels needed based on the utility information available, utility risk, and project budgetary constraints. Once the Department has contracted with the SUE firm for the required quality level(s), the SUE firm will be responsible for obtaining some or all of the following utility information in accordance with the current Department SUE CADD criteria and will be responsible for the negligent errors or omissions in the data. The following is the minimum data required:

- utility ownership information for all utilities within the project limits,
- location of all underground utilities,
- location of all aboveground utility topography,
- location of all utility poles including identification number,
- location of all aerial utility facilities, and
- utility details as required by the standard Utility Data Sheets.

5.5.5 Hydraulic Report/Scour Report

Any structures over a waterway will require a Hydraulic/Scour Study. Once the general bridge location is known, the Project Manager will prepare a request to the Hydraulic Engineer to conduct the necessary studies and prepare the applicable reports. Based on the hydrological data collected and the preliminary plan and profile, the Hydraulic Engineering Section will perform the detailed hydraulic analysis for a bridge. The Project Manager will prepare and submit the Request.

Include the following information in the Request:

- county name;
- route/road number and/or name;
- project identification number (PIN);
- file and project number;
- a brief project description;
- charge code;
- type of information needed:
    + NPDES;
    + pipe size;
    + structure type (e.g., bridge, culvert);
    + floodplain locations; and
    + detailed hydraulic analysis;
- any applicable remarks;
- name of responsible Project Manager; and
- name of Road Design Group Leader.

Once the hydraulic analysis is completed, the Hydraulic Engineer will submit a Hydraulic Report/Scour Report to the Bridge Design Team Leader documenting the findings from the evaluation. The Report will provide:

- beginning and ending stations;
- the water surface elevation for the design-year flood;
- a minimum low-chord elevation;
- a minimum finished grade;
- riprap requirements;
- the proposed number of spans;
- the necessary bridge waterway channel bottom width, side slopes, skew angle, and channel centerline station; and
- the results of the hydraulic scour analysis.

5.5.6 Initial Studies Request

The Assistant State Bridge Design Engineer will provide an Initial Studies Request to the Environmental Operations Manager in the Environmental Management Office to initiate the environmental and permitting process. The Request should provide the following information:

- county,
- road and/or route name,
- construction project identification number (PIN) number,
- file number,
- project description,
- project identification number (PIN), and
- charge code.

In addition, the Request should include any structure numbers, estimated project limits, estimated bridge limits, and traffic control requirements, where applicable.

See Chapter 2 for more information on the Initial Studies Request.

5.5.7 Request for Seismic Information

The Bridge Design Team will request seismic information from the State Geotechnical Design Engineer. The request should include the:

- county name,
- road/route name and number,
- local road and/or bridge name,
- file number,
- project identification number (PIN),
- brief project description, and
- longitude and latitude of structure.

5.5.8 Bridge Type, Size, and Location Study (Conceptual Bridge Plans)

Once the Preliminary Design Group determines the general roadway alignment and elevations, the Road Design Section will forward this information to the Bridge Design Section. At this point, the bridge designer will prepare the Bridge Type, Size, and Location Study.

The Study will provide the following information:

- Title Sheet;
- plan and profile of the bridge showing the proposed type of superstructure (e.g., prestressed concrete, steel, flat slab) and foundation (e.g., drilled shafts, piles, footings), and existing ground profiles at the bridge site;
- permanent retaining walls and temporary shoring;
- superstructure cross section showing pertinent structural elements (e.g., number and type of beams, width of bridge deck, superstructure depth);
- bridge railing/parapets, sidewalks, and/or shoulders;
- horizontal and vertical clearances;
- preliminary geotechnical subsurface information, if available;
- channel section and bent locations; and
- existing high-water elevation, if available.

The Assistant State Bridge Design Engineer will review the Study before the Project Manager forwards this information to the Road Design Section. This Study is then used to develop the Preliminary Bridge Plans.

5.5.9 Soil Boring Logs Request

The Bridge Design Team will provide the Geotechnical Design Section with the Title Sheet, Roadway Plan and Profile Sheets, and the Bridge Plan and Profile Sheet. The State Geotechnical

Design Engineer will determine the locations of the soil borings and mark these locations on the plan sheet. The State Geotechnical Design Engineer requests the Office of Materials and Research to conduct the soil borings and prepare the logs. For Consultant-designed projects, the State Geotechnical Design Engineer will approve the locations of the soil borings. The purpose of the boring logs is two-fold:

- identification of the various soil and rock strata and ground water levels; and
- the determination of the engineering properties (e.g., load-carrying capacity) of the native material.

Once the drilling is completed and recorded, the Office of Materials and Research will provide this information to the State Geotechnical Design Engineer, who will forward the information to the Bridge Design Team. The State Geotechnical Design Engineer will use this information to prepare the Geotechnical Reports. The Bridge Design Team will use this information and incorporate it directly onto the Boring Log Detail Sheets; see Section 6.3.

5.5.10 Preliminary Geotechnical Report

The Preliminary Geotechnical Report is prepared by the Geotechnical Design Section and forwarded to the Bridge Design Section when complete. The Report should summarize the findings obtained by the preliminary field review of the bridge site by the Geotechnical Design Section. The Preliminary Geotechnical Report may include the following:

- a summary of field reconnaissance of the surface indications of subsurface properties (e.g., surface soils, rock exposures, stream-deposited soils, gullies, stream banks, water surface flows, existing structures in the area, topography, vegetation);
- the initial evaluation of a boring plan and the physical characteristics of the site for the setting up of its drill rigs for the boring logs;
- a description of the necessary in-situ field testing and the necessary boring samples for laboratory testing;
- an evaluation of the embankment stability;
- for proposed cuts, a determination of the slope stability characteristics and the need for any special treatments (e.g., benching);
- an evaluation of any erosion potential within the project limits;
- anticipated foundation types and estimated fixity depths; and
- a geotechnical seismic report.

5.5.11 Bridge Geotechnical Report

The Geotechnical Design Section prepares the Bridge Geotechnical Report, based on the final geotechnical field investigation and the analysis of the boring logs, and forwards the Report to the Bridge Design Section. The Bridge Geotechnical Report will document the Geotechnical Design Section's recommendations and will include the following supporting data:

- boring log information;
- the native soil and rock types;
- bearing capacities;
- discussions on the recommended foundation type;
- for the selected foundation type, pertinent loading information, allowable bearing capacity for spread footings, depth and diameter of piles/drilled shafts, estimated pile/shaft tip elevations, and minimum pile/shaft tip elevations to maintain lateral stability;
- geotechnical-related specifications; and
- construction-related notes.

5.5.12 Asbestos/Lead Survey

For any bridge removal or portion of a bridge being removed, the Assistant State Bridge Design Engineer – Specifications will prepare a request to the Office of Materials and Research to prepare an Asbestos/Lead Survey. This task is performed by the Department on both in-house-designed and Consultant-designed bridge replacement projects. The request should include the:

- site location map,
- county name,
- road/route name and number,
- local road and/or bridge name,
- structure number,
- type of crossing,
- structure location,
- structure length, and
- structure width.

The Office of Materials and Research, or its Consultant, will conduct the Study and report the findings to the Bridge Design Section. The results of the Survey are included in the project file.

5.5.13 Design Field Review (DFR)

The Road Design Section initiates the Design Field Review. Where applicable, the Road Design Section will request the Bridge Design Section to include information on the necessary bridge elements. For a description of the Design Field Review, see Section 33.2 of the *SCDOT Highway Design Manual* and Chapter 2 of the *SCDOT Bridge Design Manual*.

5.5.14 Project Planning Report (PPR)

A PPR is conducted after the Design Field Review and identifies site characteristics, major design features, and project-related issues. The Project Manager is responsible for the preparation of the PPR. The following Sections describe the process when the Bridge Design Section is responsible for preparing the PPR.

5.5.14.1 Preparation

The following procedures will apply to preparing the PPR for bridge projects:

1. Preparation. The Project Manager is responsible for the preparation and submittal of the PPR. The Report should be organized using the format discussed in Section 5.5.14.2.

2. Signature. Prepare the PPR for the Assistant State Bridge Design Engineer's signature.

3. Distribution. After the Assistant State Bridge Design Engineer has signed the Report, copies of the PPR will typically be distributed to the project file and to the following individuals:

    - Hydraulic Engineer;
    - Road Design Engineer;
    - Road Design Group Leader;
    - District Engineering Administrator;
    - Bridge Maintenance Engineer;
    - Assistant State Bridge Design Engineer;
    - Bridge Design Team Leader;
    - Bridge Construction Engineer;
    - Environmental Manager;
    - State Geotechnical Design Engineer;
    - Utilities Engineer;
    - Traffic Engineer; and
    - others, as deemed appropriate.

5.5.14.2 Format/Content

Desirably, prepare the PPR in the order and format discussed below. This will provide a uniform presentation for all Department PPRs and will ensure that all appropriate information will be addressed. Not all of the subject areas listed below will be required for every PPR, and adjustments will be necessary to the PPR as appropriate. The level of coverage for each item will also vary from project-to-project. Although in-depth coverage of the individual design details is usually not provided in the PPR, provide sufficient detail to allow the reader to fully understand the proposed project.

The following provides the topic areas that should be addressed in the PPR:

1. Heading. Note that the heading must be completely filled out, including the project file number, project number, PPMS preliminary engineering PIN, PPMS construction PIN, Structure ID Number, and charge code. The project number is used by the Department to identify the main focus of an intended project. Include the distribution list in the heading of the PPR.

2. General Summary of Project Recommendations. In this section, list the type of project (e.g., bridge replacement, new bridge).

3. Project Location. Describe the project location. Some of the descriptions that may be used to briefly describe the project location include:

   - county name;
   - city/town name;
   - route number and local road name, if available;
   - nearby mile markers (for railroad purposes);
   - project length;
   - location with respect to existing structures;
   - crossing feature (e.g., river, highway, railroad) and name; and
   - distance and direction from nearby towns/cities.

4. Description of the Proposed Action. Provide a very brief description of the proposed project. For example, “The existing 42 ft by 24 ft deficient bridge will be replaced with a flat slab bridge, 150 ft in length and having a 28-ft clear roadway width. The new bridge will be located on the existing horizontal alignment, and the vertical alignment will be raised approximately 2.5 ft.” The description should indicate whether the project is a new structure, replacement structure, or rehabilitated structure.

5. Purpose. Include a brief discussion explaining the reason why the proposed project was selected.

6. Approaches. Indicate the offices that will be involved in the bridge approach work. Also, state whether or not the following information is required:

- Traffic Control Plans,
- Survey,
- Hydrology,
- Roadway Approach Plans, and
- Environmental Assessment-Initial Studies Request date.

7. Requirements to be Met. Provide a breakdown of the cost requirements for the project. The cost breakdown may include costs for the following:

   - bridge,
   - approach slabs,
   - roadwork,
   - structure removal and disposal,
   - contingency factor,
   - engineering and incidental,
   - preliminary engineering,
   - utility relocations,
   - right-of-way, and
   - the total cost.

8. Permits. Identify any permits required for the project.

9. Traffic Data. If available, include the following traffic data in the PPR:

   - latest year ADT,
   - design year ADT, and
   - percent of trucks (T).

10. Right-of-Way. Provide a brief description on the type of right-of-way required.

11. Detour. Provide the length of the detour, if necessary.

12. Utilities. Provide the type and the names of the utility companies that will be affected by the proposed project.

13. Attachments. Include a site location map. For the Environmental Management Office, include the road plan and profile sheets.

5.6 RECORDS AND FILES

5.6.1 Bridge Design Files

The project files provide information on the project and a history of the project's development. Separate files are maintained for each project.

5.6.1.1 Design Files

The Bridge Design Team that has responsibility for the design of the project maintains this portion of the file. Typically, it is the responsibility of the Bridge Design Team Leader. The project design file is typically comprised of the following:

1. Design Computations/Notes. Design computations are maintained for reference throughout the life of the structure. They provide a record of design analysis methods, materials specified, loadings, and structure dimensions.

2. Quantities. Estimated quantities are retained until construction is completed. They are available to check the estimated quantities against the actual pay quantities. The quantity calculations are kept separate from the design calculations. Upon completion of the project construction, the quantities folders are discarded.

3. Project Reports. Retain all engineering-related project reports (e.g., hydraulics, foundation, boring logs) within the design file.

5.6.1.2 Correspondence

The correspondence portion of the project file provides a single-source location for administrative information on the project and a history of the project's development. This includes all written and electronic correspondence. The following correspondence is typically located in the project correspondence file:

1. Agreements. Include copies of any project agreements in the correspondence folder (e.g., Consultant, Bi-State, Participation, Utility).

2. FHWA Correspondence. Include all correspondence sent to or received from FHWA.

3. Project Planning Report. Include a copy of the Project Planning Report and all related correspondence prepared by the Bridge Design Section.

4. Other. Other miscellaneous documents may include programming information, any special instructions or concerns, problems that may have arisen during design, and any other information related to the project administration.

5.6.2 Miscellaneous Files

5.6.2.1 As-Built Plans

As-built plans are kept by the Final Plans Section. The as-built plans are used to determine what was actually constructed. They are most important for structure rehabilitation projects.

5.6.2.2 Shop Plans

The Bridge Design Section maintains a file for all shop plans used on structure projects. These plans are filed according to the file number. The old shop plans are an invaluable resource when an existing structure is repaired, modified, or rehabilitated. Fabrication-related correspondence is located in the shop plans file. Some of the shop plans that are retained include:

- seismic restrainers,
- prestressed concrete beams,
- structural steel,
- bearings,
- SIP forms,
- prestressed piles,
- deck expansion joints, and
- structure drainage system.

5.6.2.3 Proposal Bids

The Assistant State Bridge Design Engineer – Specifications is responsible for preparing the bridge-related portion of the proposal bid; see Section 9.1. The Department retains project estimates from the letting process for a period of three years after the project is accepted.

5.7 HIGHWAY SYSTEMS

5.7.1 Functional Classification System

The functional classification concept is one of the most important determining factors in highway design. The system recognizes that the public highway network serves two basic and often conflicting functions — travel mobility and access to property. In the functional classification scheme, the overall objective is that the highway system, when viewed in its entirety, will yield an optimum balance between its access and mobility purposes.

The functional classification system provides the guidelines for determining the geometric design of individual highways and streets. Based on the function of the facility, the designer can select an appropriate design speed, roadway width, roadside safety elements, amenities, and other design values. The *SCDOT Highway Design Manual* is based upon this systematic concept to determining geometric design.

The following briefly describes the characteristics of the various functional classifications. See Chapter 9 of the *SCDOT Highway Design Manual* for more information.

5.7.1.1 Arterials

Arterial highways are characterized by a capacity to quickly move relatively large volumes of traffic and sometimes a restricted function to serve abutting properties. The arterial system typically provides for high travel speeds and the longest trip movements. The arterial functional class is subdivided into principal and minor categories for both rural and urban areas.

Principal arterials provide the highest traffic volumes and the greatest trip lengths. The freeway, which includes Interstate highways, is the highest level of arterial. In rural areas, minor arterials will provide a mix of interstate and interregional travel service. In urban areas, minor arterials may carry local bus routes and provide intra-community connections.

5.7.1.2 Collectors

Collector routes are characterized by a roughly even distribution of their access and mobility functions. Traffic volumes will typically be somewhat lower than those of arterials. In rural areas, collectors serve intra-regional needs and provide connections to the arterial system. In urban areas, collectors act as intermediate links between the arterial system and points of origin and destination.

5.7.1.3 Local Roads and Streets

All public roads and streets not classified as arterials or collectors are classified as local roads and streets. These facilities are characterized by their many points of direct access to adjacent properties and their relatively minor value in accommodating mobility.

5.7.2 Federal-Aid System

5.7.2.1 Background

The Federal-aid system consists of those routes within South Carolina that are eligible for the categorical Federal highway funds. The Department, working with the local governments and in cooperation with FHWA, has designated the eligible routes. The following briefly describes the components of the Federal-aid system. See Chapter 7 of the *SCDOT Highway Design Manual* for more information.

5.7.2.2 National Highway System

The National Highway System (NHS) is a network of principal arterial routes identified as essential for international, interstate, and regional commerce and travel and for national defense. It consists of the Interstate highway system, logical additions to the Interstate system, selected other principal arterials, and other facilities that meet the requirements of one of the subsystems within the NHS.

5.7.2.3 Surface Transportation Program

The Surface Transportation Program (STP) is a flexible funding program that provides Federal-aid funds for:

- highway projects on all functional classes (except facilities functionally classified as “local”),
- bridge projects on any public road (including “local” functional classes),
- transit capital projects, and
- public bus terminals and facilities.

The basic objective of STP is to provide Federal-aid for improvements to facilities not considered to have significant national importance (i.e., facilities not on the NHS) and to minimize the Federal requirements for funding eligibility. The Federal funds allocated to STP are comparable to those funds previously designated for use on the former Federal-aid primary, Federal-aid urban, and Federal-aid secondary systems. STP funds are distributed to each State based on its lane-miles of Federal-aid highways, total vehicle-miles traveled on those highways, and estimated contributions to the Highway Trust Fund.

5.7.2.4 Highway Bridge Program

The Highway Bridge Program (HBP), formerly known as the Highway Bridge Rehabilitation and Replacement Program, provides funds for eligible bridges located on any public road. The HBP is the cornerstone of FHWA's efforts to correct, on a priority basis, deficient bridges throughout the nation. The number of structurally deficient and/or functionally obsolete bridges in South Carolina compared to the number nationwide basically determines South Carolina's share of HBP funds.

HBP funds available to non-State highway facilities are based on the provision that no less than 15% of the funds must be used on public roads that are functionally classified as local roads (urban and rural) or rural minor collectors.

HBP funds can be used for total replacement or for rehabilitation. HBP funds can also be used for a nominal amount of roadway approach work to tie the new bridge in with the existing alignment or to tie in with a new gradeline. Funds cannot be used for long approach fills, causeways, connecting roadways, interchanges, ramps, and other extensive earth structures.

Eligibility for HBP funding is based on a Sufficiency Rating (SR) (0-100), which is calculated by the Bridge Maintenance Office. The SR is based on a complex numerical equation that considers many aspects of a bridge (e.g., structural adequacy, safety, serviceability, functionality, detour length). The following applies:

1. <u>Replacement</u>. Bridges scheduled for replacement require an SR less than 50 and must be classified as structurally deficient or functionally obsolete.
2. <u>Rehabilitation</u>. Bridges scheduled for rehabilitation require an SR less than 80 and must be classified as structurally deficient or functionally obsolete.
3. <u>Exception</u>. If the cost of rehabilitation is greater than replacement, then coordination with FHWA is required to determine if the bridge can be replaced.
4. <u>10-Year Rule</u>. If a bridge has been rehabilitated with HBP funds, it is not eligible for additional HBP funds for 10 years.
5. <u>SR ≥ 80</u>. If a bridge has an SR greater than or equal to 80, it is not eligible for HBP funds.

5.7.2.5 Major Bridge Program

The Major Bridge Program is a subset of the Highway Bridge Program, and there is a special provision to use a portion of these funds for the seismic retrofit of bridges. The Major Bridge

Program allocates funds for bridges that may be either on or off the State Highway System that have estimated construction costs exceeding $1,000,000.

5.7.2.6 Innovative Bridge Research and Development Program

The Innovative Bridge Research and Development Program (IBRD) emphasizes new cost-effective, innovative bridge applications.

5.7.3 South Carolina Jurisdictional Responsibilities

This Section briefly discusses the jurisdictional responsibility for the public highway system in South Carolina.

5.7.3.1 State Highway System

The South Carolina State Highway System represents those public highways, roads, and streets for which the SCDOT has direct jurisdictional responsibility for all planning, design, construction, and maintenance. The State Highway System may be identified by the route shield used on the facility, which may be:

- an Interstate Route,
- a US Route,
- an SC Route, or
- an S- (Secondary) Road.

5.7.3.2 County/Municipal System

For all public roads and streets not on the State Highway System, either a county or local municipality has jurisdictional responsibility for the facility.

5.7.4 Roadway Definitions

The *SCDOT Highway Design Manual* provides an in-depth glossary of terms that are used in road design. The following defines selected roadway elements that often have an application to the roadway design portion of a bridge:

1. Average Annual Daily Traffic (AADT). The total volume of traffic passing a point or segment of a highway facility, in both directions, for one year, divided by the number of days in the year.

2. Average Daily Traffic (ADT). A general unit of measure for traffic expressed as the total volume during a given time period, greater than one day and less than one year, divided by the number of days in that time period.

3. Average Daily Truck Traffic (ADTT). The total number of trucks passing a point or segment of a highway facility, in both directions, during a given time period divided by the number of days in that time period.

4. Cross Slope. The slope in the cross section view of the travel lanes, expressed as a percent or ratio based on the change in horizontal compared to the change in vertical.

5. Design Speed. The maximum safe speed that can be maintained over a specified section of highway.

6. K-Values for Vertical Curves. The horizontal distance needed to produce a 1% change in longitudinal gradient.

7. Longitudinal Grade. The rate of roadway slope expressed as a percent between two adjacent Vertical Points of Intersection (VPI). Upgrades in the direction of stationing are identified as positive (+). Downgrades are identified as negative (–).

8. Median. On a multilane facility, the area (or distance) between the inside edges of the two traveled ways. Note that the median width includes the two inside (or left) shoulders.

9. Normal Crown (NC). The typical cross section on a tangent section of roadway (i.e., no superelevation).

10. Overpass. A grade separation where the subject highway passes over an intersecting highway or railroad.

11. Point of Grade (Finished Grade). The line at which the profile grade is measured on the pavement.

12. Roadway. The portion of a highway, including shoulders, for vehicular use. A divided highway includes two roadways.

13. Superelevation. The amount of cross slope provided on a horizontal curve to counterbalance, in combination with the side friction, the centrifugal force of a vehicle traversing the curve.

14. Superelevation Transition Length. The distance needed to transition the roadway from a normal crown section to the design superelevation rate. Superelevation transition length is the sum of the tangent runout (TR) and superelevation runoff (L) distances.

15. Traveled Way. The portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

16. Truck. A heavy vehicle engaged primarily in the transport of goods and materials, or in the delivery of services other than public transportation. For geometric design and capacity analyses, trucks are defined as vehicles with six or more tires.

17. Truck Percentage (T). The percentage of trucks in the total traffic volume on a facility.

18. Underpass. A grade separation where the subject highway passes under an intersecting highway or railroad.

5.8 FHWA OVERSIGHT AND INVOLVEMENT

5.8.1 Project Oversight

The following applies:

1. Interstate System. All new construction and reconstruction projects involving the Interstate system will be developed with full FHWA oversight and approval as shown in Figure 5.8-1. Upon agreement by the FHWA Division Administrator and the Department, large or complex rehabilitation projects (e.g., freeway projects) may also be considered for full FHWA oversight.

2. NHS System. For new construction and reconstruction projects on the non-Interstate NHS system, FHWA oversight and approval will be required where the total project cost exceeds $50 million. For new construction and reconstruction projects less than $50 million, SCDOT is responsible for all facets of the project in accordance with Section 106 of Title 23 USC.

3. All Other Projects with Federal Funding Participation. SCDOT is responsible for all project activities in accordance with Section 106 of Title 23 USC. This applies to all design activities, PS&E approvals, concurrence in awards, and construction and maintenance activities. This precludes the need for any FHWA approval or concurrence, except those actions that require FHWA approval outside of Title 23 USC (e.g., *National Environmental Policy Act* (NEPA), Title VI of the *Civil Rights Act*, the *Fair Housing Act*, the *Uniform Relocation Assistance and Land Acquisition Policies Act*).

5.8.2 Obligation of Funds

SCDOT requests an obligation of funds, and FHWA responds to those requests using its electronic Financial Management Information System (FMIS).

SCDOT does not submit requests for funding obligation on any Federal-aid project until the NEPA approval process has been completed and the projects for which funds are being sought are listed in South Carolina's Statewide Transportation Improvement Program (STIP).

5.8.3 Certification

SCDOT follows all Federal and State laws, regulations, and directives for the design, construction, operation, and maintenance of all Federal-aid projects, including the following, plus any other applicable laws and regulations:

Project Level Actions	**Highway Systems**		
	Interstate or NHS > $50 million	**NHS ≤ $50 million**	**Non-NHS**
All Preliminary Engineering	x		
National Environmental Policy Act (NEPA)	x	x	x
Uniform Relocation Assistance Act and all ROW Matters	x	x	x
Utility Relocation/Railroads	x		
All PS&E Approvals	x	x	
Authority to Advertise for Bid	x		
Approvals of the Award of the Contract	x		
Disadvantaged Business Enterprise (DBE) Program	x	x	x
All Construction Engineering	x		
Davis-Bacon Act Regarding Wages	x	x	x
Approval of Extra Work, Time Extensions, and Claims	x		
Approval of Minor Construction Supplemental Agreements and Contract Modifications	x		
Final Acceptance	x		
Interchange Modifications and New Access Requests	x		
Utility Crossings and Encroachments	x		
Changes in Right-of-Way	x		
Highway Beautification	x		
Landscape and Roadside Development	x		
Bridge Type, Size, and Location	x		
Geometric Design Approval and Design Exceptions	x		

x = FHWA Involvement Required

Notes:

1. *SCDOT is responsible for all FHWA responsibilities for design, plans, specifications, estimates, contract awards, and inspection of all projects except as shown in the chart.*
2. *Projects not on the NHS will be designed, constructed, operated, and maintained according to applicable State laws, regulations, standards, and procedures.*
3. *SCDOT can request FHWA involvement on any project any time or for any phase of work. SCDOT can request technical assistance on any project issue.*
4. *Any State function is subject to all Title 23 requirements and is subject to FHWA review. FHWA will include a sampling of non-Interstate NHS projects and projects not on the NHS as part of all process reviews and product evaluations.*

FHWA PROJECT OVERSIGHT ACTIONS

Figure 5.8-1

- Title 23 USC – *United States Code,* “Highways”;
- 23 CFR – *Code of Federal Regulations,* “Highways”;
- 49 CFR Part 26, “Participation by Disadvantaged Business Enterprises in Department of Transportation Financial Assistance Programs”;
- *The Federal Managers’ Financial Integrity Act of 1982;*
- Title 57 of the *South Carolina Code of Laws;* and
- *Americans with Disabilities Act.*

FHWA is not precluded from reviewing or investigating any phase of the Federal-aid program including control documents on any Federal-aid project, especially those that contain unique features or those with unusual circumstances. Furthermore, this does not preclude SCDOT from requesting FHWA involvement in projects. This does not change any of the responsibilities of FHWA regarding the requirements of NEPA, Title VI of the *Civil Rights Act,* the *Fair Housing Act,* and the *Uniform Relocation Assistance and Land Acquisition Policies Act.*

Chapter 6

PLAN PREPARATION

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 6

PLAN PREPARATION

Part II of the *SCDOT Bridge Design Manual* provides the bridge designer with the Department's policies, practices, and criteria for the design of structures. These designs must be incorporated into the construction plans so that the structural components can be clearly understood by Contractors, material suppliers, and Department personnel assigned to supervise and inspect the construction of the project. Chapter 6 provides guidelines for the preparation of structural plans including the recommended plan sequence, drafting guidelines, and plan sheet content.

6.1 GENERAL INFORMATION

6.1.1 Plan Sheet Size

The Department only uses 22 in by 36 in size plan sheets for project development. Provide a 2-in left-binding margin and ½-in right, top, and bottom margins around the sheet.

6.1.2 Plan Sheet Numbering

In the upper right-hand corner of the sheet, provide the sheet number and the total number of sheets for the project. Number all sheets sequentially including the Title Sheet, which is Sheet 1. If additional sheets are added to the set of plans after the plans are submitted to the Contract Administration Office for letting, add a letter suffix, A, B, C, etc., to the number of the inserted sheets (e.g., 8A, 8B, 8C). Note this in the Index of Sheets.

When bridge plans are included within a set of roadway plans, bridge plan sheets are numbered separately from road plans with a "BR" prefix.

6.1.3 Plan Sheet Sequence

To provide consistency from project-to-project, assemble the bridge plan sheets in the recommended sequence listed in Figure 6.1-1. Note that not all plans will have all of these sheets and that sheets may be combined (e.g., General Notes and General Details). Generally, the bridge plan sheet sequence is dependent on the structure and span layout.

6.1.4 Abbreviations

Where practical, avoid using abbreviations. Figure 6.1-2 includes common abbreviations that should be used where it is necessary to abbreviate elements within the plans.

Title	Section Reference
Title Sheet	Section 6.3.1
Summary of Estimated Quantities Sheet	Section 6.3.2
General Notes Sheet	Section 6.3.3
General Details Sheet	Section 6.3.3
Reinforcing Bending Details Sheet	Section 6.3.4
Roadway Typical Section Sheet	Section 6.3.5
Roadway Plan and Profile Sheet	Section 6.3.6
Stages of Construction Sheet	Section 6.3.7
Bridge Plan and Profile Sheet	Section 6.3.8
Boring Logs Sheet	Section 6.3.9
Foundation Layout Sheet	Section 6.3.10
Bent Sheet	Section 6.3.11
Detailed Drawings Sheet	Section 6.3.11.4
Reinforcing Steel Schedule Sheet	Section 6.3.11.5
Prestressed Concrete Pile Sheet	Section 6.3.12
Superstructure Plan Sheet	Section 6.3.13
Framing Plan Sheet	Section 6.3.14.2
Prestressed Concrete Beam Details Sheet	Section 6.3.14.3
Structural Steel Details Sheet	Section 6.3.14.4
Girder Details Sheet	Section 6.3.14.5
Camber/Blocking Diagram Sheet	Section 6.3.14.6
Bearing Details Sheet	Section 6.3.14.7
Seismic Restrainer Details Sheet	Section 6.3.14.8
Joint Details Sheet	Section 6.3.14.9
Top of Slab Elevations Sheet	Section 6.3.14.10
Sidewalk and Railing Details Sheet	Section 6.3.14.11
Approach Slab Sheet	Section 6.3.15
Slope Protection Paving Details Sheet	Section 6.3.16
Drainage Details Sheet	Section 6.3.17
Utilities Details Sheet	Section 6.3.18
Existing Bridge Plans Sheet	Section 6.3.19

RECOMMENDED BRIDGE PLAN SEQUENCE

Figure 6.1-1

DESIGNATION	ABBREVIATION
-A-	
Abutment	Abut.
Acre	Ac.
Alternate or Alternative	Alt.
American Association of State Highway and Transportation Officials	AASHTO
American Society for Testing Materials	ASTM
Angle	∠
Approach	Appr.
Approximate	Approx.
At (for spacing)	@
Average	Avg.
Average Annual Daily Traffic	AADT
Average Daily Traffic	ADT
Average Daily Truck Traffic	ADTT
-B-	
Baseline	BL
Bearing	Brg.
Benchmark	B.M.
Bent	Bt.
-C-	
Cast Iron	C.I.
Catch Basin	CB
Center	Ctr.
Centerline	℄
Clean Out	C.O.
Clearance	Cl.
Concrete	Conc.
Connection	Conn.
Construction	Const.
County	Co.
Cross Section	X-Sect.
Cubic Ft (Foot)	CF
Cubic Ft Per Second	CFS
Cubic Yard	CY
Culvert	Culv.
Curb and Gutter	C & G

DESIGNATION	ABBREVIATION
-D-	
Decimal	Dec.
Degree	Deg. or (°)
Department	Dept.
Design	Dgn.
Diagonal	Diag.
Diameter	Dia. or ϕ
Diaphragm	Diaph.
Dimension	Dim.
Distance	Dist.
Drawing	Dwg.
Drive	Dr.
Ductile Iron Pipe	DIP
-E-	
Each	Ea.
Each Face	EF
East	E
Elevation	Elev.
Engineer	Engr.
Equal	Eq.
Estimate	Est.
Existing	Exist.
Expansion	Exp.
Exterior	Ext.
-F-	
Far Side	FS
Feet or Foot	ft. or ′
Figure	Fig.
Finished Grade	F.G.
-G-	
Gallon	Gal.
Gallons Per Minute	GPM
Galvanized	Galv.
Galvanized Iron	G.I.
Grade	Gr.
Guard Rail	GR
-H-	
High Water	H.W.
Highway	Hwy.
Horizontal	Horiz.

PLAN ABBREVIATIONS

Figure 6.1-2

DESIGNATION	ABBREVIATION
-I-	
Inch	in. or ″
Including	Inc.
Inside Diameter	ID
Inside Face	IF
Interior or Intermediate	Int.
-J-	
Joint	Jt.
-L-	
Lateral	Lat.
Left	Lt.
Linear Ft	LF
Longitudinal	Longit.
Lump Sum	L.S.
-M-	
Material	Mat'l
Maximum	Max.
Mean Low Water	MLW
Mean High Water	MHW
Mean Sea Level	MSL
Miles Per Hour	MPH
Minimum	Min.
Minute	Min. or (′)
Miscellaneous	Misc.
-N-	
National Pollutant Discharge Elimination System	NPDES
Near Side	NS
Necessary	Nec.
North	N
Not to Scale	NTS
Number	No. or #
-O-	
On Center	O.C.
Outside Diameter	OD
Outside Face	OF
-P-	
Palmetto Utility Protection Service	PUPS
Percent	%
Plate	PL
Prestressed	Prestr.
-R-	
Radius	R
Reinforced Concrete	RC
Reinforcement	Reinf.
Removal	Rem.
Required	Req'd
Revise (Revision)	Rev.
Right	Rt.
Right-of-Way	R/W
Road	Rd.
Roadway	Rdwy.
Route	Rte.
-S-	
Second	Sec. or ″
Sheet	Sh.
Sidewalk	Sdwlk.
South	S
Square	Sq.
Square Foot	SF
Square Yard	SY
Standard	Std.
Station	Sta.
Street	St.
Structure	Str.
Subsurface Utility Engineering	SUE
Superelevation	S.E.
Survey	Surv.
Symmetrical	Sym.
System	Sys.
Space	Sp.
-T-	
Temporary	Temp.
Tie Equality	Tie. Eq.
Thousand Square Yards	MSY
Topography	Topo.
Typical	Typ.
Thousand Board Feet	MBF
-U-	
US Geological Survey	USGS

PLAN ABBREVIATIONS

Figure 6.1-2 (Continued)

DESIGNATION	ABBREVIATION	DESIGNATION	ABBREVIATION
Unless Noted Otherwise	UNO	-W-	
-V-		West	W
Vehicle	Veh.	With	w/
Vertical	Vert.	Without	w/o
Volume	Vol.	-Y-	
		Yard	Yd.
		Year	Yr.

PLAN ABBREVIATIONS

Figure 6.1-2 (Continued)

6.1.5 Plan Cover

The purpose of a Plan Cover is for easy referencing to the project's general information and for filing accessibility. The county, file number, route number/road number, and project description should be permanently marked on the Plan Cover. This information must match the information on the Title Sheet. Generally, the weight of the paper used for the Plan Cover is 110 lb. See Figure 6.1-3 for a sample plan cover and its dimensions.

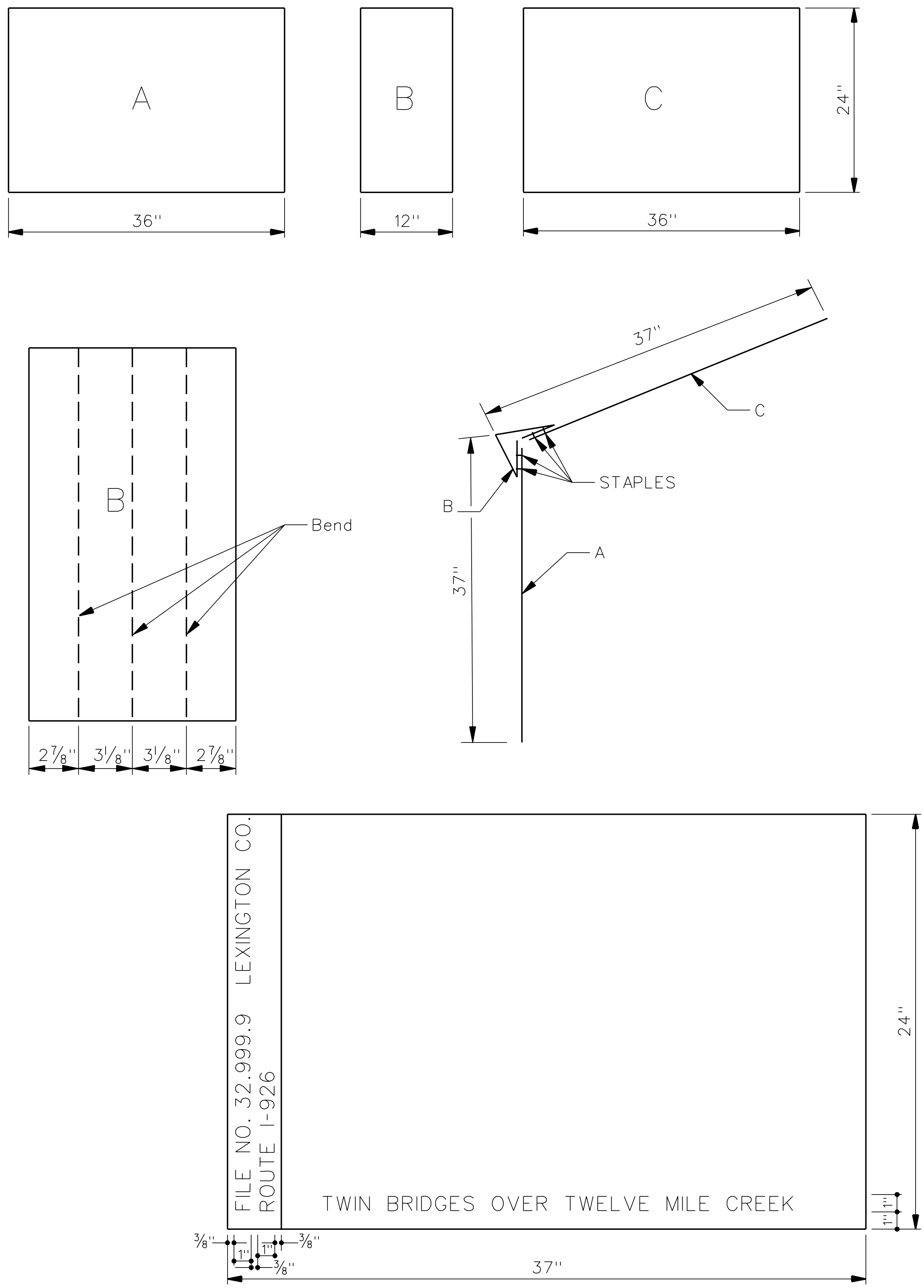
6.1.6 *SCDOT Bridge Drawings and Details*

The *SCDOT Bridge Drawings and Details* provides bridge elements that are consistent from project-to-project (e.g., flat slab details, bridge rails). The *SCDOT Bridge Drawings and Details* can be accessed on the Department's website. The *SCDOT Bridge Drawings and Details* are updated by the Bridge Design Section on an as-needed basis.

6.1.7 General Drafting Guidelines

The Department's project drafting is performed using Computer-Aided Drafting and Design (CADD). All bridge CADD work must be developed using MicroStation software. For more information on CADD symbols, line styles, and CADD cells used by the Department, see Section 6.2.

The following presents some general guidelines on CADD drafting:



SAMPLE PLAN COVER

Figure 6.1-3

1. Overcrowding. Avoid overcrowding a sheet. If all details that normally appear on a particular sheet will result in overcrowding, use an additional sheet.

2. Stationing. SCDOT uses the US Customary stationing of 100 ft. Stationing is shown in the plans to the hundredth of a foot (i.e., Sta. 1 + 00.01). Indicate the direction of stationing in plan and elevation views.

3. Dimensioning. When preparing plan dimensions, consider the following:

   a. Units. Show all dimensions in inches (″) or feet (′) or a combination (to the nearest 1/16″). All elevations are measured to three decimal places (i.e., 0.001).

   b. Tie-downs. Ensure that sufficient "over-all" and "tie-down" dimensions are given in the plans. Arrange tie-down and over-all dimensions so that the reader need not add or subtract dimensions to determine the length, width, or height of an element.

   c. Repetitive Dimensions. Duplicate dimensions may create problems if a dimension is changed on one detail and not another. If duplicate dimensioning is used, ensure that it is consistent from one detail to another.

   d. Location. Preferably, dimensioning should be written so that it can be read from the bottom or right side of the sheet. If practical, place the dimension below or to the right of a detail. See Figure 6.1-4 for an example of text positioning.

   e. Text Size. See Section 6.2 for information on the Department's criteria for text sizes.

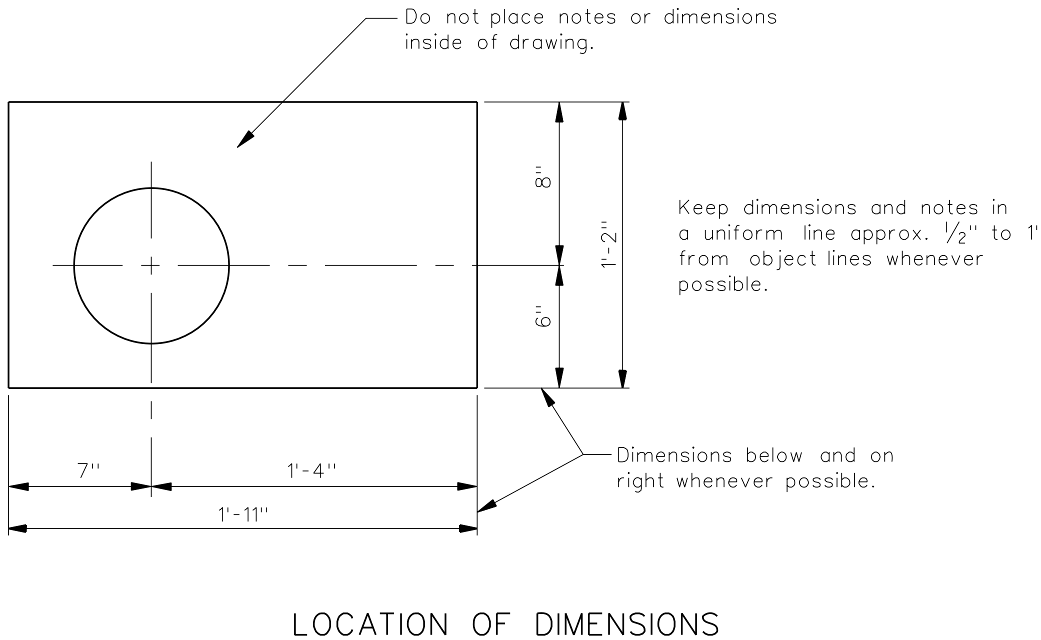
4. Scales. Drawings and details should be drawn to scale. When a scale cannot be shown in all practicality, adjustments (i.e., a relative scale) may be used for clarity. The scales used on a set of plans will vary from sheet-to-sheet and may vary from detail-to-detail within a sheet. In general, scales should be large enough to clearly show all dimensions and details necessary for construction of the structure and yet allow the detail or view to fit on a sheet. See Section 6.2 for additional information. It is not necessary to indicate the scale of the drawing or detail.

5. Angles. Express angles in degrees, minutes, and seconds (e.g., 9°-07′-00″).

6. North Arrow. Provide a North arrow on the Title Sheet, Plan and Profile Sheet, and Foundation Layout Sheet.

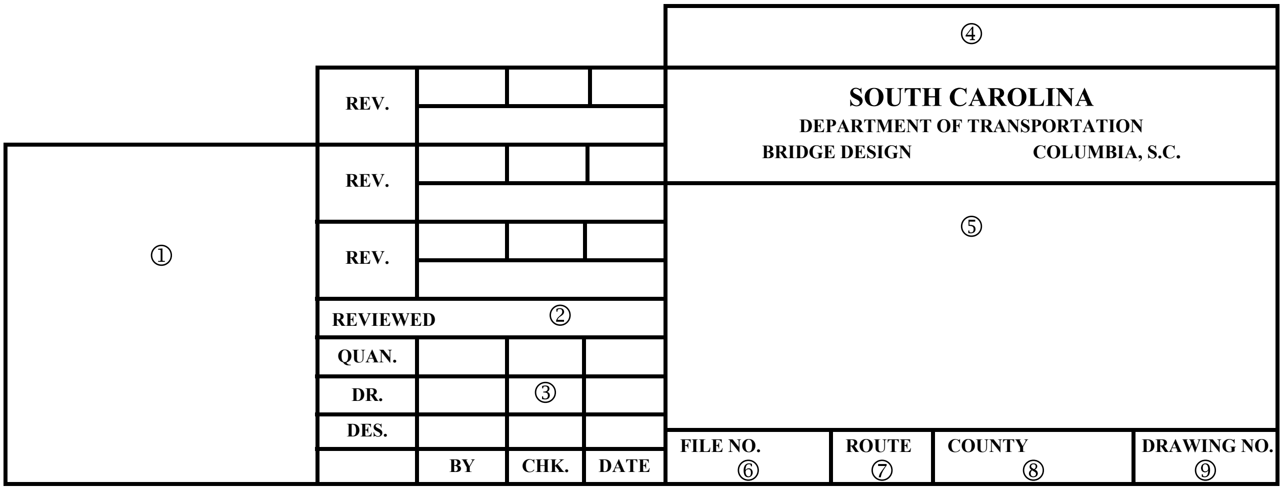
6.1.8 Project Title Blocks

On each sheet, except the Title Sheet, provide a title block in the lower right-hand corner. The information in the title block will vary depending on the sheet. Figure 6.1-5 illustrates a typical title block used on the plan sheets.



TEXT PLACEMENT EXAMPLE

Figure 6.1-4



Notes:

① *Engineer's Seal. The engineer's seal is required on all design sheets along with the signature of the engineer and date signed. Note that the seal may vary within the plans depending on the engineer who prepared the sheet.*

② *Reviewed. The reviewing engineer initials.*

③ *Initials. The initial block will include spaces for the bridge designer, drafter, and checkers to initial the plans.*

④ *Consultant. Provide the name of the Consultant and logo, if applicable.*

⑤ *Sheet Title. Each sheet should be labeled.*

⑥ *File Numbers. Include bridge file number.*

⑦ *Route Number. Note the route number(s) on which the structure is located.*

⑧ *County. Note county name(s) where the project is located.*

⑨ *Drawing Number. This block will be blank unless this sheet is an* SCDOT Bridge Drawings and Details *sheet.*

BRIDGE PLAN SHEET TITLE BLOCK

Figure 6.1-5

6.2 CADD DRAFTING

Project drafting will be performed on CADD. To help in providing consistency from project-to-project and among bridge designers, the following sections provide Department guidelines for the CADD drafting of bridge plan sheets.

6.2.1 CADD Software

SCDOT uses MicroStation as its Department-wide computer-aided drafting and design software package. The following sections provide the Department's CADD criteria for plan development (e.g., cell libraries, levels, text sizes, fonts).

All users outside of the Department network should consult with the SCDOT CADD/Computer Support Unit in the Road Design Section to determine which versions of the software programs are acceptable to the Department. All Consultants submitting CADD contract plans to the Department must use the same version of MicroStation as the Department.

6.2.2 File Setup

All projects are stored on the Department's file servers. Each Bridge Design Team is responsible for creating the Project Folder (i.e., directory) on the server using the project identification number (PIN) as the folder's title. All project-related drawings will be saved in this folder. When naming files in MicroStation, use the filename format and the file codes provided in Figure 6.2-1.

6.2.3 File Backup

It is the Bridge Design Team's responsibility to backup its work to the file servers every day. Only those files that are changed must be backed up to the server.

6.2.4 Drafting Level Names

MicroStation allows the user to select multiple level names to input the figure data. Figure 6.2-2 provides the Bridge Design Section's guidelines for what information should be provided on each level.

Because units other than the Bridge Design Section may use the information contained on the various level names, placement of data on the correct level names is essential. Presenting the project data on different level names allows the user to see or print only the desired data by turning on or off the various level names. When printing, ensure that the appropriate level names are turned on or off; otherwise, the data presented on the screen may not match the printout.

Code (**)	Description
as	approach slabs
bl	boring logs
bp	bridge plan and profile
bt	interior bents
cd	camber/blocking diagram
dd	drainage details
dt	general details
eb	end bents
fl	foundation layout
gn	general notes
gnd	general notes and details (flat slabs)
jt	joint details
la	layout
ms	miscellaneous
pg	prestressed girder
pp	prestressed pile
rb	reinforcing bending details
rw	retaining walls
sc	stages of construction
sp	slope protection
sq	summary of estimated quantities
sr	seismic restrainer details
ss	superstructure
sx	superstructure details
ts	title sheet
ud	utility details
ww	wing wall

Filename Format: b#####**$.dgn

Where:

b = Bridge

= 5-digit PIN – pin identification number including zeros

** = Unique code from the above table

$ = Unique number for multiple files

CADD FILE NAMING CONVENTION

Figure 6.2-1

Level Name	Color Code	Color	Style	Weight
BR_CONCRETE	15	Green		8
BR_CENTER LINES	58	Pink	4	1
BR_STRUCTURAL STEEL	14	Light Red		2
BR_REBAR	3	Red		2
BR_PRESTRESSED BEAM	12	Green		6
BR_GROUND LINES	22	Light Brown		1
BR_TABLE LINES	27	Violet		3
BR_BORDER LINES	21	Gray		8
BR_AUTO DIMENSION	136	Yellow		2
BR_TEXT	106	Blue		2
BR_USER NOTES	16	Light Blue		2
BR_GRID LINES	14	Light Red		4
BR_GRID DOTS	58	Pink		2

Note: All lines are typically solid, except the centerline. Consultants will need to obtain SCDOT's pen tables for the appropriate line weights.

MICROSTATION LEVEL SYMBOLOGY

Figure 6.2-2

6.2.5 Annotation Guidelines

To provide uniformity from sheet-to-sheet, the following steps are required when generating a figure in MicroStation:

Step 1. Open a blank MicroStation file.

Step 2. Create all graphics using a scale of 1:1 without placing dimensions or text.

Step 3. Scale the blank sheet model to the required size rather than scaling the drawings to fit the plan sheet.

Step 4. Once the correct plan sheet size is obtained, the inverse of the Active Scale (AS) used becomes the final scale.

Step 5. Ensure that all dimensions and notes are ⅛ in on the Final Bridge Plans.

Step 6. Ensure that all titles are ¼ in on the Final Bridge Plans.

Step 7. Set text size as presented in Figure 6.2-3. Use of these text sizes will ensure that the text size will be shown correctly when it is referenced into the main file.

Active Scale (AS) Sheet	**Scale**	**⅛″ Text or Dimension***	**¼″ Text***
0.333	3″ = 1′-0″	0:0.5	0:1
0.667	1½″ = 1′-0″	0:1	0:2
1.000	1″ = 1′-0″	0:1.5	0:3
1.333	¾″ = 1′-0″	0:2	0:4
2.000	½″ = 1′-0″	0:3	0:6
2.667	⅜″ = 1′-0″	0:4	0:8
4.000	¼″ = 1′-0″	0:6	1:2
5.333	3⁄16″ = 1′-0″	0:8	1:6
8.000	⅛″ = 1′-0″	1:0	2:0
10.000	1″ = 10′-0″	1:3	2:6
20.000	1″ = 20′-0″	2:6	5:0
30.000	1″ = 30′-0″	3:9	7:6
40.000	1″ = 40′-0″	5:0	10:0
50.000	1″ = 50′-0″	6:3	12:6
100.000	1″ = 100′-0″	12:6	25:0

** Values are for a full-size plan sheet.*

TEXT SIZES

Figure 6.2-3

6.3 PLAN SHEET PRESENTATION

The following sections provide information on the layout and content that should be included on each sheet within a set of bridge plans. The bridge designer should note that not all elements discussed for the various sheets will be required on every project. Also, note that if the information does not fit on one sheet, it may be placed on a second sheet or added to another sheet. Sample plan sheets can be obtained from the Department's Bridge Design Section.

6.3.1 Title Sheet

The Title Sheet is the first sheet for a set of bridge plans. It identifies the project information, project location, list of bridge drawings, approval signatures, etc. This information is discussed in the following sections. Blank Title Sheets for in-house use and for Consultant use are provided in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website.

6.3.1.1 Title Information

Show the project title information in the top center of the sheet and add the following to the title:

- file number,
- county name,
- route/road number and local road name, and
- project description.

Also, include the project identification number (PIN) on the Title Sheet next to the sheet number.

6.3.1.2 Index of Sheets

In the upper left-hand corner of the Title Sheet, provide a table of contents listing each drawing included within the set of bridge plans. Format the table of contents as follows:

1. Title. Use the title "Index of Sheets."

2. Sheet No. Section 6.1 provides the criteria for numbering sheets and the recommended sequence.

3. Description. Provide the sheet title next to the sheet number. The description should match the title shown on the corresponding sheet.

6.3.1.3 Project Length

Include the following information in the Project Length Box:

- net length of roadway,
- net length of bridges,
- net length of project,
- length of exceptions, and
- the gross length of the project.

All lengths are truncated at a thousandth of a mile (i.e., 0.001 mi). Approach slabs are not included in the net length of bridges.

6.3.1.4 Traffic Data

The Traffic Data Box should include the most recent ADT and the design year ADT. Include with the ADT the year the count was made and the design year. Note the percentage of trucks in the ADT. Denote the design year and design ADT with an asterisk indicating that it is the design traffic data.

6.3.1.5 Project Layout Map

Under the title information, include a Project Layout Map. Use a scale so that enough information can be shown on the map that will allow the user to easily determine the location of the project. Project maps can be obtained from the CADD/Computer Support Unit in the Road Design Section. On the map, use a bold circle to indicate the structure location. Use the term "site location" with a leader to the circle. Include the North arrow oriented in the appropriate direction for the map. Indicate the direction of stationing of the project.

6.3.1.6 Location Box

Indicate the approximate location of the roadway by longitude and latitude, which should be shown to the nearest second.

6.3.1.7 National Pollutant Discharge Elimination System (NPDES)

Where roadway approach plans are incorporated, include a note on the Title Sheet indicating the NPDES disturbed area in acres. For additional information on NPDES requirements, see the *SCDOT Requirements for Hydraulic Design Studies* and *SCDOT Road Design Plan Preparation Guide*.

6.3.1.8 Signature Blocks

The information provided in the signature block will vary depending upon if it is an in-house-designed project or a Consultant-designed project. The signature blocks should be located in the lower, right-hand corner of the Title Sheet. For in-house-designed projects, the signature block should include the following information:

1. Prepared By. The Bridge Design Team Leader that is responsible for the preparation of the plans will sign and date the plans.

2. Reviewed By. The appropriate Assistant State Bridge Design Engineer and the State Geotechnical Design Engineer will review, sign, and date the bridge plans.

3. Recommended By. The Project Manager will sign and date the plans, indicating that the plans have been reviewed and are recommended for approval.

4. Approved By. In a separate signature box, the State Bridge Design Engineer will sign and date the bridge plans. This Approval Block will also include the State Bridge Design Engineer's professional engineer's seal.

For Consultant-designed projects, the Consultant should provide a signature block that includes:

- the name and address of the Consultant,
- name and signature of the lead bridge designer(s),
- date the plans were signed,
- the lead bridge designer's professional engineer seal, and
- the firm's Certification of Authorization seal.

6.3.1.9 CADD Drawing Information

In the binding margin, include the date and time the drawing was printed. In the upper left-hand corner of the sheet, indicate the file name.

6.3.2 Summary of Estimated Quantities Sheet

The Summary of Estimated Quantities Sheet will generally consist of two tables — Tabulation of Estimated Quantities and Summary of Estimated Quantities. These two tables are described in the following sections.

6.3.2.1 Tabulation of Estimated Quantities

The Tabulation of Estimated Quantities lists the bid items found within the bridge plans according to bents, superstructure, approaches, etc. Prepare this table in the following manner:

1. Tabulation. Tabulate the quantities according to the following:

   a. Structure Element. Tabulate the quantities accordingly for each bent, span, and approach slab. List the bents in order of increasing stations, then the spans, and finally the approach slabs.

   b. Number of Structures. Where two or more structures are provided, also tabulate the quantities for each structure in the same manner as described in "a." above. Provide a subtotal for each structure. List the structures in order of increasing stations.

   c. Phases. Where more than one stage is used to construct the structure, tabulate the quantities for each stage. Provide a subtotal for each stage.

2. Quantities. Only use the pay items and units provided in the *SCDOT Standard Specifications*, Supplemental Specifications, or Special Provisions. Where practical, list the pay items, from left to right on the sheet, in the order presented in Figure 7.1-1. Figure 7.1-1 also lists the rounding criteria that should be used in the table.

3. Total. Provide a total for all structures and stages at the bottom of the table. For lump-sum items, indicate that the total quantity is "NECESSARY." For more information on lump-sum items, see Section 7.2.

6.3.2.2 Summary of Estimated Quantities

The Summary of Estimated Quantities provides a summary of all bid items on the project. The table should have four columns for the following elements:

- pay item number,
- bid item,
- unit, and
- total quantity of each bridge item used on the project.

Where structural steel is provided, provide a footnote indicating the approximate weight, in pounds, of the structural steel.

6.3.3 General Notes Sheet and General Details Sheet

The *SCDOT Bridge Drawings and Details*, available at the SCDOT website, provides sheets that contain general notes and details that are generally consistent from project-to-project.

The bridge designer is responsible for reviewing the notes and dimensions to ensure that they are applicable for the project. If a note is revised or a new note is added, place it in a double-lined box to alert the reader. However, the bridge designer is not required to provide a double-lined box around the note where values are intended to be incorporated into the note (e.g., seismic design).

On the General Notes Sheet, it is not necessary to delete or strike through notes that are not applicable to the project.

If a detail is not applicable, the detail and its associated notes should be removed from the General Details Sheet.

6.3.4 Reinforcing Bending Details Sheet

6.3.4.1 General

The Reinforcing Bending Details Sheet should include all bar types used on the project. Each bar type should have a bar diagram clearly showing the dimensions or applicable marker (e.g., a, b, c, d). The Reinforcing Bending Details Sheet can be found in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website.

Reinforcing steel bars should be noted in all plan, elevation, and cross section views throughout the plans. Where noted, clearly indicate the bar type, bar size, and series for reference to the Reinforcing Bending Details Sheet. Also, see Section 6.3.11 for a description of the Reinforcing Steel Schedule.

6.3.4.2 Metric vs US Customary Reinforcing Bars

SCDOT performs design work in US Customary units of measurement, and the *SCDOT Bridge Design Manual* is presented in US Customary units only. Therefore, the reinforcement bar designations for all structural design work are in US Customary units. However, materials suppliers provide reinforcement bars to construction sites stamped with (nominal) metric (or SI) designations, although the properties of the reinforcing bars (e.g., diameter) are based on US Customary units.

SCDOT policy is that all construction plans shall be detailed with metric reinforcing bar designations to avoid confusion in the field. Therefore, the bridge designer must use metric reinforcing bar designations for presentation in the plans. See Figure 6.3-1.

6.3.5 Roadway Typical Section Sheet

Include the Roadway Typical Section Sheet for the roadway approaches in the construction plans. If the approach roadway typical section varies from one side of the bridge to the other, include both roadway typical sections.

US Customary Reinforcing Bar Designation	Metric Reinforcing Bar Designation
#3	#10
#4	#13
#5	#16
#6	#19
#7	#22
#8	#25
#9	#29
#10	#32
#11	#36
#14	#43
#18	#57

REINFORCING BAR DESIGNATIONS

Figure 6.3-1

For most projects, roadway approach plans are bound separately, and the typical section is included in the bridge plans for information only. Place the statement, in a large font, "For Information Only" on the Roadway Typical Section Sheet, preferably in the lower right-hand area of the sheet. However, for projects where the road and bridge plans are combined (i.e., one set of plans), this sheet should not include the "For Information Only" stamp.

6.3.6 Roadway Plan and Profile Sheet

Incorporate the Roadway Plan and Profile Sheet that includes the bridge structure.

For most projects, roadway approach plans are bound separately, and the Roadway Plan and Profile Sheet is included in the bridge plans for information only. Place the statement, in a large font, "For Information Only" on the Roadway Plan and Profile Sheet, preferably in the lower right-hand area of the sheet. However, for projects where the road and bridge plans are combined (i.e., one set of plans), this sheet should not include the "For Information Only" stamp.

6.3.7 <u>Stages of Construction Sheet</u>

On non-complex bridge projects, the construction sequence and control of traffic is easily determined, and any needed clarification is shown by the use of plan notes. On more complex projects, the need arises for additional clarification through the development and inclusion of both construction sequences and control of traffic details and notes. This information will be shown on the Stages of Construction Sheet. This is particularly important where traffic must be maintained over the existing bridge during construction and/or the bridge is reconstructed in stages.

Use clear drawings that depict only the existing conditions, and detail the new work for each stage until all work is completed. The bridge designer should include a description for each stage of construction for the traffic control plan as required in each stage of the work. For each stage of construction, show the following information:

- the areas of the existing structure that will be removed during that stage;
- where traffic will be accommodated;
- locations of traffic control devices, including temporary concrete barriers;
- the new portions of the structure that will be constructed during the stage; and
- all appropriate dimensions, notes, and other information required for construction.

Work zone traffic control items (e.g., temporary median barriers, temporary plastic drums, temporary pavement markings) used for the control of traffic during various construction stages generally are quantified separately on the Summary of Estimated Quantities Sheet as a pay item in the road plans. For this situation, ensure that a note is placed on the Stages of Construction Sheet indicating that the quantities for these items are included in the road plans. Construction staging sheets should be coordinated with the Traffic Engineering Division.

6.3.8 <u>Bridge Plan and Profile Sheet</u>

The Bridge Plan and Profile Sheet illustrates the basic layout of the structure. Where practical, the Bridge Plan and Profile Sheet should be presented on one sheet. The Bridge Plan and Profile Sheet can be found in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website. The following sections list the basic information that should be included on this sheet.

6.3.8.1 Plan View

The plan view of the structure is placed in the upper half of the sheet. Label the top half of the sheet "Plan" using the appropriate text size; see Figure 6.2-3. Consider the following when preparing the plan view:

1. <u>Scale</u>. Select the largest engineering scale practical that will allow the plan view of the bridge to fit within the margins of the sheet and still allow the user to clearly identify the

important information on the sheet. For longer bridges, it may be necessary to use two or more sheets to clearly illustrate the proposed structure.

2. Existing Structures. Show the existing structure with light dashed lines. Include a note on the size, material, and disposition of the existing structure.

3. Proposed Structure. Show the concrete outline of the new structure and approach slab with solid heavy lines.

4. Centerlines. Show the centerlines for the following:

   - roadway construction or survey centerline across the structure, and
   - centerlines of roadways and/or railroads under the structure.

   All tangent centerlines should be labeled with their bearings. Where the roadway is on a horizontal curve, the centerline should be labeled with the applicable PC and PT for the roadway and horizontal curvature information; see Item 7.

5. Stationing. In general, draw the structure so that the stationing is increasing left to right on the sheet. All stationing should be shown to the nearest hundredth of a foot (i.e., 0 + 00.01). Where applicable, note the stationing at the following locations:

   - along the top of the sheet, perpendicular to the construction centerline, indicate the roadway stationing at 100-ft increments (e.g., 14 + 00, 15 + 00, 16 + 00);
   - the crossroad stationing;
   - the railroad stationing, if a railroad is involved;
   - matchline stationing where the structure is drawn on two or more sheets; and
   - at tie equality points where the intersection of the design centerline crosses with the crossroad and/or railroad centerlines.

6. Dimensions. Where applicable, include the following dimensions on the plan view:

   - the overall roadway width across the structure;
   - the width from the construction centerline to each edge of the roadway;
   - bridge barrier parapet and median widths;
   - travel lane, shoulder, and median widths prior to and/or beyond the structure;
   - travel lane, shoulder, and median widths for the roadway passing under the structure;
   - sidewalk widths;

- right-of-way limits for railroads;
- minimum horizontal clearances for roadways and railroads passing under the structure;
- horizontal distance between construction centerlines for dual structures;
- offset width between the roadway construction centerline and the structure centerline;
- offset from the detour bridge to the construction centerline;
- width of each stage, for staged projects; and
- any other dimensions, provided that they do not reduce the clarity of the drawings (e.g., boring locations, berms, toes of slopes).

7. Horizontal Curve Data. If the structure is on a horizontal curve, include the curve data on the plan view on the inside of the horizontal curve. If the roadway is superelevated across the structure, provide a detail showing the cross section view of the superelevated section. If the superelevation transitions on the structure, provide a detail showing the method of superelevation.

8. Deck Drains. Indicate the spacing of deck drains and to which side(s) they apply. If deck drains are not required, indicate this in a note on the sheet.

9. Railroad Crossings. Where the structure passes over a railroad, include a table with the elevation for each rail at each railroad station along with the date of the survey. Show the distance to the nearest railroad milepost from the intersection of the centerline track and centerline of the bridge. Include the following note:

   Prior to beginning construction, the Contractor shall check the horizontal alignment and the top-of-rail elevations to confirm that they match the alignment and elevations shown in the plans. The Contractor shall notify in writing the RCE of his finding. All cost of this work shall be included in the lump-sum price bid for Construction Stakes, Lines, and Grades.

10. Miscellaneous Information. Where applicable, note the following information on the plan view:

- North arrow;
- skew angle between the construction centerline, or long chord on curved bridges, and the centerline at one or more of the bents;
- location of expansion joints and deflection joints;
- approximate toes of fills and/or tops of cuts;

- name of stream and flow direction;
- highway route numbers;
- traffic direction and name of nearest locality, major street, landmark, etc.;
- traffic directions for crossing highway;
- name of crossing facility (e.g., waterway, railroad, highway);
- limits and type of slope protection;
- locations of temporary shoring;
- structure-mounted signs or luminaires;
- locations of utilities;
- boring locations;
- all utility attachments to the structure; and/or
- any other notes applicable to the drawing.

6.3.8.2 Profile View

Show the profile view of the structure directly below and in the same scale as the plan view. Label the bottom half of the sheet "SECTION ALONG ℄ SURVEY" in the appropriate text size; see Figure 6.2-3. Consider the following when preparing the profile view:

1. Structure. In general, only show the proposed structure at the profile view (i.e., do not show an existing structure to be removed). However, if sections of the existing structure will remain, they should be shown and noted.

2. Stationing. Note the stationing at the following locations:

   - the station should be shown at 100-ft increments, along the bottom of the profile view (e.g., 807 + 00, 808 + 00) and the appropriate in-between stations (e.g., +10, +20, +30 or +20, +40, +60), depending on the scale;
   - beginning and ending of each approach slab;
   - beginning and ending of the bridge;
   - where the centerline of each bent crosses the construction centerline; and
   - if applicable, the PVI, PVC, and/or PVT station.

3. Profiles. Show the following profiles in the elevation view:

- Show the finished grade line profile at the construction centerline with a solid line.
- Show existing ground lines with a light dashed line.
- If available, include profiles left and right of the centerline. Use different types of dashed lines (e.g., dash-dot lines) to indicate the various profile grade lines and label each line with the distance to the centerline.
- For stream crossings, show the 100-year and 500-year scour lines.

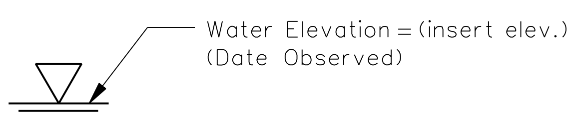
4. Vertical Curvature. Where applicable, include the following vertical curve data on the profile:

- the length of curve expressed in feet,
- the intersection (PVI) of the forward and back tangent grade lines expressed by stationing with PVI elevation, and
- grade in and out in percent.

5. Bent Numbering. Under each bent, consecutively number the bents by increasing stations matching the plan view. Use a number within a small circle. Also, provide a label to indicate that these are the bent numbers (i.e., BENT NO. →). Bent numbering is not necessary if the structure is a single-span structure and there are no interior bents.

6. Elevations. Provide an elevation scale along the left and right side of the profile view. The vertical and horizontal scales should be the same. Show all elevations on the sheet to the nearest thousandth of foot (i.e., 0.001 ft). Where applicable, note the elevations for the following:

- the finished grade at the bridge;
- the finished grade at the beginning and ending of each approach slab;
- the finished grade at the intersection of the construction centerline and each bent centerline;
- the water surface at the time of the survey (see Figure 6.3-2);



SYMBOL FOR SHOWING WATER ELEVATIONS

Figure 6.3-2

- the 100-year, 50-year, 25-year, and highest recorded high-water elevations (as applicable); and/or

- benchmark elevations and description.

7. Dimensions. Dimensions on the profile view may include:

   - the approach slab lengths;

   - the out-to-out horizontal distance of the overall bridge length;

   - the length of continuous spans;

   - the span distance between bents, measured horizontally (when necessary, label spans);

   - the distance between the beginning and ending of bridge and the centerlines of the end bents; and

   - the minimum vertical clearances for railroad and highway bridges.

8. Substructures. For structures on pile-supported footings, note the type of pile to be used. Show drilled shafts, rock sockets, and columns.

9. Hydraulic Data. Where the bridge is crossing a waterway, include all applicable hydraulic data pertinent to the design of the structure. Include the following information:

   - the drainage area, in square miles;

   - design year flow rate (e.g., 25-year, 50-year, 100-year), in cubic feet per second;

   - the elevation (feet) and area (square feet) provided under the structure for each design year flow rate;

   - the velocity; and

   - the overtopping flood flow rate, in cubic feet per second, along with the probability of overtopping the structure.

10. Miscellaneous. Where applicable, note the following information on the elevation view:

   - cross section view of the roadway or railroad under the structure;
   - the type of bearing (i.e., fixed, expansion) at each bent;
   - construction notes applicable to the drawing;
   - the slope rate for end fills at the end bents;
   - type of slope protection;
   - clearances between the toe of slope and railroad tracks; and/or
   - other construction requirements (e.g., earth to be removed and by whom).

6.3.8.3 Other Information

Include the following information on the Bridge Plan and Profile Sheet, where applicable:

1. Benchmarks. Show at least two benchmarks. Indicate the location of the benchmark by station and distance left or right of the construction centerline. Note the type of benchmark (e.g., nail in 10-in pine tree). Include the elevation of the benchmark to the nearest hundredth of a foot (i.e., 0.01 ft).

2. Notes. Include all applicable notes. This includes notes to Contractors for contacting railroads, SCDOT, etc., and construction notes.

6.3.9 Boring Logs Sheet

In general, boring locations should be shown on the plan view of the Bridge Plan and Profile Sheet. For in-house-designed projects, the Geotechnical Design Section will provide the designer with the Bridge Geotechnical Report. The Report will provide boring log information to allow the bridge designer to directly incorporate the information onto the Boring Logs Sheet. Insert the boring logs by their number (e.g., B-1, B-2, B-3).

6.3.10 Foundation Layout Sheet

Draw the foundation layout to scale using the largest scale practical that will allow the foundation layout to fit on one sheet. When preparing the Foundation Layout Sheet, consider the following guidelines:

1. Footings. Show the footing plan for each bent. Note all applicable dimensions to determine the locations of all piles or drilled shafts. Where footings are the same from one bent to another, only show the dimensions on one bent and include a note that the dimensions for the other bents are the same.

2. Pile/Drilled Shaft Locations. Show the locations of all piles or drilled shafts and note the size of the piles or the diameters of the drilled shafts. Also, note the locations and sizes of all load test piles or index piles. For structures supported by piles, include the appropriate Wave Equation parameters in a table on the Foundation Layout Sheet, Bent Sheet, or Bent Details Sheet. The Wave Equation parameters should be similar to the examples presented in Figure 6.3-3.

3. Stationing. Show the stations where the construction centerline intersects the centerline for each bent.

4. Dimensions. In addition to the footing dimensions (see Item 1), indicate the overall length of the structure. This dimension will be same as that shown in the profile view on the Bridge Plan and Profile Sheet.

Parameters	**Bearing Graph Option 1 Proportional Resistance**	**Bearing Graph Option 2 Constant Shaft Resistance**	**Bearing Graph Option 3 Constant End Bearing**
Skin Quake (QS)	0.10 in	0.10 in	0.10 in
Toe Quake (QT)	0.10 in	0.10 in	0.10 in
Skin Damping (SD)	0.20 s/ft	0.20 s/ft	0.20 s/ft
Toe Damping (TD)	0.15 s/ft	0.15 s/ft	0.15 s/ft
Pile Penetration	100%	100%	100%
Shaft Resistance	70%	68 kips	—
End Bearing	—	—	10 kips
Distribution Shape No.	0.0	0.0	0.0

Note: Indicate level of field pile capacity verification that is required.

WAVE EQUATION PARAMETERS

Figure 6.3-3

5. Substructure Location Conflicts. Where the substructure location of the new structure conflicts with the existing structure, note the location of these conflicts on the plan view. Ensure that all structural, geotechnical, and construction engineers are notified as early in the project as practical to eliminate possible delays.

6. Miscellaneous. Include the following information on the Foundation Layout Sheet:

   - North arrow;
   - location of existing foundations;
   - traffic or stream flow directions;
   - construction centerline and alignment data;
   - offset distances from the designated working line (i.e., tangent on chord) to centerline of substructure units;
   - skew angle;
   - bearing and lengths of span and long chords; and/or
   - stage locations.

For additional information on foundations, see Chapter 19.

6.3.11 <u>Bent Sheets</u>

6.3.11.1 General

Each bent generally consists of one or more sheets depending on the features and complexity of the bent. All bents are numbered consecutively, in order of increasing stations (see Section 6.3.8). Where two or more bents are essentially the same, they can be combined onto one sheet and the differences noted on the sheet. For example, this may require including a Table of Elevations to distinguish the different elevations for each bent.

In general, place all necessary details for each bent on one sheet, if practical. Where this is not practical, additional Bent Details Sheets may be placed immediately after the Bent Sheet. Bent Sheets and/or Bent Details Sheets generally should include the following information:

- plan view;
- elevation view;
- cross sections;
- notes;
- drivability analysis parameters (if not included on the Foundation Layout Sheet);
- reinforcing steel schedule;
- quantities for each bent;
- tables of elevations, if warranted;
- pile or shaft load data;
- estimated pile tip elevations;
- minimum pile tip elevation to maintain lateral stability;
- splice lengths;
- bent details; and
- other miscellaneous details, as applicable (see Section 6.3.11.6).

The following sections discuss these elements in detail. Additional information on bents can be found in Chapter 20.

6.3.11.2 Plan View

When drafting the plan view of the bent, consider the following guidelines:

1. <u>Scale</u>. Select a scale that will allow both the plan view and elevation view of the bent to fit on one page and still clearly show the reinforcing details. Section breaks may be used to reduce overcrowding. A second sheet may be used, if needed, to clearly show the details of the bent.

2. <u>Direction</u>. Note the direction of the view (e.g., the direction of stationing) for each bent.

3. <u>Centerlines</u>. For each bent, show the centerlines for the following:

- construction, survey, and/or bridge centerline;
- bearing and bent centerline; and
- each girder/beam centerline.

Indicate the skew angle between the bridge centerline and the bearing and bent centerlines. For end bents, note the location where the bridge centerline crosses the beginning and ending of the bridge.

4. Dimensions. In the plan view, show the following elements:

   - the overall length of the bent;
   - the distances between the outside edges of the bent to construction, survey, or bridge centerline;
   - the distance from the outside edge of the bent to the first and last girder/beam;
   - distance from girders/beams to the construction centerline;
   - the distances for stage construction;
   - the bent width, including:
     + the overall width of the bent,
     + the width from the centerline of the bent to each side of the bent, and
     + for end bents, the distance from the bent centerline to the beginning/ ending of the bridge;
   - for stage construction, note the location and distance from the bridge centerline to the construction joint; and
   - other dimensions as necessary for construction.

5. Beam Seats. Show an outline of all beam seats. If the beam seats are the same, only one beam seat needs to be completely dimensioned. In one beam seat, note the horizontal reinforcing location and bar notation. Show the location, size, and applicable dimensions to the anchor bolts. Include a note informing the Contractor to see the bearing details for additional information.

6. Girders/Beams. Girders/beams are numbered numerically from left to right in the direction of the stationing. Show the dimensions for the following:

   - between the construction centerline and adjacent girders/beams on either side of construction centerline,
   - between the centerlines of each girder/beam, and

- from the centerline of the outside girder/beam to the edge of the cap or foundation.

7. Wing Walls. For end bents, and where applicable, show the width and length of wing walls. Wing wall details (e.g., reinforcing details, height) may be shown on the Bent Details Sheets or on the Superstructure Plan Sheet.

8. Other Information. The following are generally shown and labeled in the plan view:

   - the type and thickness of expansion joint materials;
   - references to other details;
   - other necessary construction details or notes; and
   - shear keys, if applicable.

6.3.11.3 Elevation View

Show the elevation view directly below the plan view and in the same scale as the plan view. When preparing the elevation view, consider the following:

1. Reinforcing Details. Reinforcing bars are typically illustrated in the elevation view. If the bent is essentially symmetrical or similar throughout, it will be acceptable, for clarity, to only show the reinforcing bars on a portion of the bent. Ensure that enough of the reinforcing bars detail is shown so that the bent can be correctly constructed. For information on bar detailing, see Section 6.3.4.

   Plastic hinge zones for column reinforcing shall be clearly identified as "No-Splice Zones" in the plans. All mechanical splices shall be shown in the plans and located outside of the "No-Splice Zones."

2. Dimensions. Consider the following when providing dimensions on the elevation view:

   - Indicate the spacing from the edge of the bent and between the centerlines of piles/drilled shafts/columns and tie-downs to the construction centerline.

   - Show all necessary dimensions that are required to construct the bent.

   - Do not repeat dimensions shown in other views on the sheet.

   - Where more than one bent is represented in the drawing, note where there are differences.

3. Elevations. Elevations should be noted to the nearest thousandth (i.e., 0.001) of a foot. Record the elevation at the following locations on the bent:

   a. Level Caps. For level caps, typically only show the elevation once for the top of the bent cap.

b. Sloped Caps. For sloped caps, note the elevation at the top corner of each cap and at the construction centerline. Also note the slope along the cap.

c. Caps with Build-ups. For caps with build-ups, note the elevation at the top of each build-up, as applicable.

4. Multiple Bents. Where the same detail drawing represents two or more bents, identify where the centerline of each girder/beam crosses the top of the bent with a capital letter, beginning with A. The girder/beam seats should be alphabetized from left to right looking in the direction of stationing. On the same sheet, provide a Table of Elevations indicating the bent number and the elevation at each girder/beam location (e.g., A, B, C).

5. End Walls. The details for end walls can either be shown on the End Bent Sheets or on the Superstructure Plan Sheet. If the bridge designer has elected to show the end wall on the End Bent Sheets, show the elevations at the top of the bridge deck slab at the outside edges and at the construction centerline and at the finished grade line if different from the construction centerline.

6. Piles/Drilled Shafts or Columns. Show the location of piles or drilled shafts/columns in the Elevation View. Number the piles or drilled shafts in numerical order from left to right in the direction of stationing. In addition, the following will apply:

a. Piles. If piles are used, note the following:

- Only show the top portion of pile (i.e., it is not necessary to draw the complete pile to scale).
- Note the type and size of the pile used.
- Note the typical length that the pile is embedded into the bent cap.
- Include the Pile Anchor Detail on the Bent Sheet or on the Bent Details Sheet.
- Show the distance from the edges of bent to the centerline of the first adjacent pile, the distance between the centerlines of each pile, and the distance from the construction centerline to the first piles left and right of the construction centerline.

b. Drilled Shafts or Columns. If drilled shafts/columns are used, note the following:

- Use break lines to show the complete drilled shaft.
- Note the diameter of the columns, drilled shaft, and the diameter of the rock socket.

- For columns, drilled shafts, and rock sockets, provide section views of the reinforcing details. Show spacing of vertical reinforcing along the inside of the hoop.

- On the Bent Sheets or on the Bent Details Sheets, provide a cross section view of the bent showing the horizontal and vertical reinforcing details. If two or more diameters are used (e.g., drilled shaft, rock socket), provide a cross section view for each change in diameter.

- Show the distance from the edges of the bent to the centerlines of the first adjacent drilled shaft, the distance between the centerlines of each drilled shaft, and the distance from the construction centerline to the centerlines of the first drilled shaft left and right of the construction centerline.

- Show vertical spacing of hoops. Include the following note on the sheet:

  > Butt welds of adjacent hoops shall be staggered around the perimeter of the column/shaft by a minimum distance of ⅓ of the hoop circumference.

7. Other Information. The following may be shown or noted in the elevation view:

   - location, width, and type of expansion material;
   - location of construction joints; and
   - other necessary construction notes.

6.3.11.4 Detailed Drawings

Additional detailed drawings are generally required on a Bent Sheet or a Bent Details Sheet to illustrate construction details, the end diaphragm, reinforcing steel type and locations, and other information for various elements that cannot be adequately addressed in the plan and elevation views. Where practical, place these views on the same sheet as the plan and elevation views. However, for large or complex designs, detailed drawings may be placed on a Bent Details Sheet. Only show the details that are applicable to that Bent Sheet (i.e., do not combine all of the bent details onto one sheet). The following bent details may be included on the Bent Sheets or the Bent Details Sheets:

- end elevations;
- section through cap;
- reinforcing splice stagger detail;
- pile anchorage detail;
- pile installation detail;
- prestressed concrete piles;
- cross sections of drilled shafts and columns;
- bearing details (e.g., elastomeric bearing pad, sole plates);

- wing wall detail;
- shear key detail;
- anchor bolt layout;
- footing detail (e.g., reinforcement);
- construction joint details;
- cross section of build-up and wall height detail;
- bridge seat detail; and/or
- any other detail determined to be necessary to construct the bent.

For vertical reinforcing, show the location, spacing, and bar type. If the reinforcing details and spacing are similar for all columns, it is acceptable to show the reinforcing details in only one column. However, if the spacing and bar locations vary, then show the vertical reinforcing details in all columns.

6.3.11.5 Reinforcing Steel Schedule

For each bent, include a Reinforcing Steel Schedule table listing the reinforcing steel used in the bent. Figure 6.3-4 presents a sample Reinforcing Steel Schedule. The information presented in the table should be as follows:

1. Mark. List the bars in the table beginning with the "TYPE" (e.g., A, S, V) in alphabetical order. With each "TYPE" of bar, place the "SIZE" (e.g., 16, 22, 25) of the bars in ascending order and with each "SIZE" of bar, place the "SERIES" (e.g., 01, 02, 03) in ascending order.

2. Number. Note the total number of each bar required for the bent. For stage construction, the bar total should be shown for each stage.

3. Dimension. The letters in these headings correspond to the Reinforcing Bending Details Sheet and indicate the bending dimensions of each side of the bar (e.g., "a," "b," "c," "d") to 1/16th of an inch.

4. Length. The last column indicates the overall length of the reinforcing bar. Bar length is calculated along the centerline and rounded up to the next inch. The maximum lengths of reinforcing steel are as follows:

    - black steel is 60 ft,
    - galvanized steel is 40 ft, and
    - #4 (#13 metric) is 30 ft.

On large projects to assist the Contractor, the bridge designer may elect to place the Reinforcing Steel Schedule tables for each of the bents onto one sheet. Each table must clearly indicate the bent to which it applies. Place this sheet after the last Bent Details Sheet.

Mark	One End Bent						
	No. Required		Bending Dimensions				Length
	Stage 1	Stage 2	"a"	"b"	"c"	"d"	
A1601	2	4	37′-2″	—	—	—	37′-2″
A2501	8	20	1′-4″	—	—	—	1′-4″
A2502	2	8	37′-2″	—	—	—	37′-2″
S1601	16	36	2′-2″	2′-2″	6″	—	9′-11″
SA1601	7	10	2′-2″	2′-2″	6″	—	7′-6″
V2201	4	10	2′-2″	—	—	—	4′-4″
1½″ Dia. Anchor Bolts	8	16	—	—	—	—	2′-1″

SAMPLE REINFORCING STEEL SCHEDULE

Figure 6.3-4

6.3.11.6 Miscellaneous

In addition to the details discussed in the previous sections, the following may appear on the Bent Sheets or on Bent Details Sheets as necessary:

1. Notes. General notes may be placed anywhere there is room on the sheet. Where practical, try to group these general notes in one location, preferably on the right side of the sheet. Notes that apply to a specific detail should be placed next to or within the detail itself.

2. Quantities. Provide a quantities table for each bent presented on a Bent Sheet. If the bents are the same, only include the quantities for one bent. However, note in the header to which bents the quantities apply. See Figure 7.1-1 or the *SCDOT Standard Specifications* for a list of applicable quantities. For projects requiring stage construction, quantities should be broken down by stage.

3. Loads. For bridges with piles, drilled shafts, or footings, include a load and resistance table as illustrated in Figures 6.3-5, 6.3-6, and 6.3-7. Provide a table for each end bent and all interior bents as necessary.

Pile Bearing	
	One Pile
Factored Design Load	56 tons
Geotechnical Resistance Factor	0.40
Estimated Scour	N/A
Liquefaction-induced Downdrag	N/A
Required Ultimate Bearing	140 tons

Note: Method of controlling installation of piles and verifying their capacity: Bearing graph from Wave Equation analysis without stress-wave measurements during driving.

Drivability Analysis	
Skin Quake (QS)	0.10 in
Toe Quake (QT)	0.08 in
Skin Damping (SD)	0.20 s/ft
Toe Damping (TD)	0.15 s/ft
% Skin Friction	80%
Distribution Shape No.	1.0
Toe No. 2 Quake	0.15 in
Toe No. 2 Damping	0.15 s/ft
End Bearing Fraction (Toe No. 2)	0.95
Pile Penetration	80%

PILE LOAD AND RESISTANCE TABLES

Figure 6.3-5

Drilled Shaft Bearing	
Factored Design Load	369 tons
Geotechnical Resistance Factor	0.5
Estimated Weight of Drilled Shaft	103 tons
Required Ultimate Bearing	841 tons

DRILLED SHAFT BEARING

Figure 6.3-6

Maximum Footing Reaction	
Factored Design Load	193 kips
Factored Live Load	132 kips
Factored Backfill (3 ft)	21 kips
Total Factored Design Load	346 kips
Geotechnical Resistance Factor	0.45
Average Bearing	2.7 tsf
Eccentricity	2.3 ft

Note: If footings of different types are used in the design, include a load table in each type of footing.

MAXIMUM FOOTING REACTIONS

Figure 6.3-7

6.3.12 Prestressed Concrete Pile Sheet

If prestressed concrete piling is used, include the Prestressed Concrete Pile Sheet, which can be found in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website. If an alternative design is required, ensure that all information shown in the *SCDOT Bridge Drawings and Details* is shown on the Prestressed Concrete Pile Sheet.

6.3.13 Superstructure Plan Sheet

6.3.13.1 General

The general purpose of the Superstructure Plan Sheet is to illustrate the placing of reinforcing steel within the slab and to note the location of various details within the superstructure (e.g., cross sections of diaphragms, expansion joints, seismic restrainers).

6.3.13.2 Plan View

The plan view shows the bridge deck or a portion of the deck. When detailing this view, note the following:

1. Scale. In general, select a scale that will allow the superstructure plan view to fit on one sheet with the other necessary details and still be large enough to allow clear detailing of the reinforcing steel. However, for longer bridges, it will be acceptable to show the superstructure on two or more sheets by using match lines.

2. Partial Sections. For sections that are essentially symmetrical about the centerline, only half the section needs to be shown. Note in the title for the detail that it is a half side elevation. Variable sections or dissimilar overhangs will require a complete section view.

3. Bar Detailing. For each bar, record the bar mark, the bar size and type, the spacing between bars, and the number of bars in the top and bottom rows. If the reinforcing is similar through the cross section, only a representative portion of the reinforcing may need to be shown on the drawing. Also, include the minimum cover requirements for both the top and bottom mats.

   Use the following as an example for the format of bar spacing:

   A1606: 448 sp. @ 8″ = 298′-8″ (typ. top and bottom)

4. Dimensions. In addition to the length of reinforcing bars, also provide dimensions for the following:

   - all necessary dimensions from the bent and/or roadway centerlines to determine the location and placement of miscellaneous reinforcing bars,
   - concrete outlines,
   - spacing and orientation of reinforcing bars,
   - splice lengths required for slab reinforcing steel,
   - the width of the barrier,
   - the distance between the barrier and the edge of slab, and
   - the overall width of the slab.

5. Miscellaneous Information. The following items may be identified on the plan view:

   - construction centerline of the roadway;
   - centerlines of each bent;
   - the skew angle;
   - high and low sides of superelevated sections;
   - partial sections of beams, girders, diaphragms, etc.;
   - section call-outs (e.g., A-A, B-B);
   - construction joints;
   - gutter lines;
   - utilities; and/or
   - special notes.

6.3.13.3 Side Elevation View

When preparing the side elevation view, consider the following:

1. Scale. The scale for the side elevation view should match the selected scale for the plan view. Ensure that the selected scale will adequately show the necessary details of the section.

2. Girders/Beams. A side elevation view may illustrate the type and size of steel girder or concrete beam used on the structure. However, they are generally detailed on the Superstructure Details Sheets.

3. Reinforcing. The section view should indicate the location of the reinforcing steel within the sidewalk and barrier. Show all applicable spacing and location dimensions for the placement of reinforcing bars.

4. Barrier/Rail Details. Show the bridge barrier parapet on this sheet. Bridge rail construction details may be included as a separate detail sheet; see Section 6.3.14. For concrete barriers, construction and reinforcement details may be included on a separate detail sheet.

5. Miscellaneous Information. Include the following miscellaneous information in the side elevation view:

   - top of rail,
   - top of sidewalk,
   - top of slab/deck,
   - location of guardrail attachments,
   - construction joints, and/or
   - other special notes.

6.3.13.4 Detailed Drawings

The Superstructure Details Sheets present the details of each of the elements that comprise the superstructure. If space allows, some of these details may be placed on the Superstructure Plan Sheet. The following sections discuss many of the details that should be provided on the Superstructure Details Sheets.

6.3.13.4.1 Typical Section

Include a typical section of the superstructure at each bent and at mid-span. If the structure is essentially symmetrical around the centerline, both typical sections may be shown on one detail. However, ensure that the detail is labelled accordingly. The typical section detail should include the following:

1. Centerlines. Show the construction centerline and centerlines for each girder/beam.

2. Dimensions. Show the following dimensions on the typical section detail:

   - total out-to-out widths,
   - widths between the construction centerline to the gutter line,
   - the width of the rail/barrier parapet,
   - stage construction widths,
   - any other widths necessary to construct the structure, and
   - sidewalks.

3. Flat Slab or Slab on Girder. Indicate the following:

   - reinforcing details, including the bar type, spacing, clearances, etc.;
   - thickness of the slab;
   - direction and cross slope of the slab;
   - finished grade;
   - size and location of the drip groove; and
   - deck drains.

4. Reinforcing. If the reinforcing is similar through the cross section, only a representative portion of reinforcing may need to be shown on the drawing. Also, include the minimum cover requirements for both the top and bottom mats. Show all applicable spacing and location dimensions for the placement of reinforcing bars.

5. Barrier Parapet/Railing Wall. The barrier parapet/railing wall may be shown in the typical section detail if the details can be clearly shown.

6. Girders/Beams. Show the girders/beams to scale, and number the girders/beams and details as discussed in Section 6.3.11. For structures with concrete beams and diaphragms, the diaphragm reinforcing details may either be shown on the typical section detail or in a separate detail drawing.

7. Miscellaneous. Other details that may be shown on the typical section detail include:

   - location of utilities attached to the structure,
   - special pouring locations,
   - stage construction widths, and
   - special construction notes.

6.3.13.4.2 Slab Pouring Sequence

If required, include a slab pouring sequence detail on the Superstructure Plan Sheet or as a separate detail on a Superstructure Details Sheet. Chapter 17 discusses the criteria for determining the order of slab pouring. The slab pouring sequence detail should include the following information:

1. Notations. Note the pour sequence with numbers inscribed in circles.

2. Dimensions. Show the length and width of each pour segment.

3. Direction of Pour. Include the direction of pour for each segment.

4. Minimum Pour Rate. Include the minimum pour rate if greater than the minimum required by the *SCDOT Standard Specifications*.

5. Additional Information. Show the following information on the slab pouring sequence detail:

   - the centerline of bents,
   - different hatching for adjacent segments, and
   - the location of the various project stages.

6.3.13.4.3 Miscellaneous Details

The Superstructure Plan Sheet or a Superstructure Details Sheet should include the following details as required:

1. Section Call-Outs. For any call-outs (e.g., A-A, B-B) noted on the Superstructure Plan Sheet, include a detailed section showing the necessary reinforcing details and dimensioning. If the detailed section is located on another sheet, reference the sheet number where the detail can be found.

2. Reinforcing Steel Schedule. Include a Reinforcing Steel Schedule table as shown in Figure 6.3-4. On large projects, the bridge designer may elect to place the Reinforcing Steel Schedule on a separate sheet. Place this sheet after the last superstructure reinforcing detail. See Figure 6.3-8 for an example of a superstructure reinforcing detail.

3. Quantities. Include a table of quantities for the superstructure items. The table should indicate the item, unit, and total quantities.

4. Other Details. Note that several of these details may also be placed on the Framing Plan Sheet. Other details may include:

   - girder/beam details,
   - camber diagram with a dead load deflection table,
   - cross frame details,
   - jacking points,
   - field splice details,
   - stud/shear connection details,
   - drain details,
   - wing wall details,
   - diaphragm details,

Reinforcing Steel Schedule							
Mark	**No. Required**		**Dimension**				**Length**
	Stage 1	**Stage 2**	**"a"**	**"b"**	**"c"**	**"d"**	
A1601	400	564	34′-8″	—	—	—	34′-8″
AV1601	242	—	31′-8½″	3′-8″	59′-9″	5⅝″ *	Varies
AV1602	—	24	32′-7″	31′-4″	33′-10″	2¾″*	Varies
1¼ ″ Dia. Tie Bar	6	—	42′-1″	—	—	—	42′-1″
BB	1″ Ht.			As Necessary			
BBU	2″ Ht.			As Necessary			

** Two bars per incremental length.*

Note: The sample shown is for a staged construction project.

SAMPLE SUPERSTRUCTURE REINFORCING DETAIL

Figure 6.3-8

- tie rod details,
- construction joint details,
- parapet details,
- sidewalk details,
- slab build-down details, and
- all special construction notes.

6.3.14 Other Superstructure Sheets

6.3.14.1 General

The bridge plans may require sheets in addition to those listed in Section 6.3.13. This Section describes these other superstructure sheets.

6.3.14.2 Framing Plan Sheet

The Framing Plan Sheet illustrates the placement of steel girders, concrete beams, splice locations, stiffener locations, diaphragm/cross frame locations, skew angle(s), and other details. The extent of details placed on this sheet will depend upon whether the structure is steel or concrete, the project complexity, the degree of skew, etc. To determine the information that should be placed on this sheet, the bridge designer should consider the following:

1. Prestressed Concrete Beam Bridges. For prestressed concrete bridges, the Framing Plan Sheet may consist of the following items:

   - dead load deflection table, and
   - other miscellaneous details.

   These items may be included on the Superstructure Plan Sheet.

2. Steel Girder Bridges. The Framing Plan Sheet for the steel bridge will consist of the plan view and one or more of the following details depending on the space on the sheet:

   - longitudinal elevation,
   - stiffener details,
   - cross frame elevations,
   - dead load deflection table,
   - shear connector/welded stud details,
   - paint limits, and
   - other miscellaneous details.

3. Scale. Draw the framing plan detail to scale using the largest scale practical that will show the necessary girder/beam placement and still fit on the sheet.

4. Symmetry. Where the structure is symmetrical about a line, only half the structure needs to be shown. If only half the structure is shown, note that the structure is symmetrical about a line, typically about the construction centerline.

5. Girder/Beam Numbering. For reference purposes, the bridge designer may elect to label each girder or beam (e.g., Girder 1, Girder 2, Beam 1, Beam 2). Where used, consecutively number the girders/beams left to right in the direction of stationing.

6. Dimensions. Tie all dimensions to the construction, bearing, or bent centerlines. Show the following dimensions on the Framing Plan Sheet:

   a. Girder/Beam Spacing. All distances are measured from the centerlines of the girders/beams. Show the spacing between:

      - each girder/beam,

      - the construction centerline and adjacent girders/beams on either side of the construction centerline, and

      - the overall width between the two outside girders/beams.

   b. Field Splice Location. For steel structures, indicate the location of the field splice and distance between:

- the bearings and the field splice, and
- intermediate field splices.

c. Diaphragm Spacing. Label the spacing of diaphragms/cross frames from the centerline of the beginning of the bridge to the centerline of the end of the bridge.

d. Stiffeners. For steel structures, provide dimensions to the location of all stiffeners.

7. Dead Load Deflection Table. Include a Dead Load Deflection Table showing the dead load in kips/ft and the deflection in inches for the following elements:

- structural steel,
- slabs,
- stay-in-place forms, and
- sidewalks/rails.

For continuous steel girders, this table is located on the Camber/Blocking Diagram Sheet (see Section 6.3.14.6).

8. Miscellaneous Information. Note the following applicable information on the detail:

- construction centerline,
- bearing and bent centerlines,
- the degree of skew, and
- the girder or beam type.

6.3.14.3 Prestressed Concrete Beam Details Sheet

Include a separate Prestressed Concrete Beam Details Sheet after the Framing Plan Sheet. Refer to the *SCDOT Bridge Drawings and Details*, available at the SCDOT website, for more information on prestressed concrete beam details. Consider the following:

1. Reinforcing Steel Schedule. Include a Reinforcing Steel Schedule in the top right-hand corner of the sheet. See Section 6.3.11.

2. Quantities Table. Include the quantity items required for one beam (e.g., concrete, class, reinforcing steel, strands, structural steel) in a table directly underneath the Reinforcing Steel Schedule.

3. Notes. Include all applicable notes below the quantities table.

4. Half Side Elevation. Provide an elevation view of the beam noting dimensions, reinforcing steel, centerlines, etc.

5. Beam Camber and Deflection Table. Include a table presenting the beam camber and deflections in inches due to:

   - stay-in-place forms,
   - slab and diaphragm, and
   - sidewalks/rails.

6. Sections Through Beam. Include details of beam sections at the end elevation, at the center of the beam, and at the end of the beam.

7. Other Information. Other information that should be included on this sheet includes the following:

   - design data,
   - prestressing strand data,
   - tolerances, and
   - other applicable details.

For additional information on concrete structures, see Chapter 15.

6.3.14.4 Structural Steel Details Sheet

Where necessary, include a Structural Steel Details Sheet that presents all applicable details for structural steel girders. Consider the following when developing this sheet:

1. Details. The following detailed drawings may be included:

   - typical end cross frame,
   - typical intermediate cross frame,
   - bearing stiffeners,
   - transverse stiffeners,
   - intermediate cross frame (*type*),
   - studs, and/or
   - splice plates.

2. Dimensions. Show sizes and types of applicable elements on each of the details.

3. Notes. Place any applicable notes directly under the detail.

For additional information on detailing steel structures, see Chapter 16.

6.3.14.5 Girder Details Sheet

For steel structures, a separate Girder Details Sheet may be provided. However, if space is available, these details may be placed on the Framing Plan Sheet. When preparing the Girder Details Sheet, consider the following:

1. Girder Elevation. Place the girder elevation view in the upper portion of the sheet. The view must be sufficiently large to illustrate the placement of shear connectors, splices, stiffeners, and diaphragms. When detailing the girder elevation view, consider the following:

   a. Steel Dimensions. For plate girders, note all the plate sizes and lengths for the top flange, web, and bottom flange. Also note the plate size for the stiffeners. Identify any rolled beams.

   b. Shear Connectors. Show the location of the shear connector/weld stud on the girder and note the spacing of the shear connectors. Specify the spacing directly above the girder with the number of connectors and the corresponding spacing.

   c. Field Splices. Note the distances between the end bearing and first field splice and the distances between field splices.

   d. Tension Zones. Note the locations in the top and bottom flanges of all tension zones and the distance over which they apply.

   e. Dimension Lines. Note the various dimension line types (e.g., shear connector spacing, field splice spacing, top flange, bottom flange).

   f. Centerlines. Show the centerlines for all bearings.

2. Splice Details. If room is available on the sheet, include the field splice details. If there is limited space on the sheet, these details may be included on a separate sheet. The splice details, as applicable, should show the following:

   a. Welded Splices. Show all necessary welding details for the flanges and web. Note the weld sizes, testing requirements, type, and the minimum allowable distances between the flange and web splices and the stiffeners. See Section 16.7.

   b. Bolted Splices. Three views may be required to show all necessary details for the bolted spices — an elevation view of the girder and a top and bottom view of the flange, if different. Each view should show:

      - the bolt hole locations, including all necessary dimensions;
      - the diameter of the bolt holes;
      - the bolt holes as filled;
      - the splice and fill plates (also note the plate sizes); and
      - a note near the detail stating the size and type of bolts.

3. Shear Connector Detail. Include on the sheet a cross section detail of the girder with the shear connectors. The detail should note the:

   - location of the studs (i.e., the edge distance and the spacing between the studs); and

   - size of the studs.

4. Notes. Place all applicable notes on the right-hand side of the sheet.

6.3.14.6 Camber/Blocking Diagram Sheet

For complex designs, it may be necessary to include a Camber/Blocking Diagram Sheet to show the deflection and design criteria. For simpler structures, the camber information may be included as part of another sheet. A Camber/Blocking Diagram Sheet should include the following:

1. Table of Camber Information. This table indicates the amount of camber, to the hundredth of an inch (i.e., 0.01 in), that will be necessary for each girder at the tenth points of each span and at the field splices. Note the camber distances for each girder using the girder numbering as discussed in Section 6.3.11. However, girders with the same camber designs can be combined in the table. The Table of Camber, at each tenth point of a span and at the field splice, should include the following information:

   - the amount of deflection in decimal due to the dead load weight of the diaphragms and girders;

   - stay-in-place forms;

   - the dead load weight of each superstructure component (e.g., steel, slab, rail, barrier, sidewalk);

   - superevelation;

   - where necessary, the necessary correction for a vertical curve; and

   - the total camber required.

2. Girder Camber/Blocking Diagram. A girder camber/blocking diagram shall be included on the sheet to illustrate:

   - the location of the deflections for each tenth point on the span (or twentieth point for longer spans),

   - the location of field splices, and

   - the vertical curve offset.

The diagram is drawn using an exaggerated vertical scale.

3. Camber Note. Include the following note on the Camber/Blocking Diagram Sheet:

   The information on this sheet is for use in the fabrication of the girder. The cambers shown are based on each girder deflecting independently and on all deck concrete being placed simultaneously. The contractor shall determine the screed grades required to achieve the proper finished grade, concrete depth, and reinforcing steel cover based on his/her equipment, procedures, and pouring sequence.

4. Notes. Note all assumptions used to make the calculations and any other applicable notes.

6.3.14.7 Bearing Details Sheet

A separate sheet should be placed after the Camber/Blocking Diagram Sheet for bearing details. The Bearing Details Sheet, as applicable, should show the following:

1. Plan View of Bearing. Include a detailed drawing in a plan view of the bearing. The following information should be shown on the drawing:

   - centerlines of girders/beams,
   - centerlines of bearings, and
   - all necessary dimensions.

2. Bearing Design Load Data. For elastomeric bearings, include the bearing design load and specify the design method. Also, indicate the Grade of the elastomer.

3. Details. The following are other details that may be presented on this sheet:

   - booster/shim plates,
   - sole plate details,
   - sole plate dimensions,
   - flange clip details,
   - weld details,
   - elevation views at end bents,
   - bearing assembly details (including Grade for elastomeric pads), and
   - expansion/fixed bearing details.

4. Notes. Provide all applicable notes beneath the detailed drawing. Ensure that the following note is provided where welds are detailed:

   Caution shall be exercised where a field weld or shop weld will be made while elastomeric bearing pad is in contact with metal. In no case shall the elastomer or elastomer bond be exposed to instantaneous temperatures greater than 400˚F. Any damage to elastomeric bearing due to welding will be cause for rejection. Temperature shall be controlled by use of heat crayons furnished by the Contractor.

For additional information on detailing bearings, see Section 21.2.

6.3.14.8 Seismic Restrainer Details Sheets

For projects requiring seismic restrainers, the Seismic Restrainer Details Sheets should be included in the bridge plans. These sheets may be obtained from the *SCDOT Bridge Drawings and Details*, available at the SCDOT website. Consider the following guidelines:

1. Section View of Restrainer. Provide a section view of the restrainer at the expansion joints. The section view should be from the expansion end of the restrainer to the fixed end of the restrainer.
2. Ambient Temperature Data. Include a table that presents the formulas to calculate the movement of the restrainer at temperatures below, equal to, and greater than 70°F.
3. Other Information. Also place the following information on the Seismic Restrainer Details Sheets:
   - all necessary dimensions,
   - details of sections of restrainer,
   - cable restrainer unit details, and
   - all applicable notes.

6.3.14.9 Joint Details Sheet

The following provides information on the preparation of the Joint Details Sheet for strip seal and compression joints that is supplementary to the sheets in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website. For additional information on expansion joints, see Section 21.1.

The following information should be presented on this sheet:

1. Movement Table. The Movement Table should be completed to include information pertaining to the thermal expansion/contraction of the strip seal. Figure 6.3-9 provides an example of a Movement Table.

Movement Table						
Location	**Expansion**	**Contraction (Thermal)**	**Contraction (Shrinkage)**	**Joint "W" Width at 70°F**	**Total Rated Movement**	**Δ Temp ±10°F**
Bent 7	1-7/16″	1-7/8″	1/4″	2-7/16″	3-5/16″	1/2″

SAMPLE MOVEMENT TABLE FOR STRIP SEAL

Figure 6.3-9

2. Deck Joint Seals Description. Include the following information in tabular form:
   - joint type (e.g., strip seal);
   - manufacturer; and
   - designation (e.g., S-500 with Type WBL Steel Extrusion).

3. Typical Section. Include a typical section of the joint with the following information:
   - locations/descriptions of anchor studs,
   - centerline of joint, and
   - dimensions of the deck joint seal.

4. Other Information. Other information to consider placing on this sheet includes:
   - elevation view along joint at sidewalk/barrier parapet;
   - section/plan view of expansion joint cover plate at the sidewalk, if applicable; and
   - any necessary notes.

The *SCDOT Bridge Drawings and Details*, available at the SCDOT website, provides additional information on expansion joints.

6.3.14.10 Top of Slab Elevations Sheet

The Top of Slab Elevations Sheet is typically provided for bridges with superelevation transitions, and in other situations where the elevations on the structure may vary significantly.

Include a cross section of the bridge deck and top of slab elevations tables. More than one sheet may be required.

Consider the following guidelines when developing a Top of Slab Elevations Sheet:

1. Cross Section/Plan View of Deck Slab Elevations. Show deck elevation points at every 5 ft or 10 ft in even station intervals (e.g., Sta. 809 + 05.00, Sta. 809 + 10.00) along the following elements for each span:

   - left edge of slab,
   - left gutter,
   - finished grade,
   - longitudinal construction joints,
   - right gutter, and
   - right edge of slab.

   Also, show the beginning/ending of bridge, centerlines of each bent, and the direction of stationing.

2. Top of Slab Elevations Tables. These tables should present each line shown on the schematic section view of deck slab elevations along with the corresponding station and elevation. The elevations should be presented to three decimal places.

6.3.14.11 Sidewalk and Railing Details Sheet

Where needed, provide a separate detail sheet for the sidewalk and railing. Consider the following for the Sidewalk and Railing Details Sheet:

1. Side Elevations. Provide a side elevation of each span that includes the length of the span to the beginning or ending of bridge, whichever is applicable. Also, show the following:

   - location of joints,
   - location of bridge rail attachment,
   - dimensions of bridge rail, and
   - section call-outs (where necessary).

2. Cross Sections. Place a cross section for all section call-outs on the side elevation view. Include all necessary dimensions.

3. Miscellaneous Details. Some of the details that may be included on the Sidewalk and Railing Details Sheet are:

   - guardrail attachment,
   - connection plate,
   - rail cap,

- rail splice,
- anchor bolt,
- anchor plate,
- stud,
- shim,
- plate washer, and
- base plate.

4. Notes. Include all applicable notes on the right-hand side of the sheet.

6.3.15 Approach Slab Sheet

The Approach Slab Sheet should present the following information:

1. Plan View. Include a plan view of the beginning and ending of bridge. If the beginning and ending of the bridge are similar, only show one end and note that the other end of the bridge is similar. Include the following:

   - all necessary dimensions;
   - gutter line;
   - sidewalk, if applicable;
   - type and location of reinforcement;
   - skew angle;
   - centerline of bridge;
   - centerline of survey;
   - deflection joints; and
   - any section call-outs.

2. Details. Include applicable details (e.g., deflection joints, sidewalk reinforcing, transition barrier).

3. Cross Sections. Include a cross section for each call-out of the plan view with all of the necessary dimensions and labels.

4. Reinforcing Steel Schedule. Include a Reinforcing Steel Schedule for the reinforcing quantities included in the approach slab (see Section 6.3.11).

5. Quantities. Include a quantities table that provides the total quantities for the approach slab (e.g., concrete).

6. Notes. Provide all necessary notes for the elements of the approach slab.

7. Adjoining Trend Guardrail. When detailing an approach slab that has an adjoining Trend Guardrail, terminate the edge of the approach slab 4½ in inside the bridge gutter line. This is necessary to avoid conflicting with the concrete pad footing required for the Trend Guardrail.

6.3.16 Slope Protection Paving Details Sheet

The *SCDOT Bridge Drawings and Details*, available at the SCDOT website, provides a Fiber Reinforced Slope Protection Paving Details Sheet. Where this sheet must be tailored to a specific project, or where it is necessary to develop a project-specific Slope Protection Paving Details Sheet, include the following information on the sheet:

1. Plan View. Provide a plan view of the bridge that includes the following information:
   - beginning and ending of bridge,
   - slope dimensions,
   - construction centerline of the bridge,
   - limits of protection,
   - type of protection,
   - location/type of underdrain,
   - edge of shoulder treatment,
   - edge of superstructure,
   - beginning of berm, and
   - any section call-outs.
2. Section View Along Construction Centerline of the Bridge. Show a section view depicting the following information:
   - slope;
   - depth of slope protection;
   - location of fill;
   - beginning of bridge;
   - edge of curb and gutter, if applicable; and
   - any detail call-outs.
3. Details and Cross Sections. Provide the applicable details and cross sections with all necessary information.
4. Pouring Diagram. Include a pouring diagram that includes dimensions between pours and a description of the pouring sequence.
5. Notes. Include all applicable notes.

6.3.17 Drainage Details Sheet

When a closed drainage system is required, include a sheet depicting the drainage for the bridge. Include all of the necessary dimensions and notes. In the plan view of the Drainage Details Sheet, include the following information:

- material,
- clean-outs,

- each run of pipe between drains,
- pipe diameter and length,
- gradient, and
- fittings and hardware.

Also, provide a cross section of the pipe showing all necessary dimensions (e.g., diameter, type, length).

6.3.18 Utilities Details Sheet

If necessary, provide a separate sheet detailing the type and size of the utility. Include the following:

1. Section Views. Include a section view where the utility is located. Include the size and type of conduits and any applicable notes.

2. Typical Conduit Layout at End Bents. Provide a typical conduit layout and any applicable notes. Include the location of the conduit, parapet, and slip coupling.

3. Notes. Include general notes at the right-hand side of the sheet.

6.3.19 Existing Bridge Plans Sheets

Existing Bridge Plans Sheets should be provided for information only and stamped as such.

Chapter 7

QUANTITY ESTIMATES

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 7

QUANTITY ESTIMATES

The designer must compile an accurate estimate of the project construction quantities. This information leads directly to the Engineer's Estimate, which combines the computed quantities of work and the estimated unit bid prices. An accurate estimate of quantities is critical to prospective contractors interested in submitting a bid on the project. This Chapter presents information on estimating quantities for bridge projects.

7.1 GENERAL

7.1.1 Summary of Estimated Quantities Sheet

Bridge quantities are generated and placed on the Summary of Estimated Quantities Sheet. For information on the Summary of Estimated Quantities Sheet, see Section 6.3.

7.1.2 Guidelines for Preparing Quantity Estimates

When preparing quantity estimates, the designer should consider the following guidelines:

1. Units of Measurement. Report the quantity estimates for all contract bid items consistent with the terms and units of measurement presented in the *SCDOT Standard Specifications*. Figure 7.1-1 illustrates the units of measurements and rounding criteria for typical bridge items that should be used on the Summary of Estimated Quantities Sheet.

2. *SCDOT Standard Specifications*. Cross check all items against the *SCDOT Standard Specifications* and the SCDOT Supplemental Specifications to ensure that the appropriate pay items, methods of measurement, and basis of payment are used. Structural items are presented in Division 700 of the *SCDOT Standard Specifications*.

3. Rounding. Prepare a computation for each item used on the project. Include all computations in the project file. Round the output quantities from these computations according to Figure 7.1-1, and place them on the Summary of Estimated Quantities Sheet as discussed in Section 6.3.

4. Final Bridge Cost Estimate. All items described in the bridge plans that are included in the cost estimate must be shown in the Summary of Estimated Quantities Table. Chapter 8 provides the Department criteria for preparing construction cost estimates.

Item	**Unit**	**Rounding Accuracy**
Temporary Shoring Wall	LF	5
Removal & Disposal of Existing Bridge	LS	—
Wet and Dry Excavation for Bridges	CY	5
Rock Excavation for Bridges	CY	1
Cofferdam (*type*)	EA	1
Permanent Sheet Piling	SF	5
Concrete for Structures (*class*)	CY	0.1
Partial Depth Patching for Existing Decks	SY	0.1
Spall Repair	SF	1
Grooved Surface Finish	SY	1
Reinforcing Steel for Structures (Bridge)	LB	1
Spiral Reinforcing Steel for Structures (Bridge)	LB	1
Hoop Reinforcing Steel for Structures (Bridge)	LB	1
Galvanized Reinforcing Steel for Structures (Bridge)	LB	1
Prestressed Concrete Beam (*type*)	LF	0.1
Prestressed Concrete Bulb Tee Beam (*size/type*)	LF	0.1
(size) Prestressed Concrete Inverted Tee Beam	LF	0.1
(size) Cored Slabs	LF	0.1
Detour Bridge No. 1	LS	—
Concrete Bridge Barrier Parapet	LF	0.1
Concrete Bridge Barrier Parapet with Railing	LF	0.1
Concrete Bridge Median Barrier	LF	0.1
Concrete Bridge Barrier Parapet Extension	LF	0.1
Concrete Bridge Barrier Parapet Transition	EA	1
Concrete Bridge Railing Wall (*size)(type*)	LF	0.1
(type) Structural Timber	MBF	0.1
Structural Steel *(type)*	LS	—
Modular Joints	LF	0.1
Compression Seal Joint	LF	0.1
Expansion Joint System with Concrete Header	LF	0.1
Expansion Dam	LF	0.1
Pot Bearings *(type)*	EA	1
PTFE Bearings (*type)*	EA	1
Disk Bearing (*type)*	EA	1
Seismic Restrainer	EA	1
Structure Drainage System	LS	—
Dynamic Pile Analyzer Test Set-up	EA	1

ROUNDING CRITERIA FOR QUANTITIES

Figure 7.1-1

Item	Unit	Rounding Accuracy
Prestressed Concrete Piling (*size*)	LF	1 (for each pile)
Pile Build-up Prep (*size*)	EA	1
Pile Load Test for Prestressed Concrete Piling *(size)*	EA	1
Prestressed Index Piling (*size*)	LF	1 (for each pile)
Predrilling for Prestressed Concrete Piling *(size)*	LF	1
Prestressed Pile Points (*type)*	LF	0.5
Reinforced Pile Tips (*type*)	EA	1
Predrilling for Steel Piling *(type*)	LF	1
Steel H Bearing Piling (*type*)	LF	1
Pile Load Test-Steel H Bearing Pile (*type*)	EA	1
Galvanized Steel H Bearing Piling (*type*)	LF	1
Steel H Bearing Index Piling *(type*)	LF	1
Galvanized Steel H Bearing Index Piling *(type)*	LF	1
Steel Pipe Piling *(size)*	LF	1
Pile Load Test for Steel Pipe Piling *(size)*	EA	1
Predrilling for Steel Pipe Piling *(size)*	LF	1
Steel Pipe Index Piling *(size)*	LF	1
Conical Steel Pile Pipe Tip for Steel Pipe Piling	EA	1
Crosshole Sonic Logging Set-up	EA	1
Soil Excavation for Drilled Pile Foundations (*size*)	LF	0.1
Rock Excavation for Drilled Pile Foundation (*size*)	LF	0.1
Drilled Shaft with Wet & Dry Excavation (*size*)	LF	0.1
Drilled Shaft with Rock Excavation (*size*)	LF	0.1
Trial Shaft *(size)*	LF	0.1
Shaft Load Test (*size*)	EA	1
Construction Casing (*size*)	LF	0.1
Drilled Pile Foundation Concrete (Class 4000DS)	CY	0.1
MSE Wall Backfill (*type*)	CY	5
MSE Wall *(type)*	SF	1
Coping for MSE Wall (*type*)	LF	1
Deck Joint Strip Seal	LF	0.1
Elastomeric Bearing	EA	1
Elastomeric Bearing Assembly (Flat Slab)	EA	1
Seismic Isolation Bearing	EA	1
Removal of Epoxy, Bituminous & Foreign Overlay	SY	1
Machine Preparation of Existing Surface	SY	1
Hydro-Demolition of Existing Surface	SY	1

ROUNDING CRITERIA FOR QUANTITIES
(Continued)

Figure 7.1-1

Item	Unit	Rounding Accuracy
Grinding and Texturing for Concrete Bridge Deck	SY	1
Blast Cleaning	SY	1
Concrete Overlay *(type)*	CY	0.1
Epoxy-Sand Slurry	SF	1
Clean and Texture Existing Bents	SY	1
Polymer Modified Asphalt Expansion Joint	LF	0.1
Aggregate Underdrain (AGG #789) with 4″ Perforated Pipe for Structures	TON	1
Slope Protection – 4″ Concrete (Fiber Reinforced)	SY	5
Waterproofing (Substructure – Second Method)	SY	0.1

ROUNDING CRITERIA FOR QUANTITIES
(Continued)

Figure 7.1-1

7.1.3 Pay Item Numbers

Each pay item has an official title and item number that is tied to the *SCDOT Standard Specifications*. These items are listed in the *SCDOT Standard Specifications* and the pay item spreadsheet on the Department's website. The Department uses these coded item numbers for tracking and as a historic database. In most cases, the AASHTO Trns•Port Proposal and Estimates System (PES) will already have the pay item number. See Section 36.2.2 of the *Highway Design Manual* for additional information on computer tracking.

For some specialty or new items, the pay item number may not be in the database. Therefore, if the designer is unable to locate a pay item, the designer will be required to conduct the following:

1. Check. The designer should ensure that there is not an actual number for the item within the system by entering the item into PES.

2. *SCDOT Standard Specifications*. The designer should review the *SCDOT Standard Specifications* and SCDOT Supplemental Specifications to determine if there is a method of payment for the item.

3. New Pay Item. If an item does not exist in the PES, the designer may request a new pay item through the Bridge Design Section.

7.2 QUANTITIES

7.2.1 General

The following Sections discuss the procedures that should be used to determine the cost estimate for some of the typical bridge items used on the project.

7.2.2 Reinforcing Steel

The quantity estimate for reinforcing steel is based on the weight of the reinforcing bar. The typical sizes the Department uses are presented in Figure 7.2-1. When estimating the quantity for reinforcing steel, use Figure 7.2-1 to obtain the weight in pounds for the appropriate design size. Anchor bolts and tie-bar assemblies are included in the weight of reinforcing steel. The weight of incidental items (e.g., reinforcing steel bolsters, couplers) are not included in this quantity estimate.

7.2.3 Structural Steel

The quantity estimate for structural steel is based on the weight of the steel components in the structure. Structural steel is bid as a lump sum, but the steel weight and grade is provided for information only to assist the Contractor in preparing the bid. Include the weight of all beams, plates, diaphragms, stiffeners, bearing plates, bolts, shear studs, etc., in the estimate.

Calculate the weight of the steel using the following guidelines:

1. Structural steel has a weight density of 490 lb/ft^3.
2. Weld metal weights are not calculated.
3. Calculate the weight on the rectangular dimensions for all plates and overall lengths for all structural shapes with no deductions for copes, clips, sheared edges, punching, or borings.
4. Measure bolts, nuts, and washers for payment on the basis of computed weight as presented in the AISC *Manual of Steel Construction.*
5. Round the total to the nearest 100 lbs.

Reinforcing Steel Sizes				
Bar Size		**Diameter**	**Area**	**Weight**
US Customary Designation	**Metric Designation**	**in**	**in^2**	**lb/ft**
#3	#10	0.375	0.11	0.376
#4	#13	0.500	0.20	0.668
#5	#16	0.625	0.31	1.043
#6	#19	0.750	0.44	1.502
#7	#22	0.875	0.60	2.044
#8	#25	1.000	0.79	2.670
#9	#29	1.128	1.00	3.400
#10	#32	1.270	1.27	4.303
#11	#36	1.410	1.56	5.313
#14	#43	1.693	2.25	7.650
#18	#57	2.257	4.00	13.600

REINFORCING STEEL SIZES AND WEIGHTS

Figure 7.2-1

7.2.4 Construction Stakes, Lines, and Grades

The Assistant State Bridge Design Engineer – Specifications will request this information from the Construction Office, which in turn will request the information from the District. This item is included in the Bid Proposal Package, but is not included in the Summary of Estimated Quantities Table in the bridge plans.

7.2.5 Construction Estimates and Final Plans (As-Built Plans)

The Assistant State Bridge Design Engineer – Specifications will request this information from the Construction Office, which in turn will request the information from the District. This item is included in the Bid Proposal Package, but is not included in the Summary of Estimated Quantities Table in the bridge plans.

7.2.6 On-The-Job Training (OJT)

When applicable, the cost estimate information for OJT requirements is provided to the Bridge Cost Estimate Coordinator by the Roadway Specifications and Estimate Group.

Chapter 8

CONSTRUCTION COST ESTIMATES

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CHAPTER 8

CONSTRUCTION COST ESTIMATES

To adequately define the project scope and budget, cost estimates are required during the various stages of project development. As the project progresses, the estimates are refined to verify that the project is still cost effective, sufficient funds are available for construction, and the Contractor's bid price is reasonable. This Chapter discusses the various project estimates that are required and who is responsible for their preparation.

8.1 PROGRAMMING ESTIMATES

8.1.1 Bridge Replacement Projects

For bridge replacement projects, cost estimates are generally provided at the following stages of project development:

1. Program Action Request (PAR). The Project Manager is responsible for determining the construction cost estimate at this stage of project development. The cost estimate typically is developed based on the area of the proposed bridge deck (ft^2), the type of structure (e.g., steel, concrete), recent similar projects in the geographic area, and engineering judgment. This estimate is completed before the Preliminary Bridge Plans are prepared; however, it should include all project elements from all units including road items, traffic items, etc. Include this cost estimate with the PAR. See Section 5.5 for a description of the PAR.

2. Project Planning Report (PPR). The Project Manager is responsible for updating the cost estimate determined for the PAR at this stage of project development. This estimate is prepared in a similar manner as for the PAR. Include this estimate with the PPR. See Section 5.5 for a description of the PPR.

3. Engineer's Estimate. The Engineer's Estimate is a very detailed construction cost estimate developed from final computed quantities and the appropriate unit costs. For information on preparing the Engineer's Estimate, see Section 8.2.

8.1.2 Other Projects

Through various stages of project development, the Bridge Design Section will be responsible for providing the appropriate Project Manager with a cost estimate of the structural elements included in a road design project.

8.1.3 Additional Costs

In addition to the costs developed for the structure and approach roadways, the following will apply:

1. Preliminary Engineering. Preliminary engineering costs are generally calculated to be between 10% and 15% of the construction cost estimate. This percentage may be adjusted upwards for projects that require a considerable effort relative to the amount of construction involved, or the percentage could be less for projects that do not require as much time and effort for studies and plan preparation.

2. Utilities. The Utilities Office will provide the utilities relocation cost estimate.

3. Right-of-Way. The Right of Way Office will provide all right-of-way costs. Right-of-way costs are initially calculated using an estimated acreage and the number of relocations denoted during the scoping review. The estimates should include an appropriate percentage increase to cover personnel services and equipment, appraisals, condemnation settlements, and other miscellaneous costs that are difficult to anticipate during the initial stages of project development.

4. Traffic Control. The Traffic Engineering Division will provide a cost estimate for traffic control.

5. Construction Engineering and Contingencies Costs. After the construction cost estimate has been determined, 10% to 15% is added for engineering and contingencies costs.

6. Project Scope Changes. If the project scope changes or if the project cost significantly increases at any point during the planning or design process, the Project Manager will notify the State Bridge Design Engineer.

8.2 ENGINEER'S ESTIMATE

The Engineer's Estimate provides the Department with a basis for evaluating the bids for bridge and highway construction and allows the Department to determine if the low bid price is fair and reasonable for the work involved. This Estimate, plus the data used to generate the Estimate, is considered confidential and is not for general distribution. This Section discusses the procedures for developing this cost estimate. Engineer's Estimates for all Department projects (e.g., bridge projects, road improvements, safety improvements) are forwarded to the Specifications and Estimate Group in the Road Design Section.

8.2.1 Responsibilities

8.2.1.1 Design Units

The following discusses the responsibilities of the various units for the preparation of the Engineer's Estimate:

1. Bridge Design Section. The Bridge Design Teams are responsible for entering all quantities into the Department's estimating software package (i.e., Trns•port's Proposal and Estimates System (PES)). The Bridge Design Teams are responsible for providing the Bridge Cost Estimate Coordinator with a set of plans for the project and any information that may influence the cost of the project (e.g., special commitments, experimental materials, special equipment, expected construction delays). Other Department Sections and Divisions will prepare their own cost estimates (e.g., Utilities, Traffic).

2. Road Design Section. The Road Design Groups are responsible for providing the Specifications and Estimate Group with a complete set of quantities and plans for the road design portion of the project.

3. Utilities Office. The Utilities Office will provide the Specifications and Estimate Group with completed costs and specifications for any utilities work to be included in the contract.

4. Traffic Engineering Division. The various Sections within the Traffic Engineering Division (e.g., Signing, Traffic Signals, Highway Lighting, Pavement Markings) are responsible for supplying the Specifications and Estimate Group with a complete cost estimate for their applicable design work for direct incorporation into the Engineer's Estimate.

5. Changes. If an estimated quantity or pay item is changed, the Bridge Design Team should immediately notify the Bridge Cost Estimate Coordinator of the change. The Bridge Cost Estimate Coordinator will revise the estimate accordingly.

8.2.1.2 Bridge Cost Estimate Coordinator

The Bridge Cost Estimate Coordinator will develop the Engineer's Estimate for in-house-designed bridge projects. See Section 8.2 for a description of the computer programs and guidelines for completing an Engineer's Estimate.

8.2.1.3 Consultants

The Consultant is responsible for preparing the Engineer's Estimate for Consultant-designed projects. The Project Manager is responsible for reviewing the cost estimate and forwarding it to the Bridge Cost Estimate Coordinator for review.

8.2.2 Computer Programs

Trns•port is AASHTO's information system for managing transportation programs, beginning with planning and estimating, and continuing through to the development of bidding documents, letting and contract award, and management of construction operations. Trns•port also provides a database of historical costs.

The Department uses two modules from the AASHTO Trns•port software program to track cost estimates. These programs are described below:

1. PES. The Trns•port Proposal and Estimates System (PES) is an interactive, online system for managing project information during the pre-letting phase of a construction project. PES permits the flexible definition of a project and its associated funding requirements to track and manage project cost information and set up the bidding proposal prior to the bid letting activity.

   With PES, data can be entered at the project, category, and item level. Grouping of multiple projects is allowed to track all related costs and funding sources. PES supports the preparation of the PS&E for Federal-aid bridge construction projects and allows projects to be combined into proposals for bid letting. The Bridge Design Section is responsible for entering the required data into PES for in-house-designed bridge projects, and the Project Manager is responsible for entering the required data into PES for Consultant-designed projects.

2. LAS. The Trns•port Letting and Award System (LAS) provides the capabilities to automate the many tasks that are necessary during the letting and award stages of a transportation construction project. LAS aids in advertising bids, tracking plan and proposal holders, processing bid information, evaluating bids, and making award decisions. It provides online and batch data entry with full edit checking and verification for vendor bids, produces the bid tabulation report, and performs analyses on received bids. LAS also maintains the Planholder's List, produces mailing lists, and maintains information for invoicing vendors for proposals and plans purchased.

8.2.3 Estimating Guidelines

The estimator should consider the following:

1. Historical Data. The Bridge Cost Estimate Coordinator maintains a database with unit prices on similar projects in similar geographic areas allowing the estimator to compile cost data for like structural elements and construction costs.

2. Unit Costs. Based on the proposed scope for the project, the estimator may revise unit prices based on the following factors:

   - geographic location (e.g., urban/rural, engineering district);
   - similarity to recent bridge projects;
   - inflation (adjustments to past prices to reflect the current year);
   - reliability of recent construction cost data;
   - recent trends in cost of materials, labor, and equipment;
   - anticipated difficulty of construction;
   - project size relative to size of similar projects;
   - proposed project schedule;
   - anticipated construction staging;
   - expected environmental problems (e.g., hazardous wastes, wetlands);
   - use of experimental materials; and
   - engineering judgment.

3. Lump-Sum Items. Desirably, lump-sum items should not be used on a project. However, this is not always practical. In determining the unit price for lump-sum items, the estimator should consider the following:

   a. Components. Most lump-sum items can be divided into individual parts for estimating purposes. Once the elements have been tabulated, the estimator should use engineering judgment to determine the appropriate cost for each component. The following are some example components of a bridge project:

      - Structural Steel. Base the cost of the steel for the structure on the weight of the steel.

      - Drainage System. Calculate the cost of the drainage system by determining the number of drains plus the total length of pipe required for the project.

      - Utility PVC Conduit. Calculate the cost of PVC conduit by the length of the conduit used for the project. When the PVC conduit is provided at the request of a Utility company, the utility is required to reimburse the Department for the cost.

b. Mobilization. Use 5% of the total project cost for mobilization. Mobilization costs consist of preparatory work and operations necessary for the movement of personnel, equipment, supplies, and incidentals to and off the project site; for the establishment and removal of offices, buildings, and other facilities necessary for work on the project; and for all other work or operations that must be performed or costs incurred when beginning or ending work on the project.

c. Traffic Control. Maintaining traffic is a lump-sum item and the estimated cost is provided by the Traffic Engineering Division. Elements that should be considered include traffic volumes, traffic composition, peak times, number of lanes, length of construction, and type of work.

d. Existing Bridge Removal/Disposal. The cost of removing and disposing of an existing bridge is based on the project location, bridge type, bridge length and width, traffic control, type of crossing, historical data, and engineering judgment.

4. Engineering and Contingencies. Use between 10% and 15% of the total project cost for engineering and contingencies.

Chapter 9

BID DOCUMENTS

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CHAPTER 9

BID DOCUMENTS

9.1 BID DOCUMENT PROCESSING

This Section discusses the responsibilities and activities in processing the Plans, Specifications, and Estimates (PS&E) package for letting. The PS&E package is then made available to the appropriate SCDOT Units to prepare for letting.

9.1.1 Plan Completion and Approval

9.1.1.1 Roadway Plans

For information regarding the roadway portion of the Final Construction Plans, see Section 37.1 of the *SCDOT Highway Design Manual*.

9.1.1.2 Bridge Plans

The bridge portion of the Final Construction Plans is ready for review and approval once the Plans reach the 95% completion design stage. The following defines the process for completing and signing the Final Bridge Plans:

1. Quantities. For consultant-designed projects, the Project Manager is responsible for entering the applicable quantities into the Department's software package (i.e., Trns•port's Proposal and Estimates System (PES)). For in-house-designed projects, the Bridge Team Leader is responsible for entering the quantities. The Cost and Estimates Coordinator is responsible for estimating the cost of bridge bid items and entering the costs. See Chapter 8 for more information.

2. Plan Review. The Assistant State Bridge Design Engineer will conduct a quality control review of the in-house-designed plans. The plans are checked to determine if they meet the following:

    - the approved project scope of work and Project Planning Report;
    - the design criteria presented in the *SCDOT Bridge Design Manual*, except where revised by a design exception;
    - the criteria presented in the Design Memorandums;

- any reports or studies for the project; and
- the plan preparation information presented in Chapter 6.

The Project Manager will verify that, for both in-house-designed and Consultant-designed plans, the following is completed prior to letting:

- all project commitments have been met;
- all issues from the Design Field Review have been resolved;
- all agreements with utility companies, railroad companies, local municipalities, etc., have been prepared;
- all applicable permits have been approved; and
- any right-of-way acquisitions, easements, agreements, etc., have been secured.

3. Revisions/Corrections. The plans will be returned to the designer for corrections or clarifications. Upon completing the corrections, the designer will resubmit the bridge plans to the Assistant State Bridge Design Engineer.

4. Plans Submittal Process for Bid Package. The following describes this process for projects designed by the Department or Consultants:

   a. In-house-designed Projects. The Bridge Design Team Leader will sign and submit the plans to the appropriate Assistant State Bridge Design Engineer for review. Once the Assistant State Bridge Design Engineer is satisfied with the Final Bridge Plans, they are forwarded to the State Geotechnical Design Engineer, Project Manager, and State Bridge Design Engineer for signature.

   b. Consultant-designed Projects. The Project Manager is responsible for reviewing the bridge plans submitted by a Consultant. After reviewing the Consultant plans, the Project Manager submits the Final Bridge Plans for processing and printing.

   The Project Manager should ensure that Final Bridge Plans include the following:

- full-size set of original bridge and road plans, signed, sealed, and with plan covers;
- half-size set of bridge plans;
- list of Supplemental Specifications applicable to the project;
- any project-specific Special Provisions (Word format);
- Engineer's Construction Cost Estimate;

- Engineer's Construction Time Estimate (detailed with bar charts);
- prebid conference date, time, and location, if applicable;
- boring logs in .pdf format, if they are not included in plans;
- rock compressive strengths, if applicable;
- any geotechnical or hydraulic data that needs to be included in the proposal documents;
- asbestos/lead-based paint report, if prepared by the design consultants;
- type of contract to be used (e.g., Standard, A+B, A+B+C, etc.);
- daily and maximum amount of incentive, if used;
- copy of required permit(s);
- detour specifications, if applicable;
- salvage specifications, if applicable;
- commitments that need to be included in the proposal; and
- road closure and traffic detour information:
    + detour length;
    + detour speed;
    + detour map for secondary roads. Provide detour map electronically in .pdf format (8½″ by 11″);
    + staged construction and detour bridge information;
    + length of project;
    + normal speed;
    + posted work zone speed limit; and
    + hourly traffic data, if traffic congestion is expected during construction.

This submittal should occur in accordance with the published schedule.

9.1.2 Bid Package Preparation

9.1.2.1 Bid Package Content

The Letting Preparation Group in the Road Design Section is responsible for completing the bid proposal documents. These documents include:

- Notice to Contractors,
- Instructions to Bidders for Federal-aid Projects,
- Project Special Provisions,
- Supplemental Specifications,
- required Contract Provisions for Federal-aid construction projects,
- standard Federal Equal Employment construction contract specifications for Federal-aid Projects,
- wage regulations for Federal-aid Projects,
- bid bond,
- proposal form,
- OJT (on-the-job training) requirements, and
- DBE (Disadvantaged Business Enterprise) Committal Sheet for Federal-aid Projects.

9.1.2.2 Assistant State Bridge Design Engineer – Specifications

The Assistant State Bridge Design Engineer – Specifications is responsible for the following:

1. Cost of Plans. Calculate the cost of plans. This information is used by the Contract Administration Office to sell the bridge plans to prospective bidders.
2. Bridge Construction Time. Obtain the bridge construction time from the Bridge Construction Office or the Consultant, whichever is appropriate.
3. *SCDOT Standard Specifications*. Prepare the following for inclusion in the Bid Package:
    - incorporating all required bridge Special Provisions;
    - ensuring that all bridge pay items are covered by the *SCDOT Standard Specifications*, SCDOT Supplemental Specifications, or Special Provisions; and

- preparing or incorporating bridge project-specific Special Provisions noted during the plan preparation and review.

4. Checklist. Submit the "List of Items Checklist" to the Letting Preparation Group for the Bid Package.

9.1.2.3 Letting Preparation Group

The Letting Preparation Group within the Road Design Section will assemble the bid proposal documents for the Bid Package.

For information regarding the roadway portion of the bid proposal preparation, see Section 37.2 of the *SCDOT Highway Design Manual*.

9.1.3 Construction Bids

The Contracts Administration Office is responsible for the following:

1. Advertising. The Contracts Administration Office will prepare and publish an ad for the highway letting. This ad is placed on the Department's website approximately five weeks prior to letting. Authorization to bid is issued to prequalified contractors who have work ratings that indicate their ability to complete the work. The Contracts Administration Office determines this prequalification list. For large and/or multi-phased projects, it may be determined necessary to conduct a pre-bid meeting.

2. Conducting Bid Opening. Unless otherwise specified, on the second Tuesday of each month, the Contracts Administration Office will receive the Contractor's electronic bid. After the specified time, no additional bids will be accepted. The total of each bid, including alternatives and combinations, if any, are recorded and read publicly.

3. Reviewing the Bids. The Contracts Administration Office will incorporate the bid information into the Trns•port System and check the bid for accuracy to ensure that the Contractor has correctly submitted the bid. If the bids have been properly submitted, the Contracts Administration Office will forward the lowest bid to the Program Manager and/or the Bridge Project Engineer for review. The Program Manager and/or the Bridge Project Engineer will resolve any substantial differences between the Contractor's bid and the Engineer's Estimate amounts. The Contracts Administration Office will coordinate the award with FHWA on all oversight projects. See Section 5.8 for information on FHWA oversight and involvement on SCDOT bridge projects.

4. Awarding the Project. If the low bid is determined to be acceptable, the Contractor and Program Manager and/or the Bridge Project Engineer are notified of the approval. Once the contract has been approved and signed, the project responsibilities are then transferred to the Resident Construction Engineer.

Once the contract has been accepted and signed, and the notice to proceed has been issued, the Contractor can begin construction on the project. During construction, the Bridge Design Section may be requested to clarify the construction plans, offer guidance, review shop plans, etc. See Chapter 24.

9.2 BID DOCUMENTS

9.2.1 <u>General</u>

The *SCDOT Standard Specifications,* SCDOT Supplemental Specifications, Special Provisions, and Final Road and Bridge Plans are all essential parts of the contract. They are intended to complement each other and are used to describe and provide complete instructions for the work to be accomplished. If a discrepancy exists between these documents, the following presents the hierarchy of importance among them:

1. Special Provisions.
2. Final Road and Bridge Plans.
3. SCDOT Supplemental Specifications.
4. *SCDOT Standard Specifications.*

9.2.2 <u>*SCDOT Standard Specifications*</u>

The Construction Division is responsible for the *South Carolina Standard Specifications for Highway Construction.* The *SCDOT Standard Specifications* presents the work methods and materials approved by the Department for the construction of road, traffic, and bridge projects. The publication presents information on:

- bidding,
- awarding the contract,
- Contractor duties,
- controlling material quality,
- Contractor and Department legal requirements,
- executing the contract, and
- measuring and paying for contract items.

9.2.3 <u>SCDOT Supplemental Specifications</u>

SCDOT Supplemental Specifications modify the requirements set forth in the latest version of the *SCDOT Standard Specifications*. The SCDOT Supplemental Specifications can only be modified by writing a Special Provision.

9.2.4 <u>Special Provisions</u>

Special Provisions are additions or revisions to the *SCDOT Standard Specifications* and the SCDOT Supplemental Specifications setting forth conditions and requirements for a special situation on a specific project. Special Provisions are included in the contract documents for that project and are not intended for general use. Special Provisions supersede all other contract documents. The designer prepares the Special Provisions for inclusion in the project documents. Section 9.3 discusses guidelines for preparing Special Provisions.

9.2.5 Standard Drawings

9.2.5.1 *SCDOT Bridge Drawings and Details*

The *SCDOT Bridge Drawings and Details* provides details on various bridge elements that are consistent from project-to-project (e.g., prestressed concrete beams, slab details, diaphragm details, bridge rails). The *SCDOT Bridge Drawings and Details* may be obtained from the Department's Internet website. The Bridge Design Section, on an as-needed basis, updates the *SCDOT Bridge Drawings and Details*.

9.2.5.2 *SCDOT Standard Drawings*

The *SCDOT Standard Drawings* provides road and traffic details for various design elements that are consistent from project-to-project (e.g., guardrail, sign posts, fencing, drainage details). They provide information on how to layout or construct the various design elements.

Copies of the *SCDOT Standard Drawings* can be obtained from the Road Design Section or from the Department's Internet website. The Road Design Section, on an as-needed basis, updates the *SCDOT Standard Drawings*.

9.3 SPECIAL PROVISION PREPARATION

Special Provisions are required whenever a project contains work, material, sequence of operations, or any other requirements that are necessary for the completion of the project but are not "described completely" in the construction plans, *SCDOT Standard Specifications* or SCDOT Supplemental Specifications. "Described completely" should be interpreted to mean that the prospective bidder will be able to clearly understand the work to be accomplished, type of materials or equipment required, construction methods or details to be used, how the item of work will be measured, and the basis of payment. The following Sections provide guidelines for preparing Special Provisions.

9.3.1 Preparation Steps

The designer should use the following steps when preparing a Special Provision:

1. Define Need. Review the existing *SCDOT Standard Specifications*, Supplemental Specifications, standard details, or construction plans to ensure that there is a need for the Special Provision. If the topic is not adequately covered in one of the other contract documents, only then should a Special Provision be prepared.

2. Research. Research the topic so that complete and detailed information is available before writing the Special Provision. This may require contacting manufacturers, contractors, or suppliers for the latest information. Local conditions and problems should also be fully investigated.

3. Format. Prepare Special Provisions in the same manner as the *SCDOT Standard Specifications*. Section 9.3.2 presents the format that should be used.

4. Type. Analyze the type of construction to be covered in the Special Provision to determine the type of Special Provision to be used. There are two basic types of Special Provision presentations — (1) performance or end-result presentation, and (2) material or method presentation. The preferred type is the performance or end-result presentation that describes the end result of construction. The types of procedures and resources to achieve the end result are at the Contractor's discretion. The material or method presentation describes the procedure or materials that should be used to construct the element.

   Do not mix the presentation types within a Special Provision. However, the assembly of Special Provisions may contain both types of presentations.

5. Develop Outline. The outline should cover the basic requirements of the work to be completed or the materials to be used. It should define the essential physical characteristics of the material or work (e.g., dimensional limitations, time, strength, weight, size, shape, configuration). Organize all relevant factors under each appropriate heading.

6. Writing the Special Provision. Once the outline has been developed and all research has been completed, write the first draft with the following in mind:

   a. Wording. Write the Special Provision in the active voice (sentence begins with a verb) and the imperative mood (sentence expresses a command).

      Active Voice: "Apply rubbed finish to exposed surface."

      Passive Voice: "Rubbed finish shall be applied to exposed surface."

   b. Sentences. Prepare the Special Provision using simple language and words. Keep words and sentences short (20 words or less), unless complexity is unavoidable.

   c. Paragraphs. Limit paragraphs to three to four sentences.

   d. Terminology. Use words consistent with their exact meaning. Use the same word throughout; do not use synonyms. Avoid any words that have a dual meaning. Section 9.3.4 presents the recommended terminology that should be used. Omit extraneous words and phrases.

   e. Pronouns. Avoid the use of pronouns, even if this results in frequent repetition of nouns.

   f. Punctuation. Carefully consider the punctuation using the minimum number of punctuation marks consistent with the precise meaning of the language. Make certain that there can be no doubt on the meaning of any sentence.

   g. Parentheses. Avoid the use of parentheses ( ). Instead, use commas or rewrite the sentence.

   h. Numbers. It is usually unnecessary to write numbers both in words and figures. For example, do not write "Use four (4) 1-in bolts." Instead, write "Use four 1-in bolts." Write numbers less than or equal to ten as words. Write numbers higher than ten numerically. When writing dimensions, always use numerals (e.g., 2.0 in, 10 ft, 20 yd^3). Do not write 2 in x 4 in, but 2 in by 4 in. Times and dates should be written numerically. Write fractions as decimals. Decimals less than one should be preceded by the zero (e.g., 0.25 in).

7. Reviewing. The designer should review the previously completed paragraphs as succeeding ones take shape. Where necessary, redraft preceding paragraphs to reflect later thoughts.

8. Presentation. Special Provisions that are specific to a project should be in Word format. Store these files in a long-term retention file until the project is advertised.

9.3.2 Format

Prepare Special Provisions in the same format as the *SCDOT Standard Specifications*. The sections of the Special Provision that should be addressed include:

1. Description. Describe the work to be performed, with references to specifications, plans, or other Special Provisions that further define the work. Where necessary or desirable for clarity, describe the relationship of this work item to other work items or other phases of construction.

2. Materials and/or Equipment. Designate the materials and/or equipment to be used in the work item and establish its requirements. Delineate complete specifications of the properties of each material and the method of tests. References may be made to AASHTO, ASTM, or other recognized specifications.

3. Construction Details. Describe the sequence of construction operations or the desired end product. Do not mix the two types of presentations described in Section 9.3.1. Where practical, only use the performance presentation. This will permit the contractor to use improved equipment and new and advanced ideas in construction methods. Only use the method presentation for the sequence of construction operations if it is critical to achieving the desired result. Specify quality control and quality assurance requirements, and specify who is responsible for testing.

4. Method of Measurement. Describe the components of the completed work item that will be measured for payment, provide the units of measurement and whether measured in original position, in transporting vehicles, or in the completed work. Designate any modifying factors and other requirements needed to establish a definite, measured unit (e.g., disturbed or undisturbed, temperature, waste).

5. Basis of Payment. Describe the units for which payment will be made, and define the scope of the work covered by such payment.

9.3.3 Guidelines

In addition to Sections 9.3.1 and 9.3.2, the following presents several guidelines the designer should consider when developing Special Provisions:

1. Completeness. When developing the Special Provision, ensure that the essentials have been included and that each requirement is definitive and complete.

2. Clarity. To ensure that the Special Provision is clearly presented, the designer should review the following:

a. Clearly delineate the method of measurement and payment.

b. Make a clear, concise analysis of the job requirements for general conditions, types of construction, and quality of workmanship. Do not leave the bidder in doubt on what he, as the Contractor, will be required to do.

c. Give directions, never suggestions.

d. Do not use phrases such as “as approved by the engineer,” “at the discretion of the engineer,” or “as directed by the engineer” in place of definite workmanship requirements. These types of phrases may lead to confusion or misunderstanding. The Contractor may not know what the engineer is thinking.

e. Avoid conflicting or ambiguous requirements. Every specification should have only one meaning.

f. Never conceal difficulties or hazards from the Contractor.

3. Conciseness. Write each Special Provision as concise as practical. When reviewing the Special Provision, the designer should consider the following suggestions:

a. Avoid duplications between the Special Provision and any related contract documents.

b. Do not give reasons for a specification requirement.

c. Do not provide additional information that is unnecessary for the preparation of bids and the accomplishment of the work.

d. Once stated, do not repeat any instruction, requirement, direction, or information given elsewhere in the contract documents.

e. Do not include mandatory provisions that are required in general by the contract.

f. Minimize the use of cross-references.

g. Write the specification in the positive form.

4. Correctness. To ensure that the Special Provision is written correctly, the designer should review the following:

a. Where practical, independently cross-check every factual statement.

b. Do not include items that cannot be required or enforced.

c. Ensure that the specification does not punish the Contractor or Supplier.

d. Ensure that the specification does not unintentionally exclude an acceptable product, construction method, or any equipment.

e. Ensure that the provision does not change the basic design of the item.

f. Do not specify impossibilities. The practical limits of workers and materials must be considered.

g. Specify standard sizes wherever practical.

h. Avoid personal preferences.

i. Ensure that the Contractor will not be held responsible for the possible inaccuracy of information furnished by the Department.

j. Ensure that sufficient attention has been provided to assessing the durability or reliability of the material or procedure discussed. The use of permanent and recognized standards should be quoted to ensure that the specified performance or characteristics are achieved. If not, completely and accurately define the testing criteria.

k. Make a careful, critical examination of manufacturers' or trade associations' recommendations, and require supporting evidence before adopting them.

l. Keep requirements stringent. A stringent requirement can be relaxed if the need arises; however, adding requirements after the contract has been awarded may increase cost.

m. Ensure that the Special Provision gives directions that are consistent with the standard practice currently used by the Department.

9.3.4 Terminology

1. Abbreviations. Generally, avoid abbreviations. However, abbreviations may be used if they are defined and the definitions are consistent with the accepted meanings.

2. Amount, quantity. Use "amount" when writing about money only. When writing about measures of volume (e.g., yd^3, gallons), use "quantity."

3. And/or. Avoid using "and/or"; instead, use "and" alone, or "or" alone, or "or ... or both." For example, "Unless otherwise specified by the plans or Special Provisions or both, ..."

4. Any, all. The word "any" implies a choice and may cause confusion. Use the term "all" in place of "any." For example, "Make good all defects."

5. As per. Do not use "as per"; instead, use "as stated," "as shown," "conforming to," or other similar phrases.

6. At the Contractor's expense. Do not use the phrase "at the Contractor's expense"; instead use, "at no cost to the Department" or "included in the cost of other contract items."

7. Balance, remainder. Use the term "balance" when referring to money. Use "remainder" to describe something or material left over.

8. Coarse, course. Use "coarse" to describe textures and "course" for layers.

9. Conform. Use the word "conform" to refer to dimensions, sizes, and fits that must be strictly adhered to (e.g., "cut bolt threads conforming to ASA Standards, Class 2 fit, coarse thread series"). Where a better product is acceptable, use the phrase "meeting the requirements of..."

10. Contractor. Use the word "contractor" in place of the word "bidder" when writing Special Provisions for construction. Only use "bidder" for proposals.

11. Approved Equal. Do not use the phrase "approved equal." The Contractor may not know what is truly equivalent before awarded the contract. It is better to clearly specify those items that will be accepted as "equal."

12. Proposal. Do not use the word "proposal" when the word "contract" is intended. Only use the term "proposal" to describe requirements during the bidding process.

13. Resisting, resistant. Do not use "corrosion-resisting," but instead use "corrosion-resistant."

14. Said. Do not use "said pipe" or "said aggregates" but, instead, use "this pipe" or "these aggregates."

15. Same. Do not use "same" to replace a pronoun such as "it" or "them" standing alone, as in "connected to same," "specified for same," "same will be given consideration," or "conforming to requirements for same." Rewrite the sentence to clearly describe what is meant.

16. Shall. Avoid using the word "shall." The Department has adopted "active voice" specifications. Rewrite the sentence using the active voice.

17. Such. Do not end a sentence with the word "such." "Such" usually means "of this or that kind," or similar to something stated. Instead, state that which is actually meant or name the work to be completed, or rephrase the sentence.

18. Symbols. Do not use the following symbols when writing Special Provisions:

Symbol	Write Instead
/	per, or "a"
%	percent
+	plus
-	minus
x	by

19. The. Do not eliminate "the" for brevity.

20. Thoroughly. Avoid using the adverb "thoroughly," as in thoroughly wet, thoroughly dry, thoroughly clean, etc., because it is unenforceable. Preferably, state the value of the intended requirements in percent, dimensions, number of passes, etc.

21. Will. Only use the word "will" for actions to be performed by the Department.

Chapter 10

RESERVED

SCDOT BRIDGE DESIGN MANUAL

April 2006

CHAPTER 10

RESERVED

Chapter 11

GENERAL REQUIREMENTS

SCDOT BRIDGE DESIGN MANUAL

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CHAPTER 11

GENERAL REQUIREMENTS

11.1 BASIC APPROACH

The following describes the basic approach for Part II of the *SCDOT Bridge Design Manual*:

1. Application. The *Manual* is an application-oriented document.

2. Theory. The *Manual* is not a structural design theory resource nor a research document. The *Manual* provides background information as absolutely necessary so that the user understands the basis for the Department's bridge design criteria and application.

3. Details. Where beneficial, the *Manual* provides design details for various bridge elements.

4. Coordination with *LRFD Bridge Design Specifications*. The *SCDOT Bridge Design Manual* is basically a Supplement to the *LRFD Bridge Design Specifications* (*LRFD Specifications*) that:

    - in general, does not duplicate information in the *LRFD Specifications*, unless absolutely necessary for clarity;
    - elaborates on specific articles of the *LRFD Specifications*;
    - presents interpretative information, where required;
    - modifies sections from the *LRFD Specifications* where the Department has adopted a different practice;
    - indicates the Department's preference where the *LRFD Specifications* presents more than one option; and
    - indicates bridge design applications presented in the *LRFD Specifications* that are not typically used in South Carolina.

    In addition, the *SCDOT Bridge Design Manual* discusses, for selected applications, the original intent in the development of the *LRFD Specifications*, which will assist the bridge designer in the proper application of the *LRFD Specifications*.

11.2 *SCDOT MANUAL* APPLICATION

11.2.1 Project Responsibility

The *SCDOT Bridge Design Manual* applies to all bridge design projects under the responsibility of the SCDOT, including bridge projects designed by:

- in-house personnel,
- consultants retained by the Department,
- contractors retained by the Department for design/build projects, and
- local agencies where the project is funded with State and/or Federal money.

11.2.2 Hierarchy of Priority

Where conflicts are observed in those publications and documents used by SCDOT, the following hierarchy of priority shall be used to determine the appropriate application:

- Bridge Design Memoranda,
- *SCDOT Bridge Design Manual*,
- *SCDOT Seismic Design Specifications for Highway Bridges*,
- *LRFD Bridge Design Specifications*, and
- all other publications.

11.2.3 Design Exceptions

This Section discusses the Department's procedures for identifying, justifying, and processing exceptions to the structural design criteria in the *SCDOT Bridge Design Manual* and *LRFD Specifications*.

11.2.3.1 Department Intent

The general intent of the South Carolina Department of Transportation is that all design criteria in this *Manual* and the *LRFD Bridge Design Specifications* shall be met. However, recognizing that this may not always be practical, the Department has established a process to evaluate and approve exceptions to its structural design criteria.

11.2.3.2 Procedures

Formal, written design exception approvals are only required where criteria or policies in either the *SCDOT Bridge Design Manual* or *LRFD Specifications* are presented in one of the following contexts (or the like):

- “shall,”
- “mandatory,” or
- “required.”

In addition, at many locations in Part II, the text specifically states that any proposed exceptions to the indicated structural design criteria must be approved by the State Bridge Design Engineer.

When the bridge designer proposes a design element that does not meet the requirements of the *SCDOT Bridge Design Manual* or *LRFD Bridge Design Specifications* in the above context, the following procedure will apply:

1. Documentation. The bridge designer will present the justification for the exception at the earliest possible stage of the project, which may include:

    - site constraints,
    - construction costs,
    - construction considerations,
    - environmental impacts, and/or
    - right-of-way impacts.

2. Approval. All proposed exceptions must be approved, in writing, by the State Bridge Design Engineer.

11.3 STRUCTURAL DESIGN LITERATURE (National)

This Section discusses the major national publications available in the structural design literature. It provides 1) a brief discussion on each publication, and 2) the status and application of the publication by the Department. This Section is not all inclusive of the structural design literature; however, it does represent a hierarchy of importance. In all cases, designers must ensure that they are using the latest edition of the publication, including all interim revisions to date.

11.3.1 ***LRFD Bridge Design Specifications***

11.3.1.1 Description

11.3.1.1.1 General

The AASHTO *Load and Resistance Factor Design* (LRFD) *Bridge Design Specifications* serves as the national standard for use by bridge engineers or for the development of a transportation agency's own structural specifications. The *LRFD Specifications* establishes minimum requirements, consistent with current nationwide practices, which apply to common highway bridges and other structures such as retaining walls and culverts. Long-span structures may require design provisions in addition to those presented in the *LRFD Specifications*. Because of the continually changing nature of structural design, interim revisions are issued annually, and periodically AASHTO publishes a completely updated edition.

11.3.1.1.2 LRFD Methodology

The *LRFD Specifications* presents a load and resistance factor methodology for the structural design of bridges, which replaces the load factor and allowable stress methodologies of the AASHTO *Standard Specifications*. The *LRFD Specifications* applies live-load factors that are lower than the traditional AASHTO *Standard Specifications* load factors but balances this reduction with an increase in vehicular live load that more accurately models actual loads on our nation's highways. Basically, the LRFD methodology requires that bridge components be designed to satisfy four sets of limit states: Strength, Service, Fatigue-and-Fracture, and Extreme-Event limit states. Through the use of statistical analyses, the provisions of the *LRFD Specifications* reflect a uniform safety index for all structural elements, components, and systems.

The *LRFD Specifications* reflects a fundamentally different approach to design theory than the AASHTO *Standard Specifications for Highway Bridges*. The information in the *LRFD Specifications* supersedes, partially or completely, several AASHTO structural design publications. However, although superseded, some of these publications contain background information or other presentations that may be useful to a bridge designer. The *LRFD Specifications* supersedes the following publications:

1. *Standard Specifications for Alternate Load Factor Design Procedures for Steel Beam Bridges Using Braced Compact Sections*. This publication provides information on the inelastic design of compact steel members (resistance beyond first yield), historically known as autostress. An Appendix to the *LRFD Specifications* contains an updated inelastic design process for compact steel sections.

2. *Guide Specifications for Strength Design of Truss Bridges*. This document provides provisions for the design of steel trusses using the Load Factor Design (LFD) methodology. Herein, the load combination for long-span bridges (i.e., the Strength IV load combination of the *LRFD Specifications*) first appeared.

3. *Standard Specifications for Seismic Design of Highway Bridges*. See Section 11.3.3.

4. *Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members*. This document provides recommended requirements for identifying, fabricating, welding, and testing of fracture critical, non-redundant steel bridge members whose failure would be expected to cause a bridge to collapse. This document includes specifications on welding requirements that are in addition to those in the ANSI/AASHTO/AWS *Bridge Welding Code*. This document also discusses the need for proper identification of fracture critical members on plans, and it contains useful information addressing background, example problems, etc., that are not included in the *LRFD Specifications*.

5. *Guide Specifications — Thermal Effects in Concrete Bridge Superstructures*. This publication provides guidance on the thermal effects in concrete superstructures with special attention to the thermal gradient through the depth of the superstructure. These provisions have been incorporated into the *LRFD Specifications*.

6. *Guide Specifications for Fatigue Design of Steel Bridges*. This publication provides an alternative procedure to that of the AASHTO *Standard Specifications for Highway Bridges* wherein the actual number of cycles are used for fatigue design. Such a procedure has now been adopted in the *LRFD Specifications*.

7. *Guide Specifications for Design and Construction of Segmental Concrete Bridges*. This document provides details on the design and construction of segmental concrete bridges. The most important details have subsequently been included in the *LRFD Bridge Design Specifications* and the *LRFD Bridge Construction Specifications*, respectively.

8. *Guide Specification and Commentary for Vessel Collision Design of Highway Bridges*. This publication is a comprehensive document that includes information relative to designing bridges to resist damage from vessel collisions. To the extent feasible, it is based on probabilistic principles. The *LRFD Specifications* contains only the load section of this document. The *Guide Specification and Commentary for Vessel Collision Design of Highway Bridges* contains considerably more information.

11.3.1.1.3 Significant Features

A few significant features of the *LRFD Specifications* are:

1. The *LRFD Specifications* are supplemented with a comprehensive commentary placed immediately adjacent to the *LRFD Specifications* provisions in a parallel column.

2. The vehicular live load is designated HL-93. This live-load model retains a truck configuration similar to the HS-20 design truck and a tandem slightly heavier than the traditional military loading. However, the model has been modified to include simultaneously applied lane loading over full or partial span lengths to produce extreme force effects.

3. Maximum and minimum load factors have been introduced for permanent loads that must be used in combination with factored transient loads to produce extreme force effects. The minimum load factors are most significant for substructure design.

4. Fatigue loading consists of a single truck with axle weights and spacings that are the same as an HS-20 truck with a constant 30-ft spacing between the 32-kip axles that can be located anywhere on the bridge deck to produce the maximum stress range.

5. In addition to regular load combinations, two design trucks are used for negative moments and interior bent reactions in combination with the lane load; the distance between the rear axle of the first truck and the front axle of the second truck cannot be less than 50 ft; and the combined force effect is reduced by 10%.

6. The *LRFD Specifications* includes two methods for the design of concrete bridge decks — the traditional bending method and an empirical deck design, which allows for reduced deck reinforcement. SCDOT does not allow the use of the empirical deck design method.

7. The *LRFD Specifications* allows for relatively easy and more precise estimates of live-load distribution by tabulated equations.

8. The *LRFD Specifications* allows the optional use of deflection criteria. SCDOT requires the use of the optional deflection criteria.

9. The method of shear design in concrete has been revised; modified compression field theory and strut-and-tie models are used.

10. The *LRFD Specifications* recognizes the detrimental effect of salt-laden water seeping through deck joints and promotes a reduction in the number of such joints to an absolute minimum.

11.3.1.2 Department Application

11.3.1.2.1 State Highway System

The South Carolina Department of Transportation has adopted the use of the AASHTO *LRFD Bridge Design Specifications* as the mandatory document for the structural design of highway bridges on the State highway system. Exceptions to this policy must be approved by the State Bridge Design Engineer and may be appropriate for:

- widening of existing bridges, or
- bridge rehabilitation projects.

Part II presents the Department's specific application of the *LRFD Specifications* to structural design, which modify, replace, clarify, or delete information from the *LRFD Specifications* for SCDOT's application.

11.3.1.2.2 Off State Highway System

For bridge projects not on the State highway system, the Department's policy is:

1. Federal and/or State Funds. For off State highway system projects funded with Federal and/or State funds, Department policy on the use of the *LRFD Specifications* is identical to projects on the State highway system. See Section 11.3.1.2.1.
2. Locally Funded Projects. For projects funded with 100% local money, SCDOT encourages the use of the *LRFD Specifications* and the *SCDOT Bridge Design Manual*.

11.3.2 *Standard Specifications for Highway Bridges*

11.3.2.1 Description

The AASHTO *Standard Specifications for Highway Bridges* was first published in the late 1920s with annual interim revisions and, until the adoption of the *LRFD Bridge Design Specifications*, served as the national standard for the design of highway bridges. The final version of the AASHTO *Standard Specifications* is based on the Service Load Design and Load Factor Design methodologies. AASHTO maintained the AASHTO *Standard Specifications* through 2000, and published the final comprehensive 17th edition in 2002.

11.3.2.2 Department Application

SCDOT only allows the use of the AASHTO *Standard Specifications* with approval by the State Bridge Design Engineer, which may be appropriate for:

- widening of existing bridges, or
- bridge rehabilitation projects.

The minimum highway live load for strength considerations in the application of the AASHTO *Standard Specifications* shall be HS-25. The HS-25 live-load model is defined as 1.25 times the HS-20 live loading as given in the AASHTO *Standard Specifications*. The standard HS-20 live-load model shall be used for fatigue considerations.

11.3.3 *Standard Specifications for Seismic Design of Highway Bridges*

11.3.3.1 Description

The AASHTO *Standard Specifications for Seismic Design of Highway Bridges* presents design criteria for the seismic design of highway bridges to, within reason, limit significant structural damage or structural failure of a highway bridge during an earthquake. This document is based upon the observed performance of bridges during earthquakes and upon research that has been conducted worldwide. As stated in Section 11.3.1, the *Standard Specifications for Seismic Design of Highway Bridges* is superseded by the *LRFD Specifications*.

11.3.3.2 Department Application

The Department has published and adopted the *SCDOT Seismic Design Specifications for Highway Bridges*, which supersedes Division 1-A "Seismic Design" of the AASHTO *Standard Specifications for Highway Bridges* and the seismic requirements of the *LRFD Specifications.*

11.3.4 *Guide Specifications for Seismic Isolation Design*

11.3.4.1 Description

AASHTO published the *Guide Specifications for Seismic Isolation Design*, which is supplemental to the *Standard Specifications for Seismic Design of Highway Bridges.* The *Guide Specifications for Seismic Isolation Design* presents specifications for the design of bearings to seismically isolate the superstructure from the substructure of highway bridges.

11.3.4.2 Department Application

The AASHTO *Guide Specifications for Seismic Isolation Design* should be used, where applicable, in conjunction with the *SCDOT Seismic Design Specifications for Highway Bridges*.

11.3.5 ***Guide Specifications for Horizontally Curved Steel Girder Highway Bridges***

11.3.5.1 Description

The AASHTO *Guide Specifications for Horizontally Curved Steel Girder Highway Bridges* presents specifications and methodologies for the design of steel I-girder and steel box girder bridges that are on a horizontal curve. This document is applicable to simple and continuous spans and to composite or non-composite structures of moderate length employing either rolled or fabricated sections. The design methodology is based on both working stress and load factor principles and, therefore, is not compatible with the *LRFD Specifications*.

11.3.5.2 Department Application

A 2005 interim change to the *LRFD Specifications* integrates horizontally curved girders, both I-shaped and box girders, in common equations for both straight and curved girders. Therefore, SCDOT only allows the use of the *Guide Specifications for Horizontally Curved Steel Girder Highway Bridges* for the same applications as for the AASHTO *Standard Specifications for Highway Bridges*. When this document is used, the analysis shall be performed using refined methods as described in Article 4.3.2.

11.3.6 ANSI/AASHTO/AWS ***Bridge Welding Code D1.5M/D1.5***

11.3.6.1 Description

The *Bridge Welding Code* presents current criteria for the welding of structural steel in bridges. The *Code* superseded the 1981 AASHTO *Standard Specifications for Welding of Structural Steel Highway Bridges* and supplements the *Structural Welding Code, AWS D1.1*.

For the first time, with the 2002 edition, the *Code* includes a commentary on selected sections.

11.3.6.2 Department Application

The Department has adopted the use of the *Bridge Welding Code D1.5* for the design and construction of structural steel highway bridges. However, for items not specifically addressed in D1.5, such as welding of existing structures or welding of reinforcing steel, refer to the current edition of ANSI/AWS D1.1 and ANSI/AWS D1.4.

11.3.7 ***Manual on Subsurface Investigations***

11.3.7.1 Description

The AASHTO *Manual on Subsurface Investigations* discusses many of the techniques used in the highway industry for subsurface geotechnical investigations. The objective is to describe accepted procedural and technical methods to determine the geotechnical properties of soils and rocks that will support the highway facility. The range of topics includes data requirements, field reviews, evaluation of geotechnical data, subsurface water impacts, equipment, and laboratory testing procedures.

11.3.7.2 Department Application

The Department recommends that this publication be used for all subsurface investigations, which is primarily the responsibility of the SCDOT Office of Materials and Research.

11.3.8 *LRFD Movable Highway Bridge Design Specifications*

11.3.8.1 Description

The AASHTO *LRFD Movable Highway Bridge Design Specifications* addresses the design of movable highway bridges using the *LRFD Bridge Design Specifications*. This document provides guidance for the structural design and machinery design of swing, bascule, and vertical-lift spans.

11.3.8.2 Department Application

The AASHTO *LRFD Movable Highway Bridge Design Specifications* shall be used for the design of any movable bridges.

11.3.9 *Guide Specifications for Design of Pedestrian Bridges*

11.3.9.1 Description

The AASHTO *Guide Specifications for Design of Pedestrian Bridges* applies to bridges intended to carry pedestrian traffic and/or bicycle traffic. This document is not based upon the LRFD design methodology, but is based upon allowable stress design (ASD) and load factor design (LFD) methodologies.

11.3.9.2 Department Application

The AASHTO *Guide Specifications for Design of Pedestrian Bridges* shall be used for the design of pedestrian bridges in conjunction with the AASHTO *Standard Specifications for Highway Bridges*. The publication shall not be used in conjunction with the AASHTO *LRFD Specifications*.

11.3.10 ***Guide Specifications for Distribution of Loads for Highway Bridges***

11.3.10.1 Description

The AASHTO *Guide Specifications for Distribution of Loads for Highway Bridges* provides more refined live-load distribution factors than the traditional “S over” factors of the AASHTO *Standard Specifications for Highway Bridges*. Although the refined equations appear similar, they are not the same as those provided in the *LRFD Specifications* and shall not be used with the *LRFD Specifications*.

11.3.10.2 Department Application

SCDOT does not allow the use of the AASHTO *Guide Specifications for Distribution of Loads for Highway Bridges*.

11.3.11 ***Guide Design Specifications for Bridge Temporary Works***

11.3.11.1 Description

The AASHTO *Guide Design Specifications for Bridge Temporary Works* has been developed for use by State agencies to include in their existing construction Standard Specifications for falsework, formwork, and related temporary construction used to construct highway bridge structures.

11.3.11.2 Department Application

The AASHTO *Guide Design Specifications for Bridge Temporary Works* may be used at the discretion of the individual bridge designer.

11.3.12 ***Guide Specifications for Structural Design of Sound Barriers***

11.3.12.1 Description

The AASHTO *Guide Specifications for Structural Design of Sound Barriers* provides criteria for the structural design of sound barriers to promote the uniform preparation of plans and specifications. The publication allows the design of masonry sound barriers in addition to concrete, wood, steel, synthetics and composites, and aluminum.

11.3.12.2 Department Application

The AASHTO *Guide Specifications for Structural Design of Sound Barriers* shall be used for all sound barrier designs.

11.3.13 *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*

11.3.13.1 Description

The AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* presents structural design criteria for the supports of various roadside appurtenances. The publication presents specific criteria and methodologies for evaluating dead load, live load, ice load, and wind load. This document also includes criteria for several types of materials used for structural supports such as steel, aluminum, concrete, and wood.

11.3.13.2 Department Application

The Department has adopted the use of the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*. The SCDOT Traffic Engineering Division is primarily responsible for the design of these supports.

11.3.14 AISC *LRFD Manual of Steel Construction*

11.3.14.1 Description

The *LRFD Manual of Steel Construction*, published by the American Institute of Steel Construction (AISC), provides dimensions, properties, and general design guidance for structural steel for various applications. Although the *Manual* contains AISC criteria for steel buildings, the properties of the rolled structural shapes are useful for designing bridge structures.

11.3.14.2 Department Application

Designers may use the AISC *LRFD Manual of Steel Construction* at their discretion.

11.3.15 AREMA *Manual for Railway Engineering*

11.3.15.1 Description

The AREMA *Manual for Railway Engineering*, published by the American Railway Engineering and Maintenance-of-Way Association (AREMA), provides detailed structural specifications for the design of railroad bridges. The AREMA specifications has approximately the same significance for railroad bridges as the *LRFD Specifications* has for highway bridges; i.e., the structural design of railroad bridges shall meet the AREMA requirements.

11.3.15.2 Department Application

For the design of railroad bridges, the specifications of the AREMA *Manual* must be met, except as modified by railroad companies operating in South Carolina. In addition, the AREMA *Manual* contains the AREMA requirements for the geometric design of railroad tracks passing beneath a highway bridge. As appropriate, these criteria have been incorporated into Chapter 22 of the *SCDOT Bridge Design Manual*.

11.3.16 Other Structural Design Publications

The structural design literature contains many other publications which may, on a case-by-case basis, be useful. The following briefly describes several other structural design publications:

1. *Prestressed/Precast Concrete Institute (PCI) Design Handbook*. This publication includes information on the analysis and design of precast and/or prestressed concrete products in addition to a discussion on handling, connections, and tolerances for prestressed products. It contains general design information, specifications, and standard practices. Designers may use their discretion in the use of this publication.

2. *Prestressed/Precast Concrete Institute (PCI) Bridge Design Manual*. This two-volume, comprehensive design manual includes both preliminary and final design information for standard girders and precast, prestressed concrete products and systems used for transportation structures. This document contains background, strategies for economy, fabrication techniques, evaluation of loads, load tables, design theory, and numerous design examples. This publication is designed to explain the application of both the AASHTO *Standard Specifications* and *LRFD Specifications*.

3. *Post-Tensioning Institute (PTI) Post-Tensioning Manual*. This publication discusses the application of post-tensioning to many types of concrete structures, including concrete bridges. This publication also discusses types of post-tensioning systems, specifications, the analysis and design of post-tensioned structures, and their construction. The use of this publication is mandatory for all post-tensioning applications.

4. *Concrete Reinforcing Steel Institute (CRSI) Handbook*. This publication meets the ACI Building Code Requirements for Reinforced Concrete. Among other information, it provides values for design axial load strength and design moment strength for tied columns with square, rectangular, or round cross sections. It also provides pile cap design information. Designers may use their discretion in the use of this publication.

5. *National Steel Bridge Alliance (NSBA) Highway Structures Design Handbook*. This document addresses many aspects of structural steel materials, fabrication, economy, and design. Recently updated with LRFD examples in both US customary units and SI units, the general computational procedure is helpful to designers using the *LRFD Bridge Design Specifications*. Designers may use their discretion in the use of this publication.

6. *American Concrete Institute (ACI) –– Analysis and Design of Reinforced Concrete Bridge Structures*. This publication contains information on various concrete bridge types, loads, load factors, service and ultimate load design, prestressed concrete, substructure and superstructure elements, precast concrete, reinforcing details, and metric conversion. Designers may use their discretion in the use of this publication.

7. *CRSI Manual of Standard Practice*. This publication explains generally accepted industry practices for estimating, detailing, fabricating, and placing reinforcing bars and bar supports. SCDOT requires that reinforcing steel shall be detailed as shown in the *CRSI Manual of Standard Practice* as modified by SCDOT practices.

8. *PTI — Post-Tensioned Box Girder Bridges*. This publication contains information on economics, design parameters, analysis and detailing, installation, prestressing steel specifications, post-tensioning tendons, systems, and sources. The use of this publication is mandatory for all post-tensioned box girder bridge applications.

9. *United States Navy — Design Manual for Soil Mechanics, Foundations and Earth Structures*. This *Manual* is a comprehensive document that addresses embankments, exploration and sampling, spread footings, deep foundations, pressure distributions, buried substructures, special problems, seepage and drainage analysis, settlement analysis, soil classifications, stabilization, field tests and measurements, retaining walls, etc. Note that the loading sections of this document are superseded by the *LRFD Specifications*.

10. *United States Department of Agriculture (USDA) Forest Service Timber Bridge Manual*. This *Manual* is a comprehensive document that addresses all aspects of traditional timber bridge construction plus the latest developments in laminated deck systems using adhesives or prestressing forces. Designers may use their discretion in the use of this publication.

11. *Timber Construction Manual*. This document, published by the American Institute of Timber Construction (AITC), provides comprehensive criteria for the design of timber structures, including bridges. This document contains information for both sawn and laminated timber. The designer should use the AITC *Timber Construction Manual* to supplement the AASHTO publications on the design of timber bridges.

12. *Uniform Building Code*. This document, published by the International Conference of Building Officials (ICBO), provides criteria for the design of buildings throughout the United States and abroad. It is intended to be used directly by an agency or to be used in the development of an agency’s own building codes.

13. NCHRP 343 *Manuals for Design of Bridge Foundations.* This publication provides valuable additional information on the application of the *LRFD Specifications* to foundations.

14. AASHTO *Manual for Condition Evaluation of Bridges*. This publication serves as a standard and provides uniformity in the procedures and policies for determining the physical condition, maintenance needs, and load capacity of highway bridges in the United States. This publication assists bridge owners by establishing inspection procedures and load rating practices that meet the National Bridge Inspection Standards (NBIS). The load rating procedures are based upon both the allowable stress rating methodology and the load factor rating methodology.

15. AASHTO *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges*. This document is an updated version of the AASHTO *Manual for Condition Evaluation of Bridges* (see Item #14). The rating procedures in this document are based upon the LRFR methodology. If an owner does not use the LRFR methodology for load rating, this document is important because it is an update of the AASHTO *Manual for Condition Evaluation of Bridges*.

16. American Concrete Institute (ACI) 318 *Building Code Requirements for Structural Concrete* and *Commentary*. This document addresses the proper design and construction of buildings of structural concrete. Although this document is intended for building design, bridge designers may find it useful because it provides details on aspects of concrete design that are not typical in highway bridges.

17. *PCA Notes on ACI 318 Building Code Requirements for Structural Concrete with Design Applications*. The primary purpose of the PCA Notes is to assist the engineer in the proper application of the ACI 318 design standard. Each chapter of the publication starts with a description of the latest Code changes. Numerous design examples illustrate the application of the Code provisions.

11.4 SCDOT DOCUMENTS

The Department has prepared many publications in addition to the *SCDOT Bridge Design Manual* that may apply to a bridge design project. This Section briefly discusses other relevant SCDOT publications that may have a significant impact on a bridge design project.

11.4.1 ***SCDOT Seismic Design Specifications for Highway Bridges***

The Bridge Design Section is responsible for the *SCDOT Seismic Design Specifications for Highway Bridges*. This document provides guidance on seismic design criteria, analysis methods, and detailing procedures for the preparation of bridge plans.

The *SCDOT Seismic Design Specifications for Highway Bridges* presents minimum requirements for use in bridge design and are intended to:

- safeguard against major failures and loss of life,
- minimize damage,
- maintain functionality, and/or
- provide for expedited repair.

11.4.2 ***SCDOT Geotechnical Design Manual***

The Geotechnical Design Section is responsible for the *SCDOT Geotechnical Design Manual*. This document presents the Department's criteria for geotechnical investigations and designs performed by the Department. The *SCDOT Geotechnical Design Manual* discusses:

- site surveys;
- field investigations (e.g., subsurface);
- pavement section support (e.g., pavement subgrade, subgrade drainage, erosion control);
- embankments/slopes (e.g., settlement, slope stability);
- foundations for structures (e.g., geotechnical properties);
- retaining walls (e.g., external stability); and
- geotechnical involvement in construction.

11.4.3 ***SCDOT Highway Design Manual***

The Road Design Section is responsible for the *SCDOT Highway Design Manual*. The *SCDOT Highway Design Manual* presents the Department's criteria for the design of a wide range of roadway elements. These include:

- in-house procedures for road design projects;

- geometrics (e.g., cross sections, design speed, horizontal and vertical alignment, at-grade intersections, interchanges);

- roadside safety;
- special design elements (e.g., rest areas, weigh stations, bicycle accommodation);
- design criteria for individual functional classes;
- environmental procedures;
- traffic engineering;
- SCDOT criteria for compliance with the *Americans with Disabilities Act*; and
- the assembly of contract documents for road design projects (e.g., plan preparation, quantities, cost estimates).

11.4.4 *South Carolina Requirements for Hydraulic Design Studies*

The Hydraulic Engineering Section is responsible for the *South Carolina Requirements for Hydraulic Design Studies*, which presents design criteria on the following topics:

- hydraulic surveys;
- hydrologic methods used in South Carolina;
- hydraulic design of culverts, open channels, bridge waterway openings, and closed drainage systems; and
- erosion control.

11.4.5 *SCDOT Standard Specifications for Highway Construction*

The Construction Division is responsible for the *SCDOT Standard Specifications for Highway Construction*. The *SCDOT Standard Specifications* presents the work methods and materials approved by the Department for the construction of road, traffic, and bridge projects. These specifications present information on:

- contract administration (e.g., bidding, awarding the contract, contractor duties, contractor and Department legal requirements, measuring and paying for contract items);
- earthwork;
- bases and subbases;
- bituminous pavements;
- rigid pavements;

- traffic control;
- structures; and
- incidental construction items.

The *SCDOT Standard Specifications* are modified by the Supplemental Specifications. The Supplemental Specifications set forth the latest Department requirements.

11.4.6 ***SCDOT Construction Manual***

The Construction Division is responsible for the *SCDOT Construction Manual*. This document is intended for use by engineering personnel in the administration of construction contracts, especially the application of the *SCDOT Standard Specifications for Highway Construction*. As such, the *SCDOT Construction Manual* addresses each of the items listed for the *SCDOT Standard Specifications for Highway Construction*, but not within the context of a contractual document.

11.4.7 ***SCDOT Survey Manual***

The Surveys Office is responsible for the *SCDOT Survey Manual*, which presents the Department's criteria for the following:

- survey datums and coordination systems,
- survey measurements and equipment,
- errors and maximum closure,
- preliminary surveys,
- property corner ties, and
- construction surveys.

11.5 STATE PLANE COORDINATE SYSTEM

See the *SCDOT Survey Manual* and the *SCDOT Highway Design Manual* for the application of the South Carolina State Plane Coordinate System for road and bridge projects.

Chapter 12

STRUCTURAL SYSTEMS AND DIMENSIONS

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 12

STRUCTURAL SYSTEMS AND DIMENSIONS

This Chapter provides guidance to bridge designers in determining the most efficient and economical overall structure type and size to meet the structural, geometric, hydraulic, environmental, and right-of-way characteristics of the site. This decision will significantly impact the detailed structure design phase, construction costs, and operational costs over the life of the structure.

12.1 IN-HOUSE OPERATIONS

Part I of the *SCDOT Bridge Design Manual* documents the Department's in-house operations for project development (e.g., organization of the Bridge Design Section, coordination with other SCDOT Units, administrative policies and procedures).

12.2 GENERAL STRUCTURAL DESIGN CRITERIA

The bridge designer must evaluate certain general structural design criteria in the selection of the structure type and size. This Section discusses these general structural considerations.

12.2.1 <u>Definition of Terms</u>

12.2.1.1 Substructure vs Foundation

The dividing line between substructure and foundation is not always clear, especially in the case of extended pile bents and drilled shafts. Traditionally, foundations include the supporting rock or soil and parts of the substructure that are in direct contact with, and transmit loads to, the supporting rock or soil. In the *SCDOT Bridge Design Manual*, this definition will be used.

12.2.1.2 Substructure vs Superstructure

A similar difficulty exists in separating substructure and superstructure where these parts are integrated. For integral bents, the *SCDOT Bridge Design Manual* will refer to the substructure as any component or element located below the bearings. The superstructure then consists of the bearings and all of the components and elements resting upon them.

12.2.2 <u>Live-Load Deflection Criteria</u>

Reference: LRFD Articles 2.5.2.6.2 and 2.5.2.6.3

12.2.2.1 General

The *LRFD Specifications* states that the traditional live-load deflection criteria is optional for bridges both with and without sidewalks because static live-load deflection is not a good measure of dynamic excitation. Nonetheless, in the absence of a better criterion and because of concerns on durability, SCDOT has determined that it is appropriate to limit live-load deflections.

12.2.2.2 Criteria

Live-load deflections shall be limited based upon the span-length-based criteria of LRFD Article 2.5.2.6.2 with consideration to either the presence or the absence of pedestrian traffic. The minimum superstructure depth limits of LRFD Article 2.5.2.6.3 shall also be met.

12.2.3 Continuous vs Simple Spans

In general, continuous structures (and jointless bridges) provide superior structural performance when compared to bridges with simple spans and joints. However, in rare cases, it may be appropriate to use simple spans, including widenings of existing simple-span bridges and longer spans or other geometric constraints.

Back-to-back multiple simple spans should be avoided, if possible.

12.2.4 Jointless Bridges

12.2.4.1 General

When practical, a jointless bridge should be considered in design. Problems with expansion joints include:

- corrosion caused by de-icing chemicals leaking through the joints,
- accumulation of debris and other foreign material restricting the free joint movement often resulting in joint damage,
- differential elevation at the joints causing additional impact forces,
- unexpected bridge movements and settlements that affect the joint, and
- high initial and maintenance costs.

Joints can be eliminated with special consideration to:

- load path,
- gravity and longitudinal loads,
- effects of concrete creep and shrinkage,
- effects of temperature variations,
- stability of superstructure and substructure during construction and service,
- skew and curvature effects,
- the superstructure-end bent-foundation connection design and details,
- effects of superstructure and substructure stiffness,
- effects of settlement and earth pressure,
- effects of varying soil properties and type of foundation, and
- effect of approach slab and its connection to the bridge.

Jointless bridges, already in service, have demonstrated the ability to perform successfully under the previous considerations. Therefore, in the absence of in-depth analyses, it is reasonable to design a jointless bridge under the following parameters:

- 240-ft total maximum length for steel girder bridges or 300-ft total maximum length for prestressed concrete beam bridges,
- 30° skew or less,
- settlement is not anticipated, and
- end bent types that are flexible.

If one or more of these parameters are not met, the use of a jointless bridge will require a more detailed analysis.

12.2.4.2 Geotechnical Considerations for Jointless Bridges

Section 12.5 discusses the selection of a foundation type; Chapter 19 discusses the design of foundation types, and also discusses the engineering coordination between the bridge designer and Geotechnical Design Section for geotechnical issues. For more information on geotechnical engineering, see the *SCDOT Geotechnical Design Manual*.

12.2.4.2.1 Site Conditions

Geotechnical considerations for jointless bridges are generally the same as for jointed bridges, with additional consideration given to soil-structure interactions and longitudinal stiffness. Subsurface soil conditions at the bridge site must be determined to an acceptable degree prior to determining if a jointless bridge is a practical option. Consult with the Geotechnical Design Engineer regarding subsurface conditions at the bridge site.

Generally, geotechnical investigations for jointed bridges are acceptable for jointless bridges, with special consideration given to the upper strata where longitudinal foundation movements are expected. Jointless bridges require superstructure movements to be accommodated by the foundation through soil-structure interaction. These movements require “flexible” foundations that are capable of deflecting longitudinally without damage to the foundation or significant disturbance to the roadway surface. Soil conditions that allow the use of flexible foundations range from soft clay to loose sand. Generally, “poor” soil conditions result in foundations that have less lateral stiffness and accommodate larger lateral movements than “good” soil conditions. Dense sand and gravel or hard clays will often result in foundations that are too stiff and cannot deflect horizontally the amount required by long superstructures.

Softer soil conditions have a greater potential for settlement problems. Thus, soil conditions that favor longitudinal movements of the foundation also have an increased risk of significant foundation settlement. Although longitudinal deflections of the foundation are encouraged, foundation settlement is discouraged. Foundations at jointless bridges will generally require a more in-depth geotechnical analysis than jointed bridges, especially in areas exhibiting high seismic demands.

12.2.4.2.2 Foundation Type

Foundations are the structural elements that transfer vertical, lateral, and rotational loads into the soil by soil-structure interaction. Soil-structure interaction is influenced by the type and geometry of the foundation and the characteristics of the surrounding soil. In typical designs, the foundation is considered to be infinitely stiff. However, the foundation stiffness should be compared to the substructure stiffness to verify this assumption. In many cases, the longitudinal bridge stiffness will significantly decrease if the foundation stiffness is combined with the substructure stiffness. Foundation types should be matched with the intent of the design. If the foundation is considered rigid, then it should be very stiff. If the foundation is intended to accommodate translation, as is typical in jointless bridges, then it should be flexible.

Deep foundations such as piles are typically very stiff axially, but flexible laterally. Thus, they are good choices for jointless bridges, under certain soil conditions. Drilled shafts are similar to piles, except they are typically stiffer laterally and are generally used in more competent soil stratifications. Shallow foundations such as spread footings are generally very stiff both axially and laterally, especially at the embedment depths typically used for bridge foundations. Often, different foundation types are used for the interior and end bents based upon soil conditions.

The type of foundation used at an end bent of a jointless bridge will largely be determined by the type of soil at the site and the seismic performance requirements. It will also be a function of the length of the span or lateral movement expected. Thus, the soil conditions can control the foundation type, which can control the length of span used for a jointless bridge. Under certain soil conditions, jointless bridges are not practical.

Very loose to loose cohesionless soil or very soft to soft clay will require deep foundations such as piles or, possibly, drilled shafts; see Section 12.5. Deep foundations in these soil deposits will be flexible enough to accommodate large longitudinal movements at end bents associated with long jointless bridges. However, high to moderate foundation settlement can be expected in these soils. Extra conservatism may be warranted when designing the foundations to resist axial loads to limit settlement.

Dense cohesionless soils such as sandy gravel, gravelly sand, or cobbles and boulders are often not well suited for deep foundations due to the difficulty in installing the piles or drilled shafts to the required elevations to resist the axial loads. When deep foundations are used in these cases, the lateral stiffness is usually very high and typically will not permit the longitudinal movements necessary at the end bent for a long jointless bridge. Short jointless bridges, however, may use these types of foundations at end bents in these soil deposits, when significant longitudinal movement is not expected. Spread footings can be used in these soil conditions; see Section 12.5. Spread footings are typically very stiff foundations and can often be considered rigid in soil deposits of this nature. Foundation settlements in these soil deposits are likely to be negligible.

Medium dense cohesionless soil or stiff to hard clays are intermediate materials. Deep foundations or shallow foundations can both be used in these materials. However, the stiffness of shallow foundations such as spread footings is likely to be too high to be used at end bents on a long jointless bridge. Even deep foundations such as piles, which are usually flexible, are likely to be too stiff to allow enough longitudinal movement for a moderate to long jointless bridge. In these soil conditions, the length of the bridge and the foundation type will be critical. Foundation settlements may range from negligible to moderate in these soil deposits.

12.2.5 Girder Bridges

12.2.5.1 Deck and Girder Composite Action

Reference: LRFD Articles 4.5.2.2 and 9.4.1

Deck and girder composite action enhances the stiffness and economy of bridges. Bridge decks and their supporting members shall be made fully composite throughout the entire span of the bridge, in both positive and negative moment regions. Thus, the shear connectors and other connections between decks and their supporting members shall be designed to develop full composite action. In other words, the shear connections must be able to resist the horizontal interface shear at the nominal resistance of the section.

The stiffness characteristics of composite girders shall be based upon full participation of the effective width of the concrete deck. In other words, composite concrete bridge decks shall be considered uncracked throughout the span for the determination of moments and shears for Service and Strength limit states in structural analysis.

12.2.5.2 Number of Girders

Because of concerns for redundancy, new bridges shall have a minimum of four girders per span.

12.2.5.3 Girder Spacing

The typical girder spacing for SCDOT bridges is 7½ ft to 10 ft. The maximum spacing shall not exceed 10½ ft.

12.2.5.4 Interior vs Exterior Girders

Reference: LRFD Article 4.6.2.2.1

To simplify future bridge widenings and for economy of fabrication, all girders within a span should be designed identically to the governing condition, either interior or exterior girder.

12.2.5.5 Deck Overhang

The bridge deck overhang is measured perpendicular from the centerline of the exterior girder to the outside edge of the slab. SCDOT limitations on maximum deck overhang are based on the following:

1. Girder Spacing. Deck overhang shall not exceed 50% of the average girder spacing for parallel girders (i.e., either straight or curved). For chorded girders, the overhang at any point shall not exceed 50% of the average girder spacing.

2. Girder Depth/Type. Figure 12.2-1 presents SCDOT limitations on maximum deck overhang based on the depth and type of girder.

The lesser of the two values from the above will govern the maximum bridge deck overhang.

SCDOT criteria for minimum bridge deck overhang is that the slab shall extend 12 in beyond the edge of the top flange of the exterior girder or 2′-3″ beyond the centerline of the exterior girder, whichever is greater.

The deck overhang shall be designed in accordance with Section 13 of the *LRFD Specifications*.

Type of Beam	Depth of Beam[1]	Maximum Deck Overhang
Prestressed Concrete	< 54″	42″
	54″ - 63″	48″
	> 63″	54″
Structural Steel	< 36″	Depth of Beam
	36″ - 48″	42″
	> 48″	45″

[1] *For structural steel plate girders, the web depth shall be used as the depth of beam.*

MAXIMUM DECK OVERHANG

Figure 12.2-1

12.2.6 Seismic Requirements

The bridge designer shall incorporate the seismic requirements of the *SCDOT Seismic Design Specifications for Highway Bridges* with the selection of a superstructure, substructure, or foundation type. The seismic demand of the bridge and the flexibility/stiffness of the bridge are coexistent. Therefore, any selection must satisfy the seismic performance, ductility requirements, plastic hinge location, and all other design criteria as specified in the *SCDOT*

Seismic Design Specifications for Highway Bridges, which should be referenced for additional information.

12.2.7 Approach Slabs

Approach slabs are required on projects that meet one of the following conditions:

- any bridge that is located on an Interstate, US, or SC route;
- any bridge that is located on a Secondary Road that has a current ADT greater than 400 vpd or that has a new approach fill height that exceeds 10 ft; or
- any bridge having parallel wing walls (wing walls parallel to the centerline of the bridge).

12.2.8 Sleeper Slabs

A sleeper slab is a foundation slab, inverted tee-beam or L-beam placed transversely supporting the end of the approach slab away from the bridge. Sleeper slabs should be used to provide an off-bridge joint at the end of the approach slab, where:

- a jointless bridge exceeds 240 ft total length for steel girder bridges or 300 ft total length for prestressed concrete beam bridges, or
- the distance from an integral or semi-integral end bent to the nearest expansion joint exceeded 240 ft for steel girder bridges or 300 ft for prestressed concrete beam bridges.

The embankment beneath the sleeper slab shall be designed to prevent differential settlement along the length of the sleeper slab.

12.3 SUPERSTRUCTURES

This Section discusses those factors that should be considered in the initial selection of the superstructure type.

12.3.1 Superstructure Types/Characteristics

12.3.1.1 General

Throughout the nation, many types of superstructures have been developed for the myriad applications and constraints that prevail at bridge sites. However, South Carolina, like most other States, has narrowed its typical selection of superstructure types to a relatively small number based on the Department's experience, geography, terrain, environmental factors, local costs, local fabricators, the experience of the contracting industry, availability of materials, and Department preference. This promotes uniformity throughout the State and simplifies the bridge design process.

This Section presents summary information on the available superstructure types used by SCDOT and identifies their typical application. This information will assist the bridge designer in the initial selection of a superstructure type that will ultimately provide a practical, cost-effective selection for the site under consideration.

12.3.1.2 Span Length Guidelines

Figure 12.3-1 indicates the span lengths for which the typical SCDOT superstructure types will generally apply.

Structure Type	Span Length Ranges (ft)		
	≤ 40	> 40 to 100	> 100
Prestressed Concrete Girders		X	X
Flat Slabs (Reinforced, Cast-in-Place Concrete Slabs)	X		
Steel Welded Plate Girders		X	X
Steel Rolled Beams		X	
Cored Slabs (Prestressed Concrete Cored Slabs)	X	X	

Note: See Section 12.3.2 for more discussion on span ranges for each type.

SPAN LENGTH RANGES FOR TYPICAL SUPERSTRUCTURE TYPES

Figure 12.3-1

12.3.2 Typical SCDOT Superstructure Types

This Section discusses the basic characteristics of those superstructure types most frequently used in South Carolina. Collectively, these five types represent approximately 90% of all new bridges and bridge replacements constructed by the Department. The information in this Section is intended to assist the bridge designer in the selection of a superstructure type for a given site.

12.3.2.1 Prestressed Concrete Girders

Because of their economy and applicability, prestressed, precast concrete girders are the most commonly used type of superstructure used in South Carolina. This system is used wherever possible within cost and clearance constraints. Span lengths typically range from 50 ft to 120 ft. Where designs for span lengths greater than 120 ft are necessary and transportation of the beams will occur in States other than South Carolina, the Contractor must obtain approval from the DOTs for the States through which the beams must be transported. The designer must consider how this structure type will be erected and how the girders will be delivered to the site.

When compared to other bridge types, the advantages of prestressed, precast concrete girder bridges include moderate construction cost on smaller bridges to fairly low construction cost on larger bridges, low maintenance cost, no falsework requirements, relatively quick fabrication time, and reasonably fast on-site construction. Disadvantages include difficulty of lifting and transporting, difficulty of adapting to complex geometrics, and slightly higher depth-to-span ratios.

Multiple spans of prestressed girders should be made continuous in the longitudinal direction for live loads and composite dead loads. In this arrangement, their ends, which are made continuous, are connected by a common diaphragm that is cast monolithically with the slab.

See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website, for the Department's typical details for prestressed concrete beams. See Chapter 15 for SCDOT design details.

12.3.2.2 Flat Slabs (Reinforced Cast-in-Place Concrete Slabs)

The flat slab is frequently used in South Carolina because of its suitability for short spans and low clearances and its adaptability to skewed and curved alignments. The most common applications of the flat slab in South Carolina are over small creeks and swamps and as approaches to large interior spans. The limit of its application is the cost effectiveness of the required substructure and hydraulic or aesthetic issues.

Standard span lengths are 22 ft, 30 ft, and 40 ft, with 30 ft being preferred. For a 40-ft span, the bridge designer must consider the long-term deflections with respect to camber.

Typical SCDOT practice is to use constant-depth slabs with no haunches in the negative-moment regions. Equal length spans are preferred for continuous slab bridges. For ease of construction and crack avoidance, non-integral bent caps shall be used.

See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website, for typical flat slab details. See Chapter 15 for SCDOT design details.

12.3.2.3 Steel Welded Plate Girders

SCDOT typically limits the use of structural steel plate girder superstructures to longer spans (75 ft to 300 ft) or to where a concrete superstructure is not the best choice because:

- Superstructure dead load is a critical issue.
- Vertical clearances are a critical issue (Note: High-performance steel (HPS) offers good span/depth ratios).
- Geometrics are difficult (e.g., sharp horizontal curvature).

When compared to other bridge types, the advantages of structural steel girder bridges include fast on-site construction, no falsework requirements, adaptability to complex geometrics, and longer span capability. Its disadvantages include high construction and maintenance costs, longer lead time for girder fabrication, and necessary attention to detailing practices. Poor detailing will greatly increase the cost of the bridge and can decrease durability.

Steel plate girders should be designed to optimize fabrication and erection costs. Girder field sections can be transported in lengths up to approximately 120 ft. Where designs for field sections greater than 120 ft are necessary and transportation of the girders will occur in States other than South Carolina, the Contractor must obtain approval from the DOTs for the States through which the girders must be transported. The designer must consider how this structure type will be erected and how the girders will be delivered to the site.

See Chapter 16 for SCDOT design details.

12.3.2.4 Steel Rolled Beams

Because of availability concerns, the use of steel rolled beams is usually limited to bridge widening projects.

Rolled steel beams are characterized by doubly symmetrical, as-rolled cross sections with equal-dimensioned top and bottom flanges and relatively thick webs. Thus, the cross sections are not optimized for weight savings, as are the cross sections for a plate girder, but are cost effective due to lower fabrication and erection costs. The relatively thick webs eliminate the need for web stiffeners. Unless difficult geometrics or limited vertical clearances control, rolled steel beam superstructures are more cost effective in relatively shorter spans (50 ft to 90 ft).

Rolled steel beams are available in depths up to 3 ft, with beams more than 3 ft rolled less frequently. Before beginning final design, verify with one or more potential fabricators that the section size and length are available.

12.3.2.5 Cored Slabs (Prestressed Concrete Cored Slabs)

Prestressed concrete cored slabs ("cored slabs") are an alternative to flat slabs when the bridge designer anticipates the necessity of an accelerated construction schedule. Cored slab bridges consist of longitudinal, precast voided concrete slab members placed against each other to form a self-supported bridge deck. Cored slab details are available in span lengths of 30 ft, 40 ft, 50 ft, and 60 ft. See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website.

The use of cored slabs is limited because of durability concerns due to the longitudinal and transverse joints. Voided concrete slabs are not allowed on any National Highway System (NHS) route nor on any facility with an ADT that equals or exceeds 3000 vpd.

In addition to permanent installations, cored slabs may be used for temporary bridges (i.e., a design life less than 5 years).

For Contractor-designed projects, such as design/build, cored slabs will only be allowed if the bid documents specifically allow their use. The substitution of a cored slab is not a valid Value Engineering proposal.

The maximum allowable skew is 15°, and the bridge designer must ensure a proper fit on the bent caps where the bridge is on a longitudinal grade or on a skew. In addition, other geometric elements may merit special consideration in the design of a cored slab.

12.3.3 <u>Other Structure Types</u>

Structures types other than those specified herein may be used. Their acceptability may be based upon other owner's successful experiences. The State Bridge Design Engineer must provide written approval for the selection of other structure types.

12.4 SUBSTRUCTURES

12.4.1 Objective

This Section discusses those types of substructure systems used by the Department, and it presents their general characteristics and usage. The designer should use this information and the information presented in Section 12.5 to select the combination of substructure and foundation types that is suitable at the site to satisfy economically the geometric requirements of the bridge and to safely use the strength of the soil or rock to carry the anticipated loads. The designer should also consider the seismic performance criteria requirements of the bridge when determining the substructure and foundation types that will be used. See the *SCDOT Seismic Design Specifications for Highway Bridges.* Chapter 20 discusses the detailed design of substructure elements, and Chapter 19 discusses the design of foundations.

12.4.2 End Bents

Reference: LRFD Article 11.6

12.4.2.1 General

The term "end bent" is used interchangeably with the LRFD term "abutment."

An end bent includes either a backwall or an end wall, a cap, and wing walls. A backwall or end wall is the upper portion of the end bent that functions as a wall that provides lateral support for fill material that the roadway or approach slab rests on. The term "backwall" refers specifically to the upper portion of a free-standing end bent, while the term "end wall" refers to the upper portion of an integral or semi-integral end bent in which the beams or girders are encased.

End bents are typically supported on piles but may also be supported on drilled shafts or footings. Piles and drilled shafts shall extend below any compacted fill, including MSE wall backfill. Footings supporting an end bent are rare, and shall not be permitted to be placed on compacted fill materials. Where pile-supported, vertical piles are preferred over battered piles.

12.4.2.2 End Bent Types

End bents can be generally classified as rigid or flexible. This classification refers to the end bent's fixity to the foundation and should not be confused with the fixity of the beams or girders to the substructure.

Rigid end bents incorporate expansion joints at the end of the bridge between the deck and the backwall to accommodate thermal movements.

Flexible end bents eliminate expansion joints at the end of the superstructure by integrating the bridge deck and encased beam ends with the "backwall" to form an end wall. Flexible end bents must be able to accommodate the movements through elastic behavior of the bridge and the surrounding soil because the deck and beams are integral with the end bent.

An end bent may be designed as one of the following three types in descending order of preference:

1. Integral End Bent. Flexible end bent without an expansion joint between the end bent and the bridge deck (in cross section, the end wall and bent cap may appear as a monolithic rectangle with no apparent division between them). See Figure 12.4-1.

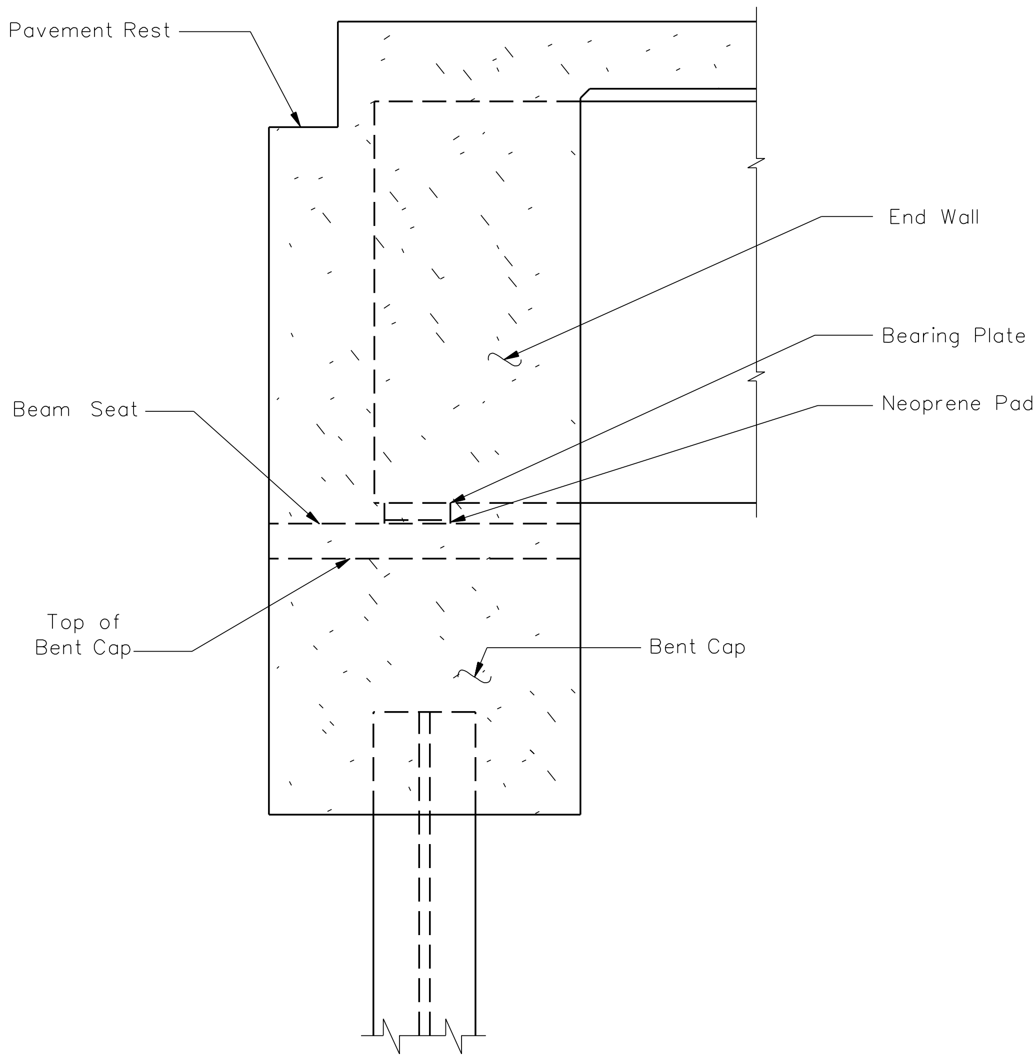
2. Semi-Integral End Bent. Flexible end bent with the bridge deck cast monolithically with the end wall but with a bearing under the beam and a bond-breaker between the end wall and bent cap to facilitate construction and subsequent maintenance. See Figure 12.4-2.

3. Free-Standing End Bent. Rigid end bent with a joint between the bridge deck and the backwall. See Figure 12.4-3.

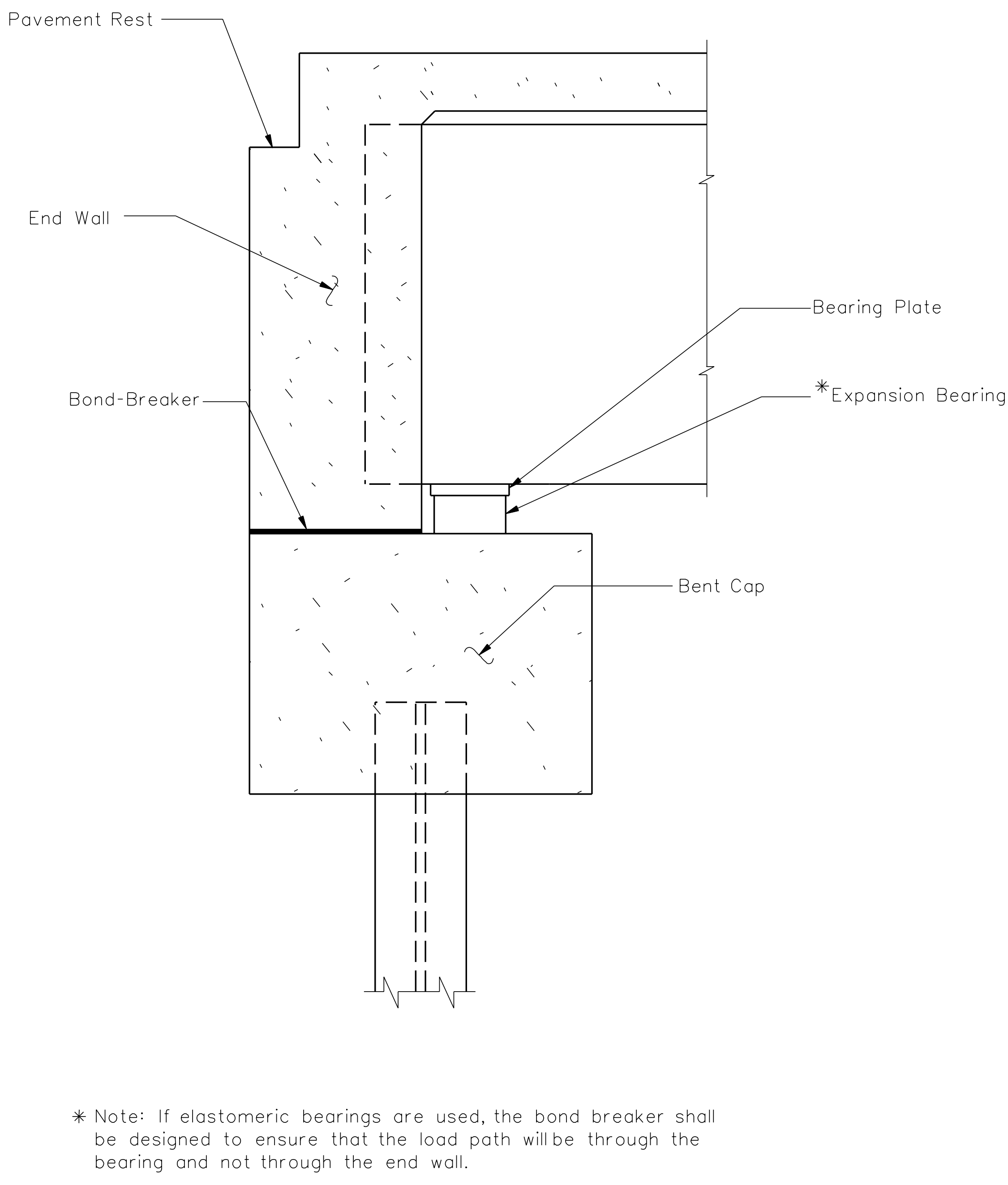
End bents shall consist of a cast-in-place, reinforced concrete cap founded on drilled shafts, piles or, on rare occasions, spread footings. End bents on piles or shafts may use MSE walls to retain the approach fill.

A jointless flexible end bent, either integral or semi-integral, is preferred. Free-standing rigid end bents shall be used where the anticipated translational movements of the piles are too great, or excessive settlement of the bent is anticipated. The force effects of these displacements shall be included in the design.

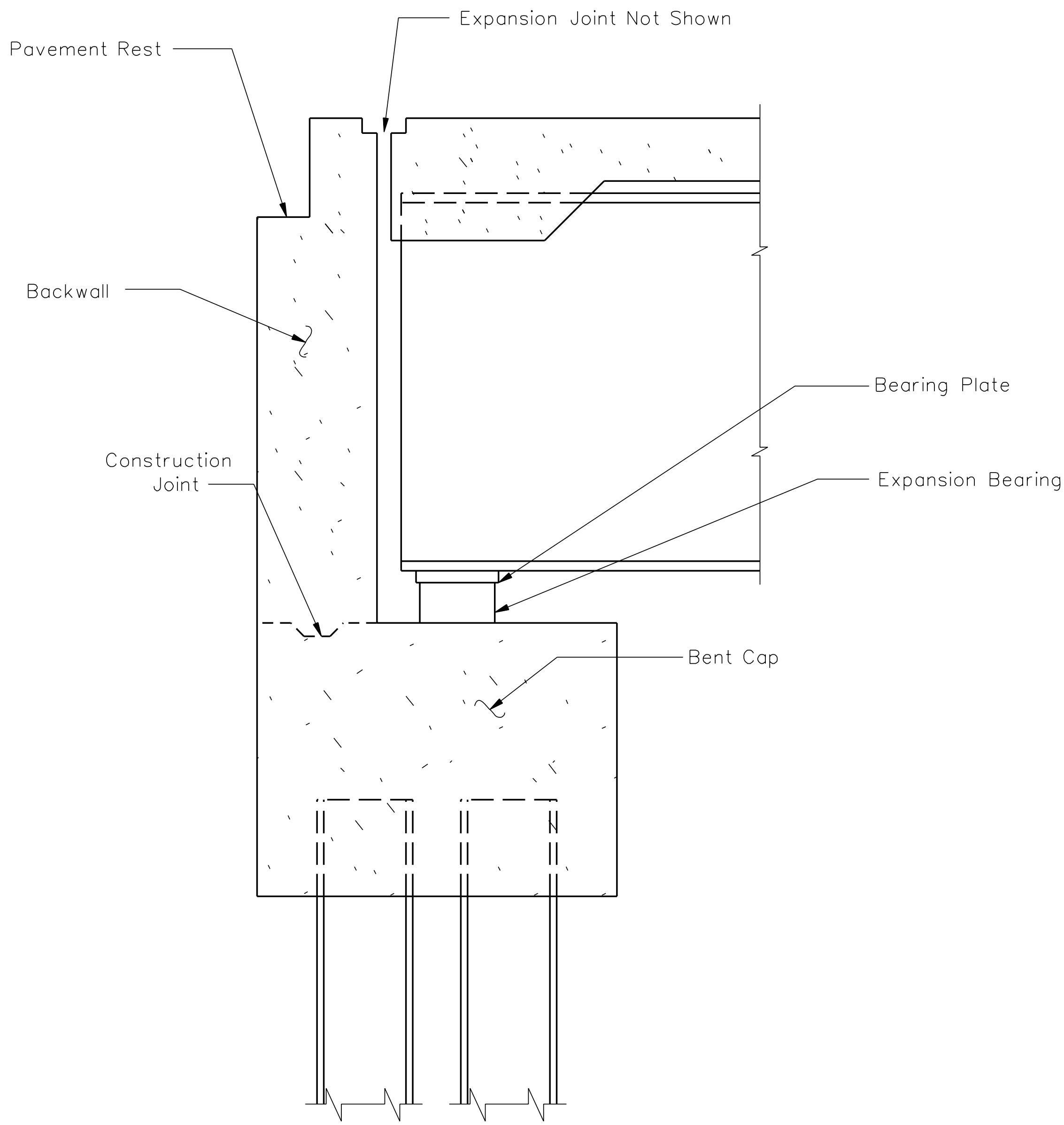
End bents are strongly impacted by the bridge geometry and site conditions; therefore, they may be designed in an infinite variety of shapes and sizes. If the wing walls are excessively large, the wing walls may be directly supported by piles or footings.



TYPICAL INTEGRAL END BENT
Figure 12.4-1



TYPICAL SEMI-INTEGRAL END BENT
Figure 12.4-2



TYPICAL FREE-STANDING END BENT
(Shown for Steel Girder)

Figure 12.4-3

12.4.2.3 Integral End Bents

Formerly, bridges were designed with expansion joints and other structural releases that allowed the superstructure to expand and contract relatively freely with changing temperatures, time-dependent effects of creep and shrinkage, and other geometric effects. Integral end bents eliminate expansion joints in the bridge decks, which reduces both the initial construction costs and subsequent maintenance costs. Therefore, an integral end bent is the first choice of the Department in selecting an end bent type.

Integral end bents are those where the superstructure is extended directly into the end bent end wall. There is no expansion joint in the bridge deck, and the end wall is rigidly connected to the pile cap. Integral end bents require flexible foundation elements to allow superstructure rotation and thermal motion. Typically, a single row of piles will provide the required flexibility, but drilled shafts or spread footings will not.

There can be no settlement in the piles because the superstructure cannot be raised for maintenance. If there is a possibility of settlement, consider a semi-integral end bent.

Integral end bents are effective in accommodating horizontal seismic forces. Minimum beam seat width requirements are not investigated for integral end bent bridges.

12.4.2.4 Semi-Integral End Bents

The semi-integral end bent is SCDOT's second choice for end bents, and it is typically used where settlement is possible. Semi-integral end bents are similar to integral end bents except that there is a bond-breaker between the end wall and the bent cap and the beams rest on a bearing. Expansion bearings can be used to reduce translation in the substructure. The bond-breaker between the end wall and the cap allows the superstructure to be raised if needed.

With the semi-integral end bent, transverse and longitudinal superstructure forces are transmitted to the substructure through anchor bolts or other means that allow rotation. Typically, the end wall and wing walls are cast around the girder ends, attached to the slab, and isolated from the bent cap. When parallel wing walls are used, the wings can either be monolithic with the end wall and isolated from the bent cap or attached to the bent cap with the end wall left free to rotate.

12.4.2.5 Free-Standing End Bents

Free-standing end bents usually consist of a bent cap, which supports the superstructure by bearings, and a backwall that retains the embankment fill in the longitudinal direction of the bridge and may support the end of the approach slab. Wing walls are usually needed to retain the fill in the transverse direction. Continuity of the riding surface between the end bent and the superstructure is provided by a deck joint.

Use free-standing end bents where integral and semi-integral end bents cannot accommodate the magnitude of the longitudinal movements. Free-standing end bents can be supported on piles, drilled shafts, or spread footings.

For restricted geometry, deep superstructures, or large relative longitudinal movements between the superstructure and the substructure, the free-standing end bent may be the only feasible alternative. Free-standing end bents are, however, generally expensive to construct. For small bridges, construction costs could be out-of-proportion with respect to other components of the bridge. With large end bents, located close to the edge of roadway or waterway below, superstructure spans can be reduced. Large end bents, however, may result in poor aesthetics of the bridge and may impair visibility at overpasses.

12.4.2.6 End Bents Using MSE Walls

Mechanically stabilized earth (MSE) walls may be used to retain approach embankment fills for end bents supported on piles or drilled shafts. This use of MSE walls must be decided during the preparation of the Conceptual Bridge Plans. End bents using MSE walls are an acceptable strategy to reduce right-of-way, utility, and environmental impacts. End bents using MSE walls may be used to reduce bridge lengths when a detailed geotechnical study indicates that the use of MSE walls is the most effective and economical solution.

Do not use spread footings to support end bents at MSE walls. An absolute minimum distance of 3 ft shall be maintained on the fill side between the inside face of the MSE wall and the face of the piling. The wall shall be detailed to provide sufficient compressible material between the end bent cap and the wall to accommodate movements.

12.4.3 <u>Interior Bents</u>

Reference: LRFD Article 11.7

12.4.3.1 General Usage

The following summarizes SCDOT typical practice for the type selection of interior bents (termed "piers" in the *LRFD Specifications*) for bridges based on the type of crossing:

1. <u>Water Crossings</u>. If lateral forces, considering scour, do not exceed the lateral design capacity of the bent, a pile bent is the preferred selection for the interior bents for spans less than 50 ft in length. Otherwise, use multi-column bents with caps or single-column bents with hammerhead caps.

2. <u>Highway Crossings</u>. Use multi-column bents with caps or single-column bents with hammerhead caps.

3. Railroad Crossings. Use multi-column bents with caps or single-column bents with hammerhead caps and crash walls, if crash walls are required by railroad clearance policies. See Chapter 22.

The following sections briefly describe the interior bents used by SCDOT. Figure 12.4-4 provides schematics in the plan and elevation views of the interior bents in combination with typical foundation types. For superstructures consisting of girders, interior bent caps may be made integral with the superstructure when necessary to provide the proper clearances.

12.4.3.2 Multi-Column Bents

Concrete multi-column bents are the Department's first choice for interior bents to support steel and prestressed concrete girder superstructures, and are strongly preferred in areas having high seismic demands. Columns shall have circular cross sections, unless a circular column cannot be designed for the required loading. In this case, an oblong cross section shall be used with specific requirements with respect to column reinforcement to sustain seismic loadings; see the *SCDOT Seismic Design Specifications for Highway Bridges*. Multi-column bents are generally applicable to bridge span lengths that exceed 50 ft, but their selection is sometimes the best even for shorter span lengths.

Figures 12.4-4(a), 12.4-4(b), and 12.4-4(c) illustrate the most common types of multi-column bents, founded on either piles, drilled shafts, or spread footings. The bents consist of vertical columns and a cap beam.

12.4.3.3 Single-Column Bents

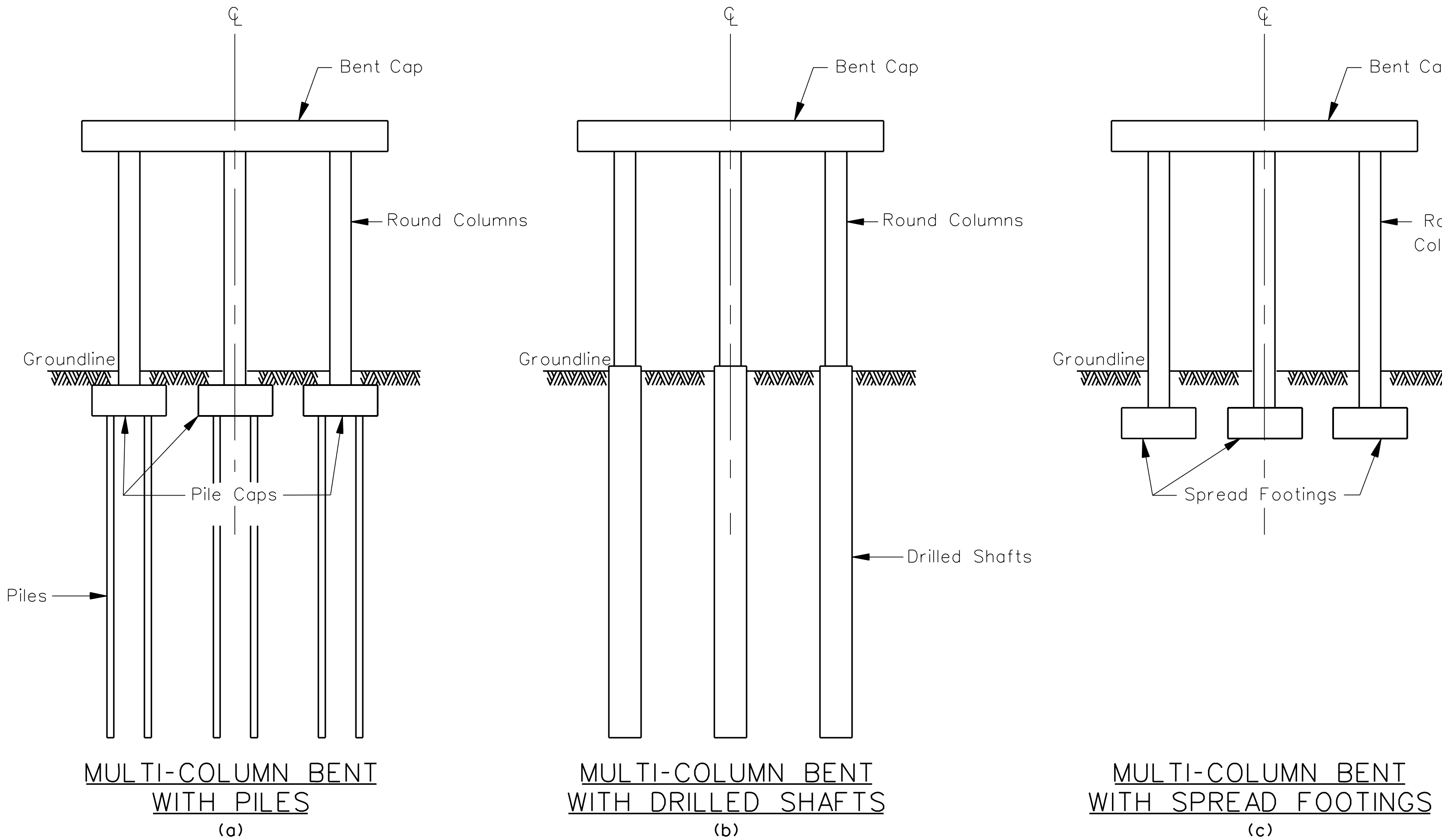
A single-column bent with a hammerhead cap may be preferred for the following applications:

- Aesthetics are important.
- The bridge is narrow.
- A stream is prone to debris.

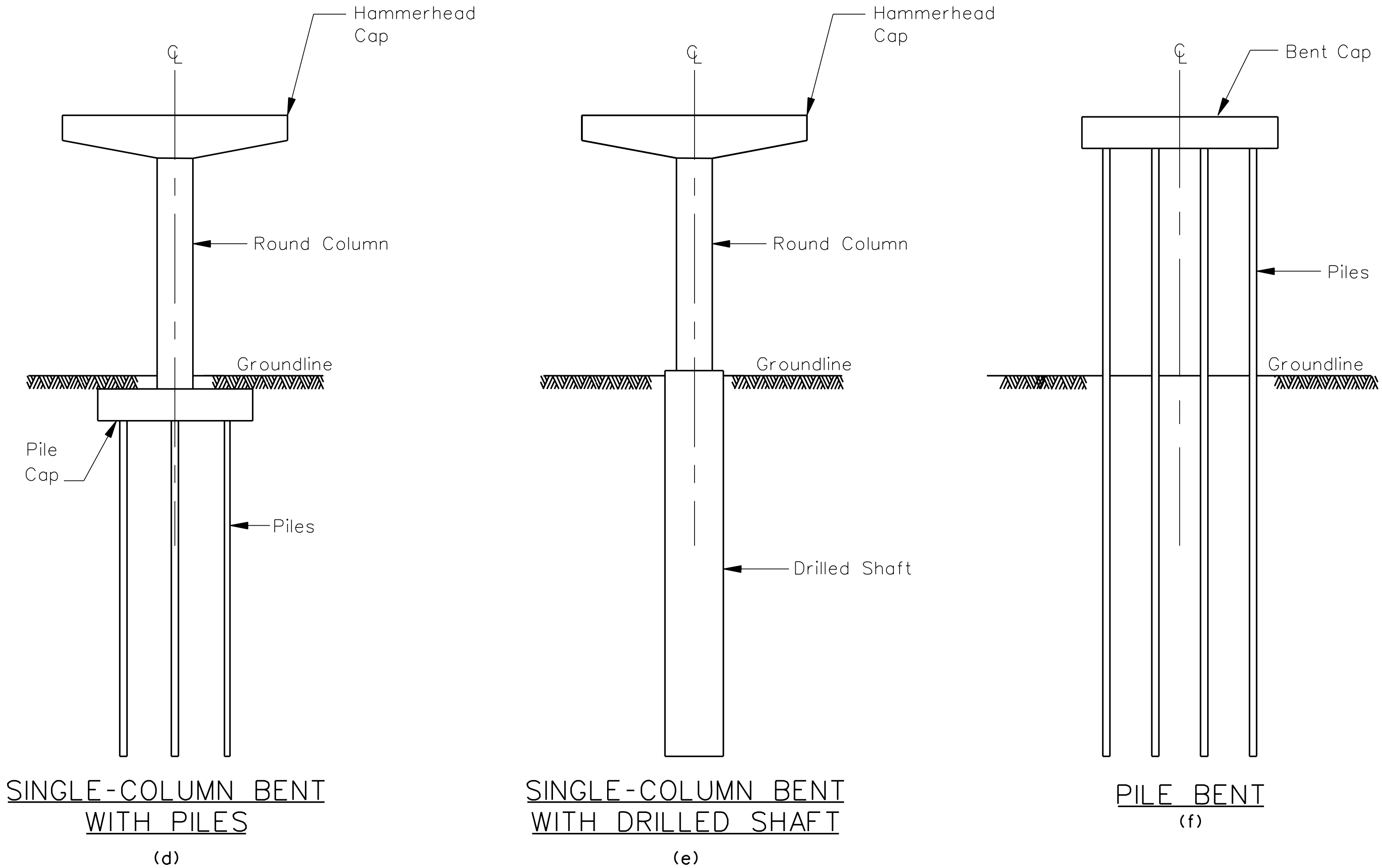
The use of a single-column bent should be carefully evaluated in areas having high seismic demands.

Columns shall have circular cross sections, unless a circular column cannot be designed for the required loading. In this case, an oblong cross section shall be used.

Figures 12.4-4(d) and 12.4-4(e) illustrate a typical single-column bent supported on either piles or a drilled shaft.



TYPICAL INTERIOR BENTS
(In Combination with Typical Foundation Types)
Figure 12.4-4



TYPICAL INTERIOR BENTS
(In Combination with Typical Foundation Types)
Figure 12.4-4
(Continued)

12.4.3.4 Pile Bents

Under certain conditions, the economy of substructures can be enhanced by extending the deep foundation above ground level to the superstructure. Pile bents shall not be used where large horizontal forces may develop due to collision by vehicles, or stream flow intensified by accumulated debris, or where large displacements are anticipated during a seismic event. A typical application of a pile bent is over shallow water where pile driving is allowed and where span lengths are less than 50 ft. Pile bents also result in minimal environmental impacts.

The extended piles always need a cap-beam for structural soundness. Figure 12.4-4(f) illustrates a typical pile bent.

12.5 FOUNDATIONS

12.5.1 Selection of Foundation Type

The selection of the foundation type is a collaborative effort between the bridge designer, the geotechnical design engineer, and (for bridges over waterways) the hydraulics engineer based on the Preliminary Geotechnical Report and/or the Hydraulic Report/Scour Report.

Typically, the selection of a foundation type is based on the foundation investigation, loads on the structure, and the engineering judgment of the Geotechnical Design Section. The bridge designer provides the geotechnical engineer with the applicable loads (axial and lateral) with a proposed foundation type. The evaluation includes examining the test boring data, the existing ground lines, whether or not the proposed foundation is below, at, or above the existing ground line, and hydraulic considerations such as scour depth. The geotechnical design engineer reviews the load data and recommends the type of foundation in coordination with the seismic engineer. The information for selection of a foundation type should include the following:

- logs of subsurface investigation; and
- plan and elevation showing proposed foundations, existing and proposed finished grade lines, and future ultimate sections.

See Section 19.1 for more discussion on the necessary coordination with the Geotechnical Design Section to determine the type of foundation. See Section 4.2 for a discussion on coordination with the Hydraulic Engineering Section.

12.5.2 Impact on Superstructure Type

The detailed foundation study is typically performed after the superstructure selection. Therefore, the designer must anticipate the nature of the foundation characteristics in the analysis. The following should be considered:

1. Number of Supports. The expected foundation conditions will partially determine the number of and spacing of the necessary substructure supports. This will have a significant impact on the acceptable span lengths.
2. Dead Load. When foundation conditions are generally poor, the economics of using structural steel and lightweight concrete over normal concrete should be considered.
3. Scour. The geologic or historic scour may have a significant impact on the foundation design which may, in turn, have a significant impact on the superstructure type selection.

12.5.3 Usage

The following summarizes SCDOT typical practices for the selection of the foundation type. Figure 12.4-4 illustrates the basic types of foundations used by SCDOT. See Chapter 19 for SCDOT design practices for foundations.

12.5.3.1 Piles

Reference: LRFD Article 10.7

A pile is a long, slender deep foundation element driven into the ground with power hammers. The bridge designer should consider the following in the selection of piles:

- Pile bents are generally applicable to span lengths up to 50 ft.
- For longer spans and at-grade separations, a footing supported on piles is used.
- Exposed steel piles shall not be used in standing water or marsh.

If underlying soils cannot provide adequate bearing capacity or tolerable settlements for spread footings, piles may be used to transfer loads to deeper suitable strata through friction and/or end bearing. The selected type of pile is determined by the required bearing capacity, length, soil conditions, and economic considerations. SCDOT typically uses steel pipe piles, steel H-piles, prestressed concrete piles, or a combination pile-prestressed concrete pile with a steel pile extension. Figure 19.2-1 provides a guide to the selection of pile type**.**

12.5.3.2 Drilled Shafts

Reference: LRFD Article 10.8

A drilled shaft is a deep-foundation element constructed by excavating a hole with auger equipment and placing concrete, with reinforcing steel, into the excavation. Casing and/or drilling slurry may be necessary to keep the excavation stable. Drilled shafts should be considered where conditions do not exist that permit the use of spread footings or piles. Drilled shafts should be considered to resist large lateral or uplift loads where deformation tolerances are relatively small. Also, use drilled shafts where significant scour is expected, where there are limitations on water crossing work, or where piles are not economically viable due to high loads or obstructions to driving. Limitations on pile-driving vibration and/or noise may also dictate the use of drilled shafts.

The following also applies to the use of drilled shafts:

- Drilled shafts are typically good for seismic applications.
- Drilled shafts are generally applicable to span lengths greater than 50 ft.

12.5.3.3 Spread Footings

Reference: LRFD Article 10.6

SCDOT rarely uses spread footings. Spread footings are not allowed at stream crossings where they may be susceptible to scour; they are not allowed as a foundation for end bents at MSE walls; and they are not allowed on fills. The use of spread footings requires firm bearing conditions; competent material must be near the ground surface.

A spread footing is a shallow foundation consisting of a reinforced concrete member that bears directly on the founding stratum. A spread footing's geometry is determined by structural requirements and the characteristics of supporting components, such as soil or rock. The primary role of spread footings is to distribute the loads transmitted by interior bents or end bents to suitable soil strata or rock at relatively shallow depths (less than 10 ft).

Settlement criteria need to be consistent with the function and type of structure, anticipated service life, and consequences of unanticipated movements on service performance. Angular distortions between adjacent spread footings greater than 0.008 radians in simple spans and 0.004 radians in continuous spans should not be ordinarily permitted.

12.6 ROADWAY DESIGN ELEMENTS

The *SCDOT Highway Design Manual* documents SCDOT's roadway design criteria. In general, the road design criteria will determine the proper geometric design of the roadway. The bridge design will accommodate the roadway design across any structures within the project limits. This will provide full continuity of the roadway section for the entire project. This process will, of course, require proper communication between the bridge designer and road designer to identify and resolve any inconsistencies. This Section provides roadway design information that is directly relevant to determining the structural dimensions for bridge design and to provide the bridge designer with some background in road design elements.

12.6.1 Roadway Cross Section (Bridges)

This Section presents criteria for the roadway cross section across bridges based on the type of highway. Section 12.6.4 presents several typical bridge sections.

12.6.1.1 *SCDOT Highway Design Manual*

Chapter 13 "Cross Section Elements" and Part III "Design of Functional Classes" of the *SCDOT Highway Design Manual* provide Department criteria for the various cross section elements for the roadway. This includes lane and shoulder widths, cross slopes, auxiliary lanes, parking lanes, medians, side slopes, and sidewalks. This Section of the *SCDOT Bridge Design Manual* provides Department criteria for roadway cross section elements specifically across bridges.

12.6.1.2 Point of Grade/Profile Grade Line

The location of the point of grade (which is in the cross section view) and the profile grade line (which is in the elevation view) on the bridge must match those on the approaching roadway. The point of grade location varies according to the type of highway and type of median. See Section 12.2 of the *SCDOT Highway Design Manual* for SCDOT criteria.

12.6.1.3 Cross Slope

Bridges on tangent sections typically provide a uniform cross slope of 48H:1V (2.08%) from the crown line to the edge of the deck. Typically, the cross slope of the shoulder (and sometimes one or more of the travel lanes) on the approaching roadway is steeper than 2.08%; therefore, the roadway must be transitioned to a uniform 2.08% slope before it reaches the bridge; this is the responsibility of the road designer when designing the roadway approaches.

On a case-by-case basis, the bridge designer may consider exceptions to the use of a uniform 2.08% cross slope on the tangent sections, including:

1. If the bridge cross section includes a third travel lane away from the crown, the cross slope of this lane may be steepened to 36H:1V (2.78%). This enhances drainage of the bridge deck.

2. A general concern for bridge deck drainage may indicate the desirability of using a cross slope steeper than 2.08%. See Chapter 18.

12.6.1.4 Bridge Roadway Widths

In general, bridge widths should match the approach roadway widths (traveled way plus shoulders). Figure 12.6-1 provides guidelines for bridge widths. However, in determining the width for major water crossings, consider the cost of the structure, traffic volumes, and potential for future width requirements.

Approach Roadway	Conditions	Bridge Width (Gutter to Gutter)
Urban Streets (Curb and Gutter)	With or without concrete sidewalk.	Provide a sidewalk on bridge matching roadway gutter hinge points with bridge gutter hinge points.
Freeways and Arterials	12-ft shoulder (10 ft paved + 2 ft unpaved).	Use 12-ft shoulder hinge point for bridge gutter line.
	10-ft shoulder (paved and unpaved).	Use 10-ft shoulder hinge point for bridge gutter line.
	10-ft shoulder (6 ft paved + 4 ft unpaved).	Use 10-ft shoulder hinge point for bridge gutter line on inside of divided highways.
	10-ft shoulder (4 ft paved + 6 ft unpaved).	
Rural Collectors and Local Roads	6- to 8- ft shoulders (2 ft paved + 4 to 6 ft unpaved) with paved roadway.	Use shoulder hinge point for bridge gutter line. Bridge width is equal to width of roadway section (outside shoulder to outside shoulder).
Ramps	In direction of traffic (left) 10-ft shoulder (4 ft paved + 6 ft unpaved).	Use 10-ft shoulder hinge point for bridge gutter line.
	In direction of traffic (right) 10-ft shoulder (6 ft paved + 4 ft unpaved).	Use 10-ft shoulder hinge point for bridge gutter line.

GUIDELINES FOR BRIDGE ROADWAY WIDTHS

Figure 12.6-1

12.6.1.5 Sidewalks

12.6.1.5.1 Warrants

In general, include sidewalks on all bridges if there is curb and gutter on the roadway approach. Sidewalk requirements for each side of the bridge will be evaluated individually; i.e., placing a sidewalk on each side will be based on the specific characteristics of that side. However, typical Department practice is to place a sidewalk on both sides of the bridge.

12.6.1.5.2 Cross Section

The typical sidewalk width is 5′-6″ as measured from the gutter line to the back of the sidewalk; i.e., this width includes the width of curb. The maximum cross slope on the sidewalk is 2% sloped towards the roadway.

12.6.1.6 Bicycle Accommodations

The bicycle is classified as a vehicle according to South Carolina law, and bicyclists are granted all of the rights and are subject to all of the duties applicable to the driver of any other vehicle. Engineering Directive Memorandum 22 discusses considerations for bicycle accommodation on SCDOT projects.

A bridge may need to be configured to accommodate bicycle traffic. This must be coordinated with the Road Design Section, which will refer to EDM 22 for bicycle accommodation. In general, the bicycle accommodation on the approaching roadway will be carried across the bridge. The preferred accommodation is to provide a shoulder wide enough to accommodate bicycles. Although a 4-ft wide shoulder is considered adequate for bicycle traffic on the roadway, this needs to be increased by 1 ft to provide a shy distance where barriers are present. Therefore, a 5-ft wide shoulder is considered the minimum shoulder width for bridges that are designed to carry bicycle traffic. In addition, on bridges, a minimum of 4 ft from the edge of travel lane should be clear of drainage inlets.

On the approaching roadway, bike lanes will have a cross slope of 24H:1V (4.16%). On bridges, this cross slope will be transitioned to 48H:1V (2.08%).

If the approaching roadway includes a separate bicycle lane, then the width of the lane will be carried across the bridge. Requests for and accommodation for anticipated future bicycle lanes are only warranted when they are part of SCDOT long-range plans.

12.6.1.7 Medians

For multi-lane facilities, the bridge designer must decide if one structure will be used for the entire roadway section (including the median) or if dual structures will be used. In general, a single structure will be used for roadways with a flush or raised median, and dual structures will be used for roadways with a depressed median. Where dual structures are used, the minimum distance between the backs of the two bridge rails is 8 in to allow for slip forming the two barriers. See Section 13.4 of the *SCDOT Highway Design Manual* for more information on medians.

12.6.2 <u>Alignment at Bridges</u>

12.6.2.1 Horizontal Alignment

The road designer will determine the horizontal alignment at the bridge based on Chapter 11 of the *SCDOT Highway Design Manual* (e.g., curve radius, superelevation transition). From the perspective of the roadway user, a bridge is an integral part of the roadway system and, ideally, horizontal curves and their transitions will be located irrespective of their impact on bridges. However, practical factors in bridge design and bridge construction warrant consideration in the location of horizontal curves at bridges. The following presents, in order from the most desirable to the least desirable, the application of horizontal curves to bridges:

1. Considering both the complexity of design and construction difficulty, the most desirable treatment is to locate the bridge and its approach slabs on a tangent section; i.e., no portion of the curve or its superelevation development will be on the bridge or bridge approach slabs.

2. If a horizontal curve is located on a bridge, the superelevation transition should not be located on the bridge or its approach slabs. This will result in a uniform cross slope (i.e., the design superelevation rate) throughout the length of the bridge and bridge approach slabs.

3. If the superelevation transition is located on the bridge or its approach slabs, the designer should place on the roadway approach that portion of the superelevation development that transitions the roadway cross section from its normal crown to a point where the roadway slopes uniformly; i.e., to a point where the crown has been removed. This will avoid the need to warp the crown on the bridge or the bridge approach slabs.

4. As a worst case, place the superelevation transition angle points at the centerline of the bents.

Specifically for maximum superelevation rates, Section 11.3 of the *SCDOT Highway Design Manual* discusses the Department's e_{max} criteria. As illustrated in Figure 11.3A, e_{max} will vary between 4% and 8% depending on the type of facility, the urban/rural location, and the design speed.

12.6.2.2 Vertical Alignment

The bridge designer and road designer will coordinate on the vertical alignment of the roadway across a bridge. Chapter 12 of the *SCDOT Highway Design Manual* provides the Department's criteria. The following applies specifically to the vertical alignment at bridges:

1. Minimum Gradient. The minimum longitudinal gradient should be limited to 0.3%. Flatter gradients will require approval from the State Bridge Design Engineer.

2. Maximum Grades. See Chapters 19 through 22 of the *SCDOT Highway Design Manual* for the Department's maximum grade criteria based on the highway type, design speed, and rural/urban location.

3. Vertical Curves. Crest and sag vertical curves will be designed according to Section 12.5 of the *SCDOT Highway Design Manual*. If practical, no portion of a bridge should be located in a sag vertical curve. If the bridge is located in a sag vertical curve, the low point of the sag should not be located on the bridge or the approach slab. See Section 18.2 for additional requirements on bridges in sag vertical curves with respect to bridge deck drainage.

12.6.2.3 Skew

Skew is defined by the angle between the end line of the deck and the normal drawn to the longitudinal centerline of the bridge at that point. Typically, the bridge skew is determined by the roadway alignment and the bridge is designed to accommodate the skew. The impacts of skew on structural design are discussed at their respective locations throughout the *SCDOT Bridge Design Manual*. In general, skew angles of more than 30° will affect the design of structural elements.

12.6.3 Underpasses

For bridges over highways, the design of the underpassing roadway will determine the length of the overpassing bridge. Section 12.6.4 presents typical sections for bridge underpasses. See Chapter 22 for railroads underpassing a highway bridge.

12.6.3.1 Roadway Cross Section

The approaching roadway cross section, including any auxiliary lanes, should be carried through the underpass. Desirably, include the clear zone width for each side through the underpass. It is important to consider the potential for further development or traffic increases in the vicinity of the underpass that may significantly increase traffic or pedestrian volumes. If appropriate, an allowance for future widening may be provided to allow for sufficient lateral clearance for one additional lane in each direction. The need for accommodating future travel lanes will be made on a case-by-case basis. See the *SCDOT Standard Drawings for Road Construction* for more information on roadway underpasses.

12.6.3.2 Vertical Clearances

The vertical clearance for underpassing roadways will significantly impact the vertical location of the overpassing structure and may dictate the selection of the superstructure type. Chapters 19 through 22 of the *SCDOT Highway Design Manual* present the Department's vertical clearance criteria for underpassing roadways based on type of highway and rural/urban location. These criteria are summarized in Figure 12.6-2.

12.6.4 Typical Sections

This Section presents the following typical section figures for bridges and underpasses:

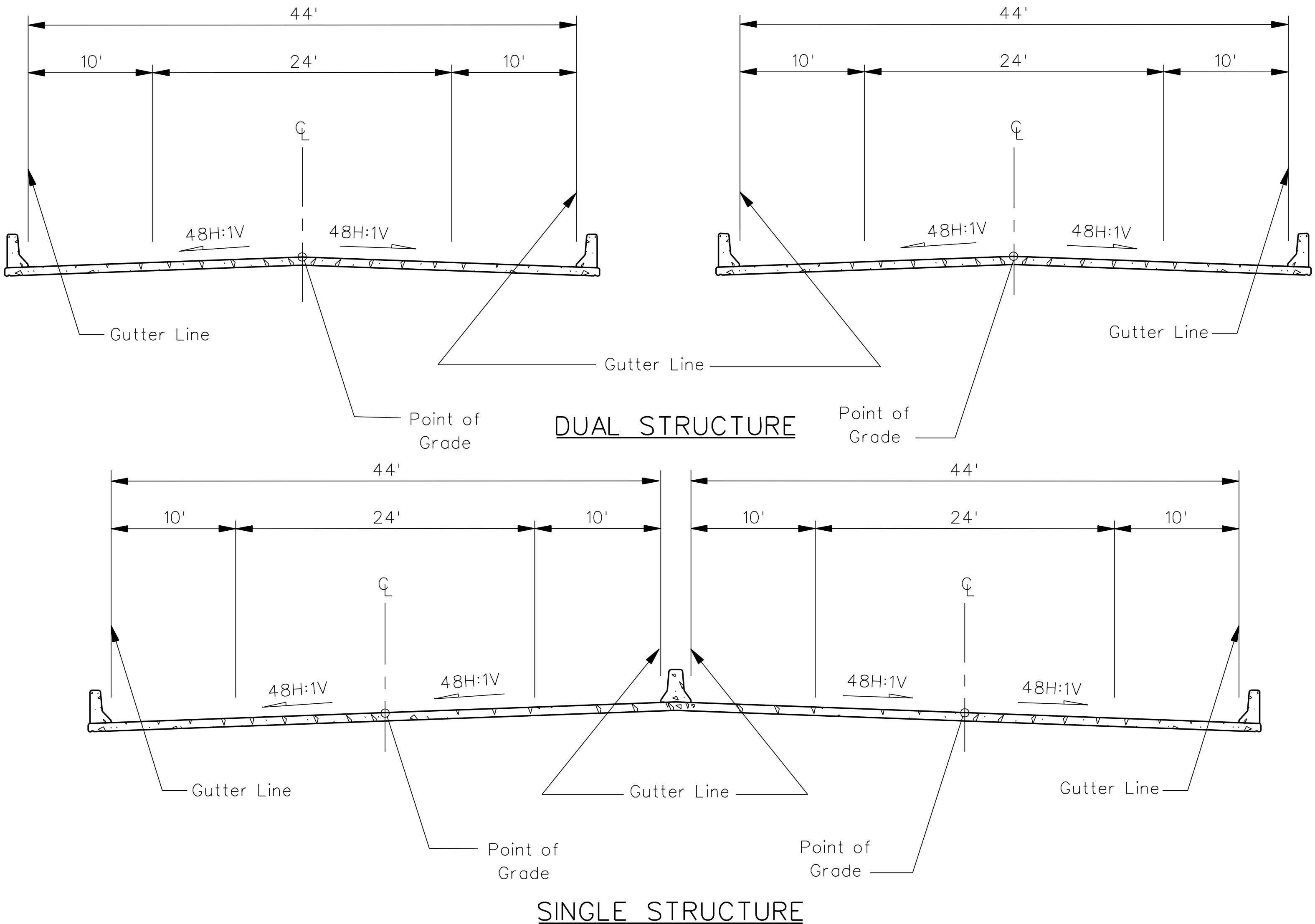
- Figure 12.6-3 "Bridge Cross Section (Four-Lane Divided Facility)."
- Figure 12.6-4 "Bridge Cross Section (Six-Lane Divided Facility)."
- Figure 12.6-5 "Bridge Cross Section (Rural Two-Lane Highway)."
- Figure 12.6-6 "Bridge Cross Section (Multi-Lane Facility with Flush Median)."
- Figure 12.6-7 "Bridge Cross Section (Urban Facility with Sidewalks)."
- Figure 12.6-8 "Multi-Lane Divided Highway Underpass."
- Figure 12.6-9 "Two-Lane Highway Underpass."

Facility	Structure	Clearance
Freeway Under	New/Replaced Overpassing Bridges	17′-0″
	Existing Overpassing Bridges	16′-0″
	Pedestrian Bridges	18′-0″
Arterial Under	New/Replaced Overpassing Bridges	17′-0″
	Existing Overpassing Bridges	16′-0″
	Pedestrian Bridges	18′-0″
Collector Under	New/Replaced Overpassing Bridges	16′-0″
	Existing Overpassing Bridges	16′-0″
	Pedestrian Bridges	18′-0″
Secondary and State “C” Roads	New/Replaced Overpassing Bridges	16′-0″
	Existing Overpassing Bridges	14′-0″
	Pedestrian Bridges	17′-0″
All Facilities Over	Railroads	* 23′-0″
	Lakes and Reservoirs	8′-0″
	Navigable Water	Contact Coast Guard

**For widenings, maintain existing clearance.*

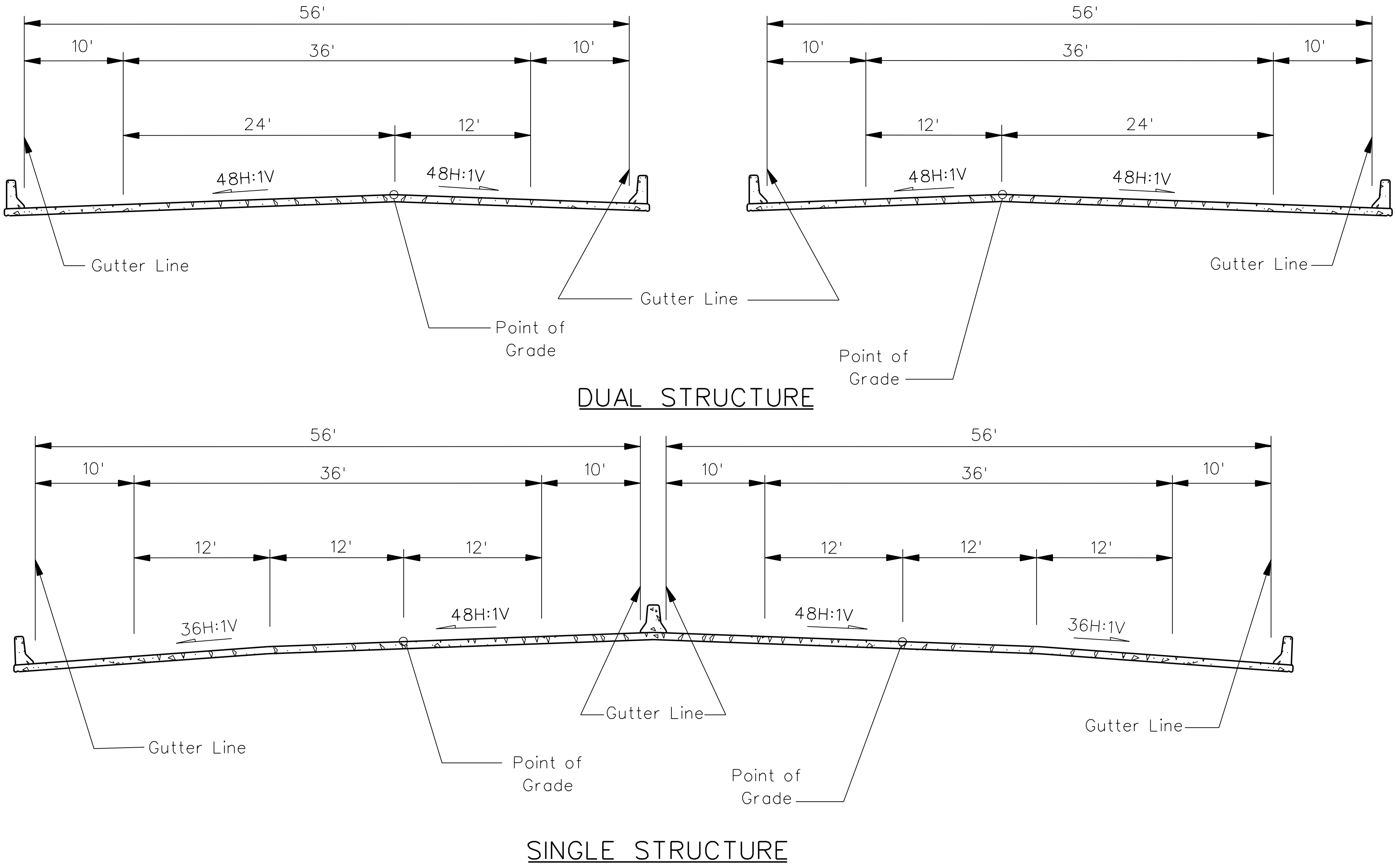
MINIMUM VERTICAL CLEARANCES

Figure 12.6-2



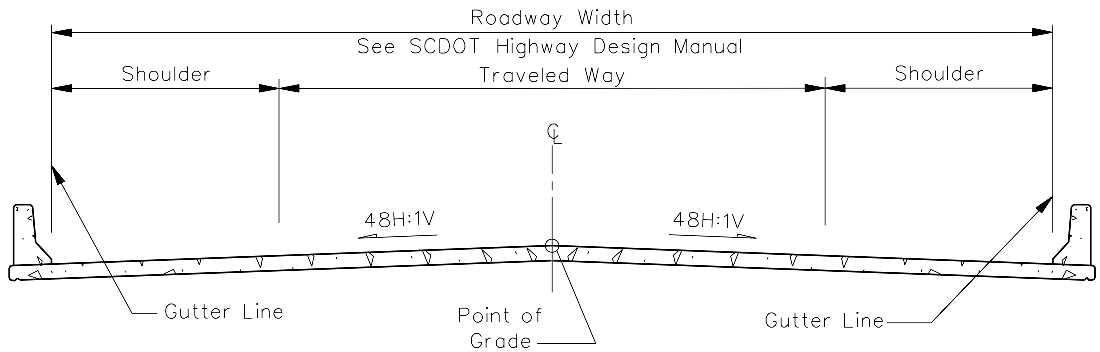
BRIDGE CROSS SECTION
(Four-Lane Divided Facility)

Figure 12.6-3



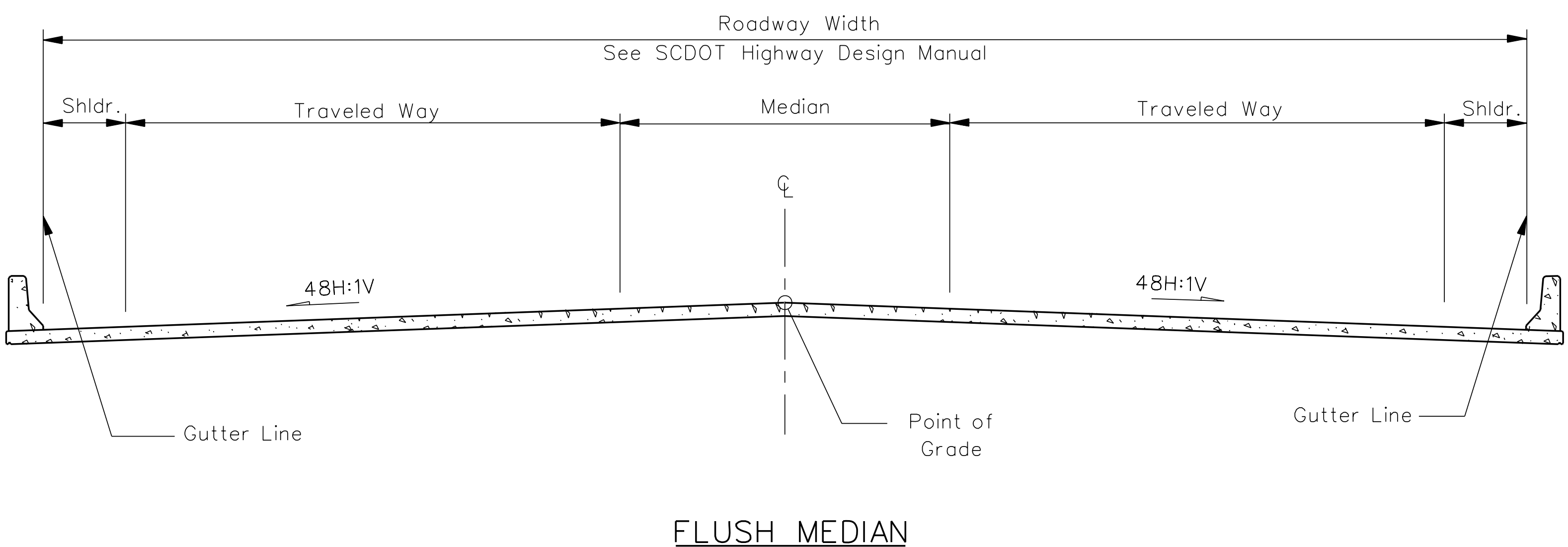
BRIDGE CROSS SECTION
(Six-Lane Divided Facility)

Figure 12.6-4



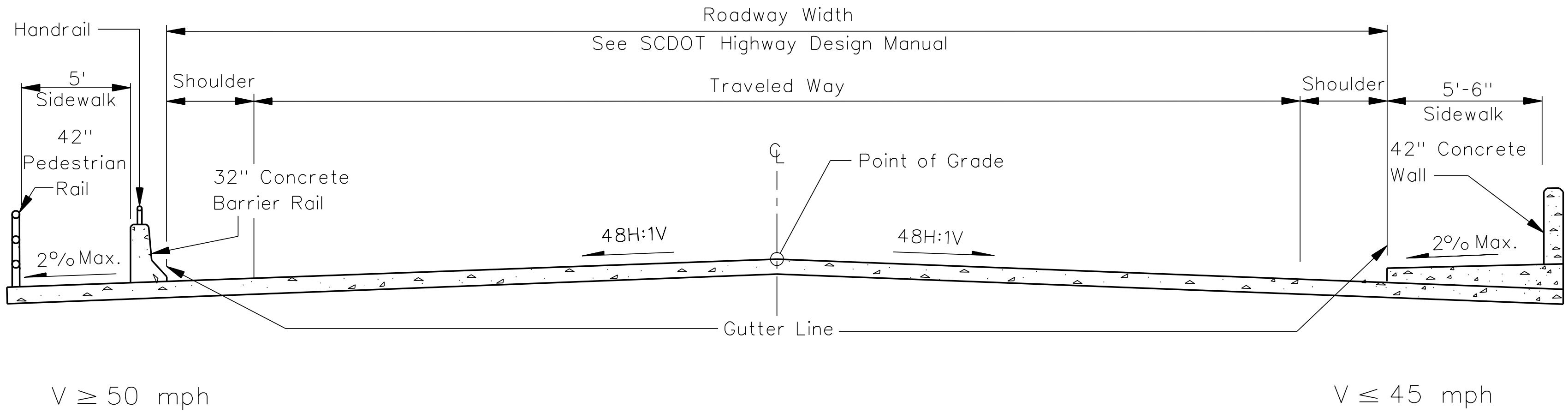
BRIDGE CROSS SECTION
(Rural Two-Lane Highway)

Figure 12.6-5



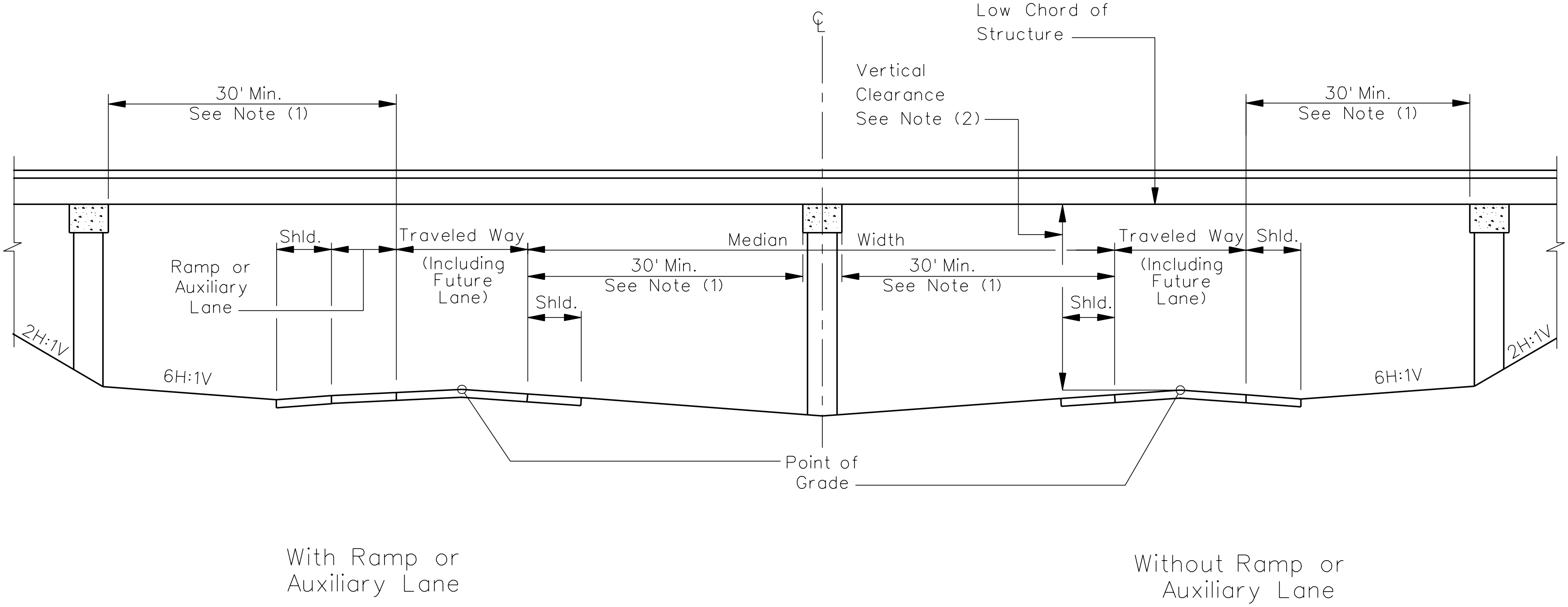
BRIDGE CROSS SECTION
(Multi-Lane Facility with Flush Median)

Figure 12.6-6



BRIDGE CROSS SECTION
(Urban Facility with Sidewalks)

Figure 12.6-7



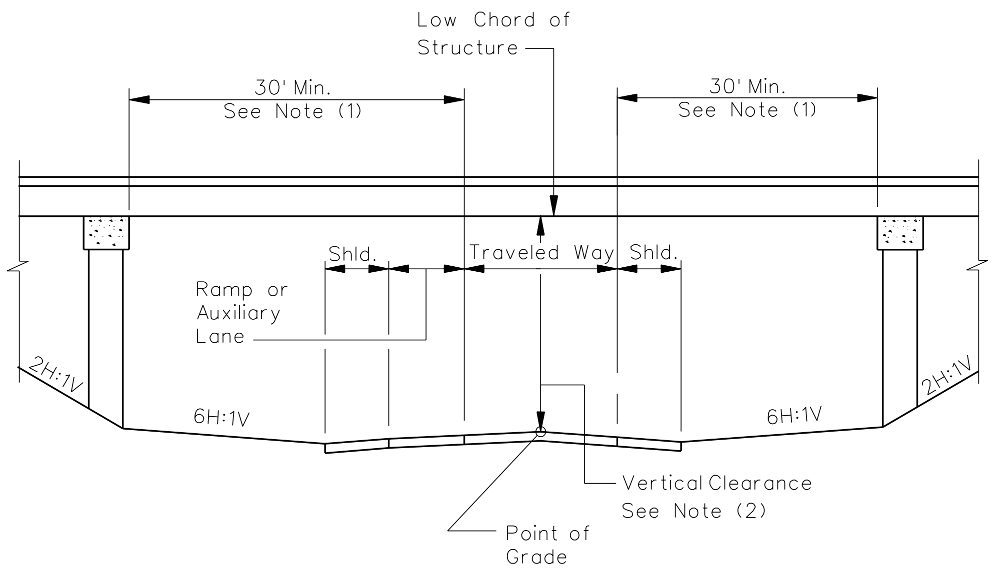
CLEARANCE CONFIGURATIONS

Notes:

1. *See Section 14.3 of the SCDOT Highway Design Manual. Where the 30-ft minimum cannot be provided, a roadside barrier must be provided.*
2. *Locate the minimum clearance point over the entire roadway section.*
3. *Locate the interior bent in the median, if required, at the median centerline.*

MULTI-LANE DIVIDED HIGHWAY UNDERPASS

Figure 12.6-8



CLEARANCE CONFIGURATIONS

Notes:

1. *See Section 14.3 of the SCDOT Highway Design Manual. Where the 30-ft minimum cannot be provided, a roadside barrier must be provided.*
2. *Locate the minimum clearance point over the entire roadway section.*

TWO-LANE HIGHWAY UNDERPASS

Figure 12.6-9

12.7 GENERAL EVALUATION FACTORS

This Section provides a brief summary of several evaluation factors not related to structural design that will impact the selected structural system and its dimensions.

12.7.1 Aesthetics

Reference: LRFD Article 2.5.5

Structures should be aesthetically pleasing to the traveling public. The *LRFD Specifications* emphasizes and SCDOT encourages the objective of improving the appearance of highway bridges in the State. The Department promotes uninterrupted lines, contours that follow the load paths, and the avoidance of cluttered appearances. The provisions on aesthetics have been prompted because many bridges have been exclusively selected and designed on the basis of construction cost and/or engineering simplicity without regard for their appearance and for their compatibility with the environment.

Any bridge design must integrate three basic elements: efficiency, economy, and appearance. Regardless of size and location, the quality of the structure, its aesthetic attributes, and the resulting impact on its surroundings must be carefully considered. Achieving the desired results involves:

- full integration of the three basic elements listed above, and
- the designer accepting the challenge and opportunity presented.

A successful bridge design will then be aesthetically pleasing in and of itself and will be compatible with the site by proper attention to form, shapes, and proportions. Attention to detail is of primary importance in achieving a continuity of line and form. In general, the rule “form following function” shall be used. In other words, the shape of the structure is not chosen merely for aesthetic reasons but also considering the load paths from the points of application to the points of support. The designer must consider the totality of the structure and its individual components and the environment of its surroundings. A disregard for continuity or lack of attention to detail can negate the best intent. The following references provide excellent guidance:

1. Billington, D.P., *The Tower and the Bridge*, 306 pp., Basic Books, New York, New York, 1983.

2. Leonahardt, F., *Bridges: Aesthetics and Design*, 308 pp., Deutsche Verlags-Anstalt (MIT Press, Cambridge, Massachusetts), 1982.

3. Stewart C. Watson and M. K. Hurd, *Esthetics in Concrete Bridge Design*, 331 pp., Library of Congress Catalog Card Number 89-85388.

4. *Aesthetic Bridges User's Guide,* Maryland Department of Transportation, State Highway Administration, Office of Bridge Development, 1993.

5. Adele Fleet Bacow and Kenneth E. Kruckemeyer, *Bridge Design, Aesthetics and Developing Technologies*, 157 pp., Library of Congress Catalog Card Number 86-061840.

6. *Bridge Aesthetics Around the World*, Committee on General Structures, Subcommittee on Bridge Aesthetics, Transportation Research Board, National Research Council, Washington, D.C., 1991.

7. *Aesthetic Guidelines for Bridge Design*, Minnesota Department of Transportation, Manual Sales Office, G-19-M.S. 260, 395 John Ireland Boulevard, St. Paul, Minnesota 55155.

The designer is expected to be familiar with the subject of bridge aesthetics and committed to fulfilling both the structural and aesthetic needs of the site. The challenge differs for major and minor structures. In fact, the challenge may be greater for the smaller project. Major structures, because of their longer spans, taller interior bents, or curving geometry, often offer inherent opportunities not available for their minor counterparts.

Guidelines for aesthetic considerations are especially significant for:

- bridges highly visible to a large number of users (e.g., Interstate overpasses);
- bridges located in or adjacent to parks, recreational areas, or other major public gathering points;
- pedestrian bridges;
- bridges in urban areas in or adjacent to commercial and/or residential areas; and
- multi-bridge projects (e.g., interchanges, corridors) should have conformity of theme and appearance by avoiding abrupt changes in structural features.

Normally, there are three general levels of aesthetic consideration at each structure's site:

1. <u>Cosmetic Improvements</u>. These improvements consist of the use of masonry coatings or color pigments in the concrete, brick pavers, texturing the surfaces (e.g., fluted columns, shadow boxes), form liners, rustication grooves, and modification to barrier walls and beams. Providing more pleasing shapes of columns and/or bent caps for the substructure should also be studied (e.g., rounded bent caps ends).

2. <u>Overall Structure Aesthetics</u>. The bridge designer should strive for full integration of efficiency, economy, and appearance into all bridge components and the structure as a whole. Consider structural systems that are inherently more pleasing such as

hammerhead or "T" shaped interior bents, oblong-shaped columns, integral caps and bents, smooth transitions at superstructure depth change locations, etc.

3. Overall Project Aesthetics. The project as a whole must be considered when passing through or under an interchange or at other sites such as historic or highly urbanized areas where landscaping or unique neighborhood features must be considered. This level may require input from an architect.

The aesthetic levels described above are not exclusive. For the second and third levels, public input may be appropriate.

12.7.2 Context Sensitive Solutions

12.7.2.1 Background

During the 1990s, highway design changed rapidly throughout the United States. Transportation agencies have learned that they must be more sensitive to the impact of highways on the environment and communities. New and better ways of designing highways and bridges are evolving following the completion of the Interstate system, based on a growing interest in the improvement of highways and their integration into the communities they serve.

Working with community stakeholders to preserve and enhance the human and natural environment has become a significant component of transportation projects. "Stakeholders" are defined as all individuals, businesses, organizations, etc., that have a direct interest in the consequences of a transportation project. To best address the challenges of transportation projects, SCDOT has implemented a Context Sensitive Solutions (CSS) approach to project development.

12.7.2.2 Principles

The following are the basic principles behind Context Sensitive Solutions:

1. Qualities of Excellence in Transportation Design. The following apply:

    - The project satisfies the purpose and needs as agreed to by a full range of stakeholders. This agreement is forged in the earliest phase of the project and amended as warranted as the project develops.

    - The project is a safe facility for both the user and the community.

    - The project is in harmony with the community, and it preserves the environmental, scenic, aesthetic, historic, and natural resource values of the area (i.e., exhibits context sensitive design).

    - The project exceeds the expectations of both designers and stakeholders and achieves a level of excellence in the public's minds.

- The project involves the efficient and effective use of the resources (e.g., time, budget, community) of all involved parties.

- The project is designed and built with minimal disruption to the community.

- The project is seen as having added lasting value to the community.

2. Characteristics of the Process Contributing to Excellence. The following apply:

   - Communication with all stakeholders is open, honest, early, and continuous.

   - A multidisciplinary team is established early, with disciplines based on the needs of the specific project, and with the inclusion of the public.

   - A full range of stakeholders are involved with transportation officials in the scoping phase. The purposes of the project are clearly defined, and consensus on the scope is forged before proceeding.

   - The highway development process is tailored to meet the circumstances. This process should examine multiple alternatives that will result in a consensus of approach methods.

   - A commitment to the process from top agency officials and local leaders is secured.

   - The public involvement process, which includes informal meetings, is tailored to the project.

   - The landscape, the community, and valued resources are understood before engineering design is started.

   - A full range of tools for communication on project alternatives is used (e.g., visualization).

12.7.3 Environmental Considerations

The evaluation of potential environmental impacts can have a significant impact on structure-type selection and configuration, especially for highway bridges over streams. In general, any bridge project should, within reason, attempt to minimize the environmental impacts, especially in sensitive areas (e.g., wetlands). The Environmental Management Office is responsible for identifying all environmental resources within the proposed project limits and for evaluating the potential project impacts on these resources. In particular, the following water-related environmental permits/approvals may be necessary for a bridge design project:

- US Army Corps of Engineers Section 404 Permit,
- Section 401 Water Quality Certification,

- Section 402 NPDES Permit,
- US Coast Guard Section 10 Permit, and
- Floodplains Encroachment Approval.

In some cases, a proposed bridge project may precipitate other environmental impacts. These include Section 106, Section 4(f), Section 6(f) and Threatened and Endangered Species. See Chapter 27 of the *SCDOT Highway Design Manual* for a detailed discussion on environmental considerations and permits.

12.7.4 Navigable Waters

Before engaging in any work activities on or near any bridges over the navigable waters of the United States, the bridge designer must notify the US Coast Guard Homeland Security Command Center in Miami. This notification includes field inspections by SCDOT employees and work performed under contract.

12.7.5 Hydraulics

The Hydraulic Engineering Section will prepare a Hydraulic Report/Scour Report in advance of the Bridge Design Section's structure type and size selection. See Section 5.5 for more information. The following sections briefly discuss hydraulic considerations that affect the various structural elements.

12.7.5.1 End Bents

The principal hydraulic concerns for end bents are orientation and protection from scour-related failure. Concerns for scour are usually resolved by protective and preventive measures that are determined by the Hydraulic Engineering Section. Orientation is usually the same as for adjacent interior bents.

12.7.5.2 Interior Bents

Economy of construction usually plays a large role in the determination of spans, interior bent locations and orientation, and substructure and superstructure design. There are hydraulic considerations, maintenance costs and risks of future costs to repair flood damages that should also be factors in making decisions on the number of interior bents and their location, orientation, and type.

The number of interior bents in any channel should be limited to a practical minimum, and interior bents in the channel of small streams should be avoided, if practical. Interior bents properly oriented with the flow do not contribute significantly to bridge backwater, but they do contribute to general scour. In some cases, severe scour develops immediately downstream of bridges because of eddy currents and because interior bents occupy a significant area in the channel. Lateral and vertical scour also occurs at some locations.

Interior bents should be aligned with flow direction at flood stage to minimize the opportunity for drift to be caught in piling or columns, to reduce the contraction effect of interior bents in the waterway, to minimize debris forces and the possibility of debris dams forming at the bridge, and to minimize backwater and local scour. Bent orientation is difficult where flow direction changes with stage or time. Single-column bents, if practical, are typically the best alternative if orientation at other than flood stage is critical.

Interior bents should not be located on a bank or in the stream channel near the bank because these bent locations are likely to cause lateral scouring of the bank. The design of interior bents located near the stream bank in the floodplain should take into consideration the potential for bank scour and meander migration of the stream.

Interior bent shape is also a factor in local scour. A solid bent will not collect as much debris as a multiple-column bent. Rounding or streamlining the leading edges of interior bents helps to decrease the accumulation of debris and reduces local scour at the bent.

12.7.5.3 Foundations

The foundation is usually the element of a bridge that is most vulnerable during floods. Examination of individual boring logs and plots of the profiles of various subsurface materials are important to the prediction of potential scour depths and to the estimation of the bearing capacity of the soils.

Piles or drilled shafts usually depend upon the surrounding material for skin friction and lateral stability. In some cases, these deep foundations can be extended to rock or other dense material for load-carrying capacity. Tip elevations for piling or drilled shafts should be based on estimates of potential scour depths and bearing to avoid losing lateral support and load-carrying capacity during floods. Pile-bearing capacity derived from driving records have little validity during floods if the material through which the piles were driven is scoured away.

The bridge designer must consider the potential scour and the possibility of channel shifts in designing foundations for bridges on floodplains and spans approaching the stream channel. The thalweg in the channel, which is the line in a stream channel connecting the lowest flow point along the bed, should not be considered to be in a fixed location when establishing founding elevations. The history of a stream and a study of how active the stream has been is important when making decisions on pile and drilled shaft tip elevations.

12.7.6 <u>Construction</u>

12.7.6.1 General

Reference: LRFD Article 2.5.3

The *LRFD Specifications* requires that, unless there is a single obvious method, at least one sequence of construction should be indicated in the contract documents. If an alternative sequence is allowed, the Contractor should prove that stresses, which accumulate in the structure during construction, will remain within acceptable limits.

12.7.6.2 Access and Time Restrictions

Bridges over water may have restrictions associated with their construction. These restrictions must be considered during structure-type evaluation.

Access to a water way beneath a bridge may be restricted for a variety of reasons. These include access restrictions required by permits (e.g., Section 404) and restrictions that limit the type of equipment that can be used during construction.

The time period that the Contractor will be allowed to work within the waterway may be restricted by regulations administered by various agencies. Depending on the time limitations, a bridge with fewer interior bents or faster interior bent construction may be more advantageous for a particular project.

12.7.6.3 Staged Construction

At times, due to the proximity of existing structures or a congested work area, it may be necessary to build a structure in multiple phases. The arrangement and sequencing of each stage of construction are unique to each project, and due consideration must be given to requirements for adequate construction clearances and the requirements of the traveling public. If stages of construction are required, then the staging sequence and controlling lane/construction dimensions must be shown on the plans.

12.7.6.4 Construction Costs

Initial construction costs should be one factor in the selection of the structure type, but not the only factor. Future expenditures during the service life of the bridge should also be considered. The initial costs depend on a variety of factors including:

- type of structure,
- economy of design,
- general state of the economy,
- experience of local Contractors,

- vicinity of fabricating shops, and
- local availability of structural materials and labor.

These factors may change rapidly, and the designer may have no control over them. A review of the cost of structural components within a bridge, and that of Contractor's claims, may direct the designer towards optimum combinations for future bridge projects.

12.7.7 Right-of-Way and Utilities

The Right of Way Office is responsible for securing project right-of-way. The designer should consider the following right-of-way factors when selecting the structure type:

1. Expensive Right-of-Way. If right-of-way will be expensive, this may lead to the use of MSE walls.

2. Structure Depth. The available right-of-way at the bridge site may affect the vertical alignment of the structure which may, in turn, affect the acceptable structure depth to meet the vertical clearance requirements.

3. Detour Bridges. For bridge widening projects, if right-of-way is not available for detour bridges, it may be necessary to maintain traffic across the existing bridge.

Any bridge design must be consistent with SCDOT utility accommodation policies. Chapter 17 discusses utility attachments to bridges.

12.7.8 Maintenance

The structure type selection will, over the life of the structure, have a major impact on maintenance costs. Based on type of material, the following is the approximate order of desirability from a maintenance perspective:

- reinforced concrete slab bridges,
- prestressed concrete,
- unpainted weathering steel, and
- painted structural steel.

The following maintenance considerations apply:

1. Deck Joints. Open, or inadequately sealed, deck joints have been identified as the foremost reason for structural corrosion of structural elements by permitting the seepage of water from the deck. To address this, SCDOT promotes the use of jointless bridges with continuous decks, integral end bents, and improvements in drainage. See Section 12.2 for a discussion on jointless bridges.

2. Paint. The environmental concern for removing paint from steel structures makes the use of weathering steel preferable to painted steel from a maintenance perspective. However, see the discussion in Chapter 16 for the aesthetic considerations and acceptable locations of using weathering steel.

3. Drainage. Closed drainage systems and elaborate piping systems should only be used where required. See Chapter 18.

4. Bridge Inspection. In addition to the maintenance needs of the structure, the designer should consider the bridge inspection logistics.

5. Structural Details. As another maintenance/inspection consideration, the designer should, as practical, limit the number of different structural details (e.g., bearings, expansion joints).

Chapter 13

LOADS AND LOAD FACTORS

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 13

LOADS AND LOAD FACTORS

13.1 GENERAL

13.1.1 Introduction

Sections 1 and 3 of the *LRFD Bridge Design Specifications* discuss various aspects of loads. Unless noted otherwise in this Chapter of the *SCDOT Bridge Design Manual*, the *LRFD Specifications* applies to loads in South Carolina. This Chapter also presents additional information on SCDOT practices.

13.1.2 Load Definitions

Reference: LRFD Article 3.3.2

13.1.2.1 Permanent Loads

Reference: LRFD Article 3.5

Permanent loads are loads that are always present in or on the bridge and do not change in magnitude during the life of the bridge. Specific permanent loads include:

1. Gravitational Dead Loads.

- DC – dead load of all of the components of the superstructure and substructure, both structural and non-structural.
  + DC_1 – dead loads of all components of the superstructure and substructure, both structural and non-structural applied to the non-composite section.
  + DC_2 – dead loads of all components of the superstructure and substructure, both structural and non-structural applied to the composite section.
- DW – dead load of additional non-integral wearing surfaces, future overlays, and any utilities crossing the bridge.
- EL – accumulated lock-in, or residual, force effects resulting from the construction process, including the secondary forces from post-tensioning (which are not gravitational dead loads).
- EV – vertical earth pressure from the dead load of earth fill.

2. Earth Pressures.

   Reference: LRFD Article 3.11

   - EH – horizontal earth pressure.
   - ES – earth pressure from a permanent earth surcharge, such as an embankment.
   - DD – loads developed along the vertical sides of a deep-foundation element tending to drag it downward typically due to consolidation of soft soils underneath embankments reducing its resistance.

13.1.2.2 Transient Loads

Transient loads are loads that are not always present in or on the bridge or change in magnitude during the life of the bridge. Specific transient loads include:

1. Live Loads.

   Reference: LRFD Article 3.6

   - LL – static vertical gravity loads due to vehicular traffic on the roadway.
   - PL – vertical gravity loads due to pedestrian traffic on sidewalks.
   - IM – dynamic load allowance to amplify the force effects of statically applied vehicles to represent moving vehicles, traditionally called impact.
   - LS – horizontal earth pressure from vehicular traffic on the ground surface above an end bent or wall.
   - BR – horizontal vehicular braking force.
   - CE – horizontal centrifugal force from vehicles on a curved roadway.

2. Water Loads.

   Reference: LRFD Article 3.7

   - WA – pressure due to differential water levels, stream flow, or buoyancy.

3. Wind Loads.

   Reference: LRFD Article 3.8

   - WS – horizontal and vertical pressure on superstructure or substructure due to wind.

- WL – horizontal pressure on vehicles due to wind.

4. Extreme Events.

- EQ – loads due to earthquake ground motions.

  Reference: *SCDOT Seismic Design Specifications for Highway Bridges* (LRFD Article 3.10 does not apply)

- CT – horizontal impact loads on bents due to vehicles or trains.

  Reference: LRFD Article 3.6.5

- CV – horizontal impact loads due to aberrant ships or barges.

  Reference: LRFD Article 3.14

- IC – horizontal static and dynamic forces due to ice action.

  Reference: LRFD Article 3.9

5. Superimposed Deformations.

   Reference: LRFD Article 3.12

- TU – uniform temperature change due to seasonal variation.
- TG – temperature gradient due to exposure of the bridge to solar radiation.
- SH – differential shrinkage between different concretes or concrete and non-shrinking materials, such as metals and wood.
- CR – creep of concrete or wood.
- SE – the effects on the superstructure due to settlement.

6. Friction Forces.

   Reference: LRFD Article 3.13

- FR – frictional forces on sliding surfaces from structure movements.

13.1.3 Limit States

Reference: LRFD Article 1.3.2

13.1.3.1 LRFD Equation

The *LRFD Specifications* groups the traditional design criteria together within the groups termed limit states. The various limit states have load combinations assigned. Components and connections of a bridge are designed to satisfy the basic LRFD Equation 1.3.2.1-1 for all limit states:

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n \qquad \text{(LRFD Equation 1.3.2.1-1)}$$

Where:
- γ_i = load factor
- Q_i = load or force effect
- ϕ = resistance factor
- R_n = nominal resistance
- η_i = load modifier as defined in LRFD Equations 1.3.2.1-2 and 1.3.2.1-3

The left-hand side of LRFD Equation 1.3.2.1-1 is the sum of the factored load (force) effects acting on a component; the right-hand side is the factored nominal resistance of the component for the effects. The Equation must be considered for all applicable limit state load combinations. Similarly, the Equation is applicable to both superstructures and substructures.

For the strength limit states, the *LRFD Specifications* is basically a hybrid design code in that, for the most part, the force effect on the left-hand side of the LRFD Equation is based upon elastic structural response, while resistance on the right-hand side of the Equation is determined predominantly by applying inelastic response principles. The *LRFD Specifications* has adopted the hybrid nature of strength design on the assumption that the inelastic component of structural performance will always remain relatively small because of non-critical redistribution of force effects. This non-critical redistribution of force effects is assured by providing adequate redundancy and ductility of the structures, which is SCDOT's general policy for the design of bridges.

13.1.3.2 Load Modifier

The load modifier η_i relates the factors η_D, η_R, and η_I to ductility, redundancy, and operational importance. The location of η_i on the load side of the Equation may appear counterintuitive because it appears to be more related to resistance than to load. η_i is on the load side for a logistical reason. When η_i modifies a maximum load factor, it is the product of the factors as indicated in LRFD Equation 1.3.2.1-2; when η_i modifies a minimum load factor, it is the reciprocal of the product as indicated in LRFD Equation 1.3.2.1-3. The LRFD-specified factors η_D, η_R, and η_I are based on a 5% stepwise positive or negative adjustment, reflecting unfavorable or favorable conditions. These factors are somewhat arbitrary; their significance is in their presence in the *LRFD Specifications* and not necessarily in the accuracy of their magnitude. The LRFD factors reflect the desire to promote redundant and ductile bridges.

SCDOT uses η_i values of 1.00 for all limit states, because bridges designed in accordance with the *SCDOT Bridge Design Manual* will demonstrate traditional levels of redundancy and ductility. Rather than penalize less redundant or less ductile bridges, such bridges are not acceptable. The Department may on a case-by-case basis designate a bridge to be of operational importance and specify an appropriate value of η_I.

The load modifier for operational importance, η_I, should not be confused with the bridge category classifications for seismic design of the *SCDOT Seismic Design Specifications for Highway Bridges*, nor for the vessel collision design of the *LRFD Specifications*.

13.1.4 Load Factors and Combinations

Reference: LRFD Article 3.4.1

LRFD Table 3.4.1-1 provides the load factors for all of the limit state load combinations of the *LRFD Specifications*.

13.1.4.1 Strength Load Combinations

The load factors for the Strength load combinations are calibrated based upon structural reliability theory and represent the uncertainty of their associated loads. Larger load factors indicate more uncertainty; smaller load factors indicate less uncertainty. The significance of the Strength limit state load combinations can be simplified as follows:

1. Strength I Load Combination. This load combination represents random traffic and the heaviest truck to cross the bridge in its 75-year design life. During this live-load event, a significant wind is not considered probable.

2. Strength II Load Combination. This load combination represents an owner-specified permit load model. This live-load event will have less uncertainty than random traffic and, thus, a lower live-load load factor. SCDOT does not specify a permit load for design purposes. Therefore, this load combination need not be used unless a specific need is identified.

3. Strength III Load Combination. This load combination represents the most severe wind during the bridge's 75-year design life. During this severe wind event, no significant live load would cross the bridge.

4. Strength IV Load Combination. This load combination represents an extra safeguard for bridge superstructures where the unfactored dead load exceeds seven times the unfactored live load. Thus, the only significant load factor would be the 1.25 dead-load maximum load factor. For additional safety, and based solely on engineering judgment, the *LRFD Specifications* has arbitrarily increased the load factor for DC to 1.5. This load combination need not be considered for any component except a superstructure

component, and never where the unfactored dead-load force effect is less than seven times the unfactored live-load force effect. This load combination typically governs only for longer spans, approximately greater than 200 ft in length.

5. Strength V Load Combination. This load combination represents the simultaneous occurrence of a "normal" live-load event and a "55-mph" wind event with load factors of 1.35 and 0.4, respectively.

For components not traditionally governed by wind force effects, the Strengths III and V Load Combinations should not govern. Unless Strengths II and IV as indicated above are needed then, for a typical multi-girder highway overpass, the Strength I Load Combination will generally be the only combination requiring design calculations.

13.1.4.2 Service Load Combinations

Unlike the Strength limit state load combinations, the Service limit state load combinations are, for the most part, material dependent. The following applies:

1. Service I Load Combination. This load combination is applied for controlling cracking in reinforced concrete components and compressive stresses in prestressed concrete components. This load combination is also used to calculate deflections and settlements of superstructure and substructure components.

2. Service II Load Combination. This load combination is applied for controlling permanent deformations of compact steel sections and the "slip" of slip-critical (i.e., friction-type) bolted steel connections.

3. Service III Load Combination. This load combination is applied for controlling tensile stresses in prestressed concrete superstructure components under vehicular traffic loads.

4. Service IV Load Combination. This load combination is applied for controlling tensile stresses in prestressed concrete substructure components under wind loads. For components not traditionally governed by wind effects, this load combination should not govern.

13.1.4.3 Extreme-Event Load Combinations

The Extreme-Event limit states differ from the Strength limit states, because the event for which the bridge and its components are designed has a greater return period than the 75-year design life of the bridge (or a much lower frequency of occurrence than the loads of the Strength limit state load combinations). The following applies:

1. Extreme Event I Load Combination. This load combination is not applicable. Seismic design shall be in accordance with the *SCDOT Seismic Design Specifications for Highway Bridges.*

2. Extreme Event II Load Combination. This load combination is applied to various types of collisions (vessel, vehicular, or ice) applied individually.

13.1.4.4 Fatigue-and-Fracture Load Combination

The Fatigue-and-Fracture limit state load combination, although strictly applicable to all types of superstructures, only affects the steel elements, components, and connections of a limited number of steel superstructures. Chapter 16 discusses fatigue and fracture for steel.

13.1.4.5 Application of Multiple-Valued Load Factors

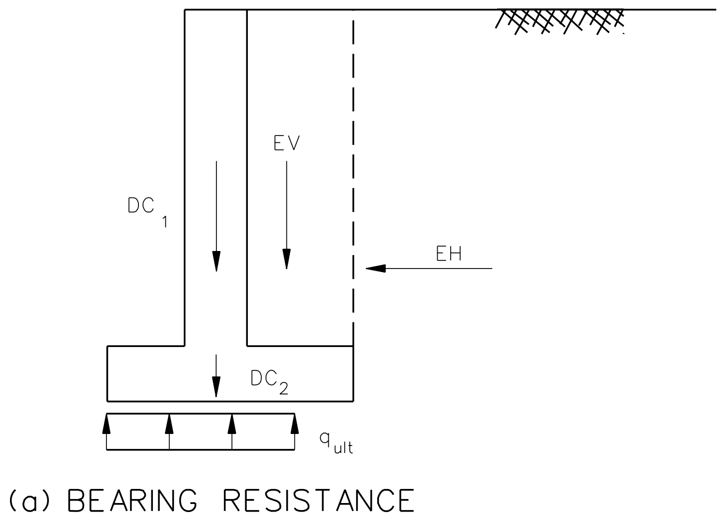
13.1.4.5.1 Maximum and Minimum Permanent-Load Load Factors

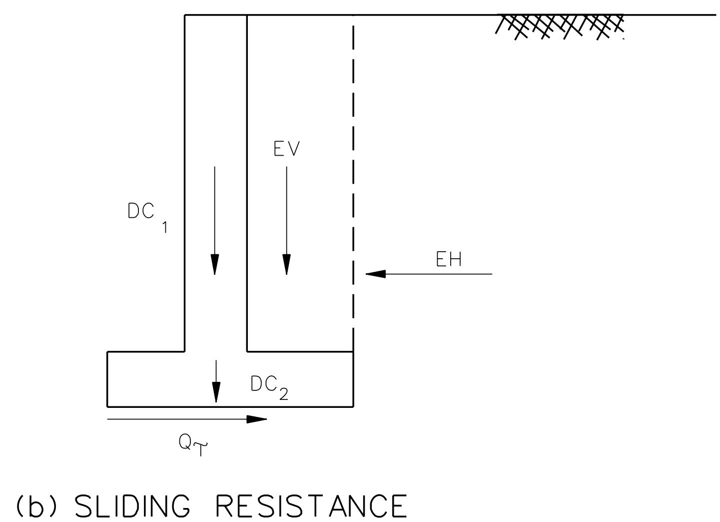
In LRFD Table 3.4.1-1, the variable γ_P represents load factors for all of the permanent loads, shown in the first column of load factors. This variable γ_P reflects that the Strength and Extreme-Event limit state load factors for the various permanent loads are not single constants, but they can have two extreme values. LRFD Table 3.4.1-2 provides these two extreme values for the various permanent load factors, maximum and minimum. Permanent loads are always present on the bridge, but the nature of uncertainty is that the actual loads may be more or less than the nominal specified design values. Therefore, maximum and minimum load factors reflect this uncertainty.

The designer should select the appropriate maximum or minimum permanent-load load factors to produce the more critical load effect. For example, in continuous superstructures with relatively short-end spans, transient live load in the end span causes the bearing to be more compressed, while transient live load in the second span causes the bearing to be less compressed and perhaps lead to uplift. To check the maximum compression force in the bearing, place the live load in the end span and use the maximum DC load factor of 1.25 for all spans. To check possible uplift of the bearing, place the live load in the second span and use the minimum DC load factor of 0.90 for all spans.

Superstructure design uses the maximum permanent-load load factors almost exclusively, with the most common exception being uplift of a bearing as discussed above. The AASHTO *Standard Specifications* treated uplift as a separate load combination. With the introduction of maximum and minimum load factors, the *LRFD Specifications* has generalized load situations such as uplift where a permanent load (in this case a dead load) reduces the overall force effect (in this case a reaction). Permanent load factors, either maximum or minimum, must be selected for each load combination to produce extreme force effects.

Substructure design routinely uses the maximum and minimum permanent-load load factors from LRFD Table 3.4.1-2. An illustrative yet simple example is a spread footing supporting a cantilever retaining wall. When checking bearing, as shown schematically in Figure 13.1-1(a), the weight of the soil (EV) over the heel is factored up by the maximum load factor, 1.35,





LOADS AND RESISTANCES OF A CANTILEVER RETAINING WALL

Figure 13.1-1

because greater EV increases the bearing pressure, q_{ult}, making the limit state more critical. When checking sliding, as shown schematically in Figure 13.3-1(b), EV is factored by the minimum load factor, 1.00, because lesser EV decreases the resistance to sliding, Q_τ, again making the limit state more critical. The application of these maximum and minimum load factors is required for foundation and substructure design in Chapters 19 and 20.

13.1.4.5.2 Load Factors for Superimposed Deformations

The load factors for the superimposed deformations for the Strength limit states also have two specified values — a load factor of 0.5 for the calculation of stress, and a load factor of 1.2 for the calculation of deformation. The greater value of 1.2 is used to calculate unrestrained deformations, such as a simple span expanding freely with rising temperature. The lower value of 0.5 for the elastic calculation of stress reflects the inelastic response of the structure due to restrained deformations. For example, one-half of the temperature rise would be used to elastically calculate the stresses in a constrained structure. Using 1.2 times the temperature rise in an elastic calculation would overestimate the stresses in the structure. The structure resists the temperature inelastically through redistribution of the elastic stresses.

13.2 PERMANENT LOADS

13.2.1 General

Reference: LRFD Article 3.5

The *LRFD Specifications* specifies seven components of permanent loads, which are either direct gravity loads or caused by gravity loads. Prestressing is considered, in general, to be part of the resistance of a component and has been omitted from the list of permanent loads in Section 3 of the *LRFD Specifications*. However, when designing anchorages for prestressing tendons, the prestressing force is the only load effect, and it should appear on the load side of the LRFD Equation. The permanent load EL includes secondary forces from pre-tensioning or post-tensioning. As specified in LRFD Table 3.4.1-2, use a constant load factor of 1.0 for both maximum and minimum load factors for EL.

13.2.2 Deck Slab Dead Load

Reference: LRFD Article 9.7.4

Bridge dead load (DL) consists of composite and non-composite components.

Loads applied to the non-composite cross section (i.e., the girder alone) include the weight of the plastic concrete, forms, and other construction loads typically required to place the deck. Calculate the non-composite DL using the full slab volume including haunch volumes times the unit weight of concrete. Because steel stay-in-place formwork is typically used by contractors in South Carolina, an additional 0.016 k/ft^2 is applied between the girder flanges to account for the concrete in the flutes of the formwork. Use the weight of the slab and formwork plus 0.05 k/ft^2 to account for construction loads to check deflections and stresses and to assess girder stability prior to the hardening of the concrete.

Loads applied to the composite cross section (i.e., the girder with the positively connected slab) include the weight of any curb, rail, sidewalk, or barrier placed after the deck concrete has hardened. The weight of any appurtenances (e.g., lighting, utilities, sign structures) must be considered. Include an allowance for a future wearing surface of 0.015 k/ft^2 over the entire deck area between the gutter lines.

13.2.3 Distribution of Dead Load to Girders

Reference: LRFD Article 4.6.2.2.1

For the distribution of the weight of plastic concrete to the girders, including that of an integral sacrificial wearing surface, assume that the formwork is simply supported between interior beams and cantilevered over the exterior beams.

Superimposed dead loads (e.g., curbs, barriers, sidewalks, parapets, railings, future wearing surfaces) placed after the deck slab has cured, may be distributed equally to all girders. For wider bridges with more than six girders, assume that the superimposed dead loads of curbs, sidewalks, parapets or railings are carried by the three girders immediately under and adjacent to the load. In some cases, such as staged construction and heavier utilities, the bridge designer should conduct a refined analysis to determine a more accurate distribution of superimposed dead loads.

13.2.4 Downdrag on Deep Foundations

Deep foundations (i.e., driven piles and drilled shafts) through unconsolidated soil layers may be subject to downdrag, DD. Downdrag is a load developed along the vertical sides of a deep-foundation element tending to drag it downward. Typically, this loading is due to consolidation of soft soils, especially at embankments. Calculate this additional load as an opposing skin-friction effect. If possible, the bridge designer should detail the deep foundation to mitigate the effects of downdrag; otherwise, it is necessary to design considering downdrag. Chapter 19 discusses mitigation methods.

13.3 TRANSIENT LOADS

13.3.1 General

The *LRFD Specifications* recognizes 19 transient loads. Static water pressure, stream pressure, buoyancy, and wave action are integrated as water load, WA. Creep, settlement, shrinkage, and temperature (CR, SE, SH, TU, and TG) are considered as "loads," being superimposed deformations which, if restrained, will result in force effects. For example, restrained elements, due to uniform-temperature increase, induce compression forces. The *LRFD Specifications* has considerably increased the vehicular braking force (BR) to reflect the improvements in the mechanical capability of modern trucks in comparison with the traditional values of the AASHTO *Standard Specifications*.

13.3.2 Vehicular Live Load (LL)

13.3.2.1 General

Reference: LRFD Articles 3.6.1.1, 3.6.1.2 and 3.6.1.3

For short and medium span bridges, which predominate in South Carolina, vehicular live load is the most significant component of load.

13.3.2.2 The Nature of the Notional Load

The HL-93 live-load model is a notional load in that it is not a true representation of actual truck weights. Instead, the force effects (i.e., the moments and shears) due to the superposition of vehicular and lane load within a single design lane are a true representation of the force effects due to actual trucks.

The components of the HL-93 notional load are:

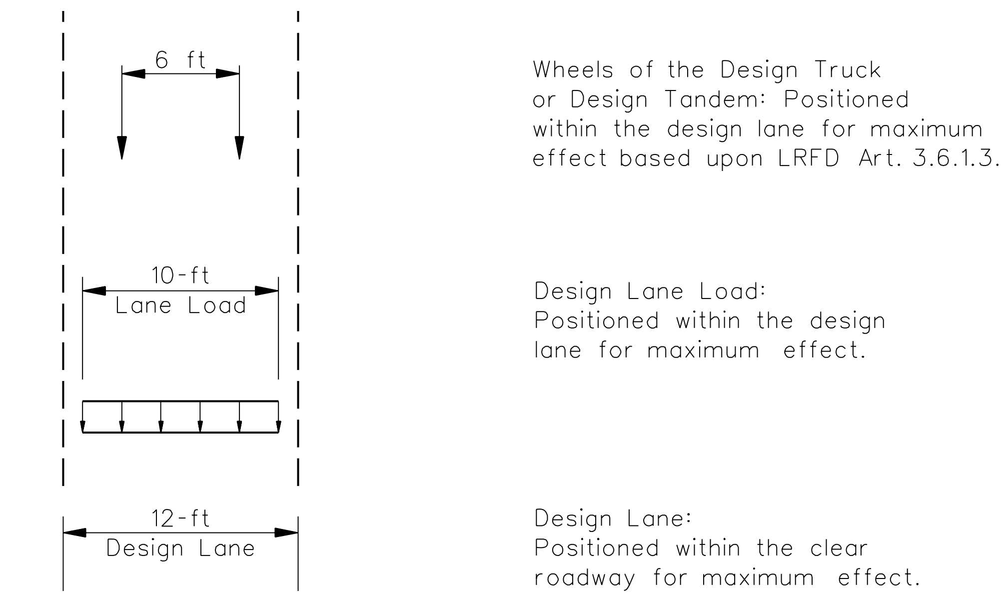
- a vehicle, either the familiar HS-20 truck, now called the design truck, or a 50-kip design tandem, similar to the Alternate Loading of the AASHTO *Standard Specifications*; and
- a 0.64 k/ft uniformly distributed lane load, similar to the lane load of the AASHTO *Standard Specifications* but without any of the associated concentrated loads.

Note that the dynamic load allowance (IM) of 0.33 is applicable only to the design trucks and the design tandems, but not to the uniformly distributed lane load.

The force effects of the traditional HS-20 truck alone are less than that of the legal loads. Thus, a heavier vehicle is appropriate for design. Originally, a longer 57-ton vehicle (termed the HTL-57) was developed to model the force effects of trucks on our nation's highways at the time of the development of the 1st Edition of the *LRFD Specifications*. Ultimately, it was deemed objectionable to specify a super-legal truck in the *LRFD Specifications*. Instead, the concept of superimposing the design vehicle force effects and the design lane force effects to yield moments and shears representative of real trucks on the highways was developed. The moments and shears produced by the HL-93 load model are essentially equivalent to those of a 57-ton truck.

The multiple presence factor of 1.0 for two loaded lanes, as given in LRFD Table 3.6.1.1.2-1, is the result of the *LRFD Specifications'* calibration for the notional load, which has been normalized relative to the occurrence of two side-by-side, fully correlated, or identical, vehicles. The multiple presence factor of 1.2 for one loaded lane should be used where a single design tandem or single design truck governs, such as in overhangs, decks, etc. The multiple-presence factors should never be applied to fatigue loads nor any other vehicle of relatively known weight such as a legal or permit load.

The *LRFD Specifications* retains the traditional design lane width of 12 ft and the traditional spacing of the axles and wheels of the HS-20 truck. Both vehicles (the design truck and design tandem) and the lane load occupy a 10-ft width placed transversely within the design lane for maximum effect, as specified in LRFD Article 3.6.1.3 and illustrated schematically in Figure 13.3-1.



PLACEMENT OF THE DESIGN LOADS WITHIN THE DESIGN LANE

Figure 13.3-1

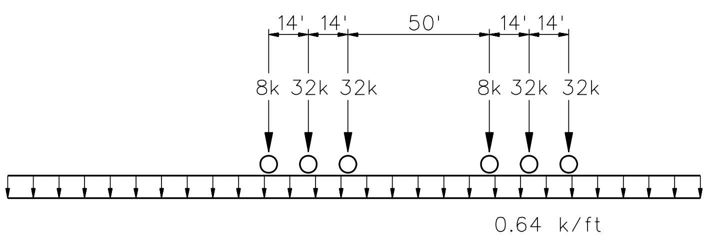
The *LRFD Specifications* requires that two closely spaced design trucks superimposed on the lane load be applied on adjacent spans of continuous structures for negative moments and reactions. The reduced probability of such an occurrence of fully correlated, or identical, vehicles is accommodated by multiplying the resulting force effects by 0.90.

13.3.2.3 Load Applications

13.3.2.3.1 Two Design Trucks in a Single Lane for Negative Moment and Interior Reactions

Reference: LRFD Article 3.6.1.3.1

The combination of the lane load and a single vehicle (either a design truck or a design tandem) does not always adequately represent the real-life loading of two heavy vehicles closely following one another, interspersed with other lighter traffic. Thus, a special load case has been specified in the *LRFD Specifications* to calculate these force effects. Two design trucks, with a fixed rear axle spacing of 14 ft and a clear distance not less than 50 ft between them, superimposed upon the lane load, all within a single design lane and adjusted by a factor of 0.90 approximates a statistically valid representation of negative moment and interior reactions due to closely spaced heavy trucks. This sequence of highway loading is specified for negative moment and interior reactions due to the shape of the influence lines for such force effects. This sequence is not extended to other structures or portions of structures because it is not expected to govern for other influence-line shapes. This loading is illustrated in Figure 13.3-2.



SPECIAL LOADING FOR NEGATIVE MOMENT AND INTERIOR REACTIONS OF CONTINUOUS SPANS

Figure 13.3-2

13.3.2.3.2 Application of Horizontal Superstructure Forces to the Substructure

The transfer of horizontal superstructure forces to the substructure depends on the type of superstructure-to-substructure connection. Connections can be fixed, pinned, or unrestrained.

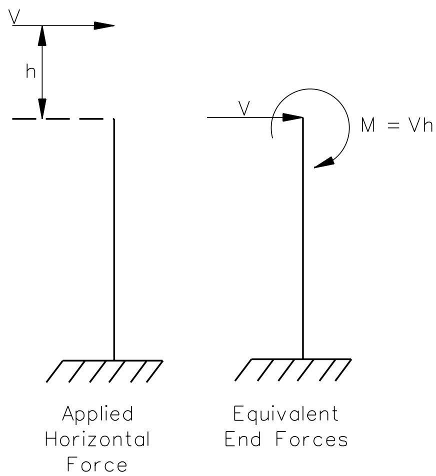
If the horizontal superstructure force is being applied to the substructure through a pinned connection, there is no moment transfer. Apply the superstructure force to the substructure at the connection.

For a fixed or moment connection, apply the superstructure horizontal force with an additional moment to the substructure as shown in Figure 13.3-3. The additional moment is equal to the horizontal force times the distance between the force's line of action and the point of application.

13.3.2.4 Fatigue Load

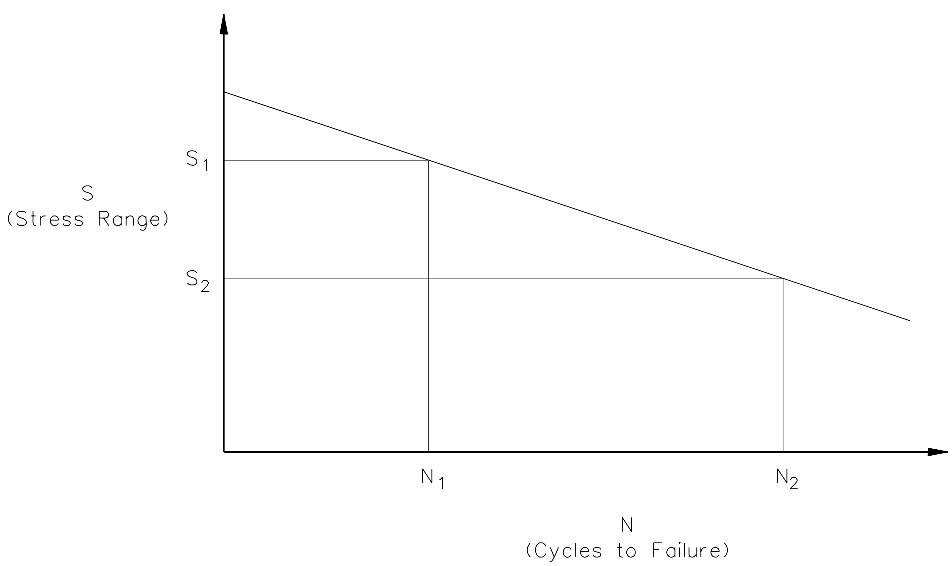
Reference: LRFD Articles 3.6.1.4.1 and 3.6.1.4.2

The *LRFD Specifications* defines the fatigue load for a particular bridge component by specifying both a magnitude and a frequency. The magnitude of the fatigue load consists of a single design truck per bridge with a load factor of 0.75 (i.e., the factored force effects are equivalent to those of an HS-15 truck). This single-factored design truck produces a considerable reduction in the stress range in comparison with the stress ranges of the AASHTO *Standard Specifications*. However, fatigue designs using the *LRFD Specifications* are virtually identical to those of the AASHTO *Standard Specifications*. This equivalence is accomplished through an increase in the frequency from values on the order of two million cycles in the *Standard Specifications*, which represented "design" cycles, to frequencies on the order of tens and hundreds of millions of cycles, which represent actual cycles in the *LRFD Specifications*. This change to more realistic stress ranges and cycles, illustrated in the S-N curve (a log-log plot of stress range versus cycle to failure) of Figure 13.3-4, depicts the extremely long fatigue lives of steel bridges. In Figure 13.3-4, S_1 represents the controlling stress range for multiple lanes of strength-magnitude loading typically in accordance with the AASHTO *Standard Specifications*, with N_1 being its corresponding number of design cycles. S_2 represents the controlling stress range for a single fatigue truck in accordance with the *LRFD Specifications*, with N_2 being its corresponding number of actual cycles. The increase in the number of cycles compensates for the reduction in stress range, yet both cases fall on the resistance curve producing a similar fatigue design.



TRANSFER OF HORIZONTAL SUPERSTRUCTURE FORCE TO SUBSTRUCTURE THROUGH MOMENT CONNECTION

Figure 13.3-3



COMPARISON OF THE FATIGUE LOADS OF THE *LRFD SPECIFICATIONS* AND THE AASHTO *STANDARD SPECIFICATIONS*

Figure 13.3-4

13.3.2.5 Distribution of Live Load to Piers

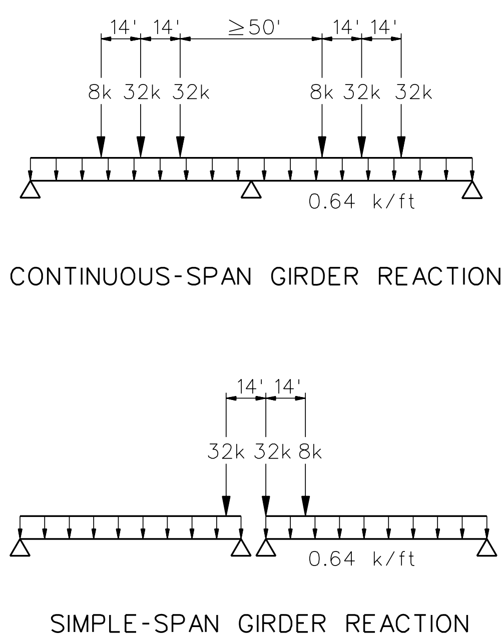
Reference: LRFD Article 3.6.1.3.1

To promote uniformity of distribution of live load to piers and other substructure components, the following procedure is suggested unless a more exact distribution of loads is used:

1. Live-Load Distribution Factor. The live-load distribution factor for each girder shall be determined assuming the deck is acting as a simple beam between interior girders and as a cantilever spanning from the first interior girder over the exterior girder.

2. Live Load on Design Lanes. Design lanes shall be placed on the bridge to produce the maximum force effect for the component under investigation. The HL-93 live load shall be placed within its individual design lane to likewise produce the maximum effect. The bridge designer shall consider one, two, three, or more design lanes in conjunction with the multiple presence factors of LRFD Table 3.6.1.1.2-1, as can be accommodated on the roadway width.

3. Reaction on Piers. For continuous girders, the bridge designer shall use two closely spaced design trucks superimposed over the lane load, with a distribution factor derived as discussed above in a line-girder analysis to determine the reaction on interior bents. This is as specified in LRFD Article 3.6.1.3 for negative moment in continuous girders and interior reactions and discussed in Section 13.3.2.3.1. For simple-span girders, evaluate each girder bearing upon the substructure component individually using a standard single vehicle per lane. See Figure 13.3-5.



REACTION ON PIERS

Figure 13.3-5

13.3.2.6 Braking Force (BR)

Reference: LRFD Article 3.6.4

For two-directional bridges that are not likely to become one-directional in the future, the number of lanes used to calculate the braking force shall be determined by dividing the number of design lanes by two and rounding to the nearest integer. For example:

1. <u>Typical Rural Bridge with 44-ft Clear Roadway Width</u>.

   Number of design lanes = 44/12 = 3.7; use 3 design lanes for live load
   3 design lanes/2 = 1.5; use 2 lanes to calculate braking force

2. <u>Typical Rural Bridge with 34-ft Clear Roadway Width</u>.

   Number of design lanes = 34/12 = 2.8; use 2 design lanes for live load
   2 design lanes/2 = 1.0; use 1 lane to calculate braking force

For bridges that are likely to become one-directional in the future, the number of lanes used to calculate the braking force shall be equal to the number of design lanes.

13.3.2.7 Vehicular Collision Force (CT)

Reference: LRFD Article 3.6.5

End and interior bents of bridges over highways or railroads within a distance of:

- 30 ft to the edge of the roadway, or
- 50 ft to the centerline of the railroad track

shall be protected as specified in LRFD Article 3.6.5.1. If this is deemed totally impractical and with the approval of the State Bridge Design Engineer, the bent shall be designed for a collision force of 400 kips acting in a horizontal plane in any direction at a distance of 4 ft above ground, as specified in LRFD Article 3.6.5.2. Typically, LRFD Article 3.6.5.1 will apply to roadway grade separations, and LRFD Article 3.6.5.2 will apply to railroad overpasses.

13.3.3 <u>Friction Forces (FR)</u>

Reference: LRFD Article 3.13

Section 21.2 discusses the determination of horizontal friction forces from an expansion bearing sliding on its bearing plate on the supporting substructure component.

The bridge designer should adjust the frictional forces from sliding bearings to account for the future degradation of the sliding surfaces. Consider the horizontal force due to friction conservatively. Include friction forces where design loads would increase, but neglect friction forces where design loads would decrease.

13.3.4 Earthquake Effects

Seismic design shall be in accordance with the *SCDOT Seismic Design Specifications for Highway Bridges*.

13.3.5 Live-Load Surcharge (LS)

Reference: LRFD Article 3.11.6.2

Where reinforced concrete approach slabs are provided at bridge ends, live-load surcharge need not be considered on the end bent; however, the bridge designer shall consider the reactions on the end bent due to the axle loads on the approach slabs. The end bents must be able to resist the reactions due to axle loads on an approach slab.

13.3.6 Vessel Collision (CV)

Reference: LRFD Article 3.14.3

For vessel-collision design considerations, the Importance Classification (IC) of bridges crossing navigable waterways is derived from the *SCDOT Seismic Design Specifications for Highway Bridges*:

1. Critical. Any bridge that has an Importance Classification of I for seismic design considerations is classified as “Critical” for vessel collision design considerations.
2. Regular. All bridges that are not classified as “Critical” for vessel collision design are classified as “Regular.”

Chapter 14

STRUCTURAL ANALYSIS AND EVALUATION

SCDOT BRIDGE DESIGN MANUAL

April 2006

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Section **Page**

CHAPTER 14

STRUCTURAL ANALYSIS AND EVALUATION

Section 4 of the *LRFD Specifications* discusses the methods of structural analysis suitable for the design and evaluation of bridge superstructures. This Chapter of the *SCDOT Bridge Design Manual* provides an elaboration on some of the provisions in the *LRFD Specifications* and discusses the SCDOT-specific application of Section 4.

14.1 LIVE-LOAD DISTRIBUTION

14.1.1 <u>General</u>

Reference: LRFD Article 4.6.3.1

14.1.1.1 Definition

Live-load distribution, for application of the *SCDOT Bridge Design Manual*, refers to the determination of the maximum number of loaded lanes that an individual girder of the superstructure will be expected to carry.

14.1.1.2 Modeling Concrete Bridge Rails

The *LRFD Specifications* allows the structural contribution of any structurally continuous railing, barrier, or median to be used to resist transient loads at the Service and Fatigue limit states as a part of the cross section of the exterior girder. This allowance of structural contribution shall not be used in South Carolina for new designs but may be considered in the evaluation or design for rehabilitation if the contribution of the railing, barrier, or median is significant.

14.1.2 <u>Approximate Methods</u>

Reference: LRFD Article 4.6.2

14.1.2.1 General

Typically, bridges are analyzed using live-load distribution factors. These distribution factors result in a simple, approximate analysis of bridge superstructures. Live-load distribution factors separate the transverse and longitudinal distribution of force effects in the superstructure. Live-load force effects are assumed to be distributed transversely by proportioning the design lanes to individual girders through the application of distribution factors. The force effects are subsequently distributed longitudinally between the supports through the one-dimensional (1-D) structural analysis over the length of the girders.

In simplifying the design process, distribution factors minimize potential modeling errors. They reduce the necessity of modeling the entire bridge from a two-dimensional (2-D) or three-dimensional (3-D) analysis to a 1-D analysis of a girder.

14.1.2.2 Live-Load Distribution Factors

Reference: LRFD Article 4.6.2.2

14.1.2.2.1 General

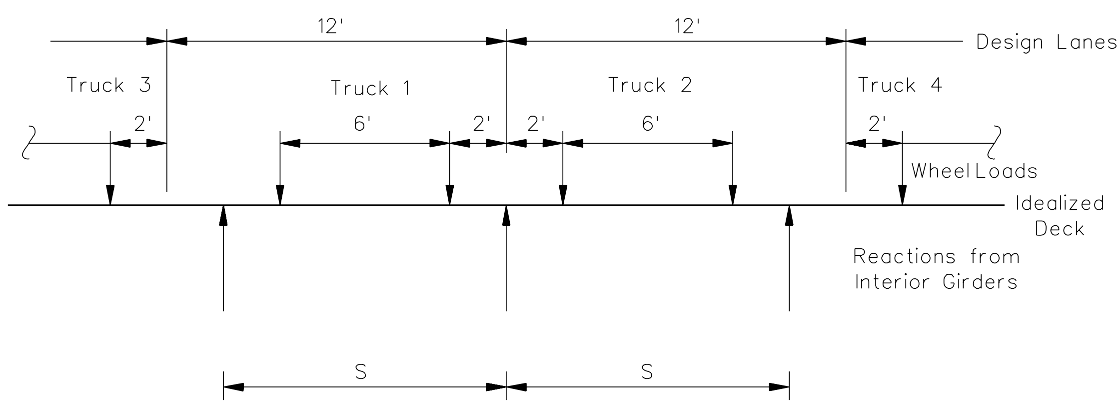
LRFD Article 4.6.2.2.2 presents several common bridge superstructure types, with empirically derived equations for live-load distribution factors for each type. These more sophisticated distribution-factor equations are analytically superior to the traditional *AASHTO Standard Specifications* "S over" factors that have been used for bridges with spans and girder spacings far beyond those for which they were originally intended. Each distribution factor provides a number of design lanes to be applied to a girder to evaluate it for moment or shear. The factors account for interaction among loads from multiple lanes.

The empirical formulas result from regression analyses performed on results of finite element analyses of a large sample of typical superstructures. The equations are intended to produce results within 5% of the finite element analyses on which they rely. The designer can find more details on the development of the distribution factors in *Distribution of Wheel Loads on Highway Bridges* by T. Zokaie, T. A. Osterkamp, and R. A. Imbsen, Final Report, NCHRP Project No. 12-26.

The distribution factors represent the placement of design lanes to generate the extreme effect in a specific girder as illustrated in Figure 14.1-1. The location of design lanes is not related to the location of striped lanes on the bridge. Summing all of the distribution factors for all girders produces a number of design lanes greater than the bridge can physically carry. This apparent overdesign occurs because each girder must be designed for the maximum load to which it could individually be subjected. Collectively, the individual load conditions producing the distribution factors cannot exist simultaneously on the bridge, yet each girder must be designed for its own worst case. In other words, if the girder distribution factors in terms of lanes per girder are summed, the resulting value of lanes per bridge is greater than the number of design lanes that can be physically positioned on the roadway.

14.1.2.2.2 Limitations

The tables of distribution factors given in LRFD Article 4.6.2.2 include a column entitled "Range of Applicability." The *LRFD Specifications* suggests that bridges with parameters falling outside the indicated ranges be designed using the refined analysis requirements of LRFD Article 4.6.3. These ranges of applicability do not necessarily represent limits of usefulness of the distribution-factor equations, but the ranges represent the range over which bridges were examined to develop the equations. Other State DOTs have conducted parametric studies to extend these ranges for typical bridges in their States that have demonstrated that the factors can be used far outside of the range of parameters that were specifically studied. Therefore, SCDOT policy is to use a refined analysis only with the approval of the State Bridge Design Engineer prior to any preliminary design and only with bridges where the parameters fall outside of the "Range of Applicability." See Section 14.2 for a discussion on refined analyses.



DESIGN LANE AND TRUCK PLACEMENT PRODUCING THE WORST CASE FOR AN INDIVIDUAL INTERIOR GIRDER

Figure 14.1-1

14.2 REFINED ANALYSIS

Reference: LRFD Articles 4.6.2.2 and 4.6.3

14.2.1 General

Refined analyses include both 2-D and 3-D models (sometimes called grid and finite-element models, respectively). Typically, in a grid analysis, longitudinal elements represent the girders including any composite deck, and the transverse elements represent the deck. LRFD Article 4.6.3.3 provides general requirements for grid and finite-element analyses in terms of numbers of elements and aspect ratios.

14.2.2 Tangent Bridges

The NCHRP study, referenced in Section 14.1.2.2.1, that developed the simple distribution factors also investigated refined analysis methods. The study demonstrated that the additional complication of performing a 3-D analysis provided no additional value for tangent bridges when compared to performing a less rigorous 2-D analysis.

14.2.3 Horizontally Curved Steel Bridges

The design of all steel superstructures must account for the effect of curvature where the components are fabricated on horizontal curves. The magnitude of the effect of horizontal curvature is primarily a function of the curve radius, girder spacing, span length, diaphragm spacing and, to a lesser degree, web depth and flange proportions. The effect of curvature develops in two ways. First, the general tendency is for each girder to overturn, which has the effect of transferring both dead and live load from one girder to another transversely. The net result of this load transfer is that some girders carry more load and others carry less. The load transfer is carried through the diaphragms and the deck. The second effect of curvature is the concept of flange bending caused by torsion in curved components being almost totally resisted by horizontal shear in the flanges. The horizontal shear results in moments in the flanges. The stresses caused by these moments either add to or reduce the stresses from vertical bending. The torsional effects should also be considered in the design of the girder webs to prevent warping of the webs.

Refined analysis methods, either grid or finite-element, shall be used for the analysis of horizontally curved steel bridges. LRFD Article 4.6.2.2.4 states that approximate analysis methods may be used for the analysis of curved steel bridges but then highlights the deficiencies of these analyses, specifically the V-load method for I-girders and the M/R method for boxes. Therefore, SCDOT does not allow the use of approximate analysis methods for curved steel bridges.

14.3 INELASTIC REDISTRIBUTION OF MOMENTS

Reference: LRFD Article 5.7.3.5; LRFD Appendices A6 and B6

The *LRFD Specifications* presents simplified approaches to inelastic redistributions of moments in girder bridges. LRFD Article 5.7.3.5 provides a simple multiplier for negative-moment redistribution based upon ductility of a reinforced concrete section. LRFD Articles 6.10 and 6.11 present a simplified approach to inelastic redistribution of moments in steel girder bridges. The simplified approach allows the moment in a section to approach 1.3 times the moment at first yield, acknowledging the inherent ability of positive moments to inelastically redistribute to negative-moment steel sections regardless of the compactness of the negative-moment section.

The Appendices to Section 6 of the *LRFD Specifications* include more rigorous inelastic procedures for steel girders. LRFD Appendix A6 specifies a more rigorous and thus more efficient redistribution of positive moments to compact negative-moment sections. LRFD Appendix B6 gives provisions for the redistribution of moments at compact negative-moment sections.

14.4 WIND LOAD DISTRIBUTION

Reference: LRFD Articles 3.4.1, 3.8.1 and 4.6.2.7.1

LRFD Article 4.6.2.7.1 discusses load paths for transferring wind loads transversely applied to the fascia girder to the bridge's bearings. The Commentary to this Article provides guidelines on how girders resist these wind loads. These provisions are directly applicable to steel girder bridges. In typical concrete girder bridges, the distribution of wind load becomes insignificant due to their greater out-of-plane stiffness in comparison with steel girders. As such, it may be assumed that typical concrete fascia girders satisfactorily resist these transverse wind loads.

14.5 DYNAMIC ANALYSIS

Dynamic analysis need only be considered for investigating earthquake effects on bridges in South Carolina. The *SCDOT Seismic Design Specifications for Highway Bridges* discusses the necessary dynamic-analysis procedures.

Chapter 15

STRUCTURAL CONCRETE

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CHAPTER 15

STRUCTURAL CONCRETE

Section 5 of the *LRFD Bridge Design Specifications* specifies unified design requirements of concrete, both reinforced and prestressed, in all structural elements. This Chapter presents SCDOT supplementary information specifically on the properties of concrete and reinforcing steel and the design of structural concrete members.

15.1 STRUCTURAL CONCRETE DESIGN

15.1.1 General

The *LRFD Specifications* has unified the design provisions for reinforced concrete members and prestressed concrete members into a single section, unlike the traditional separation of these structural member types in the AASHTO *Standard Specifications*. The American Concrete Institute (ACI) similarly uses unified provisions in ACI 318.

15.1.2 Flexural Resistance

Reference: LRFD Article 5.7

The flexural resistance of a beam section is typically obtained using the rectangular stress distribution of LRFD Article 5.7.2.2. In lieu of using this simplified, yet accurate approach, a strain compatibility approach may be used as outlined in LRFD Article 5.7.3.2.5. The general equation for structural concrete flexural resistance of LRFD Article 5.7.3.2.1 is based upon the rectangular stress block.

15.1.3 Limits for Flexural Steel Reinforcement

15.1.3.1 Maximum

Reference: LRFD Article 5.7.3.3.1

LRFD Article 5.7.3.3.1 regulates the maximum allowable steel for reinforced and prestressed members. The *LRFD Specifications* limits the maximum amount of reinforcement because an inelastic mechanism controlled by the yield of reinforcement provides more ductility, and crushing of concrete prior to the yielding of reinforcement is a more brittle failure.

15.1.3.2 Minimum

Reference: LRFD Articles 5.7.3.3.2 and 5.4.2.6

The minimum flexural reinforcement of a component should provide flexural strength at least equal to the lesser of:

- 1.2 times the cracking moment of the concrete section, defined by LRFD Equation 5.7.3.3.2-1 and assuming that cracking occurs at the Modulus of Rupture, taken as $0.37\sqrt{f'_c}$ for normal-weight concrete, or
- 1.33 times the factored moment required by the governing load combination.

15.1.4 Shear and Torsion

Reference: LRFD Article 5.8

Where it is reasonable to assume that a planar section remains a plane after loading, the *LRFD Specifications* allows two methods of shear design for concrete — the strut-and-tie model and the sectional design model. The sectional design model is appropriate for the design of typical bridge beams, slabs, and other regions of components where the assumptions of traditional beam theory are valid. This sectional design model assumes that the response at a particular section depends only on the calculated values of the sectional force effects such as moment, shear, axial load, and torsion. This model does not consider the specific details of how the force effects were introduced into the member.

In regions near discontinuities, such as abrupt changes in cross section, openings, coped (dapped) ends, deep beams, and corbels, the strut-and-tie model should be used. See LRFD Articles 5.6.3 and 5.13.2.

LRFD Article 5.8.3 discusses the sectional design model. Subarticles 1 and 2 describe the applicable geometry required to use this technique to design for shear.

The nominal shear resistance is taken as the lesser of:

$$V_n = V_c + V_s + V_p, \text{ or} \quad \text{(LRFD Eq. 5.8.3.3-1)}$$

$$V_n = 0.25 f'_c b_v d_v + V_p \quad \text{(LRFD Eq. 5.8.3.3-2)}$$

For non-prestressed sections, $V_p = 0$.

LRFD Equation 5.8.3.3-2 represents an upper limit of V_n to ensure that the concrete in the web will not crush prior to yielding of the transverse reinforcement.

The nominal shear resistance provided by tension in the concrete is computed by:

$$V_c = 0.0316\beta\sqrt{f'_c}\, b_v d_v \quad \text{(LRFD Eq. 5.8.3.3-3)}$$

The contribution of the web reinforcement is given by:

$$V_s = \frac{A_v f_y d_v \left(\cot\theta + \cot\alpha\right)\sin\alpha}{s}$$ (LRFD Eq. 5.8.3.3-4)

where the angles, θ and α, represent the inclination of the diagonal compressive forces measured from the longitudinal axis and the angle of the web reinforcement relative to the longitudinal axis, respectively.

For the usual case where the web shear reinforcement is vertical ($\alpha = 90°$), V_s simplifies to:

$$V_s = \frac{A_v f_y d_v \cot\theta}{s}$$

Both θ and β are functions of the longitudinal steel strain (ε_x) which, in turn, is a function of θ. Therefore, the design process is an iterative one. A detailed methodology and the design tables are provided in LRFD Article 5.8.3.4.2. For sections containing at least the minimum amount of transverse reinforcement specified in LRFD Article 5.8.2.5, the values of β and θ should be taken from LRFD Table 5.8.3.4.2-1. For sections that do not meet the minimum transverse reinforcement requirements, LRFD Table 5.8.3.4.2-2 should be used to determine β and θ.

Sections meeting the requirements of LRFD Article 5.8.3.4.1 may be designed using a value of 2.0 for β and a value of 45° for θ.

Transverse shear reinforcement shall be provided when:

$$V_u > 0.5\,\phi\left(V_c + V_p\right)$$ (LRFD Eq. 5.8.2.4-1)

Where transverse reinforcement is required, the area of steel shall not be less than:

$$A_v = 0.0316\sqrt{f'_c}\,\frac{b_v s}{f_y}$$ (LRFD Eq. 5.8.2.5-1)

For the usual case where the reaction introduces compression into the end of the member, the critical section for shear is taken as d_v, measured from the face of the support (see LRFD Article 5.8.3.2).

The sectional model requires a check of the adequacy of the longitudinal reinforcement in LRFD Article 5.8.3.5. This requirement acknowledges that shear causes tension in the longitudinal reinforcement. All steel on the flexural tension side of the member, prestressed and non-prestressed, may be used to satisfy this requirement.

Torsion is not a major consideration in most highway bridges. Where torsion effects are present, the member shall be designed in accordance with LRFD Articles 5.8.2 and 5.8.3.6. Situations that may require a torsion design include:

- cantilever brackets connected perpendicular to a concrete beam, especially if a diaphragm is not located opposite the bracket;
- concrete diaphragms used to make precast beams continuous for live load when the beams are spaced differently in adjacent spans; and
- bent caps, if they are unsymmetrically loaded.

15.1.5 Strut-and-Tie Model

Reference: LRFD Article 5.6.3

This method of modeling concrete components originated around 1900, but it has only recently been incorporated into the AASHTO design code. Members, when loaded, indicate the presence of definite stress fields that can individually be represented by tensile or compressive resultant forces as their vectorial sums. It has been observed that the "load paths" taken by these resultants form a truss-like pattern that is optimum for the given loading and that the resultants are in reasonable equilibrium, especially after cracking. The designer's objective is to conceive this optimum pattern in developing the strut-and-tie model. The closer the designer's assumption is to this optimum pattern, the more efficient the use of materials. For relatively poorly conceived strut-and-tie models, the materials will be used less efficiently, yet the structure will be safe. The compressive concrete paths are the struts, and the reinforcing steel groups are the ties. The model does not involve shear or moment because the stresses are modeled as axial loads alone.

The strut-and-tie model has significant application for bridge components such as interior bent caps, beam ends, post-tensioning anchorage zones, etc. A thorough presentation of the model can be found in Chapter 8 of the *PCI Precast Prestressed Concrete Bridge Design Manual*, in Richard M. Barker and Jay A. Puckett, "Design of Highway Bridges based on AASHTO *LRFD Design Specifications*," and in J. Schlaich, et al, "Towards a Consistent Design of Structural Concrete," PCI Journal, Vol. 32, No. 3, 1987. The *LRFD Specifications* provides adequately for design; even if the model is not used for actual proportioning, the strut-and-tie model provides a fast check to ensure the adequacy of the design, especially for the appropriate anchorage of the steel.

Cracking is associated with at least partial debonding and, thus, the bonding capacity of cracked concrete cannot be considered completely reliable. Improperly anchored steel is an area where design mistakes are made, and the *LRFD Specifications* generally requires that steel should not be anchored in cracked zones of concrete.

15.1.6 Fatigue

Reference: LRFD Articles 3.4.1, 3.6.1.4, and 5.5.3

The fatigue limit state is not normally a critical issue for concrete structures. Fatigue need not be considered for decks and where the permanent stress f_{min} is compressive and exceeds twice the maximum tensile live load stress. Also, fatigue need not be considered for strands in fully prestressed concrete members.

Assuming r/h = 0.3, LRFD Equation 5.5.3.2-1 for mild reinforcement may be rearranged for easier interpretations:

$$f_f + 0.33 f_{min} \leq 23.4 \text{ ksi}$$

See Section 16.4 for information on the calculation of the stress range in accordance with the *LRFD Specifications*.

15.1.7 Crack Control By Distribution of Reinforcement

Reference: LRFD Article 5.7.3.4

Reinforcing bars in all reinforced concrete members in tension shall be distributed to control cracking. This distribution shall be in accordance with LRFD Article 5.7.3.4. When designing for crack-control, the following values shall be used, unless a more severe condition is warranted:

- γ_e = 0.75 (Class 2 exposure condition) for footings and other components in contact with soil or brackish water, for decks, for slabs, for tops of bent caps below expansion joints, and for other components susceptible to deicing agent exposure; and
- γ_e = 1.00 (Class 1 exposure condition) for all other components.

Several smaller reinforcing bars at moderate spacing are more effective in controlling cracking than one or two larger bars of equivalent area at greater spacing.

15.2 MATERIALS

15.2.1 Structural Concrete (Compressive Strength)

Reference: LRFD Article 5.4.2.1

Figure 15.2-1 presents SCDOT criteria for the compressive strength of concrete in structural elements. The State Bridge Design Engineer must approve the use of concrete classes other than those in Figure 15.2-1.

Structural Element	Class	28-day Compressive Strength (f'_c)
Bridge Decks and Approach Slabs	Class 4000	4 ksi
Flat Slabs	Class 4000	4 ksi
Prestressed Concrete (Not Piles)	Class 5000 - 10,000	5 ksi to 10 ksi
Prestressed Concrete (Piles)	Class 5000 - 8000	5 ksi to 8 ksi
Concrete Bridge Rails	Class 4000	4 ksi
Bents	Class 4000	4 ksi
Wingwalls	Class 4000	4 ksi
Footings	Class 4000	4 ksi
Drilled Shafts	Class 4000DS	4 ksi
Foundation Seal	Class 4000S	4 ksi

COMPRESSIVE STRENGTH OF CONCRETE

Figure 15.2-1

15.2.2 Reinforcing Bars

Reference: LRFD Article 5.4.3.1

Reinforcing bars shall conform to the requirements of ASTM A706, Grade 60 with a 60 ksi yield strength. The modulus of elasticity, E_s, is equal to 29,000 ksi.

15.2.3 Prestressing Strands

Reference: LRFD Article 5.4.4.1

Prestressing strands shall be low-relaxation, 7-wire strands with a minimum tensile strength of f_{pu} = 270 ksi and a minimum yield strength of f_{py} = 243 ksi. The modulus of elasticity, E_p, is equal to 28,500 ksi.

15.2.4 Prestressing Bars

Reference: LRFD Article 5.4.4

Prestressing bars shall be plain or deformed bars with a minimum tensile strength of f_{pu} = 150 ksi, with a yield strength of 127.5 ksi for plain bars and 120 ksi for deformed bars. The modulus of elasticity, E_p, is equal to 30,000 ksi.

15.3 REINFORCEMENT DETAILS

15.3.1 Reinforcing Bars

15.3.1.1 Bar Sizes

Reinforcing bars are referred to in the bridge plans and specifications by number, and they vary in size from #3 to #18 in US Customary units. The designer should note that metric bar designations are shown in the bridge plans. See Section 6.3. Figure 15.3-1 presents the sizes and properties of the bars used in South Carolina.

The following summarizes SCDOT criteria for minimum reinforcing bar sizes:

- decks: #5 (#4 may be used in deck overhang when bundled with primary reinforcing)
- drilled shafts: #10 preferred minimum, #8 absolute minimum longitudinal; #6 transverse
- columns: #10 preferred minimum, #8 absolute minimum longitudinal; #6 transverse
- bent caps: #8 longitudinal (primary); #5 longitudinal (skin reinforcement); #5 transverse
- footings: #6

Bar Size Designation		**Nominal Dimensions**		
US Customary	**Metric***	**Weight (lbs/ft)**	**Diameter (in)**	**Area (in^2)**
#3	#10	0.376	0.375	0.11
#4	#13	0.668	0.500	0.20
#5	#16	1.043	0.625	0.31
#6	#19	1.502	0.750	0.44
#7	#22	2.044	0.875	0.60
#8	#25	2.670	1.000	0.79
#9	#29	3.400	1.128	1.00
#10	#32	4.303	1.270	1.27
#11	#36	5.313	1.410	1.56
#14	#43	7.650	1.693	2.25
#18	#57	13.600	2.257	4.00

**Metric bar sizes are used in the bridge plans only.*

REINFORCING BAR SIZES

Figure 15.3-1

15.3.1.2 Concrete Cover

Reference: LRFD Article 5.12.3

Figure 15.3-2 presents SCDOT criteria for minimum concrete cover for various applications. These are the minimums regardless of the w/c ratio. All clearances to reinforcing steel shall be shown in the bridge plans. The concrete cover dimensions in Figure 15.3-2 are minimums; concrete cover should be increased based on the conditions of exposure and the project design criteria.

<table>
<tr><th colspan="3">Element or Condition</th><th>Minimum Concrete Cover</th></tr>
<tr><td colspan="3">Concrete Exposed to Saltwater</td><td>4″</td></tr>
<tr><td colspan="3">Concrete Cast Against and Permanently Exposed to Earth</td><td>3″</td></tr>
<tr><td colspan="2" rowspan="2">Concrete Exposed to Earth or Weather</td><td>Primary Reinforcement</td><td>2½″</td></tr>
<tr><td>Stirrups, Ties, and Spirals</td><td>2″</td></tr>
<tr><td rowspan="4">Concrete Deck Slabs</td><td rowspan="2"></td><td>Top Reinforcement</td><td>2½″</td></tr>
<tr><td>Bottom Reinforcement</td><td>1″</td></tr>
<tr><td rowspan="2">Over Streams and Marsh</td><td>Bottom Reinforcement below elevation 20 ft</td><td>1½″</td></tr>
<tr><td>Bottom Reinforcement below elevation 10 ft</td><td>2″</td></tr>
<tr><td colspan="2" rowspan="2">Concrete not Exposed to Weather or in Contact with Ground</td><td>Primary Reinforcement</td><td>2″</td></tr>
<tr><td>Stirrups, Ties, and Spirals</td><td>1½″</td></tr>
<tr><td colspan="2" rowspan="2">Prestressed Concrete Beams</td><td>Primary Reinforcement</td><td>1½″</td></tr>
<tr><td>Stirrups and Ties</td><td>1″</td></tr>
<tr><td colspan="3">Prestressed Concrete Piles</td><td>2¼″</td></tr>
<tr><td colspan="3">Drilled Shafts in Soil (applies to hoops)</td><td>6″</td></tr>
<tr><td colspan="3">Drilled Shafts in Rock (applies to hoops)</td><td>3″</td></tr>
</table>

CONCRETE COVER

Figure 15.3-2

15.3.1.3 Spacing of Bars

15.3.1.3.1 General

Reference: LRFD Article 5.10.3

Section 15.3.1.3.2 discusses exceptions for drilled drafts, and Section 15.3.1.3.3 discusses exceptions for bridge decks on beams.

Fit and clearance of reinforcing shall be carefully checked by calculations and large-scale drawings. Skews will tend to complicate problems of reinforcing fit. Tolerances normally allowed for cutting, bending, and locating reinforcing should be considered. Some of the common areas of interference are:

- anchor bolts in bent caps;
- between slab reinforcing and reinforcing in monolithic end bents or interior bents;
- vertical column bars projecting through main reinforcing in interior bent caps;
- the areas near expansion devices;
- embedded plates for prestressed concrete beams;
- anchor plates for steel girders;
- at anchorages for a post-tensioned system; and
- between prestressing (pretensioned or post-tensioned) steel and reinforcing steel stirrups, ties, etc.

15.3.1.3.2 Drilled Shafts

The minimum clear distance between longitudinal reinforcement shall be 4 in, but no less than five times the maximum size of aggregate or 3 times the bar diameter, whichever is greater. For the clear distance limitation that is based on the bar diameter, a group of bundled bars shall be treated as a single bar of a diameter derived from the equivalent total area.

The minimum clear distance between transverse reinforcing bars shall be five times the maximum size of aggregate or 3 in, whichever is greater. Where bundled transverse bars are used, consideration shall be given to increasing the minimum clear spacing requirements to ensure that concrete will readily flow into the space between the reinforcing cage and the side of the drilled shaft.

15.3.1.3.3 Deck Slabs on Beams

A minimum of 1½ in (based on nominal bar diameters) between top and bottom mats of slab reinforcing steel shall be maintained. Where conduits are present, the 1½ in must be increased to accommodate the conduit. A minimum bar spacing of 5½ in on center shall be maintained between adjacent reinforcing bars in each mat. These spacing minimums provide adequate room to properly consolidate the concrete.

15.3.1.3.4 Bent Caps

The primary reinforcement in either the top or the bottom of bent caps is limited to two layers. This provision effectively limits the length of hammerhead cantilevers and the distance between columns in multi-column bents.

15.3.1.4 Fabrication Lengths

The maximum length for black reinforcing bars is 60 ft. Uncoated bars are generally referred to as black bars. Due to galvanizing fabrication limitations, galvanized reinforcing bars shall be limited to a fabricated length of 40 ft. The maximum length for all #3 and #4 bars is 30 ft. For ease of hauling and handling, the maximum length should be reduced when the location of the splice is arbitrary.

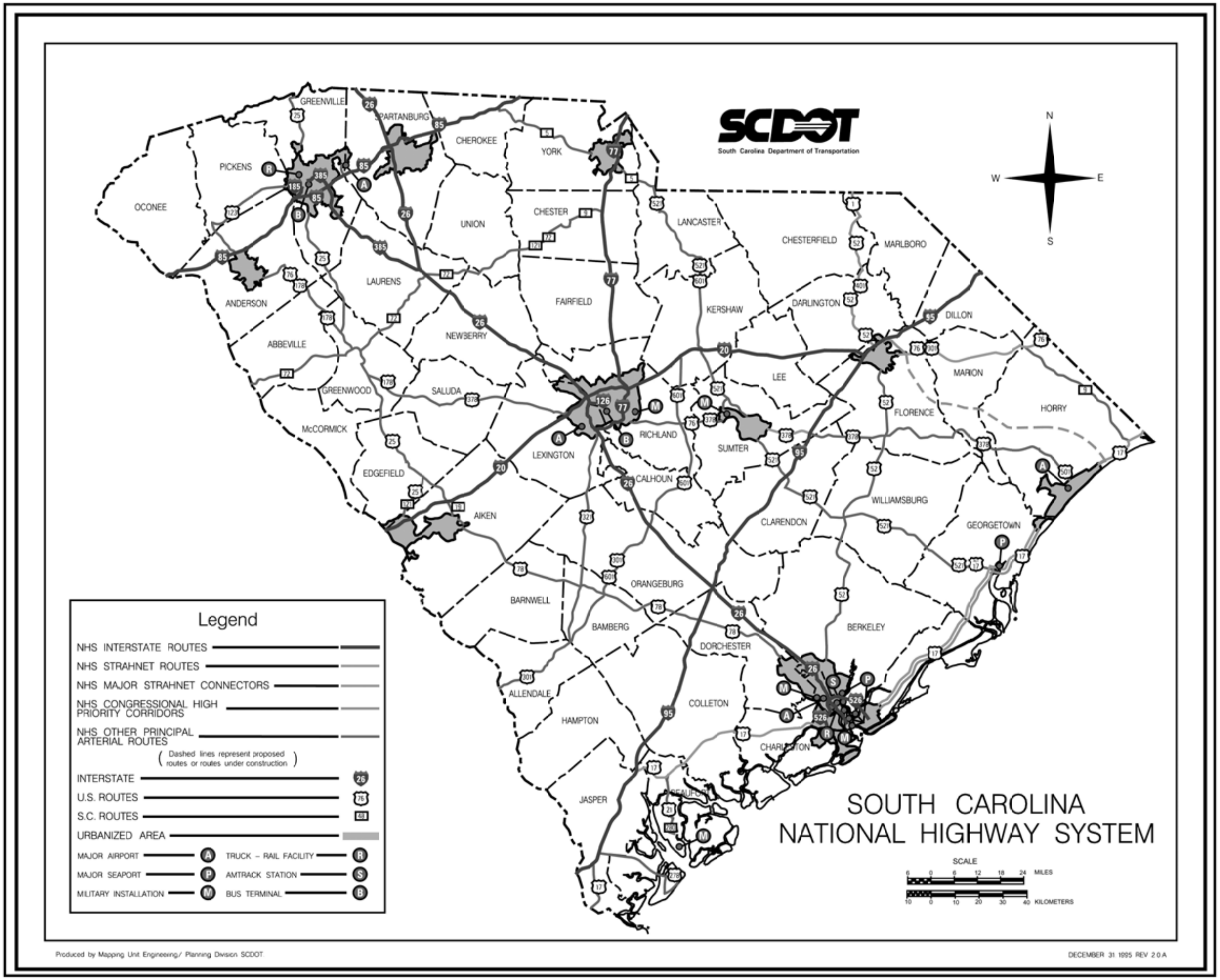
15.3.1.5 Corrosion Protection

The following presents SCDOT policies for providing corrosion protection for reinforcing bars:

1. General Policy. SCDOT only uses black reinforcing bars with increased cover or galvanized reinforcing bars.

2. Geographic Application. A corrosion protection system shall be used for bridge decks on Interstate and other National Highway System routes located North of a line along SC Route 72 from the Georgia State line to Chester, SC and North of SC Route 9 from Chester, SC to Interstate Route I-77 and West of a line along Interstate Route I-77 from the intersection of SC Route 9 and I-77 to the North Carolina State line. The State Bridge Design Engineer shall determine the need for a corrosion protection system for each project located in a coastal county. The State Bridge Design Engineer will determine the requirements of the corrosion protection system for the bridge deck, other concrete superstructure elements, and concrete substructure elements for coastal projects. See Figure 15.3-3 for the South Carolina National Highway System routes.

3. Type. Class 4000 concrete with galvanized reinforcing bars is the approved corrosion protection system for use on bridge decks.



SOUTH CAROLINA NATIONAL HIGHWAY SYSTEM ROUTES

Figure 15.3-3

15.3.1.6 Development of Reinforcement

Reinforcement is required to be developed on both sides of a point of maximum stress at any section of a reinforced concrete member. This requirement is specified in terms of a development length, l_d.

15.3.1.6.1 Development Length in Tension

Reference: LRFD Article 5.11.2

The development of bars in tension involves calculating the basic development length, l_{db}, which is modified by factors to reflect bar spacing, cover, enclosing transverse reinforcement, top bar effect, type of aggregate, and the ratio of required area to provide the area of reinforcement to be developed.

The development length, l_d (including all applicable modification factors), must not be less than 12 in.

Figure 15.3-4 shows the tension development length for uncoated Grade 60 bars for normal weight concrete with a specified strength of 4 ksi.

15.3.1.6.2 Development Length in Compression

Columns shall not be considered compression members for development length computations. When designing column bars with hooks to develop the tension, ensure that the straight length is also an adequate length to develop the bar in compression because hooks are not considered effective in developing bars in compression. This practice ensures that columns in bending will have adequate development in tension and compression.

15.3.1.6.3 Standard End Hook Development Length in Tension

Reference: LRFD Article 5.11.2.4

Standard end hooks, using 90° and 180° end hooks, are used to develop bars in tension where space limitations restrict the use of straight bars. End hooks on compression bars are not effective for development length purposes. The values shown in Figure 15.3-5 are the tension development lengths for uncoated Grade 60 hooked bars for normal weight concrete with a specified strength of 4 ksi.

The use of headed bars must be approved by the State Bridge Design Engineer.

Refer to the figure in the commentary of LRFD Article C5.11.2.4.1 for hooked-bar details for the development of standard hooks. Use the same figure for both uncoated and galvanized bars.

Grade 60 Uncoated Bars; f'_c = 4 ksi; Normal Weight Concrete

Bar Size	Area (in^2)	Diameter (in)	l_{db}	
			Top Bars (in)	Others (in)
#3	0.11	0.375	13	12
#4	0.20	0.500	17	12
#5	0.31	0.625	21	15
#6	0.44	0.750	26	18
#7	0.60	0.875	32	23
#8	0.79	1.000	42	30
#9	1.00	1.128	53	38
#10	1.27	1.270	67	48
#11	1.56	1.410	82	59
#14	2.25	1.693	114	81
#18	4.00	2.257	147	105

DEVELOPMENT LENGTHS FOR STRAIGHT BARS IN TENSION (4 ksi)

Figure 15.3-4

Grade 60 Uncoated Bars; f'_c = 4 ksi; Normal Weight Concrete

Bar Size	Area (in^2)	Diameter (in)	l_{hb} (in)
#3	0.11	0.375	8
#4	0.20	0.500	10
#5	0.31	0.625	12
#6	0.44	0.750	15
#7	0.60	0.875	17
#8	0.79	1.000	19
#9	1.00	1.128	22
#10	1.27	1.270	25
#11	1.56	1.410	27
#14	2.25	1.693	33
#18	4.00	2.257	43

DEVELOPMENT LENGTHS FOR HOOKED BARS IN TENSION (4 ksi)

Figure 15.3-5

15.3.1.7 Splices

Reference: LRFD Article 5.11.5

15.3.1.7.1 General

In columns and drilled shafts, there shall be no splices in the longitudinal reinforcing within the plastic-hinge regions. These regions shall be clearly identified as a “No-Splice Zone” by the bridge designer, and detailed and shown on the plans. Outside the “No-Splice Zone,” mechanical splices are permitted. A minimum stagger of 2 ft between adjacent splices is required for individual and bundled bars.

No lap splices, for either tension or compression bars, shall be less than 12 in.

If transverse reinforcing steel in a bridge deck is lapped near a longitudinal construction joint, the entire lap splice shall be placed on the side of the construction joint that will be poured last.

15.3.1.7.2 Lap Splices — Tension

Reference: LRFD Article 5.11.5.3

Many of the same factors that affect development length affect splice lengths. Consequently, tension lap splices are a function of the bar development length (l_d). Tension lap splices are classified, based upon the ratio of provided steel to required steel and the percent of steel spliced, into three classes — Class A, Class B, and Class C. Designers are encouraged to splice bars at points of minimum stress.

For tension splices, the length of a lap splice between bars of different sizes shall be governed by the smaller bar.

Figure 15.3-6 shows tension lap splices for uncoated Grade 60 bars for normal weight concrete with a specified strength of 4 ksi.

15.3.1.7.3 Lap Splices — Compression

Lap splices in compression members shall be sized for tension lap splices. The design of compression members, such as columns and bent walls, involves the combination of vertical and lateral loads. In other words, columns experience bending. Therefore, the policy of requiring a tension lap splice accounts for the possibility that the member design may be primarily controlled by bending where compression and tension may be experienced.

Grade 60 Uncoated Bars; f'_c = 4 ksi; Normal Weight Concrete

Bar Size	Area (in^2)	Diameter (in)	Class	Top Bars (in)	Others (in)
#3	0.11	0.375	A	13	12
			B	17	12
			C	22	16
#4	0.20	0.500	A	17	12
			B	22	16
			C	29	21
#5	0.31	0.625	A	21	15
			B	28	20
			C	36	26
#6	0.44	0.750	A	26	18
			B	33	24
			C	43	31
#7	0.60	0.875	A	32	23
			B	41	30
			C	54	39
#8	0.79	1.000	A	42	30
			B	54	39
			C	71	51
#9	1.00	1.128	A	53	38
			B	69	49
			C	90	64
#10	1.27	1.270	A	67	48
			B	87	62
			C	114	81
#11	1.56	1.410	A	82	59
			B	107	77
			C	140	100
#14	2.25	1.693	A	114	81
			B	148	106
			C	193	138
#18	4.00	2.257	A	147	105
			B	192	137
			C	250	179

SPLICE LENGTHS FOR BARS IN TENSION
(4 ksi)

Figure 15.3-6

15.3.1.7.4 Mechanical Splices

Reference: LRFD Articles 5.11.5.2.2, 5.11.5.3.2, and 5.11.5.5.2

A second method of splicing is by mechanical splices, which are proprietary splicing mechanisms. Mechanical splices are appropriate outside of the "No-Splice Zone" of columns (see Section 20.3), where interference problems preclude the use of more conventional lap splices, and in phased construction. Even with mechanical splices, it is frequently necessary to stagger splices. The designer must check clearances. In addition, fatigue shall be considered.

15.3.1.7.5 Welded Splices

Splicing of reinforcing bars by welding, although allowed by the *LRFD Specifications*, is seldom used by SCDOT and not encouraged primarily because of quality issues with field welding. However, mechanical butt-welded hoops are required as confinement reinforcement for columns. Welding of reinforcing steel is not addressed by the AASHTO/ANSI/AWS *D1.5 Bridge Welding Code*, and the designer must reference the current *Structural Welding Code — Reinforcing Steel* of AWS (D1.4).

15.3.1.7.6 Full Mechanical and Welded Splice Requirements

Reference: LRFD Articles 5.11.5.3.2 and 5.11.5.4

Full mechanical and welded splices are required where splices are in tension, or in compression where the area of reinforcement provided is less than twice that required.

15.3.1.8 Bundled Bars

Reference: LRFD Articles 5.11.2.3 and 5.11.5.2.1

SCDOT allows the use of two-bundled or three-bundled bars; SCDOT prohibits the use of four-bundled bars.

The development length of bars within a bundle shall be taken as that of an individual bar as specified in Section 15.3.1.6, increased by 20% for a three-bar bundle.

Lap splices of bundled bars shall be based upon development lengths as specified above. Entire bundles shall not be lap spliced. Individual bars within a bundle may be lap spliced, but the splices shall not overlap.

15.3.2 Prestressing Strands

15.3.2.1 Strand Size

The preferred diameter of the prestressing strands is ½ in; it is acceptable to use ½-in Special, 9⁄16 in, and 0.6 in.

15.3.2.2 Strand Spacing

The minimum spacing of strands shall not be less than 2 in center to center.

15.3.2.3 Strand Profile

15.3.2.3.1 General

For the strand profile, SCDOT preferences are:

- first: straight strands
- second: debonded strands
- third: draped strands

A combination of debonded and draped strands may be used. However, SCDOT encourages the use of one or the other, with the combination being used only when necessary to satisfy design requirements. Straight trajectories are preferred because of their simplicity of fabrication and greater safety. Debonded or draped strands are used to control stresses and camber. Debonded strands are easier to fabricate because a hold-down point is not required in the stressing bed. However, draped strands also contribute to shear resistance. For debonded strands, see Section 15.5.

15.3.2.3.2 Draped Strands

The following applies to draped strands:

- At ends of girders, maintain a minimum of 4 in between the top draped strands and any straight strands that are located directly above the draped strands.
- At each hold-down point, the vertical force should be limited to a maximum of 48 kips for all of the draped strands and 4 kips for each individual draped strand.
- The slope of the draped strands should not exceed 9°.
- Where practical, hold-down points should be located 5 ft on each side of the center of the beam (10 ft apart).

15.3.2.3.3 Strand Patterns

Frequently, beams of the same size and similar length in the same bridge or within bridges of the same project may be designed with a slightly different number of strands. In this situation, the designer should consider using the same number and pattern of strands (including height of draping) for these beams to facilitate fabrication.

15.4 FLAT SLABS

15.4.1 General

Reference: LRFD Article 5.14.4

The flat slab superstructure is frequently used by SCDOT. See Section 12.3 for information on SCDOT's typical usage of flat slabs.

This Section presents information for the design of flat slabs that amplify or clarify the provisions in the *LRFD Specifications*. The Section also presents design information specific to SCDOT practices. The *SCDOT Bridge Drawings and Details*, available at the SCDOT website, provides typical details used by the Department for flat slabs for several standardized bridge lengths.

15.4.1.1 Maximum Number of Spans

Unless approved by the State Bridge Design Engineer, continuous flat slabs shall be limited to a maximum of four spans. An exception to this is the use of five spans where the flat slab is the entire length of the structure. The practice of limiting spans within a structure facilitates construction and minimizes deck cracking.

15.4.1.2 Haunches

Department policy is to use a constant slab thickness for flat slabs.

15.4.1.3 Substructures

For both end bents and interior bents, SCDOT practice is to use non-integral bents in conjunction with flat slabs.

15.4.1.4 Minimum Reinforcement

Reference: LRFD Articles 5.7.3.3.2, 5.10.8, and 5.14.4.1

In both the longitudinal and transverse directions, at both the top and bottom of the slab, the minimum reinforcement should be determined according to the provisions of LRFD Articles 5.7.3.3.2 and 5.10.8. The first Article is based on the cracking flexural strength of a component, and the second Article reflects requirements for shrinkage and temperature. In flat slabs, the two Articles provide nearly identical amounts of minimum reinforcement in the majority of cases.

According to LRFD Article 5.14.4.1, bottom transverse reinforcement, the above minimum provisions notwithstanding, may be determined either by two-dimensional analysis or as a percentage of the maximum longitudinal positive moment steel in accordance with LRFD Equation 5.14.4.1-1. The span length, L, in the equation should be taken as that measured from the centerline to centerline of the supports. For bridges with a skew greater than 60° and/or horizontally curved bridges, the analytical approach is recommended.

Section 15.4.5 presents a simplified approach for shrinkage and temperature steel requirements.

15.4.2 Allowance for Dead-Load Deflection and Settlement

Reference: LRFD Article 5.7.3.6.2

In setting falsework for reinforced concrete spans, an allowance shall be made for the deflection of the falsework, for any settlement of the falsework, for the dead-load deflection of the span, and for the long-time dead-load deflection of the span such that, on removal of the falsework, the top of the structure shall conform to theoretical finished grade plus the allowance for long-time deflection.

Camber for the dead-load deflection of the span shall be ⅛ in for concrete flat slab spans, 22 ft or 30 ft in length, and ¼ in for concrete flat slab spans 40 ft in length.

15.4.3 Construction Joints

Longitudinal construction joints on flat slab bridges are undesirable. However, bridge width, phase construction, the method of placing concrete, rate of delivery of concrete, and the type of finishing machine used by the Contractor dictate whether or not a flat slab bridge must be poured in one or more pours.

If the flat slab will be built in phases, show the entire lap splice for all transverse reinforcing steel on the side of the construction joint that will be poured last.

15.4.4 Longitudinal Edge Beam Design

Reference: LRFD Articles 5.14.4.1, 9.7.1.4, and 4.6.2.1.4

Edge beams must be provided along the edges of flat slabs. Structurally continuous barriers may only be considered effective for the Service limit states, not the Strength or Extreme-Event limit states. The edge beams shall consist of more heavily reinforced sections of the slab. The width of the edge beams may be taken to be the width of the equivalent strip as specified in LRFD Article 4.6.2.1.4b.

15.4.5 Shrinkage and Temperature Reinforcement

Reference: LRFD Articles 5.6.2 and 5.10.8

SCDOT practice is that evaluating the redistribution of force effects as a result of shrinkage, temperature change, creep, and movements of supports is not necessary when designing flat slabs.

Figure 15.4-1 provides the shrinkage and temperature reinforcement as a function of flat slab thickness.

Slab Thickness	Reinforcement (Top and Bottom)
< 18″	#5 @ 18″
18″ to 28″	#5 @ 12″
> 28″	Design per LRFD Article 5.10.8.2

SHRINKAGE AND TEMPERATURE REINFORCEMENT FOR FLAT SLABS

Figure 15.4-1

15.4.6 Reinforcing Steel and Constructibility

The following practices for reinforcing steel should be met to improve the constructibility of flat slabs:

1. The minimum spacing of reinforcing bars in the deck shall be 6 in on center.

2. The minimum spacing of reinforcing bars in edge beams shall be 4 in on center.

3. Longitudinal steel should be detailed in a two-bar alternating pattern, with one of the bars continuous through the slab. The maximum difference between the alternating reinforcing bars shall be two standard bar sizes.

LRFD Article 5.11.1.2 presents specifications for the portion of the longitudinal positive-moment reinforcement that must be extended to the next support point in excess of that required by the factored maximum-moment diagram. Similarly, there is a more stringent provision addressing the location of the anchorage for the longitudinal negative-moment reinforcement.

15.4.7 Distribution of Concrete Barrier Railing Dead Load

The dead load of the barrier shall be assumed to be distributed uniformly over the entire bridge width.

15.4.8 Distribution of Live Load

Reference: LRFD Article 4.6.2.3

The following specifically applies to the distribution of live load to flat slabs:

1. For continuous flat slabs with variable span lengths, one equivalent strip width (E) shall be developed using the shortest span length for the value of L_1. This strip width should be used for moments throughout the entire length of the bridge.

2. The equivalent strip width (E) is the transverse width of slab over which an "axle" unit is distributed.

3. Different strip widths are specified for the flat slab itself and its edge beams in LRFD Articles 4.6.2.3 and 4.6.2.1.4, respectively.

4. In most cases, using LRFD Equation 4.6.2.3-3 for the reduction of moments in skewed slab-type bridges will not significantly change the reinforcing steel requirements. Therefore, for simplicity of design, the Department does not require the use of the reduction factor "r."

15.4.9 Shear Resistance

Reference: LRFD Article 5.14.4.1

Single-span and continuous-span flat slabs designed for moment in conformance with LRFD Article 4.6.2.3 may be considered satisfactory for shear.

15.4.10 Minimum Thickness of Slab

Reference: LRFD Article 2.5.2.6.3

SCDOT uses the minimum slab thickness requirements in accordance with LRFD Table 2.5.2.6.3-1. In using the equations in the LRFD Table, it is assumed that:

- S is the length of the longest span.
- The calculated thickness includes the ¼-in sacrificial wearing surface.
- The thickness used may be greater than the value obtained from the LRFD Table.

15.4.11 Development of Flexural Reinforcement

Reference: LRFD Article 5.11.1.2

LRFD Article 5.11.1.2 presents specifications for the portion of the longitudinal positive-moment reinforcement that must be extended beyond the centerline of support. Similarly, LRFD Article 5.11.1.2.3 addresses the location of the anchorage (embedment length) for the longitudinal negative-moment reinforcement.

15.4.12 Skews on Reinforced Concrete Slab Bridges

Reference: LRFD Article 9.7.1.3

For skew angles up to 30°, the transverse reinforcement is permitted to run parallel to the skew, providing for equal bar lengths. For skews in excess of 30°, the transverse reinforcement should be placed perpendicular to the center line of the bridge. This provision concerns the direction of principal tensile stresses as these stresses develop in heavily skewed structures and is intended to prevent excessive cracking.

15.4.13 Design Details for Flat Slabs

The Department's typical practices for flat slabs are presented in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website. Transverse flat slab sections are included along with longitudinal sections at end bents and interior bents for several span configurations.

15.5 PRESTRESSED CONCRETE SUPERSTRUCTURES

15.5.1 General

Reference: LRFD Article 5.2

The generic word "prestressing" relates to a method of construction in which a steel element is tensioned and anchored to the concrete. Upon release of the tensioning force, the concrete will largely be in residual compression and the steel in residual tension. There are two methods of applying the prestressing force, as discussed in the following Sections. A combination of these two methods may be used if approved by the State Bridge Design Engineer.

Chapter 15 does not address the design of post-tensioned concrete beams or prestressed concrete elements other than beams.

SCDOT does not permit partial prestressing.

15.5.1.1 "Pretensioning"

In the pretensioning method, tensioning of the steel strands is accomplished before the concrete is placed. When the concrete surrounding the steel strands attains a specified minimum strength, the strands are released thereby transmitting the prestressing force to the concrete by bond-and-wedge action at the beam ends. The initial prestress is immediately reduced due to the elastic shortening of the concrete. Further losses will occur over time due to shrinkage and creep of concrete and relaxation of prestressing steel.

The generic word "prestress" is often used to mean "pretensioning" as opposed to "post-tensioning."

15.5.1.2 "Post-Tensioning"

In the post-tensioning method, tensioning of the steel is accomplished after the concrete has attained a specified minimum strength. The tendons, usually comprised of several strands, are pulled or pushed into ducts cast into the concrete. After stressing the tendons to the specified prestressing level, it is anchored to the concrete and the jacks are released. Several post-tensioning systems and anchorages are used in the United States; the best information may be directly obtained from the manufacturers. Post-tensioned concrete is also subject to losses from shrinkage and creep, although at a reduced magnitude because a significant portion of shrinkage usually occurs by the time of stressing, and the rate of creep decreases with the age at which the prestress is applied. After anchoring the tendons, the ducts are pressure filled with grout, which protects the tendons against corrosion and provides composite action by bonds between the strands and the beam. Post-tensioning can be applied in phases to further increase the load-carrying capacity and better match the phased dead loads being applied to the beam.

In the United States, where industries are more inclined toward methods of mass production, "pretensioning" is more popular. However, in many cases, flexibility and economy can justify the sophistication required in the design and construction of "post-tensioned" concrete structures.

15.5.2 Responsibilities

15.5.2.1 Designer

The designer is responsible for choosing a cross section and providing a strand size and pattern to achieve the required allowable Service limit state stresses and factored flexural resistance. The designer is also responsible for a preliminary investigation of shipping and handling issues where larger or long beams are used or where unusual site access conditions are encountered.

15.5.2.2 Contractor

The Contractor is responsible for investigating stresses in the components during proposed handling, transportation, and erection.

15.5.3 Basic Criteria

15.5.3.1 Concrete Stress Limits

Reference: LRFD Article 5.9.4

Tensile stress limits for fully prestressed concrete members shall conform to the requirements for "Other Than Segmentally Constructed Bridges" in LRFD Article 5.9.4, except that the tensile stress at the Service Limit State, after losses, shall be limited as follows: For components with bonded prestressing tendons or reinforcement, the tensile stress in the precompressed tensile zone shall be limited to a maximum of $0.0948\sqrt{f'_c}$ (ksi). This limit applies to all projects, regardless of the site location.

15.5.3.2 Concrete Strength at Release

Reference: LRFD Article 5.4.2.1

At release of the prestressing force, the minimum compressive concrete strength shall be the greater of 4.0 ksi or 0.60 of the specified 28-day strength and should not exceed 0.90 of the specified 28-day strength. The specified concrete compressive strength at release should be rounded to the next highest 0.1 ksi.

15.5.3.3 Debonded Strands

Debonding (shielding) of strands at the ends of precast/prestressed concrete beams will be allowed on projects for SCDOT with the following restrictions:

1. A maximum of 25% of the total number of prestressing strands may be debonded to satisfy the allowable stress limits. In any row, debonded strands shall not exceed 40% of the total strands in that row.

2. Not more than 40% of the shielded strands, or four strands, whichever is greater, shall be terminated at any section.

3. Strands shall be debonded in a pattern that is symmetrical about the vertical axis of the beam.

4. The theoretical number of debonded strands shall be rounded to the closest even number (pairs) of strands, except that debonded strands will not be permitted in rows containing three strands or less.

5. All exterior strands shall be fully bonded (including the entire bottom row).

6. At each end of a girder, the maximum length for debonding is 15% of the entire beam length.

In analyzing stresses and/or determining the required length of debonding, stresses shall be limited to the values in LRFD Article 5.9.4, except that tension is limited $0.0948\sqrt{f'_c}$ for all exposure conditions.

15.5.3.4 Loss of Prestress

Reference: LRFD Article 5.9.5

Loss of prestress is defined as the difference between the initial stress in the strands and the effective prestress in the member. This definition of loss of prestress includes both instantaneous and time dependent losses.

The 2005 interim changes to the *LRFD Specifications* include many revisions to the process of calculating the loss of prestress in prestressed members.

15.5.3.5 Strand Transfer Length and Development Length

Reference: LRFD Article 5.11.4

The transfer length is the length of strand over which the prestress force is transferred to the concrete by bond and friction. The *LRFD Specifications* indicates that the transfer length may be assumed to be 60 strand diameters. The stress in the strand is assumed to vary linearly from zero at the end of the member, or the point where the strand is bonded if debonding is used, to the full effective prestress force at the end of the transfer length.

The development length is the length of strand required to develop the stress in the strand corresponding to the full flexural strength of the member; i.e., strand development length is the length required for the bond to develop the strand tension at nominal flexural resistance. The transfer length is included as part of the development length. LRFD Equation 5.11.4.2-1 is used to calculate the required development length (l_d). Prestressing strands shall be considered fully bonded beyond the critical section for development length. The development length for debonded (shielded) strands shall be in accordance with LRFD Article 5.11.4.3.

15.5.4 <u>Prestressed Concrete Beam Sections</u>

15.5.4.1 General

The type of beams used in the superstructure are selected based upon geometric restraints, economy, and appearance. SCDOT currently uses the following standard prestressed concrete beam sections:

1. AASHTO I-beams Type I Modified and Types II through IV, and
2. 54″, 63″, and 72″ Modified Bulb-tee beams.

To ensure that the structural system has an adequate level of redundancy, SCDOT requires a minimum of four beam lines on new bridges. Section 12.2 provides width criteria for deck overhangs.

Alternative prestressed concrete beam sections may be considered if the designer can justify their use. Beam sections, with the exception of AASHTO Type II, shall have a minimum web width of 7 in. The use of beam sections not available through local producers will usually be more expensive if the forms must be purchased or rented for a small number of beams. Two or more beam fabricators should be contacted early in project development to determine the most practical and cost-effective alternative beam section at a specific site.

15.5.4.2 AASHTO I-Beams

Dimensions and section properties of these beams are given in Figure 15.5-1. The weights shown are computed assuming a unit weight of concrete of 150 lbs/ft^3. Typical details are presented in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website.

15.5.4.3 Modified Bulb-Tee Beams

Dimensions and section properties of these beams are given in Figure 15.5-1. The weights shown are computed assuming a unit weight of concrete 150 lbs/ft^3. Typical details are presented in the *SCDOT Bridge Drawings and Details*, available at the SCDOT website.

15.5.5 Prestressed Concrete Cored Slab Sections

Standard prestressed concrete cored slab cross sections are 3′-0″ by 1′-9″ or 3′-0″ by 2′-0″. Prestressed concrete cored slab bridges of 30-ft, 40-ft, 50-ft, and 60-ft span lengths are presented in the *SCDOT Bridge Design Drawings and Details* (available at the SCDOT website) which provide typical plans, elevations, sections, and details.

15.5.6 Design of Prestressed Concrete Beams

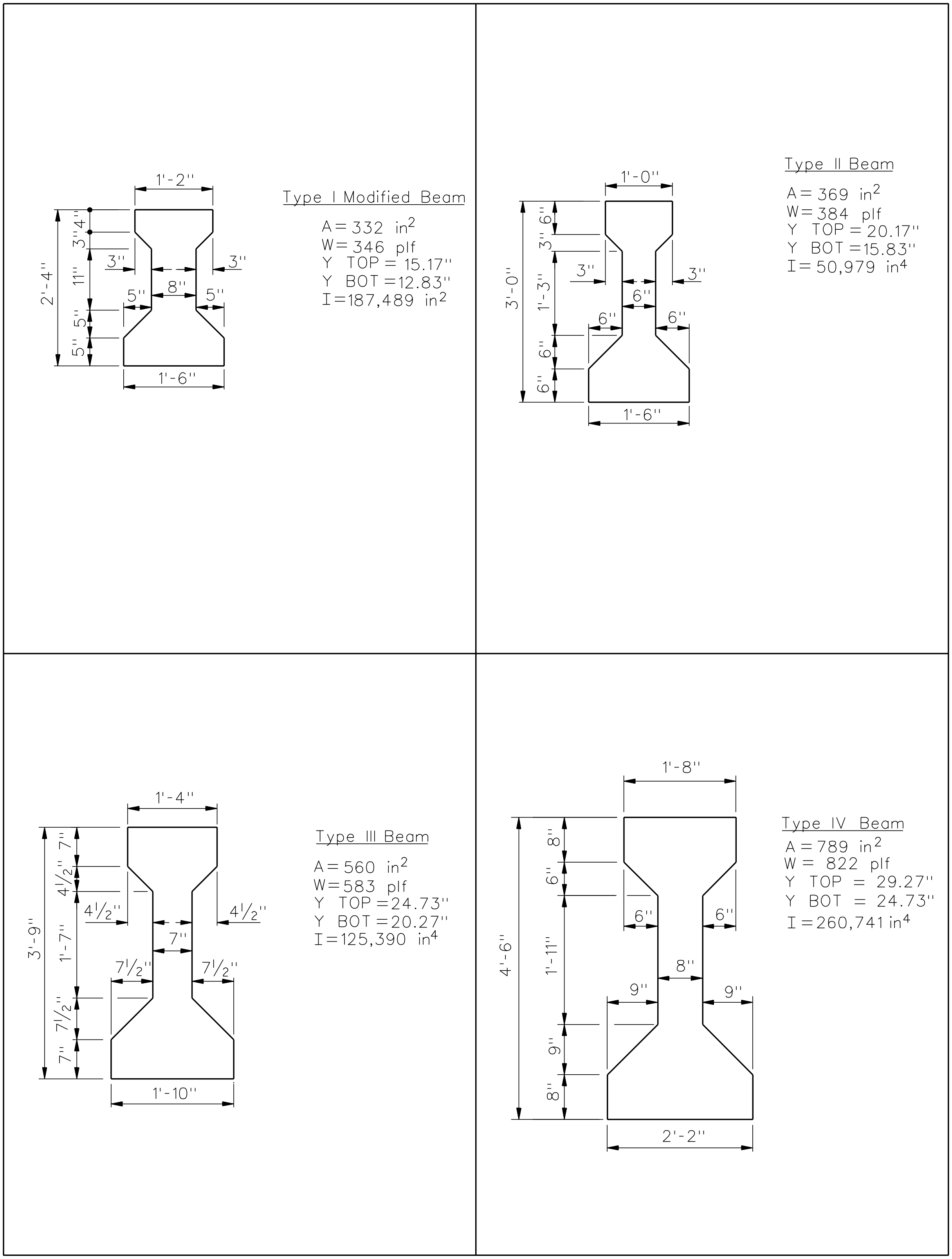
15.5.6.1 General

Reference: LRFD Article 5.9

This Section addresses the general design theory and procedure for precast, prestressed (pre-tensioned) concrete beams. For design examples, consult the *PCI Bridge Design Manual*, Chapter 9.

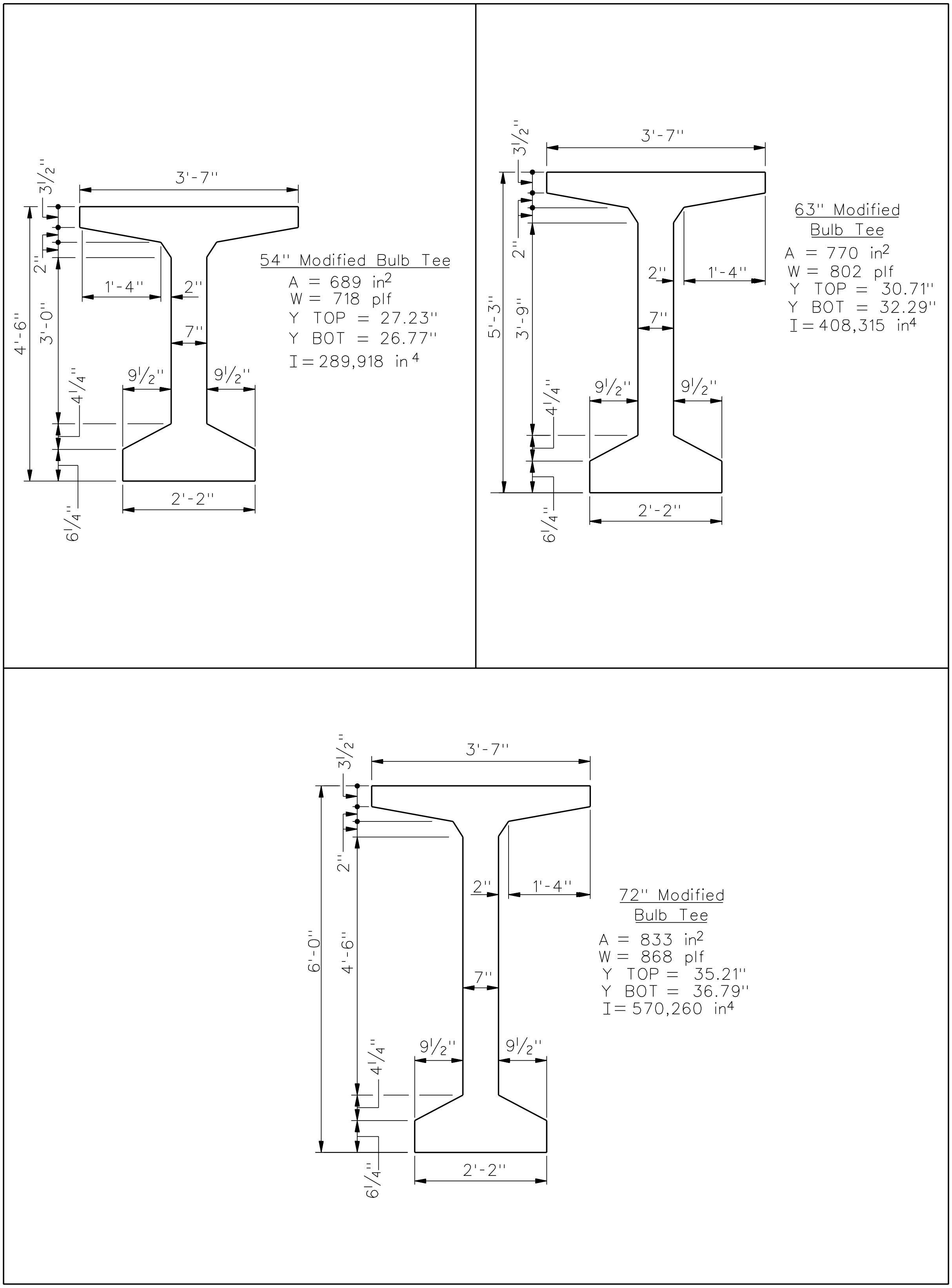
Bridges consisting of simple-span precast concrete girders and cast-in-place concrete slabs shall be made continuous for live load and superimposed dead loads by using a cast-in-place closure diaphragm at interior bents whenever possible. The design of the beams for continuous structures is similar to the design for simple spans except that, in the area of negative moments, the member is treated as an ordinary reinforced concrete section and the bottom flanges of adjoining beams are connected at the bents by reinforcement projecting from beam ends into a common diaphragm. The members shall be assumed to be fully continuous with a constant moment of inertia when determining both the positive and negative moments due to loads applied after continuity is established.

The resistance factor "φ" (LRFD Article 5.5.4) for flexure shall be 1.0 except for design of the negative-moment steel in the deck for structures made continuous for composite loads only and having a poured-in-place continuity diaphragm between the ends of the beams over the piers. For this case, the resistance factor φ shall be 0.90.



PRESTRESSED CONCRETE BEAM DIMENSIONS AND SECTION PROPERTIES
(AASHTO I-Beams)

Figure 15.5-1



PRESTRESSED CONCRETE BEAM DIMENSIONS AND SECTION PROPERTIES
(Bulb-Tee Beams)

Figure 15.5-1
(Continued)

15.5.6.2 Stage Loading

There are four loading conditions that must be considered in the design of a prestressed beam:

1. The first loading condition is when the strands are tensioned in the bed prior to placement of the concrete. Seating losses, relaxation of the strand, and temperature changes affect the stress in the strand prior to placement of the concrete. It is the fabricator's responsibility to consider these factors during the fabrication of the beam and to make adjustments to the initial strand tension to ensure that the tension prior to release meets the design requirements for the project.

2. The second loading condition is when the strands are released and the force is transferred to the concrete. After release, the beam will camber up and be supported at the beam ends only. Therefore, the region near the end of the member does not receive the benefit of bending stresses due to the dead load of the beam and may develop tensile stresses in the top of the beam large enough to crack the concrete. The critical sections for computing the critical temporary stresses in the top of the beam should be near the end and at all debonding points. At the designer's option, if he/she chooses to consider the transfer length of the strands at the end of the beam and at the debonding points, then the stress in the strands should be assumed to be zero at the end of the beam or debonding point and vary linearly to the full transfer of force to the concrete at the end of the strand transfer length.

   There are several methods to relieve excessive tensile stresses near the ends of the beam:

   - debonding, where the strands are kept straight but wrapped in plastic over a predetermined distance to prevent the transfer of prestress to the concrete through bonds;

   - adding additional strands in the top of the beam that are bonded at the ends but are debonded in the center portion of the beam. These strands are typically detensioned after the beam is erected; or

   - draping some of the strands to reduce the strand eccentricity at the end of the beam.

   The level of effective prestress immediately after release of the strands, which includes the effects of elastic shortening and the initial strand relaxation loss, should be used to compute the concrete stresses at this stage.

3. The third loading condition occurs several weeks to several months after strand release when the beam is erected and the composite deck is cast. Camber growth and prestress losses are design factors at this stage. If a cast-in-place composite deck is placed, field adjustments to the build-down thickness are usually needed to provide the proper vertical grade on the top of deck and to keep the deck thickness uniform. Reliable estimates of deflection and camber are needed to prevent excessive build-down thickness or to avoid

significant encroachment of the top of beam into the bottom of the concrete deck. Stresses at this stage are usually not critical.

See Section 8.7 of the PCI *Bridge Design Manual* for determining the beam camber at erection.

4. The fourth loading condition is after an extended period of time during which all prestress losses have occurred and loads are at their maximum. This is often referred to as the "maximum service load, minimum prestress" stage. The tensile stress in the bottom fibers of the beam at mid-span generally controls the design.

15.5.6.3 Flexure

The design of prestressed concrete members in flexure normally starts with the determination of the required prestressing level to satisfy service conditions. All load stages that may be critical during the life of the structure from the time prestressing is first applied should be considered. This is then followed by a strength check of the entire member under the influence of factored loads. The strength check seldom requires additional strands or other design changes.

For checking the allowable stresses in the beam, the following basic assumptions are made:

1. Plane sections remain plane, and strains vary linearly over the entire member depth. Therefore, composite members consisting of precast concrete beams and cast-in-place decks must be adequately connected so that this assumption is valid and all elements respond to superimposed loads as one unit. Deck concrete is transformed to girder concrete when computing section properties by multiplying the effective deck width by the ratio of the modulus of the deck concrete to the modulus of the beam concrete. The gross section properties are used (i.e., the area of prestressing strands and reinforcing steel is not transformed).
2. The girder is assumed to be uncracked at the Service limit state.
3. Allowable stresses are not checked for the deck concrete in the negative-moment region because the deck concrete is not prestressed.

15.5.6.4 Horizontal Interface Shear

Reference: LRFD Article 5.8.4

Cast-in-place concrete decks designed to act compositely with precast concrete beams must be able to resist the horizontal shearing forces at the interface between the two elements. The following formula may be used to determine the factored horizontal shear, V_h:

$$V_h = V_u / d_e \qquad \text{(LRFD Eq. C5.8.4.1-1)}$$

The required factored horizontal shear should be less than or equal to the factored nominal resistance; i.e.:

$$V_h A_{cv} \leq \phi V_n$$

where: $V_n = cA_{cv} + \mu[A_{vf}f_y + P_c]$. The permanent net compressive force normal to the shear plane, P_c, may be conservatively neglected.

15.5.7 Diaphragms

Reference: LRFD Article 5.13.2.2

For prestressed beam spans, cast-in-place concrete diaphragms shall be used at all supports with the beams embedded a minimum of 3 in into the diaphragm. For spans greater than 40 ft, intermediate diaphragms shall also be used and shall be constructed of cast-in-place concrete. At a minimum, one line of intermediate diaphragms shall be used in each span greater than 40 ft. For skews of 20° or less, the intermediate diaphragms may be placed along the skew of the bridge. For skews in excess of 20°, the intermediate diaphragms shall be placed perpendicular to the beams. The tops of the intermediate diaphragms should be detailed 3 in below the tops of the beams. Slabs shall not be poured until a minimum of seven days after the interior diaphragms are poured or until the diaphragm concrete reaches a compressive strength of 3 ksi.

For continuous prestressed beam spans, the closure diaphragms at the interior bents shall be cast concurrently with the deck slab above the support. For integral end bents, the end walls shall also be cast concurrently with the deck slab. At simple span supports and at expansion ends of continuous spans, the support diaphragms may be cast prior to the placement of the deck slab.

15.5.8 Details for Post-Tensioning

Reference: LRFD Articles 5.4.5 and 5.4.6

15.5.8.1 Ducts

In post-tensioned construction, ducts are cast into the concrete to permit placement and stressing of the tendons. Ducts may be:

- galvanized smooth (rigid),
- galvanized corrugated steel (semi-rigid),
- corrugated polyethylene, or
- high-density polypropylene (HDPP).

LRFD Article 5.4.6.1 recommends polyethylene for corrosive environments, such as bridge decks and substructure elements under joints. Typical SCDOT usage is at integral bent caps with curved girders. The contract documents shall indicate the type of duct material to be used.

Ducts for post-tensioned bulb-tee beams shall be round, semi-rigid, galvanized-metal ducts only. The wall thickness shall be no less than 28 gage. Prebending of ducts will be required for bend radii less than 30 ft and should be specified on the plans. Radii that require prebending should be avoided whenever possible. The minimum bend radius of ducts shall not be less than 20 ft, except in anchorage zones where 12 ft will be permitted. The bending radius of polyethylene or polypropylene ducts shall not be less than 30 ft.

If the bridge is constructed by post-tensioning precast components together longitudinally and/or transversely by use of a cast-in-place concrete joint, then the end of the duct should be extended beyond the concrete interface by not less than 3 in and not more than 6 in to facilitate joining the ducts. If necessary, the extension could be in a local blockout at the concrete interface. Joints between sections of ducts shall be positive metallic connections, which do not result in angle changes at the joints. Waterproof tape shall be used at all connections.

Bundling of ducts will not be permitted. The clear distance between adjacent ducts should not be less than 1½ in or 1.33 times the maximum size of aggregate in any direction.

For multiple-strand tendons, the outside diameter of the duct shall be no more than 40% of the least gross concrete thickness at the location of the duct. The internal free area of the duct shall be at least 2.5 times the net area of the prestressing steel. See LRFD Article 5.4.6.2.

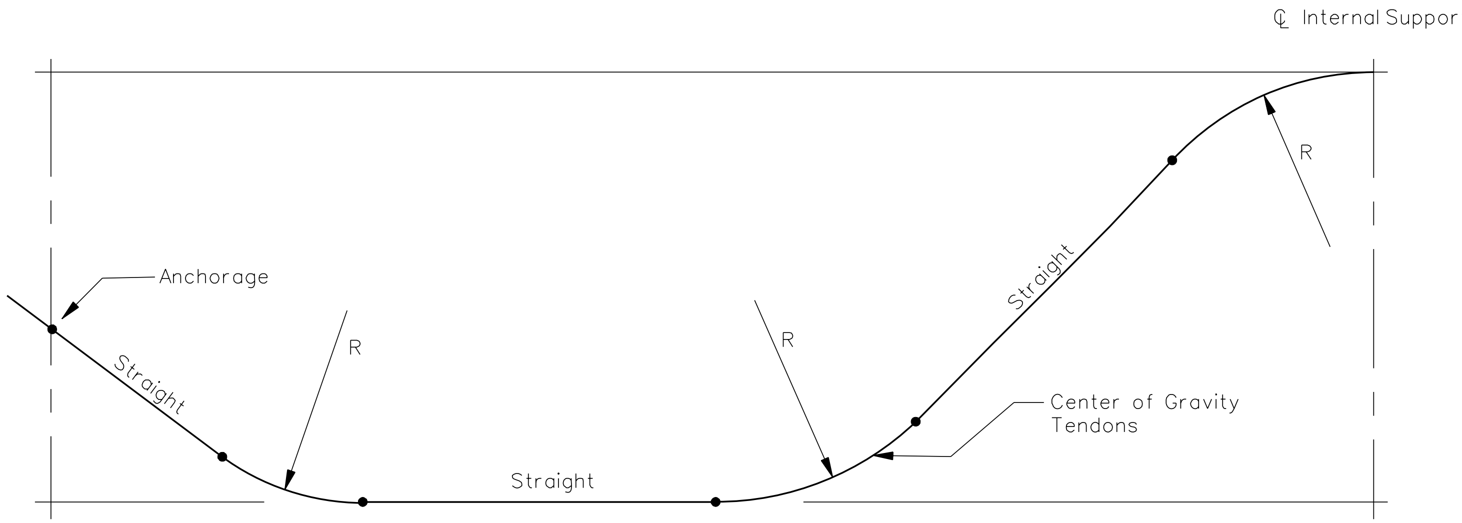
15.5.8.2 Grouting

Upon completion of post-tensioning, the ducts must be grouted. The strength of the grout should be comparable to that of the beam concrete.

For detailed, up-to-date guidance on the installation and grouting of post-tensioning tendons, see the PTI specification for Grouting of Post-Tensioned Structures and Section II of the American Segmental Bridge Institute's (ASBI) *Construction Practice Handbook for Segmental Concrete Bridges*.

15.5.8.3 Tendon Profile

Figure 15.5-2 shows a typical tendon profile for a continuous beam end span. The geometry is composed from straight and curved segments as opposed to a parabolic profile, which is sometimes used. The use of simple radii and straight segments is preferred over parabolic profiles because it is simpler to layout.



END SPAN TENDON PROFILE

Figure 15.5-2

Show offset dimensions to post-tensioning duct profiles from fixed surfaces or clearly defined reference lines at intervals not exceeding 5 ft. When the rate of curvature of the duct exceeds that rate which produces changes in offset of more than ⅛ in per foot, offsets shall be shown at intervals not exceeding 24 in. In regions of tight reverse curvature of short sections of tendons, offsets shall be shown at sufficiently frequent intervals to clearly define the reverse curve.

Curved ducts that run parallel to each other, ducts in curved girders, ducts in chorded beams where angle changes occur between segments, or ducts placed around a void or re-entrant corner shall be sufficiently encased in concrete and reinforced as necessary to avoid radial failure (pull-out into the other duct or void).

15.5.8.4 Anchorages

There are several types of commercially available anchorages. These anchorages normally consist of a steel block with holes in which the strands are individually anchored by wedges. In the vicinity of the anchor block (or coupler), the strands are fanned out to accommodate the anchorage hardware. The fanned out portion of the tendon is housed in a transition shield, often called a trumpet, which could be either steel or polyethylene, regardless of the duct material. Trumpets must have a smooth, tangential transition to the ducts.

If the distance between anchorages exceeds 300 ft, jacking at both ends should be considered. One or two end stressing will be determined by design and specified in the plans.

Values of the wobble and curvature friction coefficients and the anchor set loss assumed for the design shall be shown in the bridge plans.

15.5.9 Skew

Reference: LRFD Article 4.6.2.2

The behavior of skewed bridges is different from those of rectangular layout. The differences are largely proportional to skew angle. Although normal flexural effects due to live load tend to decrease as the skew angle increases, shear does not, and there is a considerable redistribution of shear forces in the end zone due to the development of negative moments therein. For skew angles less than 30°, it is considered satisfactory to ignore the effects of skew and to analyze the bridge as a straight bridge.

LRFD Articles 4.6.2.2.2e and 4.6.2.2.3c provide tabulated assistance to roughly estimate the live-load effects from skew. The factors shown in these tables can be applied to both simple span and continuous span skewed bridges. The correction factors for shear theoretically only apply to support shears of the exterior beam at the obtuse corner. In practice, the end shears of all beams in a multi-beam bridge are conservatively modified by the skew correction factor. Shear in portions of the beam away from the end supports do not need to be corrected for skew effects.

To obtain a better assessment of skewed behavior and to use potential benefits in reduced live-load moments, more sophisticated methods of analysis are used. The refined methods most often used to study the behavior of bridges are the grillage analysis and the finite element method. The finite element analysis requires the fewest simplifying assumptions in accounting for the greatest number of variables that govern the structural response of the bridge. However, input preparation time and derivation of overall forces for the composite beam are usually quite tedious. On the other hand, data preparation for the grillage method is simpler, and integration of stresses is not needed.

15.5.10 Construction Loads on Top Flanges of Beams

At a minimum, #4 reinforcing bars at 24-in spacing shall be placed in the top flange. The Contractor shall investigate the capacity of all bulb-tee beam flanges to ensure adequate capacity to support construction loads. This may require additional transverse steel in the top flange.

15.5.11 Design Details

15.5.11.1 Fabrication Lengths

The lengths of prestressed concrete beams shown in the plans shall be based on the horizontal projection of the beam. The fabricator shall increase the lengths as necessary to correct for concrete shrinkage, for concrete shortening at release, and for beams being on a grade.

15.5.11.2 Beam Details

The *SCDOT Bridge Drawings and Details*, available at the SCDOT website, presents typical beam end details, shear reinforcement details, and confinement steel details for prestressed concrete beams. Modified beam end details may be required on the bridge plans if the bridge is constructed on a skew. Beam ends must remain square with the exception of the top flange, which may be cast parallel to the skew.

15.5.11.3 Bearing Plates

For an instantaneous slope at the bottom of the beam greater than or equal to 1%, bearing plates shall be used and shall be beveled to allow for the level beam seats.

Chapter 16

STRUCTURAL STEEL STRUCTURES

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 16

STRUCTURAL STEEL STRUCTURES

This Chapter discusses structural steel provisions in Section 6 of the *LFRD Bridge Design Specifications* that require amplification, clarification, and/or an enhanced application. The Chapter is structured as follows:

1. Section 16.1 provides general information, mostly relating to cost-effective design practices, for which there is not a direct reference in Section 6 "Steel Structures" of the *LRFD Specifications*.

2. Sections 16.2 through 16.7 provide information that augments and clarifies Section 6 of the *LRFD Specifications*. To assist in using these Sections, references to the *LRFD Specifications* are provided, where applicable.

Section 12.3 provides criteria for the general site considerations for which structural steel is appropriate. This includes span lengths, girder spacing, geometrics, seismic vulnerability, aesthetics, and cost. Chapter 16 addresses the design and detailing of steel superstructures.

16.1 GENERAL

16.1.1 Economical Steel Superstructure Design

Factors that influence the initial cost of a steel girder bridge include, but are not limited to, the number of girders, the type of steel, type and number of substructure units, steel tonnage, fabrication, transportation, and erection. The cost of these factors changes periodically in addition to the cost relationship among them. Therefore, the guidelines used to determine the most economical type of steel girder on one bridge must be reviewed and modified as necessary for future bridges.

Based upon market factors, the availability of steel may be an issue in meeting the construction schedule. It is the responsibility of the bridge designer to verify the availability of the specified steel. Bridge designers must contact producers to ensure the availability of rolled beams and plates.

Steel plate girders should be designed to optimize weight savings in correlation with fabrication and erection costs. Top flanges of compositely designed plate girders are typically smaller than their bottom flanges. The flange section is varied along the length of the bridge following the moment envelope to save cost by offsetting the increased fabrication costs of welded flange transitions with larger savings in material costs. Typically, only flange thicknesses, not widths, are varied within a field section. The webs of plate girders are typically deeper and thinner than the webs of rolled beams. To save in total costs, minimum web thicknesses are increased to avoid the use of many or any stiffeners.

Weathering (i.e., unpainted Grades 50W and HPS70W) steel should be used whenever possible to lower the initial construction costs and future maintenance costs. Aesthetic considerations limit the application of weathering steel in highly visible applications, because the inherent staining of the substructures is unacceptable. See Section 16.2 for other factors limiting the use of weathering steel.

16.1.1.1 Rolled Beams vs Welded Plate Girders

When rolled beams are specified, ensure that the selected sections are available. Welded plate girders should be specified instead of rolled beams when:

- the bridge has a radius less than 1200 ft,
- the span lengths exceed the span capacity of rolled sections, or
- the camber is too large to be accommodated by the natural camber of the beam.

16.1.1.2 Number of Girders

Generally, the fewest number of girders in the cross section, as compatible with deck design requirements, provides the most economical bridge in the absence of girder depth restrictions. Although the tonnage of steel may be comparable between bridges with a different number of girders (i.e., fewer girders become heavier girders), fabricating and erecting fewer girders produces a cost savings. See Section 12.2 for more information.

SCDOT requires a minimum of four girders in a bridge cross section. Consider future maintenance and rehabilitation when determining the number of girders in a cross section.

16.1.1.3 Exterior Girders

The location of the exterior girder is controlled by these factors:

1. The minimum and maximum overhang widths that are specified in Section 12.2.

2. The space required for deck drains may have an effect on the location of the exterior girder lines.

3. Aesthetics should be considered when determining the location of the exterior girder lines.

16.1.1.4 Span Arrangements

Where interior bent locations are flexible, optimize the span arrangement. Steel design should not necessarily be associated with the use of longer spans. In selecting an optimum span arrangement, it is critical to consider the cost of the superstructure and substructure together as a total system.

A balanced span arrangement for continuous spans, with end spans approximately 0.8 of the length of interior spans, results in the largest possible negative moments at the interior bents, and smaller resulting positive moments and girder deflections. As a result, the optimum proportions of the girder in all spans will be nearly the same, resulting in a much more efficient design.

16.1.2 <u>Economical Plate Girder Proportioning</u>

In addition to the information in the *LRFD Specifications*, the following applies to the design of structural steel plate girders.

16.1.2.1 General

Plate girders shall be made composite with the bridge deck and should be continuous over interior supports where possible.

To achieve economy in the fabrication shop, all girders in a multi-girder bridge should be identical.

16.1.2.2 Haunched Girders

When practical, constant-depth girders (girders with constant web depths) shall be used. Haunched girders are generally uneconomical for spans less than 300 ft. Haunched girders may be used where aesthetics or other special circumstances are involved, but constant-depth girders will generally be more cost effective.

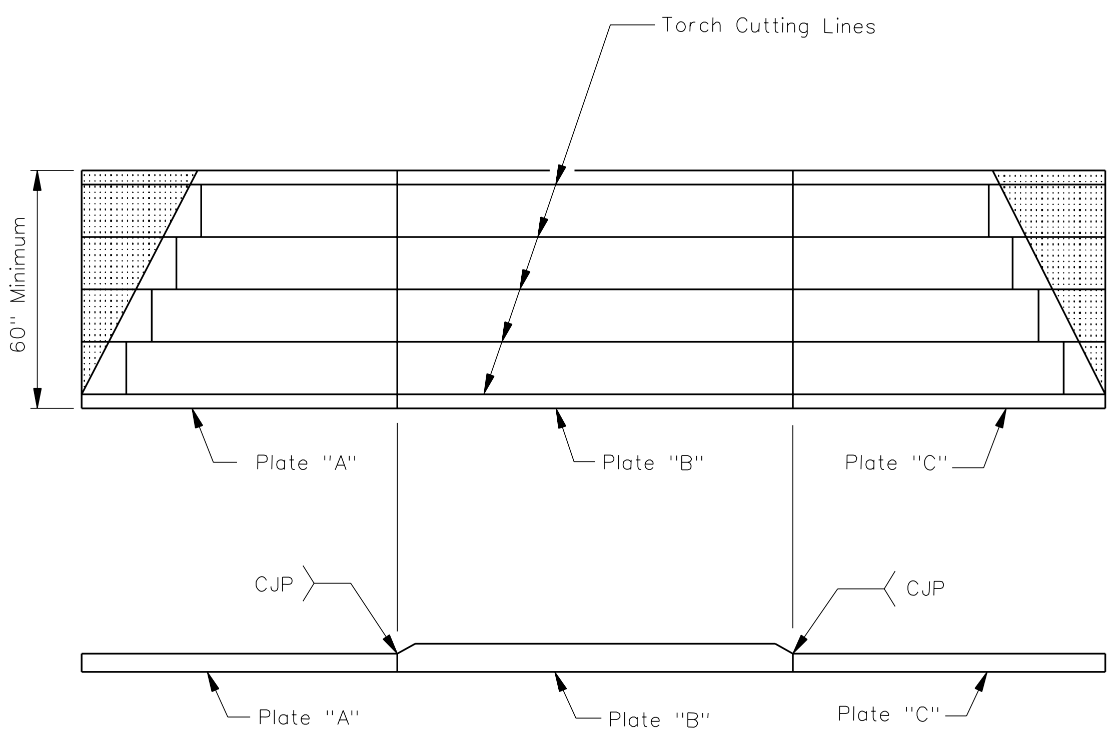
16.1.2.3 Flange Plate Sizes

The minimum flange plate size for plate girders is 12 in by ¾ in. For curved girders, the minimum flange thickness is 1 in. Designers should use as wide a flange girder plate as practical consistent with stress and b/t (flange width/thickness ratio) requirements. The wide flange contributes to girder stability and reduces the number of passes and weld volume at flange butt welds. Flange widths should be in increments of 2 in. The maximum flange thickness is 3 in.

Within a single field section (i.e., an individual shipping piece), the width of each flange should be of constant width. A design of multiple identical girders with constant-width flanges minimizes fabrication costs.

Proportion flanges so that the fabricator can economically cut them from structural plate steel between 60 in (preferably 72 in) and 96 in wide. Flanges should be grouped to provide an efficient use of the plates. Because structural steel plate is most economically purchased in these widths, it is advantageous to repeat plate thicknesses as much as practical. Many of the plates of like width can be grouped by thickness to meet the minimum width purchasing requirement, but this economical purchasing strategy may not be possible for thicker, less-used plates.

The most efficient method to fabricate flanges is to groove-weld together several wide plates of varying thicknesses received from the mill. After welding and non-destructive testing, the individual flanges are "stripped" from the full plate. This method of fabrication reduces the number of welds, individual runoff tabs for both start and stop welds, the amount of material waste, and the number of X-rays for non-destructive testing. The obvious objective, therefore, is for flange widths to remain constant within an individual shipping length by varying material thickness as required. Figure 16.1-1 illustrates the efficient fabrication of girders.



GROUPING FLANGES FOR EFFICIENT FABRICATION
(from the AASHTO/NSBA Steel Bridge Collaboration)

Figure 16.1-1

Constant flange width within a field section may not always be practical in girder spans over 300 ft where a flange width transition may be required in the negative bending regions. Though not preferred, if a transition in width must be provided, shift the butt splice a minimum of 3 in from the transition into the narrower flange plate. This 3-in shift makes it simpler to fit run-off tabs, weld, and test the splice and then grind off the run-off tabs.

16.1.2.4 Field Splices

Field splices are used to reduce shipping lengths, but they are expensive and their number should be minimized. Field sections should not exceed 120 ft in length without investigation of permits and shipping constraints. As a general rule, the unsupported length in compression of the shipping piece divided by the minimum width of the flange in compression in that piece should be less than approximately 85. Good design practice is to reduce the flange cross sectional area by no more than approximately 25% of the area of the heavier flange plate at field splices to reduce the build-up of stress at the transition. For continuous spans, the field sections over a particular interior support should be of constant length.

16.1.2.5 Shop Splices

Include no more than two shop flange splices (three plate thicknesses) in the top or bottom flange within a single field section. The designer should maintain constant flange widths within a field section for economy of fabrication as specified in Section 16.1.2.3. In determining the points where changes in plate thickness occur within a field section, the designer should weigh the cost of groove-welded splices against extra plate area. The National Steel Bridge Alliance (NSBA) and/or local fabricators should be consulted when possible to ascertain current costs. Good design practice is to reduce the flange cross sectional area by no more than approximately 50% of the areas of the heavier flange plate at shop splices to reduce the build-up of stresses at the transition. A rule of thumb used by many designers suggests that 800 lbs to 1000 lbs of steel must be saved to justify the cost of a groove-welded shop splice.

In many cases, it may be advantageous to continue the thicker plate beyond the theoretical step-down point to avoid the cost of the groove-welded splice.

To facilitate testing of the weld, locate flange shop splices at least 2 ft away from web splices, and locate flange and web shop slices at least 6 in from transverse stiffeners.

16.1.2.6 Web Plates

Where there are no depth restrictions, the web depth should be optimized. NSBA provides a service to bridge owners to assist in optimizing web depths (see www.aisc.org/Content/NavigationMenu/About_AISC/NSBA/Contact_NSBA/Contact_NSBA.htm). Other sources may also be used if they are based upon material use and fabrication unit costs. The minimum web thickness shall be ½ in. Web thickness at any splice should not be changed by less than ⅛ in.

Symmetry shall be maintained by aligning the centerlines of the webs at splices of unequal thickness.

Web design can have a significant impact on the overall cost of a plate girder. Considering material costs alone, it is desirable to make girder webs as thin as design considerations will permit. However, this practice will not always produce the greatest economy because fabricating and installing stiffeners is one of the most labor-intensive of shop operations. The following guidelines apply to the use of stiffeners:

1. Transversely unstiffened webs are generally more economical for web depths approximately 48 in or less.

2. Between 48-in and 72-in depths, consider options for a partially stiffened and unstiffened web. A partially stiffened web is defined as one whose thickness is 1/16 in less than allowed by specification for an unstiffened web at a given depth and where stiffeners are required only in areas of higher shear.

3. Above 72 in, consider options for partially stiffened or fully stiffened webs. A fully stiffened web is defined as one where stiffeners are present through the span.

16.1.2.7 Transverse Stiffeners

Flat bars (i.e., bars rolled to width of up to 8 in at the mill) are typically more economical than plates for stiffeners. The stiffeners can be fabricated by merely shearing them to length. Stiffeners that are intended to be fabricated from bars should be proportioned in ¼-in increments in width and in ⅛-in increments in thickness. A fabricator should be consulted for available flat sizes.

16.1.2.8 Longitudinally Stiffened Webs

Longitudinally stiffened webs are typically not used. In addition to being considered uneconomical, the ends of longitudinal stiffeners are fatigue sensitive if subject to applied tensile stresses. Therefore, where used, they must be ended in zones of little or no applied tensile stresses.

16.1.3 Integral End Bents

Chapter 20 discusses the design of integral end bents. The following applies to the use of integral end bents in combination with steel superstructures:

1. Deck Pour. Place a diaphragm at the end support to provide beam stability during the deck pour.

2. Anchorage. For girder anchorage considerations, see Section 20.1.

16.1.4 Falsework

Steel superstructures shall be designed without intermediate falsework during placing and curing of the concrete deck slab.

16.2 MATERIALS

Reference: LRFD Article 6.4

16.2.1 Structural Steel

Reference: LRFD Article 6.4.1

The following presents typical SCDOT practices for the selection of the type of material for structural steel members.

16.2.1.1 Grade 36

Grade 36 steel is typically used for the following structural members:

- steel piles,
- painted diaphragms, and
- galvanized bearing plates.

Grade 36 steel is becoming less used and thus less available at times. Generally, there is little or no cost difference between Grade 50 and Grade 36 steel.

16.2.1.2 Grade 50

Grade 50 steel is typically used for the following structural members:

- rolled beams,
- plate girders,
- diaphragms, and
- galvanized bearing plates.

16.2.1.3 Unpainted Weathering Steel

16.2.1.3.1 General

Unpainted weathering steel is often the more cost-effective choice for structural steel superstructures. The initial cost advantage when compared to painted steel can range up to 15%. When future repainting costs are considered, the cost advantage is more substantial. This reflects, for example, environmental considerations in the removal of paint, which significantly increases the life-cycle cost of painted steel. The application of weathering steel and its potential problems are discussed in depth in FHWA Technical Advisory T5140.22 “Uncoated Weathering Steel in Structures,” October 3, 1989. Also, the proceedings of the “Weathering Steel Forum,” July 1989, are available from the FHWA Office of Implementation, HRT-10.

The Technical Advisory's recommendation for partial painting of the steel in the vicinity of deck joints should not be considered the first choice. The best solution is to eliminate deck joints.

Despite its cost advantage, the use of unpainted weathering steel is not appropriate in all environments and at all locations. The most prominent disadvantage of weathering steel is aesthetics. The inevitable staining of the steel where susceptible to water leakage from above (e.g., below deck joints) creates a poor image (i.e., one of lack of proper maintenance) to the traveling public. Therefore, SCDOT policy is to only consider the use of weathering steel for highway bridges over railroads and over stream crossings that are not adjacent to highways; i.e., where the girders are not visible to the traveling public. Weathering steel shall not be used in Beaufort, Berkeley, Charleston, Colleton, Dorchester, Georgetown, Horry, and Jasper Counties. In addition, weathering steel shall not be used at locations where the following conditions exist:

1. Environment. Unpainted weathering steel shall not be used in industrial areas where concentrated chemical fumes may drift onto the structure. If the nature of the environment is questionable, its suitability should be determined by a corrosion consultant available from the steel industry through individual steel producers.

2. Water Crossings. Unpainted weathering steel shall not be used over bodies of water where the clearance over the normal water is 10 ft or less.

3. Grade Separations. Unpainted weathering steel shall not be used in "tunnel-like" conditions, where abutments or retaining walls bound a depressed roadway.

For additional guidance on the appropriate application of unpainted weathering steel, see the publication *Performance of Weathering Steel in Highway Bridges: A Third Phase Report* at www.steel.org.

16.2.1.3.2 Grade 50W

Grade 50W steel is typically used for the following structural members:

- plate girders (where weathering steel is allowed),
- joints, and
- armor plates.

16.2.1.3.3 Grade HPS 70W

For some plate-girder bridges, the best choice of steel may be Grade HPS 70W. In addition to increased strength, the high-performance steels exhibit enhanced weathering, toughness, and weldability properties. The premium on material costs is offset by a savings in tonnage. The most cost-effective design solutions tend to be hybrid girders with Grade 50W webs with HPS 70W tension and compression flanges in the negative-moment regions and tension flanges only in the positive-moment regions.

16.2.1.3.4 Grade HPS 100W

A new high-performance steel with a minimum specified yield strength of 100 ksi has been recently introduced. It has yet to be proven cost-effective for girder bridge applications.

16.2.1.3.5 Design Details for Weathering Steel

Where weathering steel plate girders are used, the bearing plates shall be the same steel as the girders they support. The bolts, nuts, washers, and Direct Tension Indicators (DTIs) shall be Type 3 as specified in ASTM A325/ASTM A563 and ASTM F 959.

For integral end bents, the girder shall be painted a distance of 12 in from the end wall at the beginning and end of bridge (see Figure 16.2-1(a)). Although not shown in Figure 16.2-1, the concept for the integral end bent will also apply to painting the girder at a semi-integral end bent. If a joint is used, all superstructure steel shall be painted within 10 ft of the joint or within 1.5 times the web depth, whichever is greater (see Figure 16.2-1(b)). For end bents surrounded by MSE walls, all superstructure steel shall be painted a distance of 10 ft beyond the MSE wall (see Figure 16.2-1(c)). For interior bents supporting continuous spans, all superstructure steel shall be painted a distance of 10 ft beyond each side of the centerline of bent (see Figure 16.2-1(d)). In all cases, the paint system shall be NS2 with the color of paint being brown (Federal Shade No. 30045).

When using unpainted weathering steel, the following drainage treatments shall be incorporated:

1. A drip groove under the deck shall be provided along the edge of the deck overhang. See Chapter 17.

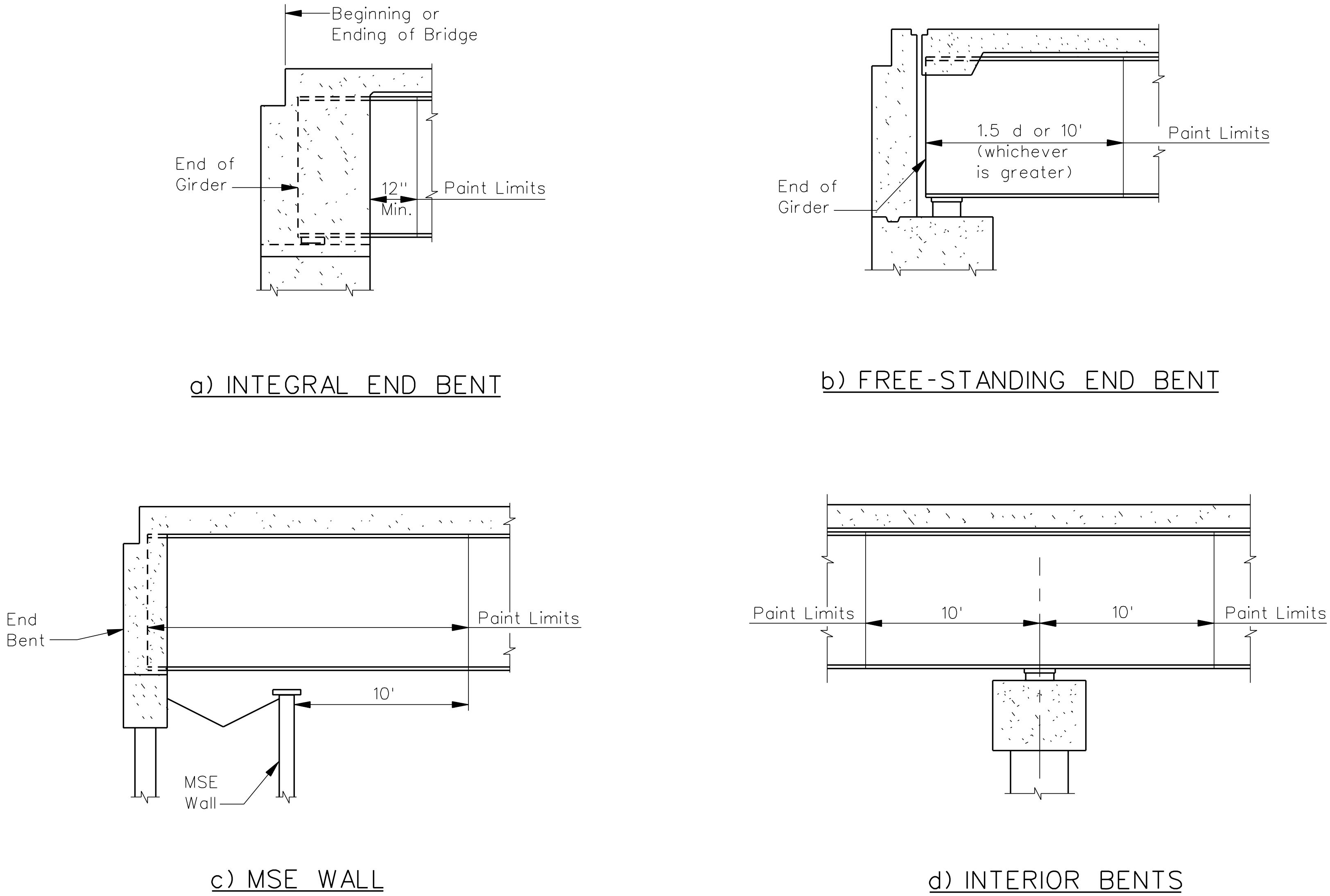
2. The number of bridge deck drains shall be minimized, and the drains shall extend below the steel bottom flange. See Chapter 18.

3. Eliminate details that serve as water and debris "traps." Seal or paint overlapping surfaces exposed to water. This sealing or painting applies to non-slip-critical bolted joints. Slip-critical bolted joints or splices should not produce "rust-pack" when the bolts are spaced according to the *LRFD Specifications* and, therefore, do not require special protection.

4. Place a drip bar or other material transverse across the top of the bottom flange in front of the substructure elements to prevent water from running off of the flange onto the concrete.

16.2.1.4 Hybrid Girders

Hybrid designs, of Grade HPS 70W in some flanges and Grade 50W in webs, results in significant economy. Tension-field action is now permitted for hybrid sections.



WEATHERING STEEL
(Paint Limits)

Figure 16.2-1

16.2.1.5 Charpy V-Notch Fracture Toughness

Reference: LRFD Article 6.6.2

The temperature zone appropriate for using LRFD Table 6.6.2-1 for the State of South Carolina is Temperature Zone 2.

16.2.2 Bolts

Reference: LRFD Article 6.4.3

For normal construction, high-strength bolts shall be:

1. Painted Steel: Use A325 (Type 1) mechanically galvanized with galvanized DTI.
2. Unpainted Weathering Steel: Use A325 (Type 3) with weathering DTI.

16.2.3 Other Structural Elements

Grade 36 steel shall not be used for secondary members when unpainted weathering steel is used in the web and flanges. In all cases, steel for all splices shall be the same material as used in the web and flanges of plate girders.

16.3 HORIZONTALLY CURVED MEMBERS

Reference: LRFD Article 6.10

16.3.1 General

The *LRFD Specifications* explicitly includes horizontally curved girders as a part of the provisions for the resistance of I-shaped girders. In addition, analysis methodologies that detail various required levels of analysis are also specified.

16.3.2 Diaphragms, Bearings, and Field Splices

Cross frames and diaphragms shall be considered primary members. All curved steel simple-span and continuous-span bridges shall have their diaphragms directed radially except end diaphragms, which should be placed parallel to the centerline of bearings.

Design all diaphragms, including their connections to the girders, to carry the total load to be transferred at each diaphragm location. Cross frames and diaphragms should be as close as practical to the full depth of the girders.

Bridges expand and contract in all directions. For typical bridges that are long in relationship to their width, the transverse expansion is ignored. For ordinary geometric configurations where the bridge length is long relative to the bridge width and the curvature is moderate, no extra consideration needs to be given to the unique expansion characteristics of curved structures. On occasion, in some urban metropolitan areas, wide sharply curved structures are required. In these circumstances, the designer must consider multi-rotational bearings and selectively providing restraint either radially and/or tangentially to accommodate the thermal movement of the structure as the bridge tries to expand in all directions.

Design the splices in flanges of curved girders to carry flange bending or lateral bending stresses and vertical bending stresses in the flanges.

16.4 FATIGUE CONSIDERATIONS

Reference: LRFD Article 6.6

In Article 6.6.1, the *LRFD Specifications* categorizes fatigue as either "load induced" or "distortion induced." Load induced is a "direct" cause of loading. Distortion induced is an "indirect" cause in which the force effect, normally transmitted by a secondary member, may tend to change the shape of, or distort, the cross section of a primary member.

16.4.1 Load-Induced Fatigue

Reference: LRFD Article 6.6.1.2

LRFD Article 6.6.1.2 provides the framework to evaluate load-induced fatigue. This Section provides additional information on the implementation of LRFD Article 6.6.1.2.

Load-induced fatigue is determined by the following:

1. the stress range induced by the specified fatigue loading at the detail under consideration;
2. the number of repetitions of fatigue loading a steel component will experience during its 75-year design life. This is determined by using anticipated truck volumes; and
3. the nominal fatigue resistance for the Detail Category being investigated.

Details that are defined as having a fatigue resistance greater than or equal to Detail Category C (i.e., Detail Categories A, B, B′, C, and C′) shall be designed for infinite life. Details that are defined as having a fatigue resistance lower or equal to Detail Category D (i.e., D, E, and E′) shall be designed in accordance with LRFD Article 6.6.1.2.

16.4.1.1 Fatigue Stress Range

The following applies:

1. Range. The fatigue stress range is the difference between the maximum and minimum stresses at a detail subject to a net tensile stress. The stress range is caused by a single design truck that can be placed anywhere on the deck within the boundaries of a design lane. If a refined analysis method is used, the design truck shall be positioned to maximize the stress in the detail under consideration. The design truck should have a constant 30-ft spacing between the 32-kip axles. The dynamic load allowance is 0.15, and the fatigue load factor is 0.75.
2. Regions. Fatigue should only be considered in those regions of a steel member that a) experiences a net applied tensile stress, or b) where the compressive stress of the unfactored permanent load is less than twice the maximum fatigue tensile stress.

3. Analysis. Unless a refined analysis method is used, the single design lane load distribution factor in LRFD Article 4.6.2.2 should be used to determine fatigue stresses. These tabularized distribution-factor equations incorporate a multiple presence factor of 1.2 that should be removed by dividing either the distribution factor or the resulting fatigue stresses by 1.2. This division does not apply to distribution factors determined using the lever rule.

16.4.1.2 Stress Cycles

For Detail Categories A, B, B′, C, and C′, the number of stress cycles for design shall be taken as infinite.

For Detail Categories D, E, and E′, LRFD Article 6.6.1.2.5 shall be used to define the total number of stress cycles (N) as:

$$N = (365)(75)n(ADTT)_{SL} \qquad \text{(LRFD Eq. 6.6.1.2.5-2)}$$

Where:

n = number of stress range cycles per truck passage. As defined in LRFD Article 6.6.1.2.5, for simple and continuous spans not exceeding 40 ft, n = 2.0. For spans greater than 40 ft, n = 1.0, except at locations within 0.1 of the span length from a continuous support, where n = 1.5.

$ADTT_{SL}$ = Average Daily Truck Traffic in a single lane = (p)(ADTT), which is LRFD Equation 3.6.1.4.2-1.

p = the fraction of truck traffic in a single lane. As defined in LRFD Article 3.6.1.4.2, when one direction of traffic is restricted to:

- 1 lane: p = 1.00
- 2 lanes: p = 0.85
- 3 or more lanes: p = 0.80

ADTT = the number of trucks per day in one direction averaged over the design life of the structure.

The portion of LRFD Equation 6.6.1.2.5-2 that is $(365)(75)(ADTT)_{SL}$ represents the total accumulated number of truck passages in a single lane during the 75-year design life of the structure. If site-specific values for the fraction of truck traffic data are unavailable from the Planning Division, the values provided in LRFD Table C3.6.1.4.2-1 may be used.

16.4.1.3 Fatigue Resistance

LRFD Article 6.6.1.2.3 groups the fatigue resistance of various structural details into eight categories (A through E′). Experience indicates that Detail Categories A, B, and B′ are seldom critical. Investigation of details with a fatigue resistance greater than Detail Category C may be appropriate in unusual design cases. For example, Category B applies to base metal adjacent to slip-critical bolted connections and should only be evaluated when thin splice plates or connection plates are used. The *LRFD Specifications* requires that the fatigue stress range for Detail Categories C, D, E, and E′ must be less than the fatigue resistance for each respective Category.

The fatigue resistance of a category is determined from the interaction of a Category Constant "A" and the total number of stress cycles "N" experienced during the 75-year design life of the structure. This resistance is defined as $(A/N)^{1/3}$. A Constant Amplitude Fatigue Threshold ($(\Delta F)_{TH}$) is also established for each Category. If the applied fatigue stress range is less than ½ of the threshold value, the detail has infinite fatigue life ($½(\Delta F)_{TH}$).

For Detail Categories C and C′, the applied fatigue stress range shall be less than ½ of the threshold value. This practice provides a theoretical design life of infinity. For Detail Categories D, E, and E′, the fatigue resistance shall be calculated in accordance with LRFD Article 6.6.1.2.3.

Fatigue resistance is independent of the steel strength. The application of higher grade steels causes the fatigue stress range to increase, but the fatigue resistance remains the same. This independence implies that fatigue may become more of a controlling factor where higher strength steels are used.

* * * * * * * * *

Example 16.4-1

Given: Total number of truck passages in a single lane during the 75-year design life (from Planning Division) = 9.75×10^6

Two spans, 160 ft each

Longitudinal connection plate located 30 ft from the interior support

Unfactored DL stress at the toe of the connection plate-to-web weld = 4 ksi compression

Unfactored fatigue stresses at the toe of the connection plate-to-web weld using unmodified single-lane distribution factor = 3.9 ksi tension and 4.5 ksi compression

Find: Determine the fatigue adequacy at the toe of a longitudinal connection plate-to-web weld with a transition radius of 4 in with the end welds ground smooth.

Solution:

Step 1: *The LRFD Specifications classifies this connection as Detail Category D. Therefore:*

- A = Detail Category Constant = 22.0 x 10^8 ksi^3 (LRFD Table 6.6.1.2.5-1)
- $(\Delta F)_{TH}$ = Constant Amplitude Fatigue Threshold = 7.0 ksi (LRFD Table 6.6.1.2.5-3)

Step 2: *Compute the factored live-load fatigue stresses by applying dynamic load allowance and fatigue load factor, and removing the multiple presence factor:*

Tension: 3.9(1.15)(0.75)/1.2	=	2.8 ksi
Compression: 4.5(1.15)(0.75)/1.2	=	3.2 ksi
Fatigue Stress Range	=	6.0 ksi

Step 3: *Determine if fatigue must be evaluated at this location:*

- Net tension = (DL stress) – (Fatigue stress)
- Net tension = 4 ksi (Compressive) – 3.9 ksi (Tensile) = 0.1 ksi (Compressive)

Although there is no net tension in the web at the location of the longitudinal connection plate, the unfactored compressive DL stress (4 ksi) does not exceed twice the tensile fatigue stress (5.6 ksi). Therefore, fatigue must be considered.

Step 4: *Check for infinite life:*

First, check the infinite life term. This will frequently control the fatigue resistance when traffic volumes are large. $(\Delta F)_n = ½(\Delta F)_{TH} = 0.5(7.0) = 3.5$ ksi. Because the fatigue stress range (6.0 ksi) exceeds the infinite life resistance (3.5 ksi), the detail does not have infinite fatigue life.

Step 5: *Determine "n" for LRFD Equation 6.6.1.2.5-2:*

The span exceeds 40 ft and the point being considered is located more than 0.1 of the span length away from the interior support. Therefore, n = 1.0.

Step 6: *Using LRFD Equation 6.6.1.2.5-2, compute the number of stress cycles:*

$N = (9.75 \times 10^6)(n)$
$N = (9.75 \times 10^6)(1.0)$
$N = 9.75 \times 10^6$

Step 7: *Compute the nominal fatigue resistance:*

Nominal Fatigue Resistance		75-Year Life Resistance		Infinite Life Resistance
$(\Delta F)_n$	=	$(A/N)^{1/3}$	≥	$\frac{1}{2}(\Delta F)_{TH}$

Step 8: *Check to see if the detail will have at least a 75-year fatigue life:*

$$(\Delta F)_n = (A/N)^{1/3} = [(22.0 \times 10^8)/(9.75 \times 10^6)]^{1/3} = 6.1 \text{ ksi}$$

The 75-year factored fatigue resistance (6.1 ksi) exceeds the fatigue stress range (6.0 ksi); therefore, the detail is satisfactory.

Example 16.4-2

Given: Two-span continuous bridge, 150-ft each
Area investigated is located 13 ft from interior support
Unfactored DL stress in the top flange = 7.9 ksi Tension
Unfactored fatigue stresses in the top flange using unmodified single lane distribution factor = 5.6 ksi Tension and 0.8 ksi Compression

Find: Determine the fatigue adequacy of the top flange with welded stud shear connectors in the negative moment region.

Solution:

Step 1: *The LRFD Specifications classifies this connection as Detail Category C. Therefore:*

- A = Detail Category Constant = 44.0 x 10^8 ksi^3 (LRFD Table 6.6.1.2.5-1)
- $(\Delta F)_{TH}$ = Constant Amplitude Fatigue Threshold = 10.0 ksi (LRFD Table 6.6.1.2.5-3)

Step 2: *Compute the factored live-load fatigue stresses by applying dynamic load allowance and fatigue load factor, and removing the multiple presence factor:*

Tension: 5.6(1.15)(0.75)/1.2	=	4.0 ksi
Compression: 0.8(1.15)(0.75)/1.2	=	0.6 ksi
Fatigue Stress Range	=	4.6 ksi

Step 3: *Check for infinite life:*

First, check the infinite life term (see Commentary C6.6.1.2.5 of the *LRFD Specifications* for a table of single-lane ADTT values for each detail category above which the infinite life check governs). This infinite-life term will typically control the fatigue resistance when traffic volumes are large. $(\Delta F)_n = ½(\Delta F)_{TH} = 0.5(10.0) = 5.0$ ksi. Because the fatigue stress range (4.6 ksi) is less than the infinite life resistance (5.0 ksi), the detail should exhibit infinite fatigue life and, therefore, the detail is satisfactory.

Provisions for investigating the fatigue resistance of shear connectors are provided in LRFD Article 6.10.10.2.

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16.4.2 Distortion-Induced Fatigue

Reference: LRFD Article 6.6.1.3

LRFD Article 6.6.1.3 provides specific detailing practices for transverse and lateral connection plates intended to reduce significant secondary stresses that could induce fatigue crack growth. The provisions of the *LRFD Specifications* are concise and direct and require no mathematical computation.

16.4.3 Other Fatigue Considerations

Reference: Various LRFD Articles

The designer is responsible for ensuring compliance with fatigue requirements for all structural details (e.g., stiffeners, connection plates, lateral bracing) shown on the plans.

In addition to the considerations in Section 16.4.1, the designer should be aware of the fatigue provisions in other Articles of Chapter 6 of the *LRFD Specifications*. These include:

- Fatigue due to out-of-plane flexing in webs of plate girders — LRFD Article 6.10.6.
- Fatigue at shear connectors — LRFD Articles 6.10.10.1.2 and 6.10.10.2.
- Bolts subject to axial-tensile fatigue — LRFD Article 6.13.2.10.3.

16.5 GENERAL DIMENSION AND DETAIL REQUIREMENTS

Reference: LRFD Article 6.7

16.5.1 Build-Down

The build-down provides adjustability between the top of the cambered girder and the roadway profile. The build-down is detailed at the centerline of bearing and varies in the span, if necessary, to accommodate variations in camber, superelevation ordinate, and vertical curve ordinate. Typical practice is to provide 1¾ in of build-down over rolled beam sections measured from the top of the flange. For plate girders, provide 1¾ in over the thickest flange plate. See Section 17.3 for more information. Note that some computer programs refer to build-downs as haunches.

16.5.2 Minimum Thickness of Steel

Reference: LRFD Article 6.7.3

For welded plate girder fabrication, minimum thickness requirements are mandated to reduce deformations and defects due to welding. The thickness of steel elements should not be less than:

- Webs Cut From Plates: ½″
- Plate Girder Flanges: ¾″ (1″ for horizontally curved girders)
- Stiffener Plates: ⅜″
- Connection Plates: ½ ″
- Angles/Channels: ¼″

16.5.3 Diaphragms and Cross Frames

Reference: LRFD Articles 6.7.4 and 6.6.1.3.1

Diaphragms and cross frames are vitally important in steel girder superstructures. They stabilize the girders in the positive-moment regions during construction and in the negative-moment regions after construction. Cross frames also serve to distribute gravitational, centrifugal, and wind loads. The spacing of diaphragms and cross frames should be determined based upon the provisions of LRFD Article 6.7.4.1. As with most aspects of steel girder design, the design of the spacing of diaphragms and cross frames is iterative. A good starting point is the traditional maximum diaphragm and cross frame spacing of 25 ft. Most economical, steel girder designs will use spacings typically greater than 25 ft in the positive-moment regions.

16.5.3.1 General

The following applies to diaphragms and cross frames:

1. Location. Place diaphragms or cross frames at each support and throughout the span at an appropriate spacing. The location of the field splices should be planned to avoid conflict between the connection plates of the diaphragms or cross frames and any part of the splice material.

2. Skew. Regardless of the angle of skew, place all intermediate diaphragms and cross frames perpendicular to the girders.

3. End Diaphragms and Cross Frames. End diaphragms and cross frames should be placed along the centerline of bearing. Set the top of the diaphragm below the top of the girder to accommodate the joint detail and the thickened slab at the end of the superstructure deck, where applicable. The end diaphragms should be designed to support the edge of the slab including live load plus impact.

4. Interior Support Diaphragms and Cross Frames. Generally, interior support diaphragms and cross frames should be placed along the centerline of bearing.

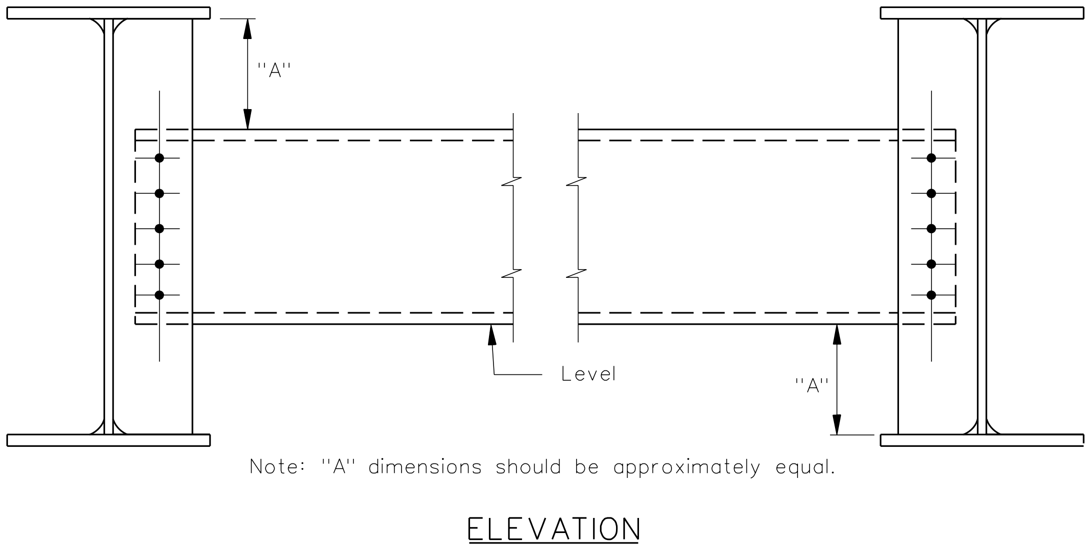
5. Curved-Girder Structures. Diaphragms or cross frames connecting curved girders are considered primary members and shall be oriented radially.

16.5.3.2 Diaphragm Details

On spans composed of rolled beams, diaphragms at interior span points may be detailed as illustrated in Figure 16.5-1. Figure 16.5-2 illustrates the typical support diaphragm connection details for rolled beams. Plate girders with web depths of 48 in or less should have similar diaphragm details. For plate girder webs more than 48 in deep, use cross frames as detailed in Figures 16.5-3 and 16.5-4.

Interior diaphragms for rolled beam spans shall be detailed with a 3-in minimum clearance between the top of the diaphragm and the bottom of the top beam flange. For bridges having a normal roadway crown, the diaphragms shall be level. For bridges having a superelevated roadway, the diaphragms shall be placed parallel to the slab.

Intermediate diaphragms should be designed and detailed as non-load bearing. Diaphragms at points of support should be designed as a jacking frame, if needed, to support dead load only. See Section 16.5.4 to determine if the need exists. Jacking diaphragms should be considered at all supports when it is impractical to jack the girders directly.



Note: Select a channel depth approximately ½ of the beam depth.

TYPICAL INTERMEDIATE DIAPHRAGM CONNECTION
(Rolled Beams)

Figure 16.5-1

16.5.3.3 Cross Frame Details

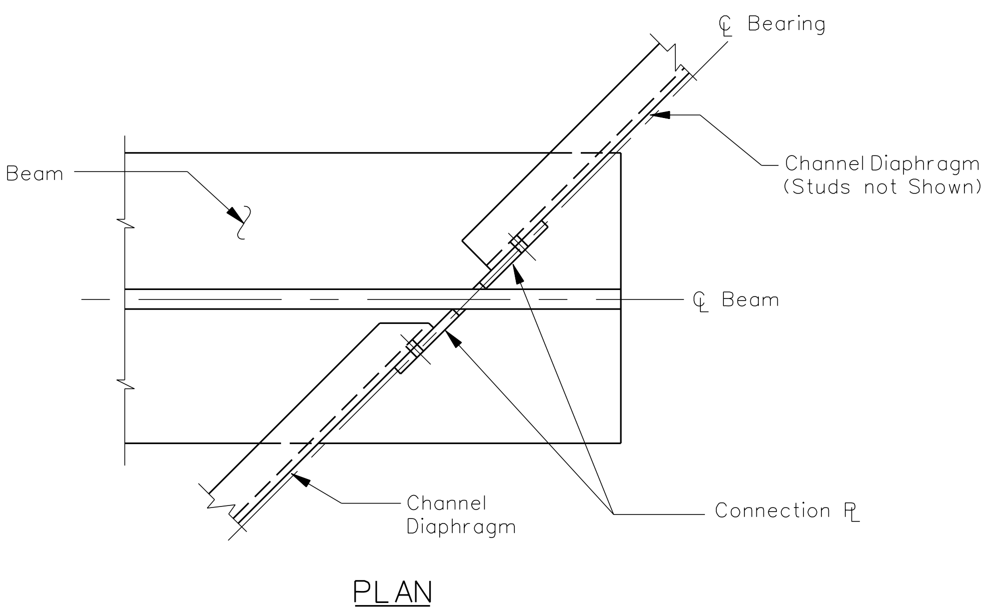
Figure 16.5-3 illustrates typical intermediate cross frame details for plate girder webs more than 48 in deep. In general, the X-frame at the top of the Figure is more cost effective than the K-frame at the bottom. However, the K-frame should be used instead of the X-frame when the girder spacing becomes much greater than the girder depth (for example, where the angle of the diaphragm is less than 30°) and the "X" becomes too shallow. A solid bent-plate diaphragm with a depth equal to ¾ the girder depth is a good option for plate girders less than 48 in deep.

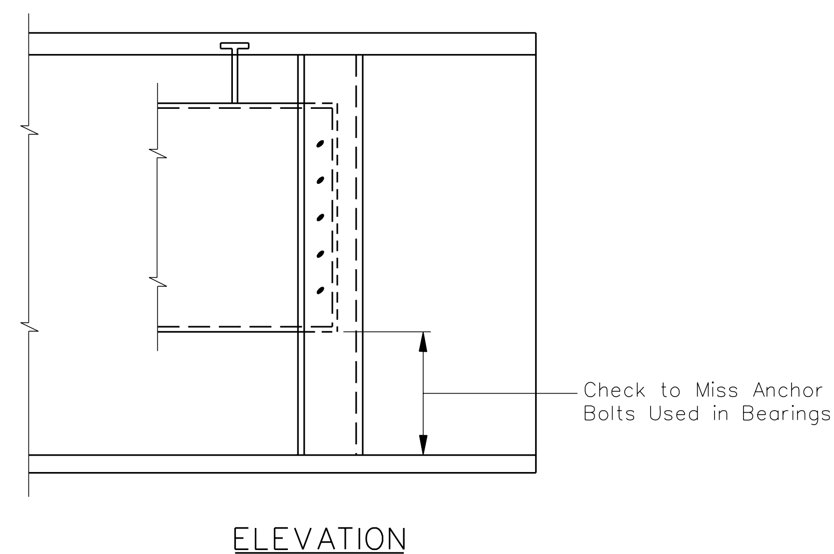
Figure 16.5-4 illustrates the typical support cross frame connection details for plate girder webs more than 48 in deep.

The rolled angles that comprise the cross frames are minimum sizes based upon the limiting slenderness ratios of LRFD Articles 6.8.4 and 6.9.3.

SCDOT practice requires that cross frame transverse connection plates, where employed, be welded to both the tension and compression flanges. The connection plate welds to the flanges should be designed to transfer the cross frame forces into the flanges.

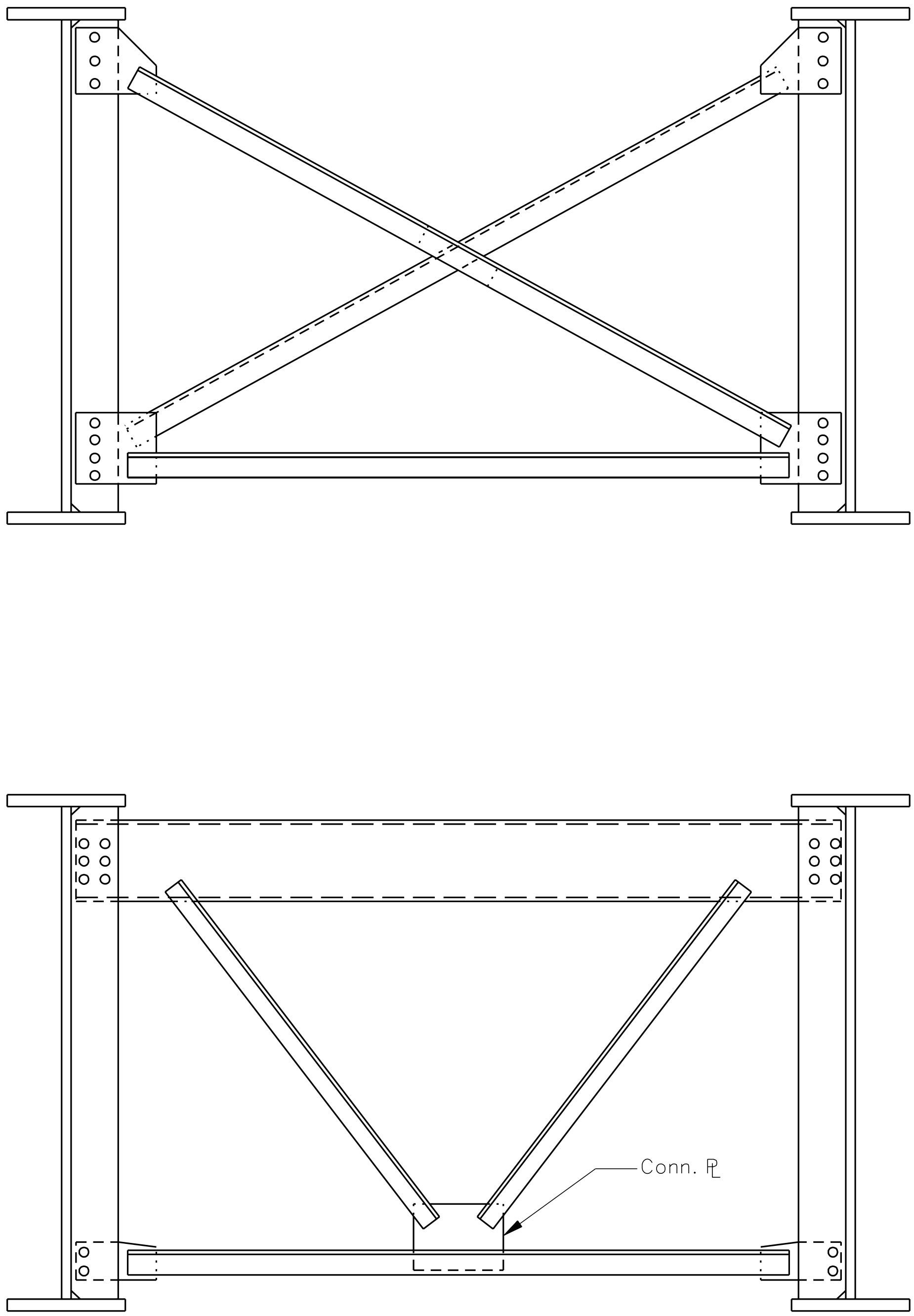
The width of connection plates should be sized to use bar stock and be not less than 5 in. When the connection plate also acts as a transverse stiffener, it shall meet the requirements of LRFD Article 6.10.8.1.





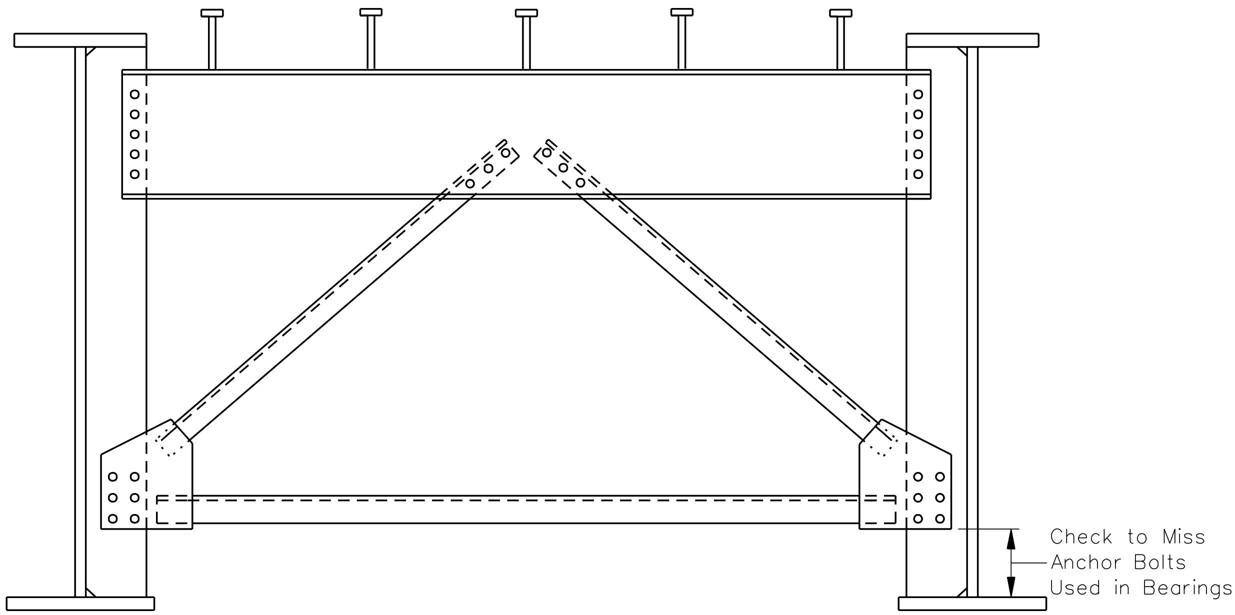
TYPICAL SUPPORT DIAPHRAGM CONNECTION
(Rolled Beams)

Figure 16.5-2



TYPICAL INTERMEDIATE CROSS FRAMES
(Plate Girder Web > 48 in)

Figure 16.5-3



TYPICAL SUPPORT CROSS FRAMES
(Plate Girder Web > 48 in)

Figure 16.5-4

See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website, for more information on connection plate details.

16.5.4 Jacking

Reference: LRFD Article 3.4.3

The plans should indicate designated points of jacking and whether or not the structure is capable of resisting 1.3 times the dead load reactions at those points. Slender beams may require web stiffeners at the jacking points. These stiffeners may either be part of the construction plans or fastened to the girder when and if the jacking is required. In general, jacking frames will not be required at the supports unless there is insufficient clearance between the bottom of beam and top of cap to place a jack. If less than a 7-in clearance is available for the jack, then the designer must decide whether the jack can be supported by temporary falsework. If temporary falsework is not feasible, then a jacking frame should be provided or the cap widened and the bearings placed on pedestals to provide sufficient space for a jack to be placed under the beam. Other locations where jacking may be required are:

- at supports under expansion joints where joint leakage could deteriorate the bearing areas of the girders; and

- at expansion bearings with large displacements where deformation induced wear-and-tear is possible.

If no jacking frame is provided, then the cross frame at the support still must be capable of transferring lateral wind forces to the bearings. For continuous structures using integral end bents, providing jacking frames at interior bents should not be considered.

16.5.5 Lateral Bracing

Reference: LRFD Article 6.7.5

The *LRFD Specifications* requires that the need for lateral bracing be investigated for all stages of assumed construction procedures. If the bracing is included in the structural model used to determine force effects, then it should be designed for all applicable limit states.

In general, lateral bracing is not required in the vast majority of steel girder bridges (short through medium spans); however, it must be checked by the designer. Typical diaphragms and cross frames will transfer lateral loads adequately to eliminate the need for lateral bracing.

LRFD Article 4.6.2.7 provides for various alternatives relative to lateral wind distribution in multi-girder bridges.

16.6 I-SECTIONS IN FLEXURE

Reference: LRFD Article 6.10

16.6.1 <u>General</u>

Reference: LRFD Article 6.10.1

16.6.1.1 Positive-Moment Region Maximum-Moment Section

For a compositely designed girder, the positive-moment region maximum-moment section may also be considered compact in the final condition. The cured concrete deck in the positive-moment region provides a large compression flange, and it laterally braces the top flange. Very little, if any, of the web is in compression.

16.6.1.1.1 Top Flange

In the final condition after the deck has cured, the top flange adds little to the resistance of the cross section. During curing of the concrete deck, however, the top flange is very important. The Strength limit state during construction when the concrete is not fully cured governs the design of the top flange in the positive-moment region as specified in LRFD Article 6.10.3.4.

16.6.1.1.2 Bottom Flange (Tension Flange)

The bottom flange, if properly proportioned, is not governed by the construction phase. The bottom flange is governed by the final condition. The Service II load combination permanent deformation provisions of LRFD Article 6.10.4.2 govern.

16.6.1.2 Negative-Moment Region Interior Bent Section

The negative-moment region interior bent section will most likely be a non-compact section during all conditions. The concrete deck over the interior bent is in tension in the negative-moment region and, thus, considered cracked and ineffective at the nominal resistance (i.e., ultimate). Thus, a good portion of the steel cross section is in compression. To qualify as compact, the web usually needs to be too thick to be cost effective. Thus, the cost-effective section will typically be a non-compact section.

Both top and bottom flanges in the negative moment region are governed by the Strength limit state in the final condition. Furthermore, the bottom flange in compression is governed by the location of the first intermediate diaphragm off of the interior bent because it provides the discrete bracing for the flange.

16.6.1.3 Negative Flexural Deck Reinforcement

Reference: LRFD Article 6.10.1.7

In the negative-moment region where the longitudinal tensile stress in the slab, due to factored construction loads or the Service II load combination, exceeds the factored modulus of rupture, LRFD Article 6.10.1.7 specifies a minimum area of steel. The total cross sectional area of the longitudinal steel should not be less than 1% of the total cross sectional area of the deck slab (excluding the wearing surface) in these regions. However, the designer shall also ensure that sufficient negative-moment steel is provided for the applied loads.

16.6.1.4 Rigidity in Negative-Moment Regions

Reference: LRFD Articles 6.10.1.5 and 6.10.1.7

LRFD Article 6.10.1.5 permits the assumption of uncracked concrete in the negative-moment regions for member stiffness. This stiffness is used to obtain continuity moments due to live load, future wearing surface, and barrier weights placed on the composite section.

For the service limit state control of permanent deflections under LRFD Article 6.10.4.2 and the fatigue limit state under LRFD Article 6.6.1.2, the concrete slab may be considered fully effective for both positive and negative moments for members with shear connectors throughout their full lengths and satisfying LRFD Article 6.10.1.7.

16.6.2 <u>Shear Connectors</u>

Reference: LRFD Article 6.10.10

The standard size for shear studs to be used on the flanges of beams and girders shall be ⅞ in diameter by 5-in. Skew the studs parallel to the bottom slab reinforcing steel. Increase the stud length in 1-in increments when necessary to maintain a 2-in minimum penetration of the stud into the deck slab. Studs placed on relatively thin elements such as girder webs should be detailed as ¾-in diameter.

16.6.3 <u>Stiffeners</u>

Reference: LRFD Article 6.10.11

16.6.3.1 Transverse Intermediate Stiffeners

Reference: LRFD Article 6.10.11.1

Straight girders may be designed without intermediate transverse stiffeners, if economical, or with intermediate transverse stiffeners placed on one side of the web plate. If stiffeners are required, fascia girders should only have stiffeners on the inside face of the web for aesthetics. Due to the labor intensity of welding stiffeners to the web, the unit cost of stiffener by weight is approximately nine times that of the unit cost of the web by weight. It is seldom economical to use the thinnest web plate permitted; therefore, the use of a thicker web and fewer intermediate transverse stiffeners, or no intermediate stiffeners at all, should be investigated. If the bridge designer decides to proceed with a design that requires stiffeners, the preferred width of the stiffener is one that can be cut from commercially produced bar stock.

Intermediate transverse stiffeners should be welded near side and far side to the compression flange. Transverse stiffeners should not be welded to tension flanges. The distance between the end of the web-to-stiffener weld and the near toe of the web-to-flange fillet weld should be between $4t_w$ and $6t_w$. See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website.

Transverse stiffeners, except when used as diaphragm or cross frame connections, should be placed on only one side of the web. The width of the projecting stiffener element, moment of inertia of the transverse stiffener, and stiffener area shall satisfy the requirements of LRFD Article 6.10.11.1.

Longitudinal stiffeners used in conjunction with transverse stiffeners on spans with deeper webs should preferably be placed on the opposite side of the web from the transverse stiffener. Where this is not practical (e.g., at intersections with cross frame connection plates), the longitudinal stiffener should be continuous and not be interrupted for the transverse stiffener.

16.6.3.2 Bearing Stiffeners

Reference: LRFD Article 6.10.11.2

Bearing stiffeners are required at the bearing points of rolled beams and plate girders. Bearing stiffeners at integral end bents may be designed for dead and construction loads only.

Design the bearing stiffeners as columns and extend the stiffeners to the outer edges of the bottom flange plates. The *LRFD Specifications* does not specify an effective column length for the design of bearing stiffeners. Because the reaction load applied at one end of the stiffener pair is resisted by forces distributed to the web instead of by a force concentrated at the opposite end, as in columns, it is not necessary to consider the stiffeners as an end-hinged column even where the flanges are free to rotate. Use an effective column length of ¾ of the web depth.

The weld connecting the bearing stiffener to the web should be designed to transmit the full bearing force from the stiffener to the web due to the factored loads.

Bearing stiffeners will be detailed with the stiffener ends bearing on the loaded flange being milled to bear. The opposite end will be tight fit only to the flange. Where bearing stiffeners are also used as diaphragm or cross frame connection plates, the stiffeners shall be detailed as previously described with the addition of fillet welds to the girder flanges.

16.6.4 Constructibility

Reference: LRFD Article 6.10.3

Before the deck is placed, the wind load is transmitted to the interior bents by the structure acting as a lateral beam. The girders equally share the wind load due to the presence of diaphragms or cross frames.

16.7 CONNECTIONS AND SPLICES

Reference: LRFD Article 6.13

16.7.1 Bolted Connections

Reference: LRFD Article 6.13.2

The following applies to bolted connections:

1. Type. For unpainted weathering steel, A325 (Type 3) bolts should be used. For painted steel, A325 (Type 1) should be used.

2. Design. All bolted connections shall be designed as slip-critical at the Service II limit state, except for secondary bracing members.

3. Slip Resistance. LRFD Table 6.13.2.8-3 provides values for the surface condition. Use Class B surface condition for the design of slip-critical connections. Class B is applicable to unpainted, blast-cleaned surfaces and to blast-cleaned surfaces with a Class B coating.

16.7.2 Welded Connections

Reference: LRFD Article 6.13.3

16.7.2.1 Welding Process

The governing specification for welding is the ANSI/AASHTO/AWS *Bridge Welding Code D1.5*. The bridge designer needs to be aware, however, that this specification does not provide control over all of the welding issues that may arise on a project. Additional reference specifications that may need to be consulted are:

- AWS D1.1 for welding of tubular members and strengthening or repair of existing structures, and

- AWS D1.4 if the welding of reinforcing steel must be covered by a specification.

The *Bridge Welding Code* accepts as *prequalified* (i.e., acceptable without further proof of suitability if applied under specified conditions) four welding processes using electric arcs. These are:

- shielded metal arc welding (SMAW). This process is also known as stick welding and is what is commonly considered welding;

- submerged arc welding (SAW);
- gas metal arc welding (GMAW). This process is also called *metal inert gas welding* or MIG; and
- flux-cored arc welding (FCAW).

Gas metal arc and flux-cored arc welding shall not be used except with written approval of the SCDOT. Electro-slag and electro-gas welding shall not be permitted.

SMAW is the principal method for hand welding; the others are automatic or semi-automatic processes. Shop practice on most weldments is automatic, offering the advantages of much higher speed and greater reliability. Hand welding is mostly limited to short production welds or tack welds during the fitting up of components prior to production welding.

Acceptable procedures for using these processes or others require the testing of the welding operations and of welds, using a filler metal that is compatible with the base metal, proper preparation of the joints, controlling the temperature and rate of welding, and control of the welding process.

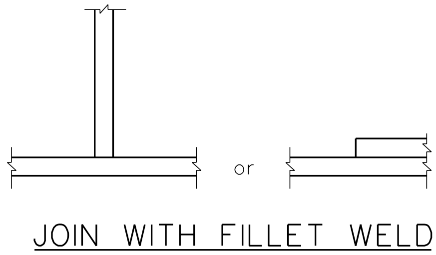
16.7.2.2 Welds for Bridges

The primary types of welds used in bridge fabrication are fillet welds and butt (or groove) welds. Figure 16.7-1 illustrates a typical cross section where specification of a fillet weld is appropriate, and Figure 16.7-2 illustrates a typical cross section where specification of a butt or groove weld is appropriate.

Field welding is prohibited for all but a few special applications. These permissible applications are welded splices for piles, connecting pile tips to piles, connecting bearing plates to girders, and connector plates between new and existing portions of widened bridges at ends of simply supported spans.

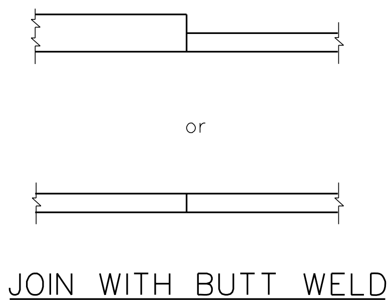
16.7.2.3 Welding Symbols

Welding symbols are used as an instruction on the type, size, and other characteristics of the desired weld. The forms of the symbols are precisely defined by AWS A2.4. When these symbols are properly used, the meaning is clear and unambiguous. If not used exactly as prescribed, the meaning may be ambiguous, leading to problems for all involved. The *AISC Manual* and most steel design textbooks have examples of welding symbols that, although technically correct, are more complicated than the typical bridge designer needs. With minor modifications, the examples in Figure 16.7-3 will suffice for the majority of bridge fabrication circumstances.



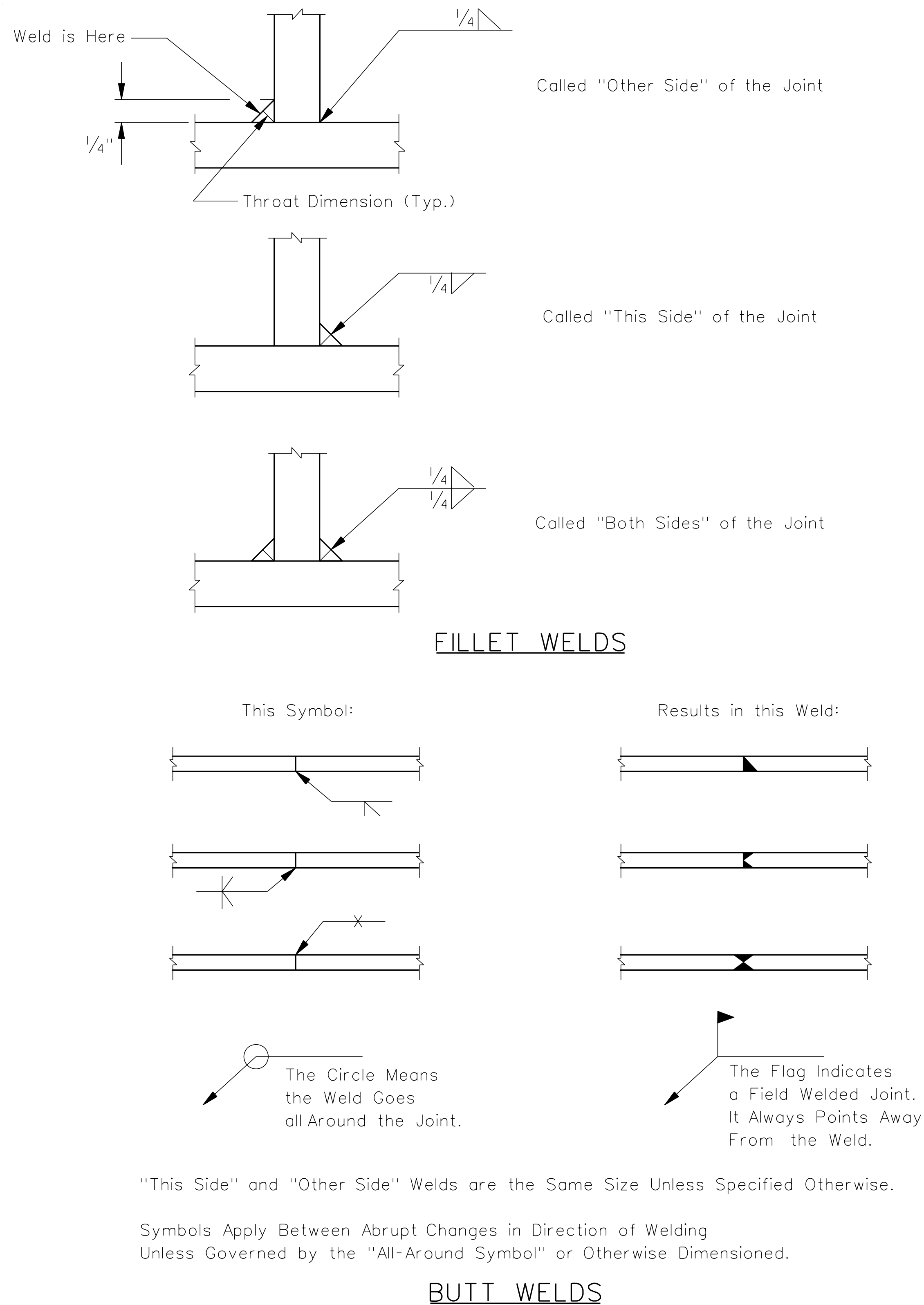
FILLET JOINT

Figure 16.7-1



BUTT JOINT

Figure 16.7-2



WELDING SYMBOLS

Figure 16.7-3

16.7.2.4 Design of Welds

The design of the weld is integral to LRFD Section 6 on Steel Design. The *LRFD Specifications* addresses topics such as resistance factors for welds, minimum weld size, and weld details to reduce fatigue susceptibility.

The weld-strength calculations of LRFD Section 6 assume that the strength of a welded connection is dependent only on the weld metal strength and the area of the weld. Weld metal strength is a fairly self-defining term. The area of the weld that resists load is a product of the theoretical throat multiplied by the length. The theoretical weld throat is the minimum distance from the root of the weld to its theoretical face. See Figure 16.7-3. Fillet welds resist load through shear on the throat, while groove welds resist load through tension, compression, or shear depending upon the application.

Often, it is best only to show the type and size of the weld required and leave the details to the fabricator.

When considering design options, note that the most significant factor in the cost of a weld is the volume of the weld material that is deposited. Over specifying a welded joint is unnecessary and uneconomical. A single-pass weld is one made by laying a single weld bead in a single move of the welder along the joint. A multiple-pass weld is one in which several beads are laid one upon the other in multiple moves along the joint. Welds sized to be made in a single pass are preferred because these are most economical and least susceptible to resultant flaws. The weld should be designed economically, but its size should not be less than ¼ in and, in no case, less than the requirements of LRFD Article 6.13.3.4 for the thicker of the two parts joined. Weld terminations should be shown.

The following types of welds are prohibited:

- intersecting welds,
- intermittent fillet welds (except for the connection of stop bars at expansion joints), and
- partial penetration groove welds (except for the connection of tubular members in hand rails).

Provide careful attention to the accessibility of welded joints. Provide sufficient clearance to enable a welding rod to be placed at the joint. Often, a large-scale sketch or an isometric drawing of the joint will reveal difficulties in welding or where critical weld stresses must be investigated.

16.7.2.5 Inspection and Testing

Indispensable to the reliable use of welding is a systematic program of inspection and testing. Inspection is done at the shop and at the field site. The function of the inspection is to guarantee that specified materials and procedures are used under conditions where proper welding is possible. If the sequence of welding has been specified, the inspector should be able to certify conformance.

Despite careful inspection, weld defects may escape detection unless all or part of the work is subjected to tests. There are two broad categories of testing — destructive testing, which is used very sparingly for big problems or forensic studies, and nondestructive testing, which is used extensively to guarantee the quality of the welds. The Department routinely uses the following types of non-destructive testing (NDT):

1. Radiographic Testing (RT). Used to find cracks and inclusions after a weld is completed. The process involves placing film on one side of the weld and a source of gamma or x-rays on the other side of the weld. Shadows on the exposed film indicate cracks or inclusions in the welds or adjacent areas. RT is most effective on full penetration butt joints with ready access to both sides.

2. Ultrasonic Testing (UT). Relies on the reflection patterns of high-frequency sound waves, which are transmitted at an angle through the work. Cracks and defects interrupt the sound transmission, altering the display on an oscilloscope. UT can reveal many defects that the other methods do not, but it relies very heavily on the interpretative skill of the operator.

3. Magnetic Particle Testing (MT). Performed by covering the surface of a weld with a suspension of ferromagnetic particles and then applying a strong magnetic field. Cracks in the weld interrupt the magnetic force lines, causing the particles to concentrate in the vicinity of the crack in patterns easily interpreted by the inspector.

4. Dye Penetrant Testing (DP). Uses a dye in liquid form to detect cracks. Capillary tension in the liquid causes the dye to penetrate into the crack, remaining behind after the surface is cleaned.

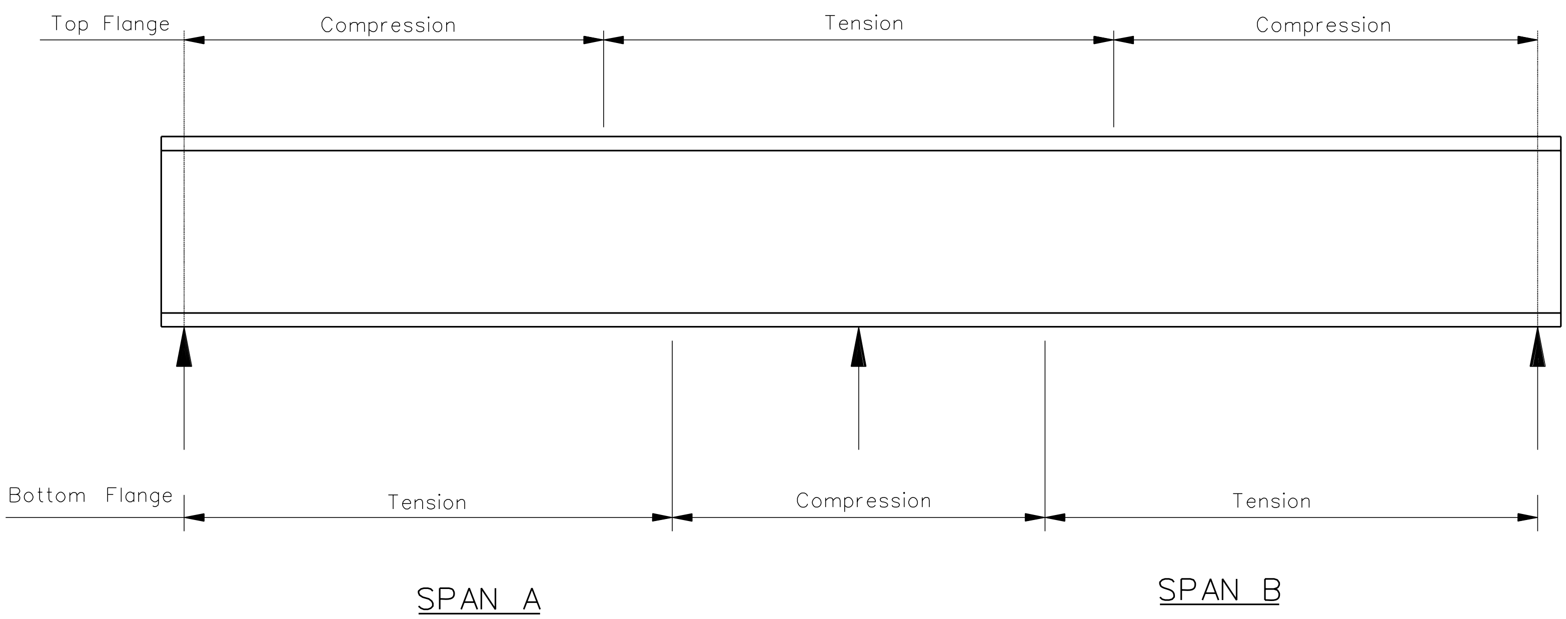
To aid the inspector, the plans for continuous structures shall include a sketch showing the location of tension regions along both the top and bottom girder flanges. Show the length of each stress region and reference these regions to the point of support. Figure 16.7-4 illustrates the information required.

16.7.3 Splices

Reference: LRFD Article 6.13.6

In addition to the provisions of LRFD Article 6.13.6, the following will apply to splices:

1. Location. In general, field splices should be located at low-stress areas and near the points of dead-load contraflexure for continuous spans. Numerous butt welds and/or butt welds located in high stress regions are not desirable. The location of shop butt splices is normally dependent upon the length of plate available to the fabricator. This length



SCHEMATIC OF FLANGE TENSION REGIONS

Figure 16.7-4

varies depending upon the rolling process. The maximum length of plates that are normalized, quenched, and tempered is 50 ft. Other plates can be obtained in lengths greater than 80 ft depending on thickness. The cost of adding a shop welded splice instead of extending a thicker plate should be considered when designing members. Discussion with a fabricator or NSBA during the design is suggested.

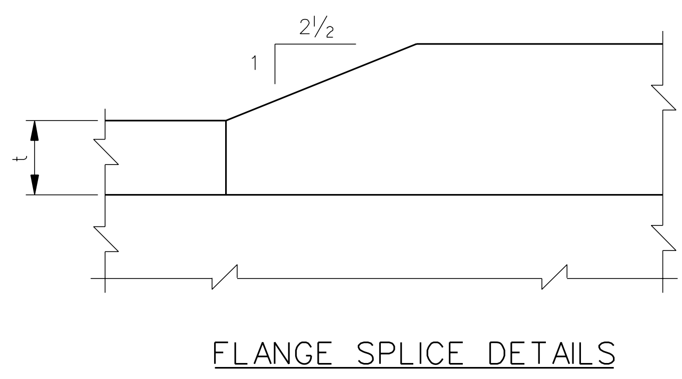
2. Swept Width. The swept width is equal to the sweep in a curved girder plus the flange width. On curved girders, the swept width between splices should generally be limited to 10 ft to accommodate the shipment of the steel.

3. Bolts. Design loads for bolts shall be calculated by an elastic method of analysis. Provide at least two lines of bolts on each side of the web splice.

4. Composite Girder. If a compositely designed girder is spliced at a section where the moment can be resisted without composite action, the splice may be designed as noncomposite. If composite action is necessary to resist the loads, the splice should be designed for the forces due to composite action.

5. Design. Bolted splices must be designed to satisfy both the slip-critical criteria under Service II loads and also the bearing type connection criteria under strength limit states.

6. Welded Shop Splice. Figure 16.7-5 illustrates welded flange splice details. See LRFD Article 6.13.6.2 for more information regarding splicing different thicknesses of material using butt welds.



TYPICAL SUBMERGED ARC WELD DETAILS

Figure 16.7-5

Chapter 17

BRIDGE DECKS

SCDOT BRIDGE DESIGN MANUAL

April 2006

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(Continued)

CHAPTER 17

BRIDGE DECKS

Sections 3, 4, and 9 of the *LRFD Bridge Design Specifications* present the AASHTO criteria for the structural design of bridge decks. Section 3 specifies loads for bridge decks, Section 4 specifies their analyses, and Section 9 specifies the resistance of bridge decks. Unless noted otherwise in this Chapter of the *SCDOT Bridge Design Manual*, the *LRFD Specifications* applies to the design of bridge decks in South Carolina. This Chapter presents information on specific SCDOT practices for bridge decks.

17.1 BACKGROUND

17.1.1 Bridge Decks and Superstructures

The *LRFD Specifications* encourages the integration of the deck with the primary components of the superstructure by either composite or monolithic action. In some cases, the deck alone is the superstructure. The *LRFD Specifications* refers to this as a "slab superstructure"; SCDOT refers to these as "flat slabs." More commonly, the deck in conjunction with its supporting components comprises the superstructure.

This Chapter documents SCDOT criteria on the design of bridge decks that are constructed compositely in conjunction with concrete I-beams or steel I-girders. Chapter 15 discusses the design of flat slabs.

17.1.2 Durability of Concrete Bridge Decks

Reference: LRFD Articles 1.2, 2.5.2.1.1, and 5.12

As stated in the commentary to LRFD Article 2.5.2.1.1, the single most prevalent bridge maintenance problem is the deterioration of concrete bridge decks. LRFD Article 5.12 discusses measures to enhance the durability of concrete components.

The distress of bridge decks, and their premature replacement, has become a serious problem in the United States. In Article 1.2, the *LRFD Specifications* defines the design life of new bridges as 75 years. Thus, designers are compelled to re-evaluate conventional wisdom regarding the long-term performance of concrete bridge decks.

17.1.3 Protection of Reinforcing Bars

See Section 15.3 for the SCDOT corrosion protection policy for reinforcing bars.

17.2 "STRIP METHOD"

17.2.1 Application of the "Strip Method" to Composite Concrete Decks

Reference: Appendix to LRFD Section 4

The application of the strip method to composite concrete decks is represented by a design table for deck slabs in the Appendix to Section 4 of the *LRFD Specifications* (LRFD Table A4-1). An introduction to the LRFD Table discusses its application.

LRFD Table A4-1 shall be used to design the concrete deck reinforcement. LRFD Table A4-1 tabulates the resultant live-load moments per unit width for slab steel design as a function of the girder spacing, S. Negative moments are distinguished from positive moments and are tabulated for various design sections as a function of the distance from the girder centerline to the design section. LRFD Article 4.6.2.1.6 specifies the design sections to be used.

17.2.2 Empirical Deck Design

SCDOT prohibits the use of the empirical deck design.

17.3 DESIGN DETAILS FOR BRIDGE DECKS

17.3.1 General

The following general criteria applies to bridge deck design:

1. Thickness. The depth of reinforced concrete decks shall not be less than 8 in.

2. Reinforcement Steel Strength. The specified yield strength of reinforcing steel shall be 60 ksi.

3. Reinforcement Cover. Typically, the bottom reinforcement cover shall be a minimum of 1 in. The top reinforcement cover shall be a minimum of 2½ in, which includes a ¼-in sacrificial wearing surface. The primary reinforcement shall be the closer reinforcement to the concrete face. See Figure 15.3-2 for additional concrete cover criteria.

4. Reinforcing Bar Spacing. A minimum of 1½ in (based on nominal bar diameters) vertically between the top and bottom reinforcing mats shall be maintained. Where conduits are present between mats, the 1½ in must be increased. A minimum horizontal spacing of 5½ in on center shall be maintained between adjacent bars within each mat. These minimum spacings are required to ensure the proper consolidation of the concrete between bars. The maximum horizontal reinforcing bar spacing is 9 in for primary (transverse) steel. See Section 15.3 for additional information on reinforcing bar spacing.

5. Reinforcing Bar Size. The minimum reinforcing bar size used for slab reinforcement is a #5 bar. However, #4 bars may be used in deck overhangs where they are bundled with the primary reinforcing. For designs that require a slab thickness exceeding 8½ in, the designer may elect to use #6 bars for the primary reinforcing.

6. Sacrificial Wearing Surface. The 2½ in top reinforcement concrete cover includes ¼ in that is considered sacrificial. Its weight shall be included as a dead load, but its structural contribution shall not be included in the structural design.

7. Concrete Strength. The specified 28-day compressive strength of concrete for bridge decks and approach slabs shall be 4.0 ksi.

8. Length of Reinforcement Steel. The maximum length of reinforcing steel in the deck shall be 40 ft for galvanized reinforcing bars and 60 ft for black (uncoated) reinforcing bars.

9. Placement of Transverse Reinforcing Bars on Skewed Bridges. The following applies:

    a. Skews ≤ 30°: Place the transverse reinforcing steel parallel to the skew.

    b. Skews > 30°: Place the transverse reinforcing steel perpendicular to the longitudinal reinforcement.

See Section 17.3.4 for a definition of skew angle and for structural considerations related to skewed reinforcing bar placement.

10. Splices/Connectors. Use lap splices for deck reinforcement unless special circumstances exist. Mechanical connectors may be used where clearance problems exist or on a phase construction project that precludes the use of lap splices. See Section 15.3 for more discussion on splices.

11. Post-Tensioning. Post-tensioning is not allowed in cast-in-place concrete decks.

17.3.2 Dimensional Requirements for Concrete Decks

17.3.2.1 General

Although the build-down varies across the width of the flange and the length of the girder, in all cases there shall be a minimum of ½-in build-down. Consider the camber tolerance when calculating the ½-in minimum.

The Control Dimension "D" is measured at the centerline of bearing for all girders, and varies in the span to compensate for variations in camber, superelevation ordinate, and vertical curve ordinate if necessary.

The build-down for deck slabs should be detailed flush with the vertical edge of the top flange.

17.3.2.2 Build-Down Dimensions for Steel Girders

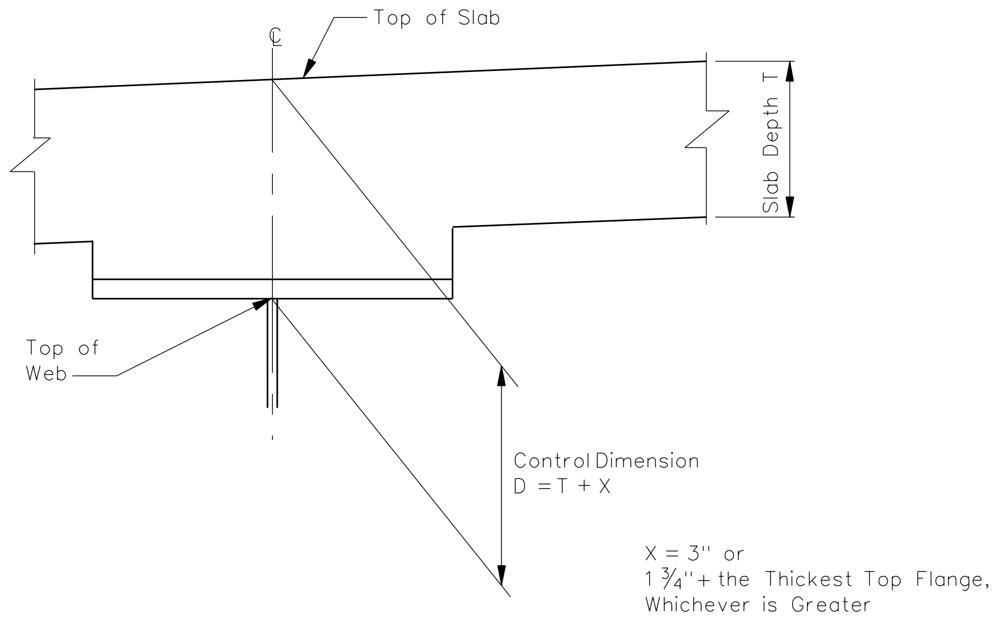
Figure 17.3-1 illustrates the controlling factors used to determine the build-down dimension for steel plate girders. Figure 17.3-2 illustrates a steel rolled beam.

17.3.2.3 Build-Down Dimensions for Concrete Beams

Figure 17.3-3 illustrates the controlling factors used to determine the build-down dimension for concrete beams.

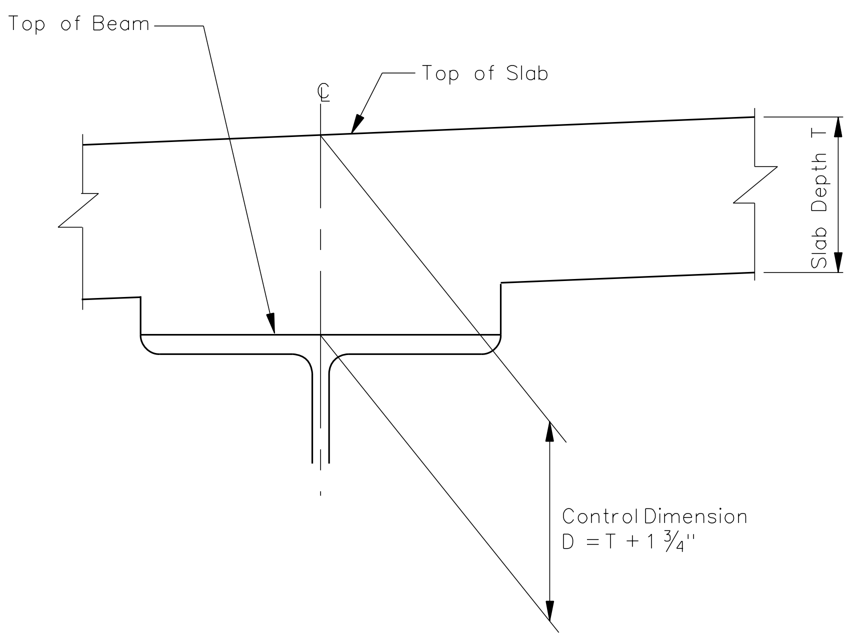
17.3.3 Stay-in-Place Forms

Steel stay-in-place forms are allowed on all projects having beams or girders. Design loads for stay-in-place forms shall be applied for all girder/beam bridges and consist of 0.016 ksf for the metal forms applied over the areas of the forms. Field welding of the stay-in-place forms to steel flanges is prohibited. Stay-in-place forms are not allowed in bays having longitudinal joints. If the contractor elects not to use stay-in-place forms, the camber calculations must be modified accordingly because the assumed weight of the non-existent forms was originally included.



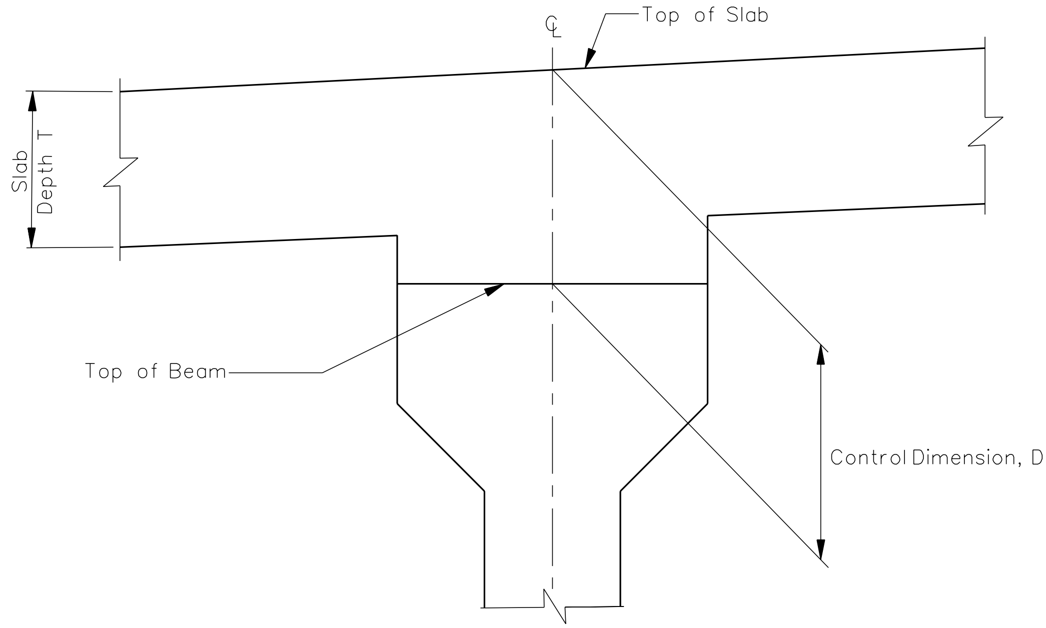
BUILD-DOWN DIMENSION FOR STEEL PLATE GIRDERS

Figure 17.3-1



BUILD-DOWN DIMENSION FOR STEEL ROLLED BEAMS

Figure 17.3-2



BUILD-DOWN DIMENSION FOR CONCRETE BEAMS

Figure 17.3-3

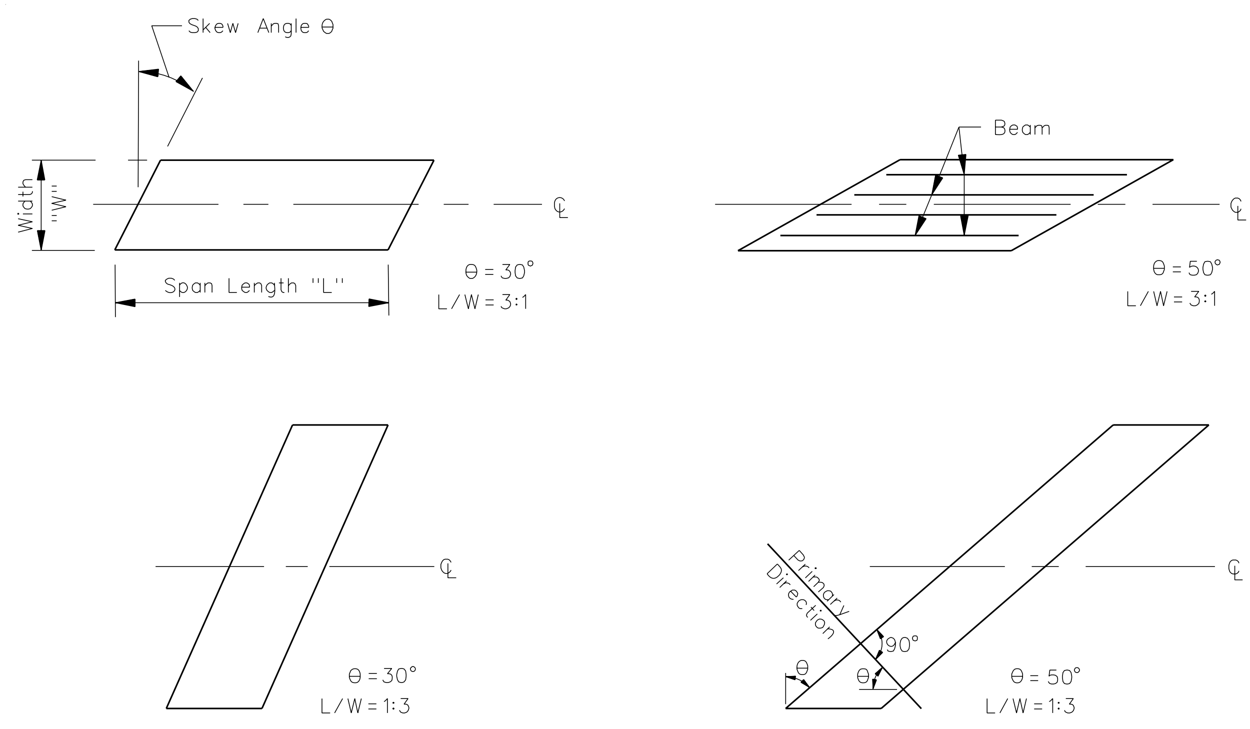
17.3.4 <u>Skewed Decks</u>

Reference: LRFD Article 9.7.1.3

Skew is defined by the angle between the end line of the deck and the normal drawn to the longitudinal centerline of the bridge at that point. See Figure 17.3-4. The two end skews can be different. In addition to skew, the behavior of the superstructure is also affected by the span-length-to-bridge-width ratio.

The *LRFD Specifications* generally implies that the effects of skew angles not exceeding 30° can be neglected for concrete decks, but the *LRFD Specifications* assumes the typical case of bridges with relatively large span-length-to-bridge-width ratios. Figure 17.3-4 illustrates four combinations of skew angles 30° and 50° and length-to-width ratios of 3:1 and 1:3.

Both the 50° skew and the 1:3 length-to-width ratio are considered extreme values for bridges, but this often occurs where the deck constitutes the top slab of a culvert. It can be judged visually that both combinations with 30° skew may be orthogonally modeled for design with the skew ignored.



SKEW ANGLE AND LENGTH/BRIDGE WIDTH RATIOS

Figure 17.3-4

The Commentary to Section 9 of the *LRFD Specifications* provides valid arguments supporting the limit of 30° concerning the direction of transverse reinforcement. It suggests that running the transverse reinforcement parallel to a skew larger than 30° will create a structurally undesirable situation in which the deck is essentially unreinforced in the direction of principal stresses. It is required that, for skew > 30°, the transverse reinforcement must be set perpendicular to the beams or longitudinal reinforcement.

The combination of 50° skew and L/W = 1:3, as indicated in Figure 17.3-4, produces an unusual layout. If the deck is a cast-in-place concrete slab without beams, the primary direction of structural action is one being perpendicular to the end line of the deck. Because of the geometry of the layout, consider running the primary reinforcement in that direction and fanning it as appropriate in the side zone. With this arrangement, the secondary reinforcement could then be run parallel to the skew, thus regaining the orthogonality of the reinforcement as appropriate for this layout.

17.3.5 <u>Deck Pouring Sequence</u>

Reference: LRFD Article 2.5.3

Maximum specified pouring rate: 60 yd^3/hr (300 yd^3 in 5 hours)
Minimum specified pouring rate: 45 yd^3/hr (225 yd^3 in 5 hours)

17.3.5.1 General

The need for a slab pouring sequence in the bridge plans will be based on the volume of concrete in the bridge deck as follows:

- Less than 225 yd^3 — not needed
- 225 yd^3 to 300 yd^3 — case-by-case decision
- Greater than 300 yd^3 — required

The 225-yd^3 and 300-yd^3 thresholds are calculated based on a minimum specified pouring rate of 45 yd^3/hr and a maximum specified pouring rate of 60 yd^3/hr, respectively, for five hours. If a pouring rate greater than 45 yd^3/hr is needed, the plans shall indicate the required pouring rate.

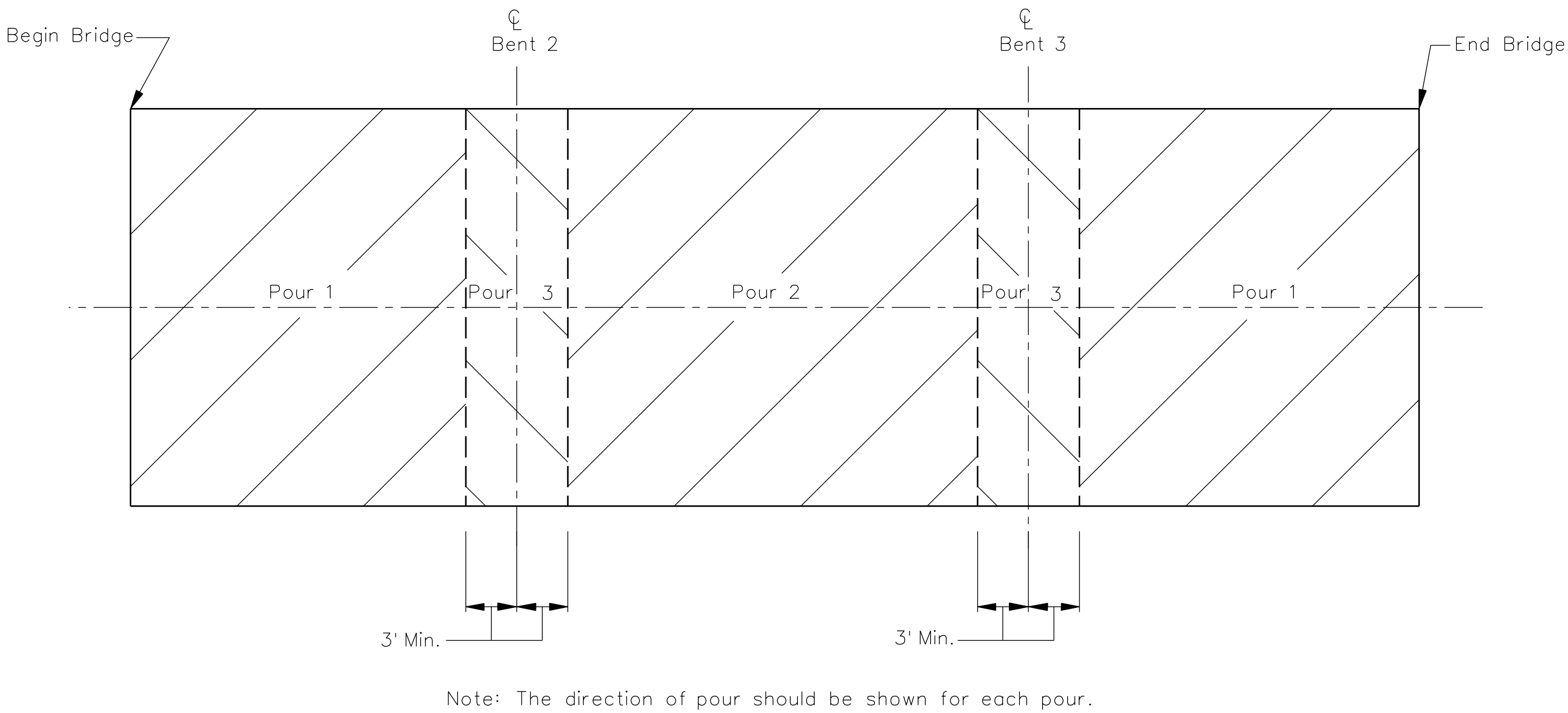
The bridge deck pouring sequence that is indicated in the contract documents is determined by the designer considering factors such as size of pour, configuration of the bridge, potential placement restrictions, direction of placement, deck tensile stresses, and any other special circumstances that might affect the bridge deck placement.

Where required, the bridge designer will present in the bridge plans the sequence of placing concrete in various sections (separated by transverse construction joints) of deck slabs on continuous spans. The designated sequence avoids or minimizes the dead-load tensile stresses in the slab during concrete setting to minimize cracking, and the sequence should be arranged to cause the least disturbance to the portions placed previously. In addition, for longer span steel girder bridges, the pouring sequence can lock-in stresses far different than those associated with the instantaneous placement typically assumed in design. Therefore, in these bridges, the designer shall consider the pouring sequence in the design of the girders.

Deck placement shall be uniform and continuous over the full width of the superstructure. The first pours shall include the positive-moment regions in all spans. The final pours shall include the negative-moment regions and shall not be placed until a minimum of 72 hours has elapsed from the start of the preceding pour. For pours on a grade of 3% or greater, the direction of pouring should be uphill.

Figure 17.3-5 illustrates a sample pour sequence diagram for continuous prestressed concrete I-beams made continuous for live load. The cast-in-place diaphragm over the bent is cast integrally at the same time as the deck above it. Also, see Chapter 6 for information on the presentation of the slab pouring sequence detail. For a continuous steel bridge, the pouring sequence will be similar, but the negative-moment regions are longer. The extent of the negative-moment regions is project-specific and shall be determined for each situation.

Prestressed concrete beams made continuous for live load and superimposed dead load shall be treated as a special case. The deck segment and diaphragm over the support provide continuity for live load in the superstructure after the previously poured center regions of the deck have been poured as simple span loads.



TYPICAL POUR DIAGRAM
(Continuous Prestressed Concrete I-Beam)

Figure 17.3-5

For integral end bents, the end wall concrete shall be cast concurrently with the deck pour of the end span.

17.3.5.2 Transverse Construction Joints

Where used, transverse construction joints should be placed parallel to the transverse reinforcing steel.

Place a transverse construction joint in the end span of bridge decks on steel superstructures where uplift is a possibility during the deck pour. A bridge with an end span relatively short (60% or less) when compared to the adjacent interior span is most likely to produce this form of uplift. Uplift during the deck pour can also occur at the end supports of curved decks and in superstructures with severe skews. If an analysis shows that uplift might occur during a deck placement, require a construction joint in the end span and require placing a portion of the deck first to act as a counterweight.

17.3.6 Longitudinal Construction Joints

Longitudinal construction joints in bridge decks can create planes of weakness that frequently cause maintenance problems. In general, construction joints are discouraged, and their use should be minimized. The following will apply to longitudinal construction joints:

1. Usage. Construction joints need not be used on decks having a constant cross section where the width is less than or equal to 60 ft. For deck widths greater than 60 ft (i.e., where the screeding machine span width must exceed 60 ft), the designer shall make provisions to permit placing the deck in practical widths. For decks wider than 90 ft, the designer shall detail either a longitudinal open joint or a longitudinal closure pour, preferably not less than 3 ft in width. Lap splices in the transverse reinforcing steel shall be located within the longitudinal closure pour. Such a joint should remain open as long as the construction schedule permits to allow transverse shrinkage of the deck concrete. The designer should consider the deflections of the bridge on either side of the closure pour to ensure proper transverse fit up. See Section 21.1 for more information on longitudinal open joints.

2. Location. If a construction joint is necessary, do not locate it underneath a wheel line. Preferably, a construction joint should be located outside the beam flange.

3. Closure Pours. For staged construction projects where the deflection from the deck slab weight exceeds ½ in, a closure pour shall be used to connect the slab between stages. A closure pour serves two useful purposes: It defers final connection of the stages until after the deflection from the deck slab weight has occurred, and it provides the width needed to make a smooth transition between differences in final grades that result from design calculations or construction tolerances. Good engineering practice dictates that the closure width should relate to the amount of dead-load deflection that is expected to

occur after the closure is placed. A minimum closure width of 3 ft is recommended. When a closure pour is used, the following apply:

- Stay-in-place forms shall not be used under the closure pour.

- Diaphragms/cross frames in the staging bay of structural steel beams or girders shall not be rigidly connected until after the adjacent stages of the deck have been poured. Omit concrete diaphragms in the staging bay of prestressed concrete beams.

- Reinforcing steel between different stages shall not be tied or coupled until after the adjacent stages of the deck have been poured.

17.3.7 Bridge Deck Overhangs

Reference: LRFD Article 9.7.1.5

17.3.7.1 Width

Bridge deck overhang is defined as the distance between the centerline of the exterior girder or beam to the outside edge of the deck (i.e., behind the bridge rail). Typically, the projection of the bridge deck slab past the exterior beam or girder is constructed by bracing the falsework against the web or bottom flange of the exterior beam or girder. Large overhang widths will cause excessive lateral distortion of the bottom flange and web of the beam or girder. Section 12.2 provides more information on bridge overhang widths.

17.3.7.2 Overhang Treatments

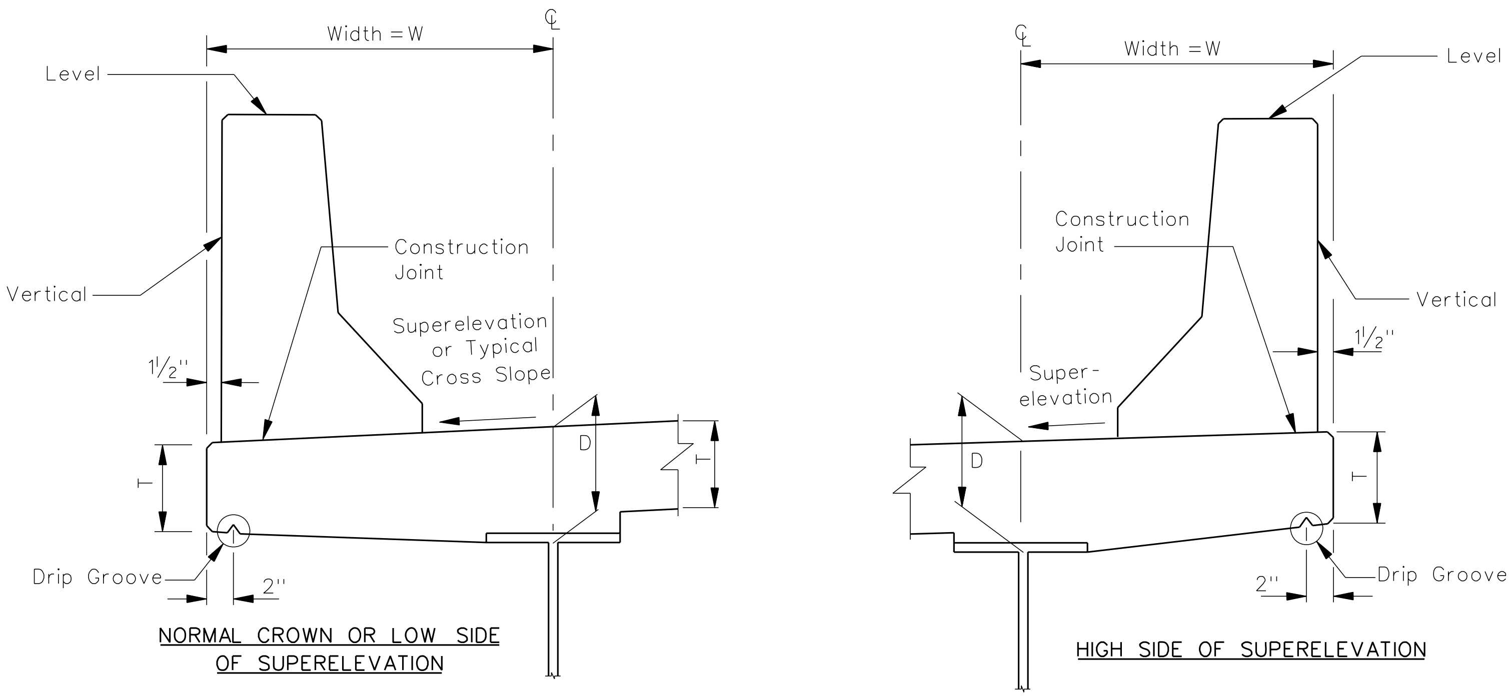
Figure 17.3-6 shows typical overhang treatments for a steel girder bridge for a normal crown and for the low and high sides of superelevation. Details for concrete beam bridges are similar using the build-down as shown in Figure 17.3-7.

Figure 17.3-8 shows typical overhang treatments at expansion joints.

17.3.7.3 Design Details

The following details pertain to the edge of deck (see Figure 17.3-7):

1. Chamfer. Provide a ¾″ chamfer at the top and bottom of the edge of the deck slab.

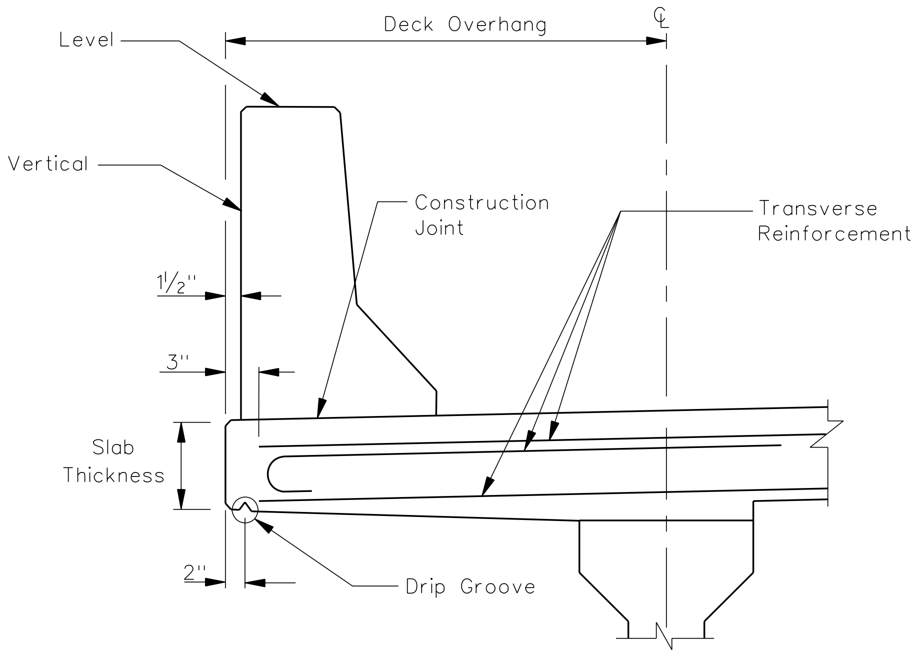


D = Control Dimension
W = Overhang Width
T = Slab Depth

Note: Concrete beam bridges are handled similarly with the build-down shown in Figure 17.3-7.

STEEL GIRDER OVERHANG TREATMENTS

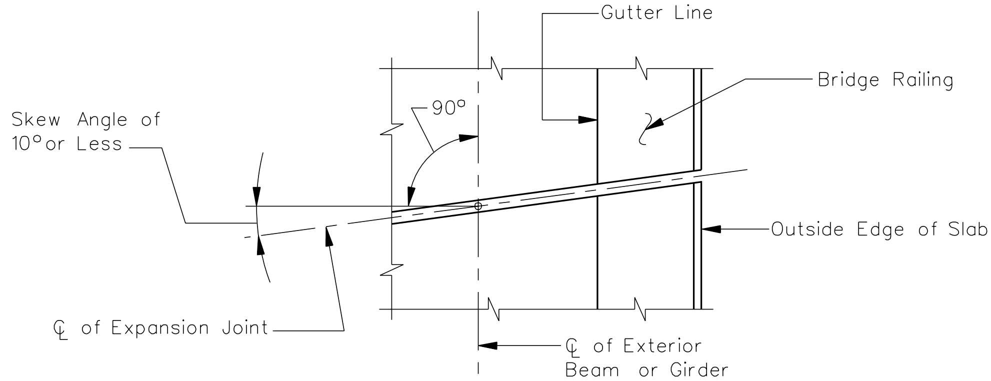
Figure 17.3-6



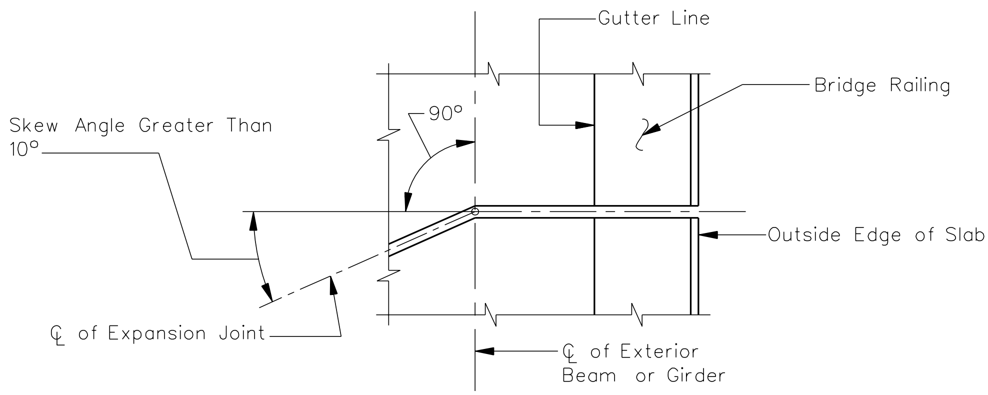
EDGE-OF-SLAB DETAIL
Figure 17.3-7

2. Slip Forming/Transverse Reinforcing Bar Ends. Bridge deck slabs shall be designed to extend 1½ in past the back face of the barrier parapet to accommodate slip forming. The transverse reinforcing bar lengths in the deck slab should be computed to maintain 3 in of clearance from the edge of slab for construction tolerances.

3. Drip Groove. Locate the drip groove 2 in from the edge of the slab.



FOR SKEW ANGLES OF 10 DEGREES OR LESS



FOR SKEW ANGLES GREATER THAN 10 DEGREES

PART PLAN OF DECK CANTILEVER AT EXPANSION JOINT
Figure 17.3-8

17.4 APPROACH SLABS

17.4.1 Usage

See Section 12.2.

17.4.2 Design Criteria

See the *SCDOT Bridge Drawings and Details*, available at the SCDOT website, for the typical approach slab design. The roadway ends of approach slabs should be designed parallel to the bridge ends. The following design criteria applies to approach slabs:

1. Materials. Class 4000 concrete and Grade 60 reinforcing bars shall be used in the design of all approach slabs.

2. Length. Approach slabs shall be 20 ft long measured parallel to the centerline of roadway.

3. Thickness/Concrete Cover. The thickness of the approach slab shall be 12 in, with 2 in of concrete cover to the top reinforcing bars and 3 in of concrete cover below the bottom reinforcing bars.

4. Reinforcement. The following applies:

   - The top reinforcing steel that is parallel to the roadway shall be #7 bars at 12 in on center.

   - For flat slabs and cored slabs, the bottom reinforcing steel that is parallel to the roadway shall be #7 bars at 6 in on center.

   - For deck slabs on girder/beam bridges, the bottom reinforcing steel that is parallel to the roadway shall be #9 bars at 6 in on center.

   - The top and bottom distribution steel shall be #5 bars at 12 in on center.

5. Approach Slab Connections. All approach slabs shall be doweled to the end bent or pavement rest with #6 bars at 12 in on center. The anchors shall be detailed to act as a hinge so that the approach slab can rotate downward without stress as the embankment settles. The minimum pavement rest dimension is 8 in.

6. Approach Slabs and Grade Location. Where concrete pavement is used for the approaching roadway, approach slabs shall be constructed at grade. Where asphalt pavement is used for the approaching roadway, approach slabs shall be constructed 2 in below grade.

7. Live Load. The approach slab shall be modeled as a simple span for the determination of live-load reactions on the end bent. Where an approach slab is used, the live-load surcharge shall not be applied to the end bent.

8. Dead Load. SCDOT policy is to include one-half of the dead load of the approach slab as an end bent dead load.

17.4.3 Special Conditions

When any of the following special conditions exist, the designer shall evaluate the design criteria for approach slabs in Section 17.4.2 and redesign as needed:

1. Skews. Where skews of 30º or greater exist, a redesign of the approach slab may be necessary.

2. Deep End Spans. The approach slab design should be reevaluated where the structure depth equals or exceeds one-half of the approach slab length.

3. Sidewalks. Where the project requires sidewalks on the bridge, the approach slab must be widened to allow for the sidewalks.

4. Sleeper Slabs. When sleeper slabs are used, the approach slab must be designed to span the entire distance between the sleeper slab and the pavement rest.

17.5 MISCELLANEOUS

17.5.1 Structural Design of Concrete Bridge Rails

Section 17.6 discusses the types of bridge rails used by the Department.

Concrete bridge railings will be built monolithically and continuous with no contraction joints. Full-depth open joints shall be provided at all expansion joints on structures, and these shall be the only locations for joints in concrete bridge rails.

Shear steel connecting any concrete barrier, curb, parapet, sidewalk, or median to the concrete decks should be determined assuming full composite action at the interface, according to the provisions of LRFD Article 5.8.4.

Superelevated sections can result in insufficient concrete cover for reinforcing bars; therefore, the designer should give special attention to barrier reinforcing steel placement for structures with superelevated sections.

17.5.2 Deck Drainage

See Chapter 18 for information on bridge deck drainage.

17.6 BRIDGE DECK APPURTENANCES

17.6.1 Bridge Rails

Reference: LRFD Article 13.7

17.6.1.1 Test Levels

Reference: LRFD Article 13.7.2

LRFD Article 13.7.2 identifies six test levels for bridge rails, which have been adopted from NCHRP 350 *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Test Levels One, Two, and Six have no application in South Carolina. The following identifies the general test level application for TL-3, TL-4, and TL-5:

1. TL-3 (Test Level 3). Generally acceptable for a wide range of high-speed arterial highways with very low mixtures of heavy vehicles and with favorable site conditions. Performance crash testing is at 60 mph with a 1.55-kip passenger car and a 4.5-kip pickup truck.

2. TL-4 (Test Level 4). Generally acceptable for the majority of applications on high-speed highways, freeways, and expressways with a mixture of passenger cars, trucks, and other heavy vehicles. Performance crash testing is at 60 mph with a 1.55-kip passenger car and a 4.5-kip pickup truck plus an 18-kip single-unit truck at 50 mph.

3. TL-5 (Test Level 5). Generally acceptable for the same applications as TL-4 plus where large trucks make up a significant portion of the vehicular mix.

17.6.1.2 Bridge Rail Types/Usage

The following identifies typical SCDOT usage for bridge rails:

1. 32-in Concrete Bridge Barrier Parapet. SCDOT typically uses this bridge rail on all bridges that do not include sidewalks; however, see Item #4. The 32-in concrete bridge barrier parapet, which has the same face configuration as the typical SCDOT concrete median barrier, meets the performance criteria for a TL-4. SCDOT typically uses the Jersey shape for the 32-in rail instead of the other available concrete bridge rail shapes (e.g., F-shape, constant-slope shape, vertical wall). The SCDOT standard concrete bridge barrier parapet transition shall be used at all barrier ends where a thrie beam guardrail bridge connector is required. A separate bid item is required for the transition. The concrete bridge rail's advantages when compared to a metal beam rail include its superior performance when impacted by large vehicles, its relatively low maintenance costs, and its better compatibility with the bridge deck system (i.e., the concrete rail can be constructed integrally with the bridge deck). The concrete bridge rail's disadvantages include its higher dead weight.

2. 42-in Concrete Wall. SCDOT typically uses this rail where sidewalks are present on the bridge. The 42-in concrete wall is vertical, and its height conforms to the LRFD requirements for pedestrian rails; therefore, its use where sidewalks are present avoids the need to extend the height of a 32-in concrete bridge rail to meet the height requirements of a pedestrian rail. However, see Section 17.6.3 for warrants for bicycle rails. The 42-in concrete wall meets the TL-5 performance criteria, although SCDOT does not typically use this barrier for those highway facilities that may warrant consideration for the TL-5 rail. Figure 17.6-1 illustrates the transition that is required for the 42-in concrete wall at all rail ends where a thrie beam guardrail bridge connector is used. For concrete bridge rails with heights other than 42 in, the length of the transition shall be modified as necessary to maintain the 6:1 taper in Figure 17.6-1. A separate bid item is not required for this transition. The length of transition shall be included in the quantity for the concrete bridge rail.

3. Metal Beam Rail. SCDOT strongly discourages the use of any metal beam bridge rail system. Its use may only be considered where aesthetics or dead loads are very important. When compared to the concrete bridge rail, a metal beam rail's advantages include lower dead weight and providing a more open view of the surrounding scenery. The comparative disadvantages include a lesser ability to contain heavier vehicles, higher maintenance costs, and a more complex structural connection to the bridge deck system.

4. 32-in Concrete Wall. For bridges that meet all of the following conditions:

   - 60 ft or less in length;
   - straight wing walls (i.e., wing walls that are parallel to the centerline of bent); and
   - where sidewalks or bikeways are not provided,

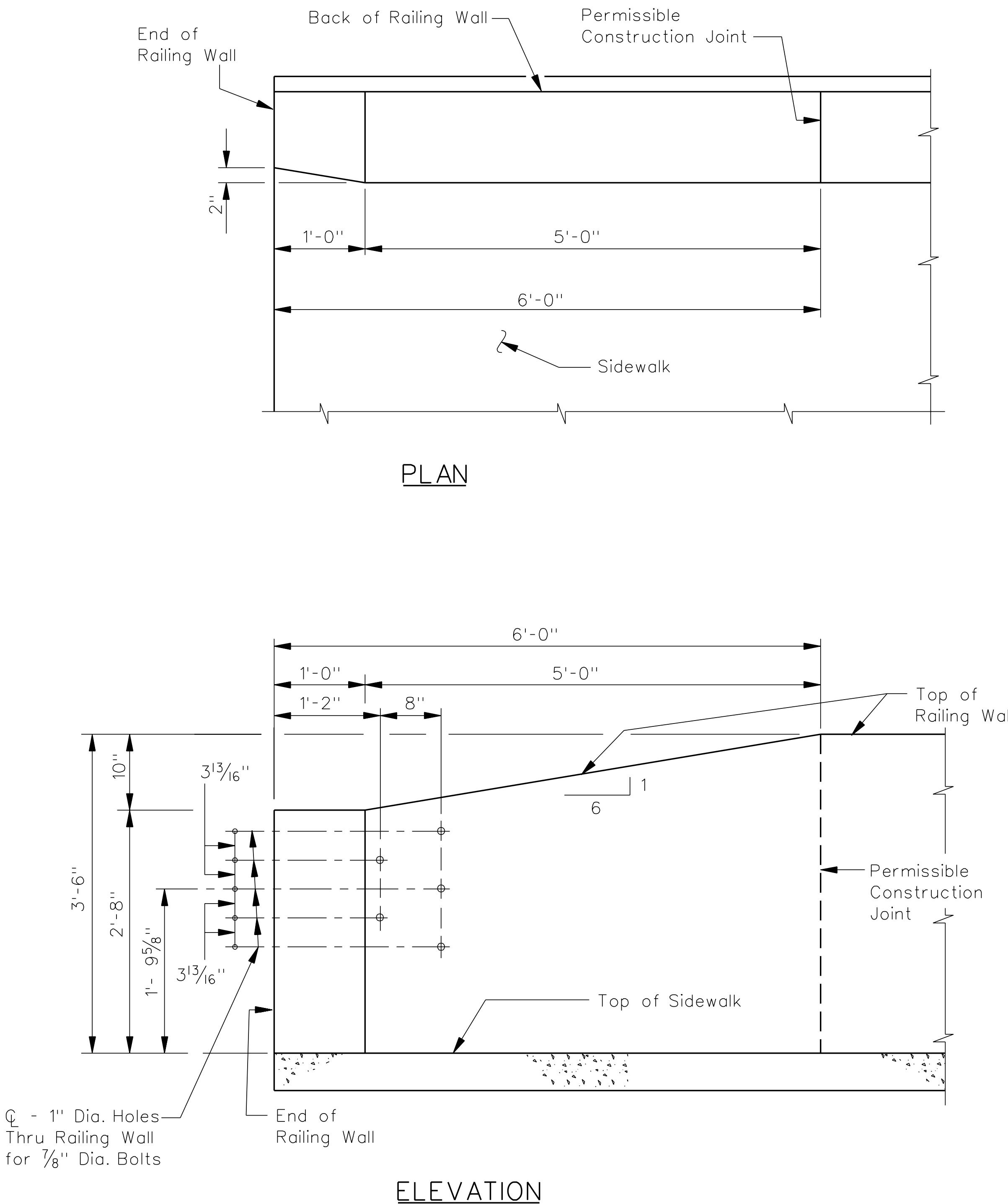
   a 32-in reinforced concrete wall with a vertical face shall be used. See Figure 17.6-2.

17.6.1.3 Guardrail-To-Bridge-Rail Transitions

The Road Design Section is responsible for designing and detailing the guardrail-to-bridge-rail transition for the approaching roadway. However, site conditions may present problems for the necessary transition. Therefore, the bridge designer should work with the Road Design Section to ensure compatibility between the guardrail-to-bridge-rail transition and the site.

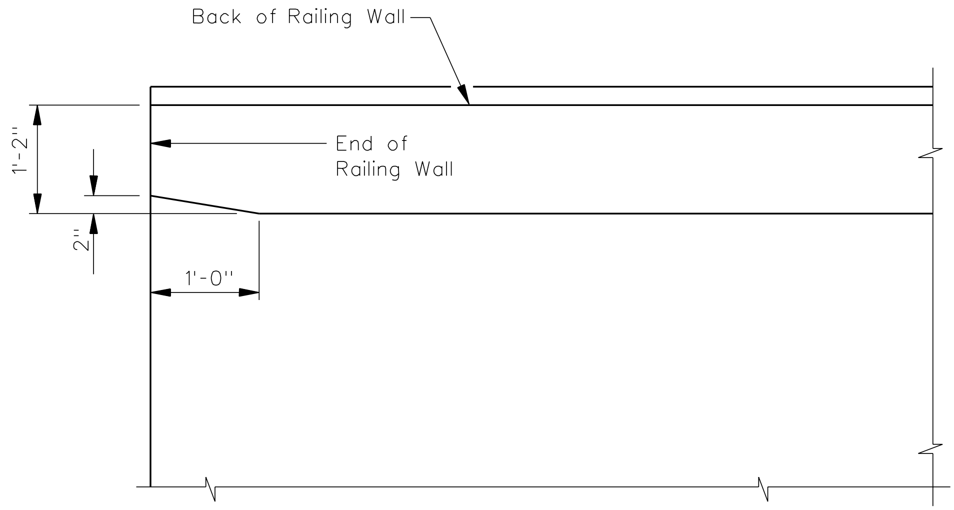
17.6.1.4 Approach Slabs with Trend Guardrail

Where an approach has an adjoining Trend guardrail, the approach slab edge shall be terminated 4½ in inside the bridge gutter line. This avoids a conflict with the Trend's concrete pad footing. In addition, the designer shall eliminate the concrete curb from the approach slab edge where adjoining a Trend guardrail.

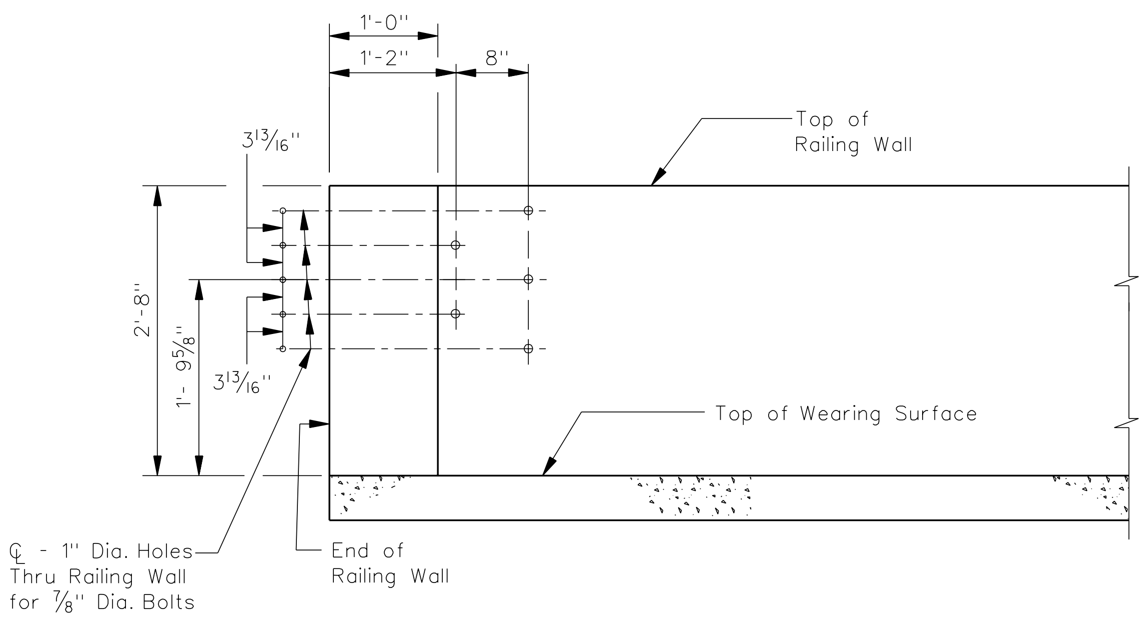


END TRANSITION FOR 42-INCH CONCRETE WALL

Figure 17.6-1



PLAN



ELEVATION

32-INCH VERTICAL WALL

Figure 17.6-2

17.6.1.5 Bridge Rail/Sidewalk

Reference: LRFD Articles 13.4 and 13.7.1.1

Section 12.6 discusses warrants for a sidewalk on a bridge. At lower speeds, the sidewalk is separated from the adjacent roadway by a vertical curb, which is typically 6 in high. However, at higher speeds, the vertical curb will interfere with the proper vehicular/bridge rail interaction. See Figure 12.6-7. Therefore, the following will apply to the location of a bridge rail in combination with a sidewalk:

1. V ≤ 45 mph. The 42-in concrete wall is typically located on the outside edge of the sidewalk.

2. V ≥ 50 mph. Place the 32-in concrete bridge barrier parapet between pedestrians and traffic; i.e., between the roadway portion of the bridge deck and the sidewalk. The 32-in concrete barrier must have a metal hand rail on top of the barrier to reach the required 42-in height for a pedestrian rail. A 42-in pedestrian rail is then used at the outside edge of the sidewalk. For this arrangement, the roadway and sidewalk portions of the bridge deck are at the same elevation.

17.6.2 Pedestrian Rails

Reference: LRFD Article 13.8

Pedestrian rails are used on bridges with sidewalks where the roadway and sidewalk are separated by a barrier.

17.6.3 Bicycle Rails

Reference: LRFD Article 13.9

Section 12.6 discusses the conditions for which bicycle accommodation is required across a bridge. Where required, a bicycle rail that meets the geometric and loading requirements of LRFD Article 13.9 must be provided. The required height of the bicycle rail is 54 in. Therefore, where bicycle accommodation is required, rail height is treated as follows:

1. Bridge Without Sidewalk. Typical SCDOT practice is to use the 32-in concrete bridge barrier parapet and extend its height to 54 in with a metal rail that meets the LRFD bicycle rail requirements.

2. Bridge With Sidewalk. Where bicyclists are not legally allowed on sidewalks, the 42-in concrete wall (as discussed in Section 17.6.1) is typically used to satisfy the height requirements of a pedestrian rail. Where bicyclists are legally allowed on sidewalks, typical practice is to use a 30-in concrete wall and extend its height to 54 in with a metal rail that meets the LRFD bicycle rail requirements.

Bicycle paths are bikeways that are physically separated from motorized vehicular traffic by an open space or barrier and may be either within the highway right-of-way or within an independent right-of-way. Bridges that are part of a bicycle path may require a 54-in bicycle rail.

17.6.4 Fences

The need for protective fencing across bridges will be determined on a case-by-case basis. Typical applications are as follows:

- on an overpass near a school, playground, or other location where it is expected that the overpass will be frequently used by children not accompanied by adults;
- on all overpasses in urban areas that are used exclusively by pedestrians and not easily kept under surveillance by law enforcement personnel;
- on overpasses with walkways where experience on similar structures indicates a need for fences;
- on overpasses where private property that is subject to damage, such as buildings or power stations, is located beneath the structure; and
- on overpasses over railroads, if requested by the railroad company (see Chapter 22).

For the majority of projects, the use of a protective screen is not warranted, and the protective screen may be erected at a later time if site conditions change.

17.6.5 Utility Attachments

The Bridge Design Section will coordinate with the Utilities Office for any utility attachments proposed on the bridge.

Utility companies frequently request the approval from SCDOT to attach utility lines or pipes to bridges. The Bridge Design Section's concern is that the function of the bridge as part of a transportation corridor not be compromised; that the safety of the individuals using the bridge not be compromised; and that the Department's maintenance of the bridge not be unduly complicated. The Bridge Design Section also recognizes that existing transportation corridors offer logical routes for utilities and that, if the Department allows utility attachments to bridges, SCDOT can reduce costs to the Utilities and ultimately to the general public.

On new or replaced bridges, the bridge designer shall detail two 2-in diameter conduits in each concrete bridge rail for the future use of the Department or Utility Companies.

The Department has established guidelines for processing utility encroachment applications on new structures. These guidelines illustrate acceptable methods for attaching utility line(s) to Department-owned structures. The following applies to utility attachments:

1. Utility line(s) can not be attached to the outside edge of the bridge where the structure crosses another highway or where aesthetics are a concern. The attachment shall be between the exterior beam and the first interior beam.
2. Utility line(s) can not hang below the bottom of the beams or below the bottom of the deck on flat slab bridges.
3. Utility line(s) can not be attached to the bottom of concrete flat slabs.
4. No field welding is allowed on steel beams and no field drilling is allowed on concrete beams.
5. All attachments to concrete shall be made with inserts or epoxy-resin anchors. Attachment hardware shall be galvanized or stainless steel.
6. If SCDOT must increase the bridge capacity or extend elements such as bent caps to support a utility, the Utility must pay for the additional design and construction costs.

17.6.6 Sign Attachments

If the Traffic Engineering Division proposes to attach a sign to a bridge, the Traffic Engineering Division must coordinate with the Bridge Design Section. The Bridge Design Section will assess the structural impact on the bridge and, if the sign attachment is approved, the Bridge Design Section will design the attachment details. Signs can not decrease the vertical clearance.

17.6.7 Lighting/Traffic Signals

The Traffic Engineering Division determines the warrants for highway lighting and traffic signals, and the Traffic Engineering Division performs the design work to determine, for example, the spacing of the luminaries and the provision of electricity. Lighting will often be included on bridges that are located in urban areas; traffic signal warrants are determined on a case-by-case basis. Where attached to a bridge, the Bridge Design Section will design the structural support details for the luminaire and/or traffic signal attachments to the bridge.

Chapter 18

BRIDGE DECK DRAINAGE

SCDOT BRIDGE DESIGN MANUAL

April 2006

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(Continued)

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CHAPTER 18

BRIDGE DECK DRAINAGE

This Chapter provides guidelines and procedures for designing bridge deck drainage systems. The Chapter describes design practices for the system components, and it provides the governing criteria that determine the hydraulic design of the system (e.g., design flood frequency, allowable water spread). Chapter 18 references the SCDOT Report "Scupper Analysis for Bridge Structures" for the analytical methods for bridge deck drainage. This Report provides the hydraulic equations to calculate the location and spacing of bridge deck inlets, and it provides example problems based on the SCDOT computer program DRAIN to illustrate its application.

18.1 GENERAL

18.1.1 Importance of Bridge Deck Drainage

The bridge deck drainage system includes the bridge deck, sidewalks, railings, gutters, inlets and, for a closed drainage system, the underdeck closed pipe system. The primary objective of the drainage system is to remove runoff from the bridge deck before it collects in the gutter to a point that exceeds the allowable design spread. Proper bridge deck drainage provides many other benefits, including the following:

- Efficiently removing water from the bridge deck enhances public safety by decreasing the risk of hydroplaning.
- Long-term maintenance of the bridge is enhanced.
- The structural integrity of the bridge is preserved.
- Aesthetics are enhanced (e.g., the avoidance of staining substructure and superstructure members). Also, good underdeck drainage design will not compromise the architectural aesthetics of the bridge.
- Erosion on bridge end slopes is reduced.

18.1.2 SCDOT Responsibilities

The following discussion outlines the responsibilities of SCDOT Units with respect to bridge deck drainage.

18.1.2.1 Open vs Closed Drainage

For every bridge, the Department must decide whether to design an open drainage system or an underdeck closed drainage system to convey runoff. The Department prefers an open drainage system because it is more effective. However, a number of factors may require a closed drainage system. For example:

- Environmental permits may require a closed drainage system. If a closed drainage system is required for this reason, consult NCHRP Report 474 *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters*. Volume 1 discusses impacts that are not severe enough to warrant a closed drainage system. Volume 2 guides the user through the appropriate level of analysis.

- The potential for erosion of earth slopes or natural ground beneath a free-falling drainage outlet may be unacceptable.

- A closed drainage system will minimize staining structural elements that would otherwise be in close proximity to free-falling drainage outlets. However, this benefit may be offset because many underdeck closed drainage systems degrade the overall aesthetics of the bridge.

- Free-falling discharge is not allowed onto travel lanes or sidewalks beneath a bridge.

- Free-falling discharge is not allowed onto railroad right-of-way.

The following identifies the SCDOT decision-making Unit:

1. <u>Bridges Over Waterways</u>. Through the National Environmental Policy Act (NEPA) process, the Environmental Management Office notifies the Project Manager if a closed bridge deck drainage system will be required on bridges over waterways. This decision will be based on environmental factors such as the potential discharge of pollutants into waterways and based on the requirements to secure any necessary environmental permits (e.g., Section 401 Water Quality Certification).

2. <u>Bridges Over Highways and Railroads</u>. For grade separation structures, the bridge designer selects between an open or closed drainage system.

18.1.2.2 Design of Open Drainage System

The Hydraulic Engineering Section:

- provides the policy for the design flood frequency for use in determining the flow on the bridge deck; and

- provides the policy for the allowable water spread onto the deck.

For in-house projects, the Bridge Design Section:

- calculates the flow of water on the deck based on the design frequency;
- determines the hydraulic inlet spacing on the bridge deck to intercept the calculated flow to meet the allowable water spread criteria;
- determines all necessary design and details of the open drainage system; and
- incorporates the drainage design information into the bridge plans.

For consultant-designed projects, the consultant is responsible for the hydraulic design for open drainage.

18.1.2.3 Design of Closed Drainage System

For in-house projects, the division of responsibilities for the above-deck portion of a closed drainage system is the same as described in Section 18.1.2.2 for an open drainage system. For the underdeck closed drainage system, the Hydraulic Engineering Section performs the hydraulic design (e.g., pipe sizes, pipe slopes). The Bridge Design Section is responsible for all other aspects of the underdeck design, including the structural layout of the underdeck system, locations of cleanouts, and preparing the bridge plan details.

For consultant-designed projects, the consultant is responsible for the hydraulic design of a closed drainage system.

For all projects, the Contractor shall be required to design all connections, hangers, and pipe expansion joints. All metal components shall be galvanized or fabricated from stainless steel. The Contractor shall be required to submit shop drawings for the closed drainage system.

18.1.2.4 Bridge End Drainage

For in-house-designed projects, the Hydraulic Engineering Section is responsible for the drainage design for any runoff approaching or leaving the bridge deck.

For consultant-designed projects, the consultant is responsible for the design of the bridge end drainage.

18.2 OPEN DRAINAGE

18.2.1 Vertical Alignment

For bridge decks designed with flat gradients or in sag vertical curves, the following applies:

1. Minimum Gradient. The minimum longitudinal gradient should be limited to 0.3%. Flatter gradients will require approval from the State Bridge Design Engineer.

2. Sag Vertical Curves. If practical, no portion of a bridge should be located in a sag vertical curve. If the bridge is located in a sag vertical curve, the low point of the sag should not be located on the bridge or the approach slab. The low point should be maintained a minimum of 10 ft from the end of the approach slab or, if approach slabs are not used, a minimum of 10 ft from the end of the bridge. Placing a low point on a bridge or approach slab will require approval from the State Bridge Design Engineer and will only be allowed if no feasible alternative exists. See Section 18.2.4.

18.2.2 Maximum Bridge Length Without Inlets

On continuous-grade bridges for a given set of conditions, there will be a bridge length below which no bridge deck drainage inlets will be necessary. In other words, the drainage basin area (i.e., the bridge deck) will not generate a sufficient runoff to produce a gutter flow that, at any point, exceeds the allowable water spread on the bridge deck.

The designer should use the following equation and the known site conditions to determine if drainage inlets are needed or if the bridge length is short enough to design the bridge without drainage inlets:

$$L = \frac{24{,}393.6(S_x^{1.67})(S^{0.5})(T^{2.67})}{CniW} \qquad \text{(Equation 18.2-1)}$$

where:

	L	=	Maximum allowable bridge length without drainage inlets, ft
	S	=	Longitudinal slope, ft/ft
	S_x	=	Cross slope, ft/ft
	W	=	Width of drained deck*, ft
	C	=	Runoff coefficient**
	i	=	Rainfall intensity, in/hr
	n	=	Manning's n**
	T	=	Maximum allowable spread, ft

* *For normal crown cross sections, this distance is typically measured from the centerline of bridge to the outside edge of parapet. For a fully superelevated cross section, this distance is measured from outside edge of parapet to outside edge of parapet.*

** *For typical decks, C = 0.9 and n = 0.016.*

If no inlets are needed on the bridge, the designer should review Section 18.2.3 to determine if other considerations require drainage inlets.

18.2.3 Methodology for Inlet Spacing

For most applications, SCDOT uses the methodology documented in the Report "Scupper Analysis for Bridge Structures," published by the Department in May 1989, to determine the spacing of drainage inlets (or scuppers) on a bridge deck. The Bridge Design Section maintains the computer program DRAIN to conduct the calculations as documented in the Report. The rainfall intensities given in the Report are based on a 10-year design flood frequency.

Consultants and in-house designers may use other hydraulic methods to determine the spacing of drainage inlets. These other methods include HEC 21 *Design of Bridge Deck Drainage* and HEC 22 *Urban Drainage Design Manual*, both published by FHWA. Software is available for both methodologies.

18.2.3.1 Reliability

The basic hydraulic equations in the SCDOT Report "Scupper Analysis for Bridge Structures" are based on the specific scupper and deck cross slope tested — a 4-in diameter scupper with a bridge deck roadway cross slope of 32H:1V, or 3.125%. The equations in the SCDOT Report allow adjustments for other scupper diameters and roadway cross slopes. *Note: The default scupper diameter value in the computer program DRAIN is 6 in, which is the standard scupper diameter used by SCDOT.*

18.2.3.1.1 Type of Inlet/Cross Slopes

If a bridge deck drainage inlet other than a circular scupper is used, the designer must reference other documents (e.g., HEC 22 *Urban Drainage Design Manual*). For example, circular scuppers at the low point of a sag vertical curve may be inadequate to remove runoff from the bridge, even with flanking scuppers on either side. It may be necessary to use a rectangular grate inlet to improve safety and meet hydraulic criteria.

18.2.3.1.2 Scuppers with Grates

The methodology in the SCDOT Report is not valid where a grate is used over the scupper.

18.2.3.1.3 Transverse and Longitudinal Slopes

The methodology in the SCDOT Report is valid when a transverse slope is maintained and when the longitudinal slope is less than or equal to 5%.

18.2.3.2 Calculate Discharge

The discharge for a bridge deck is dependent on the following factors:

- the required design flood frequency (see Figure 18.2-1),
- the bridge deck area,
- the geometry of the bridge deck surface, and
- the number and spacing of drains.

The SCDOT Report "Scupper Analysis for Bridge Structures" uses the Rational Method to calculate the basin discharge. This Method is considered appropriate for small drainage areas up to 100 acres.

18.2.3.3 Determine the Allowable Water Spread

Figure 18.2-1 presents the allowable water spread on the bridge deck for various highway conditions. The purpose of this criteria is to minimize water spread and to provide an adequate, clear traveled way width for each level of traffic serviceability during the design storm event. Because of the inherent subjectivity in DRAIN, SCDOT policy is, when using DRAIN, to use an allowable water spread of 90% of the values in Figure 18.2-1 for calculating inlet spacing to provide an additional margin of safety.

18.2.3.4 Calculate Gutter Flow

Runoff from the bridge deck will accumulate in the gutter that is formed by the surface of the bridge deck and the concrete bridge rail or, where a sidewalk is present, the sidewalk curb. The SCDOT Report "Scupper Analysis for Bridge Structures" uses Manning's Equation to calculate gutter flow, which is based on:

Type of Facility		Design Flood Frequency	Allowable Water Spread
All Interstate Routes; Other Facilities with Design ADT > 10,000	≤ 45 mph	10-year	Shoulder + 3 ft
	> 45 mph	10-year	Shoulder
	Low point on bridge	50-year	Shoulder + 3 ft
Non-Interstate Routes and Other Facilities with Design ADT ≤ 10,000	≤ 45 mph	10-year	½ driving lane
	> 45 mph	10-year	Shoulder
	Low point on bridge	10-year	½ driving lane

HYDRAULIC DESIGN CRITERIA
(For Bridge Decks)

Figure 18.2-1

- the cross-sectional geometry of the gutter,
- the longitudinal slope of the bridge deck, and
- the "roughness coefficient" of the bridge deck.

18.2.3.5 Determine Inlet Capacity

Bridge deck inlets intercept the gutter flow, and they will operate as either:

- a weir, where the water depth (H) is shallow and the water enters the inlet free-flowing; or

- as an orifice, where the depth of water (H) above the inlet is high enough to submerge the inlet.

The SCDOT Report "Scupper Analysis for Bridge Structures" provides equations to calculate the flow capacity of bridge deck inlets for both weir and orifice flow.

18.2.3.6 Determine Inlet Spacing

Using the calculated gutter flow and inlet capacity, the designer applies the analytical procedures in the SCDOT Report "Scupper Analysis for Bridge Structures" to determine the inlet spacing on a bridge deck such that the water spread never exceeds the criteria in Figure 18.2-1. If the bridge deck is located in a sag vertical curve, additional "flanking" inlets are required; see Section 18.2.4.

18.2.3.7 Additional Inlet Location Considerations

The designer uses the analytical methodology to determine the optimal hydraulic location of inlets. However, the following factors should also be considered in identifying the actual location of inlets:

- It is desirable to collect 100% of the runoff upgrade from expansion joints.

- Coordinating inlet spacing with the structural design of the bridge deck may require adjustments to inlet locations. See Section 18.2.5.

- Acceptable scupper outfall locations, as discussed in Section 18.2.5, will impact the location of inlets on the bridge deck.

- It is advisable to collect most of the runoff prior to the bridge end by locating additional inlets on the downgrade end of the bridge. See Section 18.2.6.

In many cases, these additional considerations will prove to be more of a determining factor in inlet location than the inlet spacing calculated by the hydraulic analysis. However, the spacing should not exceed the maximum allowable spacing determined by the hydraulic analysis.

18.2.4 Sag Vertical Curves

When the low point is located on the bridge, special considerations for bridge deck drainage are required due to the larger collection of gutter flow and the greater potential for clogging of the openings. In addition to the inlet spacing calculations from the SCDOT Report "Scupper Analysis for Bridge Structures," the following apply:

1. Low Point. A drainage inlet must always be located at the low point of the sag vertical curve.

2. Major Highways. On all Interstate facilities and all other facilities where the ADT > 10,000, the design flood frequency is 50 years (Q_{50}) at the low point where the drainage inlets are the only means for transporting the runoff away from the highway.

3. Flanking Inlets. Provide flanking inlets to limit spread and act in relief of the inlet at the low point if it should become clogged or if the design flood is exceeded. SCDOT practice is that flanking inlets will be provided on each side of the low point in a sag vertical curve. Typical practice is to place flanking inlets 5 ft on either side of the low point.

18.2.5 Deck Drainage Design Details

18.2.5.1 Types of Deck Drainage Inlets

Where open drainage is used, typical SCDOT practice is to use 6-in diameter scuppers for drainage inlets on all bridges. For deck-on-girder bridges, drain pipes shall be fiberglass pipe meeting the requirements of ASTM D-2996 and the accelerated UV weathering performance requirements of ASTM G154. Pipe shall be pigmented resin throughout the wall. Color shall be light gray (Federal Shade No. 26622) for concrete beam and painted steel girder bridges, or brown (Federal Shade No. 30045) for weathering steel girder bridges. Paint, gel-coat, or exterior coating will not be accepted.

On flat slab bridges, scuppers may be fiberglass; however, it is also acceptable to use PVC pipe.

Where sidewalks are located on the bridge, grates shall be used over the scuppers adjacent to the sidewalk.

In some cases, it may be advisable to use an inlet type other than a circular scupper (e.g., at low points, superelevation transitions).

18.2.5.2 Structural Considerations

The primary structural considerations in drainage system design are:

1. Coordination with Reinforcement. Inlet sizing and placement must be compatible with the structural reinforcement and other components of a bridge. For example, inlets for reinforced concrete bridge decks must fit within the reinforcing bar spacing, and consideration should be given to the details for deck drains that pass through the flanges of prestressed concrete beams.

2. Corrosion and Erosion. The drainage system should be designed to deter runoff (and the associated corrosives) from contacting vulnerable structural members and to minimize the potential for eroding embankments. To avoid corrosion and erosion, the design must include proper placement of outfalls (see Section 18.2.5.4). In addition, water should be prevented from running down the joint between the approach roadway and bridge and thereby undermining an end bent or wing wall.

18.2.5.3 Maintenance Considerations

The drainage system will not function properly if it becomes clogged with debris. Therefore, it is important that maintenance requirements be considered in the design. In particular, the bridge designer should avoid drainage designs with the following common maintenance problems:

- clogging of inlets because of flat grades or points where debris is trapped;
- lack of room for maintenance on the bridge deck or access beneath the bridge; and
- unsafe working areas for maintenance personnel.

18.2.5.4 Scupper Outlets for Open Drainage

The following discussion presents SCDOT practices for the location of scupper outlets when open drainage design is used on bridge decks. The location of these outlets also impacts the location of inlets on the bridge deck:

1. Location With Respect To Structural Elements. Scuppers typically extend to approximately 2 in below the bottom of the girder/beam or to 1½ in below the bottom of a flat slab structure. Scupper outlets should not be located within 5 ft of the edge of any substructure units or where water could easily blow over and run down a substructure element. Scupper outlets should not be located such that a 45° cone of splash beneath the scupper will touch any structural component. Scuppers shall not encroach upon the required vertical or horizontal clearances.

2. Location With Respect To Ground. A free fall exceeding 25 ft will sufficiently disperse the falling water so that minimal erosion damage will occur beneath the bridge. Where less than 25 ft of free fall is available, erosion protection on natural ground beneath the

outlet may be needed. Where the water free falls onto riprap or flowing water, free falls less than 25 ft are acceptable.

3. Railroads. Scupper outlets are not allowed over railroad right-of-way.

4. Other Exclusions. Avoid locating scupper outlets over the traveled way portion of an underpassing highway, sidewalk, or unpaved embankment.

18.2.6 Bridge End Drainage

Good drainage design at the ends of bridges is essential for proper drainage. At bridge ends where the approach roadway does not have curb and gutter and the longitudinal slope of the roadway is less than 1%, the typical Department practice is to use an asphalt flume. If the longitudinal slope of the roadway is 1% or greater, the designer must determine if the asphalt flume is appropriate. If the asphalt flume is not appropriate, an alternative design must be used to accommodate the runoff.

In addition to an asphalt flume, bridge end drainage may be designed with grate inlets, curb opening inlets, or combination inlets. The hydraulic characteristics of the inlets should be considered in selecting the type. Inlets on the bridge should be spaced to minimize runoff entering and exiting the bridge approaches. Collectors at the downslope end of the bridge should be designed to collect all of the flow not intercepted by the bridge deck inlets. If there are no bridge deck inlets, downslope inlets should be provided to intercept all of the bridge drainage. A pipe, paved channel, or trough should be used to transport the water down the surface of the embankment.

At bridge ends where the approach roadway has curb and gutter, catch basins should be detailed as close as possible to the approach slabs.

18.3 CLOSED DRAINAGE SYSTEM

18.3.1 General

The information presented in Section 18.2 for open bridge deck drainage design also applies to the closed drainage design. Section 18.3 discusses hydraulic and other design considerations that are specific to the underdeck closed drainage system.

18.3.2 Hydraulic Considerations

As discussed in Section 18.1, the Hydraulic Engineering Section performs the hydraulic design of the underdeck closed drainage system for in-house-designed projects. The Hydraulic Engineering Section will size the system to ensure that the allowable water spread criteria is met and that suitable outfalls are used. Typically, the hydraulic design will be based on the following limiting criteria:

1. Minimum Pipe Size. The minimum pipe size is 8 in.

2. Minimum Velocity. The minimum velocity is 3 ft/sec.

3. Pipe Material. SCDOT requires fiberglass for underdeck pipes.

4. Minimum Slope. In general, the steeper the longitudinal slope of the underdeck pipes the better, because this will maximize the transport of debris, sand, silt, etc., to keep the pipes clean. SCDOT has not adopted a minimum pipe slope criteria; therefore, the longitudinal slope should be designed based on the following:

    - Ensure that the minimum velocity of 3 ft/sec will be generated.

    - Avoid placing any portion of the longitudinal run below the bottom of the girder/beam to avoid any degradation of aesthetics.

5. Other Considerations. Design the underdeck closed drainage system to minimize sharp bends, corner joints, junctions, etc. These occasionally reduce the hydraulic capacity of the system but, more importantly, these features provide opportunities for debris to snag and collect. Y-connections and bends should be used for collector pipes and downspouts to help prevent clogging in mid-system.

18.3.3 Design Practices

As discussed in Section 18.1, for in-house-designed projects, the Bridge Design Section is responsible for all aspects of the underdeck closed drainage system design except the hydraulic design. Closed drainage systems are often in inlet control. When this is the case, the underdeck closed drainage should be designed for structural, aesthetic, and maintenance considerations.

18.3.3.1 Bridge Deck Inlet Location

As indicated in Section 18.3.1, the location of bridge deck inlets for a closed drainage system will be determined by the same methodology as for an open drainage system. However, it may be beneficial to adjust the location of bridge deck inlets to better accommodate the underdeck closed drainage system. The designer should consider the following:

1. Location With Respect to Superstructure. Bridge deck drainage inlets should be located outside of or between superstructure elements to facilitate maintenance and minimize potential corrosion, condensation, and leaking concerns.

2. Location With Respect to Bents. Bridge deck drainage inlets may be located near interior or end bents. These drains may then conveniently lead to pipes that are attached to the bent caps and then attached to a column discharging near the column base.

18.3.3.2 Structural and Aesthetic Considerations

The underdeck closed drainage system shall not be enclosed within the structural members. They may be enclosed in a facade or be exposed and attached to exterior surfaces. Consider the following:

1. Enclosed. Where pipes are enclosed in a facade, the outlet should be daylighted above the ground to provide access for backflushing, rodding, or air-pressure cleaning equipment. From an aesthetic perspective, this is the preferred choice.

2. Exposed. Where aesthetics are not an issue, attaching the underdeck closed drainage system to the structural elements is often the best choice. Where pipes will be exposed, the designer should devote some attention to aesthetics. Pipes affixed to exterior surfaces of structures can detract from the bridge's architectural aesthetics. To avoid this, pipes can be located in slots in the back of columns. Exposed pipes should be parallel to the existing lines of the structure and pigmented to match the color of the bridge. Any exposed hardware should be painted. See Section 18.3.4 for coloring requirements.

18.3.3.3 Maintenance Considerations

The following will help facilitate the proper maintenance of the closed drainage system:

1. Inlet Traps. All closed drainage systems shall have grated inlets. The configurations of manufactured inlet chambers, grate openings, and curb openings often are arranged to attempt to prevent debris except sand and grit from entering the piping system. Not all schemes are successful and all require periodic maintenance to have any chance of performing their intended function. Designers need to evaluate the manufacturers' configurations to ensure inlets can be easily maintained.

2. Cleanouts/Maintenance Downspouts. Cleanouts (maintenance access) should be provided at key points within the system to facilitate the removal of obstructions. Downspouts should be located so that the maintenance crew can access them from underneath the bridge and preferably from the ground. Figure 18.3-1 shows possible upward and downward cleanouts.

   Preferably, water should be conveyed straight down from the inlet.

   Access holes should be provided at the bottom end of a system for pressure backflushing. An open hole into a catch basin provides the best backflushing access. Where manual flushing systems are provided, the valves should be easily accessible without hazard from passing traffic.

18.3.3.4 Outfall Design

An outlet pipe should freely discharge into the receiving system. Placing the invert of the outfall pipe above the invert of the receiving system will help avoid clogging at the outlet.

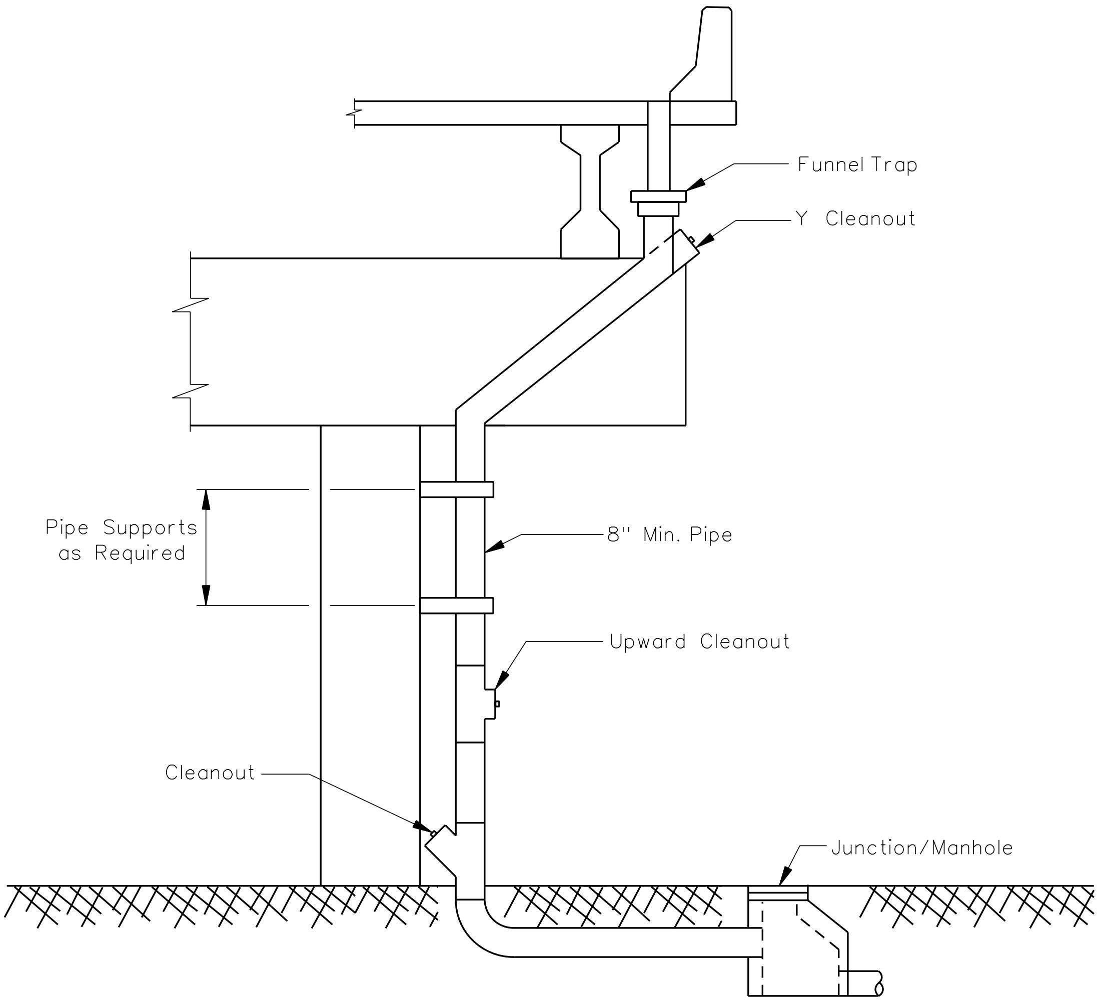
Longitudinal pipes shall not be detailed under any portion of the approach slab.

If the outlet discharges into a natural channel, the exit velocity will likely be high because of the steep slope, and erosion protection (such as riprap) will be required.

Where the outfall for the underdeck closed drainage system will free fall, the discussion in Section 18.2 on scupper outlets will also apply.

18.3.4 Type of Pipe

Underdeck drainage pipes shall be fiberglass meeting the requirements of ASTM D-2996 and the accelerated UV weathering performance requirements of ASTM G154. If the pipes are visible, they shall be pigmented to match the girders with pigmented resin throughout the wall. Color shall be light gray (Federal Shade No. 26622) for concrete beam and painted steel girder bridges, or brown (Federal Shade No. 30045) for the superstructure portion of weathering steel girder bridges.



CLEANOUT LOCATIONS

Figure 18.3-1

Chapter 19

FOUNDATIONS

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 19

FOUNDATIONS

A critical consideration for the satisfactory performance of any structure is the proper selection and design of a foundation that will provide adequate support and aesthetic compatibility. Tolerable lateral and vertical movements shall be included for this support. This Chapter discusses SCDOT-specific criteria that are supplementary to Section 10 of the *LRFD Specifications* for the design of piles, drilled shafts, and spread footings. Section 12.5 presents Department criteria for the selection of foundation type within the context of structure-type selection. This Chapter does not discuss the geotechnical design for foundations (e.g., shear strength of surrounding soil, settlement calculations), which are discussed in the *SCDOT Geotechnical Design Manual*. Seismic design requirements for foundations are presented in the *SCDOT Seismic Design Specifications for Highway Bridges*.

19.1 GENERAL

This Chapter is based upon the load and resistance factor design (LRFD) methodology. The following summarizes the concepts in the *LRFD Specifications*.

19.1.1 Design Methodology

Considering basic design principles for foundations, the *LRFD Bridge Design Specifications* implemented a major change compared to those principles in the AASHTO *Standard Specifications for Highway Bridges*. The *LRFD Specifications* makes a clear distinction between the strength of the in-situ materials (soils and rocks) supporting the bridge and the strength of the structural components transmitting force effects to these materials. The distinction is emphasized by addressing in-situ materials in Section 10 "Foundations" and structural components in Section 11 "Abutments, Piers, and Walls." It is necessitated by the substantial difference in the reliability of in-situ materials and man-made structures. The foundation provisions of the *LRFD Specifications* are essentially strength design provisions with a primary objective to ensure equal, or close to equal, safety levels in all similar components against structural failure.

The target safety levels for each type of foundation are selected to achieve a level of safety comparable with that inherent in those foundations designed with the AASHTO *Standard Specifications*. This approach differs from that for superstructures, where a common safety level has been selected for all superstructure types.

Historically, the primary cause of bridge collapse has been the scouring of in-situ materials. Accordingly, the *LRFD Specifications* introduced a variety of strict provisions in scour protection, which may result in deeper foundations.

Section 13.1 discusses the application of load factors to both superstructure and substructure design in the LRFD Equation.

19.1.2 Design Team/Geotechnical Coordination (For In-House-Designed Projects)

19.1.2.1 General

Prior to designing the foundation, the bridge designer must have a knowledge of the environmental, thermal, and loading conditions expected during the life of the proposed bridge. The primary function of the foundation is to spread concentrated loads over a sufficient area to provide adequate bearing capacity and limitation of movement. Quite often, it is necessary to transfer loads through unsuitable foundation strata to suitable strata. Therefore, a knowledge of the subsurface soil conditions, ground water conditions, and scour is necessary.

The Geotechnical Design Section (GDS) is responsible for developing a soil exploration program and preparing a Preliminary Geotechnical Report (PGR) and a Bridge Geotechnical Report (BGR). The Design Team uses these reports to design bridges and bridge-related structures. The successful integration of the geotechnical design recommendations into the bridge design will require a close coordination between the GDS and the Design Team.

19.1.2.2 Preliminary Geotechnical Report (PGR)

The PGR provides general geotechnical recommendations based on existing soil information and any preliminary subsurface investigation that may have been conducted for the project. The general geotechnical recommendations contained in the PGR are used to select the bridge foundation and perform preliminary seismic analyses/evaluations. The geotechnical recommendations contained in this Report are used in conjunction with the input of the Hydraulic Engineer and Design Team to establish the bridge length. Prior to beginning work on preliminary bridge plans, the Design Team Leader will review the PGR to gain knowledge of the anticipated soil conditions at the bridge site and possible foundation types. When drilled shafts or trestle-type pile bents are anticipated, the PGR provides estimates of preliminary point-of-fixity based on anticipated soil conditions. When drilled shaft/pile-supported footings are used, the preliminary point-of-fixity may be estimated at the top of the footing (bottom of the column). When spread footings are anticipated, the PGR provides a preliminary footing elevation and an expected allowable bearing pressure. This preliminary geotechnical information is used to estimate the sizes of foundation members and prepare preliminary bridge plans.

19.1.2.3 Bridge Geotechnical Report (BGR)

19.1.2.3.1 Subsurface Exploration

After the Design Field Review has been conducted, a detailed subsurface soil exploration is performed based on the bridge bent locations and anticipated foundation type. The GDS determines the proposed boring locations and provides the locations to the Design Team. The Design Team plots the locations on the bridge plan and profile sheets and provides copies to the GDS to be used for requesting the subsurface soil exploration. Typically, the structural design of the bridge proceeds based on the recommendations of the PGR while the geotechnical subsurface exploration is being conducted. During this time, the Design Team uses the preliminary point of fixity or preliminary footing elevation to model the substructure. The Design Team determines, verifies, and provides foundation loads or calculated bearing pressures to the GDS. For piles and drilled shafts, the Design Team provides the loads at the centerline of the bent cap or the bottom of the footing. For spread footings, the Design Team provides the calculated bearing pressure at the bottom of the footing. The Design Team also provides the elevation at which the loads or bearing pressures are applied. When the geotechnical subsurface exploration is complete, the GDS will issue a BGR based on the geotechnical data, the preliminary bridge plans, and the loads computed by the Design Team.

19.1.2.3.2 Foundation Design

The BGR is used to design foundations for bridges and bridge-related structures. For drilled shaft/pile bents and drilled shaft/pile-supported footings, the BGR provides estimated pile/shaft tip elevations, the minimum pile/shaft tip elevations required to maintain lateral stability (critical depth), and the necessary soil parameters to develop a p-y soil model of the subsurface that is used to perform foundation lateral soil-structure interaction analyses. The Design Team then performs the lateral soil-structure interaction analysis with computer programs such as LPILE or FB-Pier. The Design Team uses this information to compute lateral displacements and to analyze the structural adequacy of the columns and foundations. The lateral soil-structure interaction analysis is also used to select the appropriate method (point-of-fixity, stiffness matrix, linear stiffness springs, or p-y nonlinear springs) to model the bridge foundation in the structural design software. For spread footings, the BGR provides the estimated footing elevation, ultimate bearing factor, geotechnical resistance factor, and estimates on footing settlements and lateral displacements. The Design Team uses this information to finalize the design of the footing and verify that members are not overstressed. The BGR also includes notes and tables to be placed in the bridge plans.

19.1.2.3.3 Seismic Analysis

For drilled shaft/pile-supported bridges that require a rigorous seismic analysis, the Design Team performs lateral soil-structure interaction analyses using Extreme Event I loadings. If soil liquefaction is anticipated, the GDS will provide the Design Team with foundation downdrag loads due to liquefaction for use in developing the Extreme Event I load combination. The GDS will also provide any lateral soil forces that act on the foundation as a result of seismically induced stability movements of earth retaining structures (e.g., embankments, retaining walls) or lateral soil movements attributable to lateral spread. These additional lateral loads should be included in the Extreme Event I load combinations when performing lateral soil-structure interaction. The GDS will provide the soil parameters necessary to generate a p-y soil model of the subsurface that accounts for cyclic loadings and any liquefied soil conditions. The Design Team then performs the lateral soil-structure interaction analysis with computer programs such as LPILE or FB-Pier. The Design Team uses this information to calibrate the seismic model. The Design Team performs the seismic analysis in accordance with the *SCDOT Seismic Design Specifications for Highway Bridges*.

19.1.2.3.4 Foundation Redesign

If structural members are overstressed or if deflections exceed acceptable limits from any loading combination, then a redesign of the foundation is required. Redesign may include the adjustment of support member spacing or modification of member sizes. When a redesign of the foundation is required, the Design Team must resubmit the redesign information (new foundation layout, sizes, foundation load combinations, etc.) to the GDS. The GDS will analyze the new foundation and resubmit the necessary information to the Design Team.

19.2 PILES

Reference: LRFD Article 10.7

19.2.1 General

Piles serve to transfer loads to deeper suitable strata. Piles may function through skin friction and/or through end bearing. SCDOT uses steel H-piles, steel pipe piles, and prestressed concrete piles, or combination piles-prestressed concrete piles with steel pile extensions.

19.2.2 Pile Selection

Figure 19.2-1 provides guidance in selecting pile types based on their typical usage by SCDOT.

Pile Type	**Soil Conditions and Structural Requirements**
Steel H-pile	Rock or dense soil where lateral flexibility in one direction is desirable
Steel pipe pile	Dense soil where lateral stiffness in both directions is desirable
Prestressed concrete pile	Loose to medium dense soils
Combination pile-prestressed concrete pile with steel pile extension	Non-uniform soils (such as a soft upper layer overlying a dense lower layer)

PILE SELECTION GUIDE

Figure 19.2-1

19.2.3 Pile Types

Generally, only one pile type and size should be used throughout a project. However, it is common practice to use steel piles at end bents when prestressed concrete piles are used at interior bents.

19.2.3.1 Steel H-Piles

The steel H-piles typically used by SCDOT are as follows:

- HP12 x 53
- HP14 x 73
- HP14 x 89
- HP14 x 117 (used where penetration is minimal and driven to very large bearings)

On large projects, where a significant savings may be realized by using non-typical sizes or where the design dictates, other standard AISC sizes may be used.

19.2.3.2 Steel Pipe Piles

Reference: LRFD Articles 6.9.5 and 6.12.2.3

The following applies to the typical use of steel pipe piles on SCDOT projects:

1. Diameter. SCDOT uses pipe pile diameters of 16 in, 18 in, 20 in, or 24 in. The wall thickness is ½ in for all pipe pile sizes.

2. Interior Filler. Steel pipe piles are typically not filled with concrete.

19.2.3.3 Prestressed Concrete Piles

Typical sizes used by SCDOT for prestressed concrete piles are 18 in, 20 in, or 24 in square piles. Spiral reinforcement is permitted in prestressed concrete piles.

19.2.3.4 Combination Pile-Prestressed Concrete Pile with Steel Pile Extension

Pile extensions are used when driving into non-uniform soils. The steel pile extension is used to penetrate into a dense soil layer beneath a soft soil layer. The steel pile extensions typically used by SCDOT are as follows:

- W8 x 58
- HP10 x 57
- HP12 x 53

19.2.4 Pile Length

Reference: LRFD Articles 10.7.1.10, 10.7.1.11, and 10.7.1.12

All piles within a particular bent should be detailed to be the same length where practical. Pile lengths should be shown in whole foot increments.

Piles shall be a minimum of 10 ft in length. At end bents, if the depth to suitable rock strata is less than 10 ft, typical practice is to drive the piles in holes cored in the rock and backfill with Class 4000 DS Concrete. A minimum core depth of 5 ft into scour-resistant rock is recommended. The minimum tip elevation shall reflect the elevation where the required ultimate pile capacity can be obtained, the penetration required to resist lateral pile loads, and the penetration of any overlaying unsuitable soil strata, as specified in LRFD Article 10.7.1.11.

19.2.5 Tip Elevations

The estimated and minimum pile tip elevations shall be shown on the drawing of the structural element. Estimated pile tip elevations shall reflect the elevation where the required ultimate pile capacity is anticipated to be obtained. Minimum pile tip elevations shall reflect the penetration required, considering scour and liquefaction, to support lateral loads.

19.2.6 Design Details

Reference: LRFD Article 10.7.1

19.2.6.1 Battered Piles

Vertical piles are preferred. If battered piles are used, a refined analysis is required.

19.2.6.2 Spacing

Spacing of piles is specified in LRFD Article 10.7.1.5. Center-to-center spacing should not be less than the greater of 30 in or 2½ times the pile diameter or width of pile. The distance from the side of any pile to the nearest edge of footing shall be greater than 9 in.

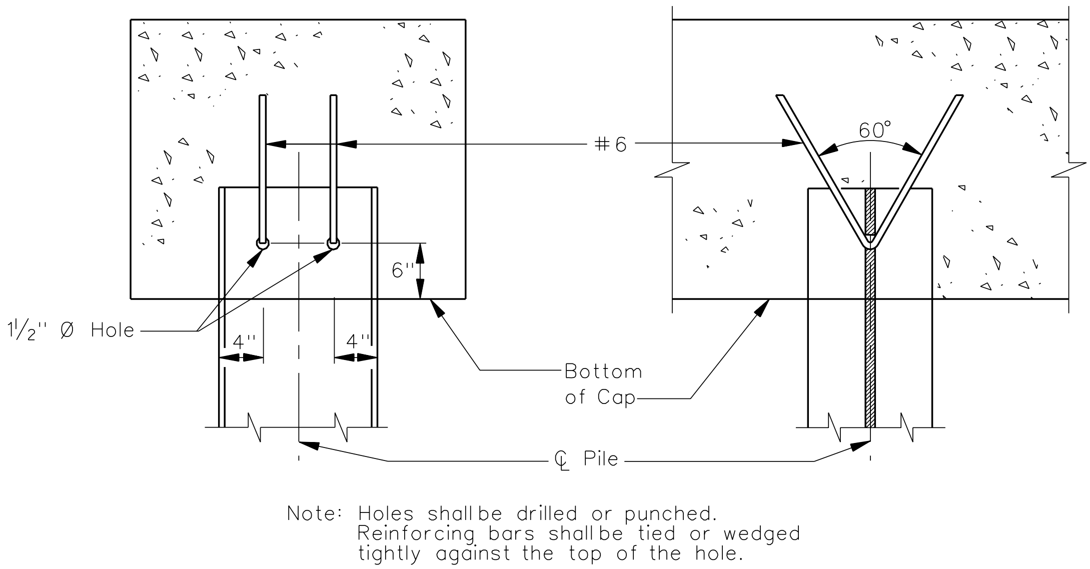
19.2.6.3 Pile Connection Details

The following applies to the connection of piles to pile-supported footings and to bent caps unless seismic analysis dictates otherwise:

1. Steel H-Piles. Two V-shaped #6 reinforcing bars should be used to anchor steel piles to pile-supported footings or bent caps. The diameter of the hole should be limited to 2 times the bar diameter (1½ in). The reinforcing bars shall be tied or wedged tightly against the top of the hole to reduce the possibility of slip between the reinforcing bar anchor and the pile. The reinforcing bars should extend into the cap or footing a minimum of 1′-8″ beyond the bottom mat of reinforcement. See Figure 19.2-2.

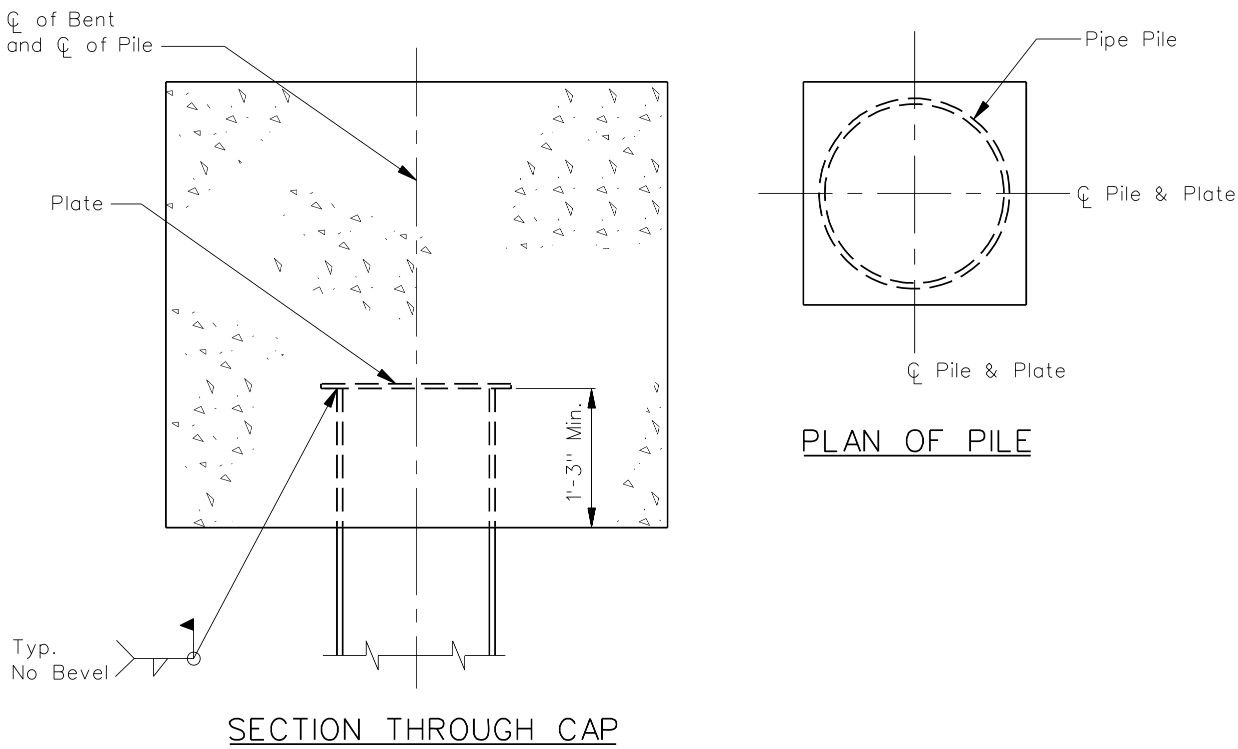
2. Steel Pipe Piles. A fillet-welded square steel end plate, as shown in Figure 19.2-3 should be used to anchor steel pipe piles to pile-supported footings or bent caps. The end plate and fillet weld is sized according to the specific requirements of the foundation. The pipe pile shall be embedded a minimum of 1′-3″.

3. Prestressed Concrete Piles. The piles may be connected to the caps or footings by simply being embedded an equivalent of one pile width. No roughening of the pile is required. However, the pile surface to be embedded shall be clean and free of any laitance prior to placement of the cap or footing concrete.



STEEL H-PILE CONNECTION

Figure 19.2-2



STEEL PIPE PILE CONNECTION

Figure 19.2-3

To allow for constructibility, the pile embedment shall have a tolerance of ±6 in. Unless approved otherwise by the State Bridge Design Engineer, the pile embedment into the cap shall not be less than 12 in.

19.2.6.4 Downdrag (DD) Loads

When a pile penetrates a soft layer subject to settlement, the designer must evaluate the force effects of downdrag or negative loading on the foundations. Downdrag acts as an additional permanent axial load on the pile. At small magnitudes, the downdrag may cause additional settlement. If the force is of sufficient magnitude, structural failure of the pile or a bearing failure at the tip is possible. For piles that derive their resistance mostly from end bearing, the structural resistance of the pile must be adequate to resist the factored loads including downdrag.

Downdrag forces can be mitigated by the following methods:

- provide friction-reducing material, such as bitumen coating or sleeves around the piles;
- construct embankments a sufficient amount of time in advance of the pile driving for the fill to settle; or
- prebore and backfill the space around the installed pile with pea gravel.

19.2.6.5 Uplift Forces

Uplift forces can be caused by lateral loads, buoyancy, or expansive soils. Piles intended to resist uplift forces should be checked for resistance to pullout and structural resistance to tensile loads. The connection of the pile to the cap or footing must also be checked.

19.2.6.6 Laterally Loaded Piles

The resistance of laterally loaded piles must be estimated according to approved methods. Several methods exist for including the effects of piles and surrounding soil into the structural model for lateral loadings including seismic loads. These methods are discussed in Section 19.4.

19.2.6.7 Group Effect

Minimum spacing requirements are not related to group effect. Group effects are specified in LRFD Articles 10.7.3.7.3 and 10.7.3.10.

19.2.6.8 Pile Loads

Applicable pile loads shall be shown in the Plans. See Section 6.3. This information will help ensure that pile driving efforts during the construction process will result in a foundation adequate to support the design loads

19.2.6.9 Reinforced Pile Tips

Where hard layers are anticipated, use reinforced pile tips to minimize damage to the piles. Where rock is anticipated, the pile tips shall be equipped with teeth designed to penetrate into the rock.

19.2.6.10 Pile Load Tests

Reference: LRFD Article 10.7.1.13

Where pile design loads are high or where the pile quantity is large, pile load tests may be justified for economy. The designer should consult with the Geotechnical Design Section if considering pile load testing. Test locations and sizes should be shown in the Plans or described in the Special Provisions.

19.2.6.11 Wave Equation Analysis

Reference: LRFD Article 10.7.1.14

The geotechnical designer performs a Wave Equation analysis for all pile foundations. A Wave Equation analysis is required in the design phase to verify the results of the static analysis and to ensure driveability without damage to the pile or the driving equipment. Another Wave Equation analysis shall be made in the construction phase for approval of the specific driving equipment and methods proposed by the Contractor.

19.3 DRILLED SHAFTS

Reference: LRFD Article 10.8

19.3.1 Usage

Drilled shafts may be an economical alternative to piles. Drilled shafts should also be considered to resist large lateral or uplift loads where deformation tolerances are relatively small. Also use drilled shafts where significant scour is expected, where there are limitations at water crossing work, or where piles are not economically viable due to high loads or obstructions to driving. Limitations on pile driving vibration and/or noise may also dictate the use of drilled shafts.

Drilled shafts derive load resistance either as end-bearing shafts transferring load by tip resistance or as friction shafts transferring load by side resistance or a combination of both. Drilled shafts are typically good for seismic applications, and they are generally applicable to span lengths greater than 50 ft.

19.3.2 Drilled Shaft Axial Resistance at the Strength Limit State

The *LRFD Specifications* provides procedures to estimate the axial resistance of drilled shafts in cohesive soils and cohesionless soils in LRFD Articles 10.8.3.3 and 10.8.3.4, respectively. In both cases, the resistance is the sum of the shaft and tip resistances. LRFD Article 10.8.3.5 discusses the determination of axial resistance of drilled shafts in rock.

19.3.3 Design

The following will apply to the design of drilled shafts:

1. Location of Top of Shaft. Drilled shafts typically extend to the ground line or to at least 12 in above the water elevation expected during construction. If the distance from the top of a shaft to the bottom of a bent cap is less than 5 ft, extend the shaft to the bottom of the bent cap.

2. Rock-Socketed Shafts. Where casing through overburden soils is required, design the shaft as one size and step down when going into a rock socket.

3. Column Design. Because even soft soils provide sufficient support to prevent lateral buckling of the shaft, it may be designed according to the criteria for short columns in LRFD Article 5.7.4.4 when soil liquefaction is not anticipated. If the drilled shaft is extended above ground to form an interior bent or part of a bent, it should be analyzed and designed as a column. The effects of scour around the shafts must be considered in the analysis.

4. Reinforcement. The shaft will have a minimum reinforcement of 1% of the gross concrete area and the reinforcement will extend from the bottom of the shaft into the footing.

5. Casing**.** A casing may be used to maintain the excavation, especially when placing a shaft within the water table. This casing, if left in place after construction, shall not be considered in the determination of the structural resistance of the shaft. However, it should be considered when evaluating the seismic response of the foundation because the casing will provide additional resistance.

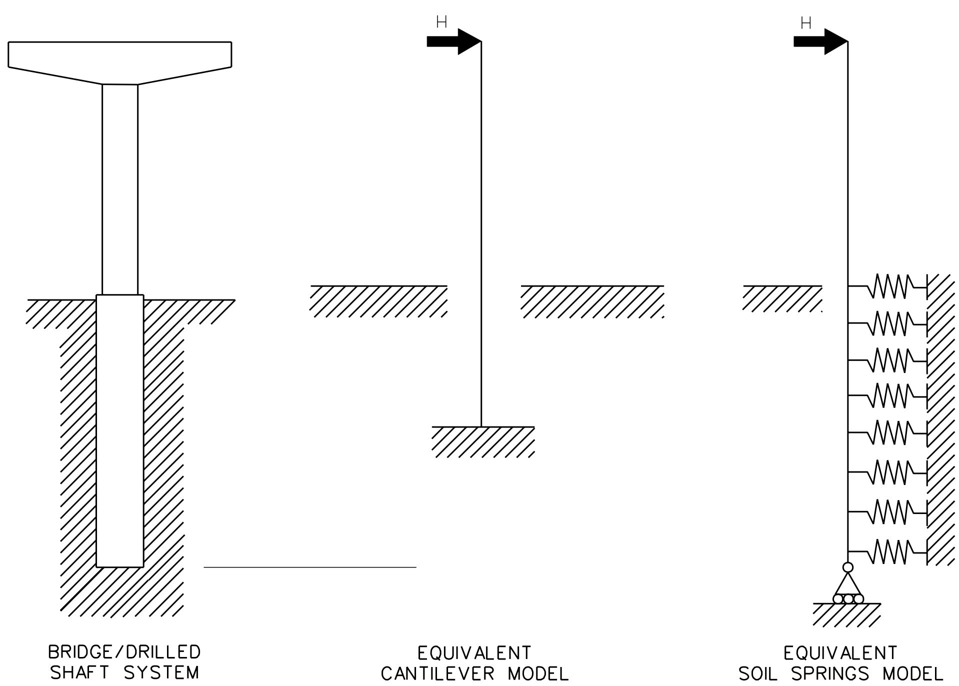
19.4 MODELING FOR LATERAL LOADING

Several possibilities exist for including the effects of piles and surrounding soil into the structural model for lateral loadings including seismic loads. Two of these methods are summarized in Figure 19.4-1 and include:

- equivalent cantilever model, and
- equivalent soil springs model.

The simplest approach is to assume that an equivalent cantilever column can be used to model the pile. The sectional properties of the cantilever are the same as that of the pile, but its length (depth to "fixity") is adjusted to provide either the same stiffness at ground level or the same maximum bending moment as in the actual soil-pile system.

The second technique noted above involves the use of p-y curves to represent the soil. The soil surrounding the pile is modeled as a set of equivalent soil "springs" indicating that the soil resistance "p" is a nonlinear function of the pile deflection "y." A disadvantage of this approach is the substantial increase in the size and complexity of the structural model. The solution's accuracy is primarily a function of the spacing between nodes used to attach the soil springs to the pile (the closer the spacing, the better the accuracy), and is not so dependent on the pile itself. Simple beam column elements are usually adequate for modeling pile behavior. SCDOT uses a computer program such as LPILE or FB-Pier to model equivalent soil springs.



METHODS OF REPRESENTING PILE FOUNDATION STIFFNESS

Figure 19.4-1

19.5 SPREAD FOOTINGS AND PILE/SHAFT-SUPPORTED FOOTINGS

This Section applies to both spread footings supported on soil and to pile/shaft-supported footings.

19.5.1 Usage

As noted in Section 12.5, SCDOT rarely uses spread footings. Spread footings may be used at grade separations where suitable soils or rock are located at a relatively shallow depth (less than 10 ft). They are prohibited:

- at stream crossings where they may be susceptible to scour,
- on fills, and
- beneath bents that are located within the reinforced soil mass associated with MSE walls.

Spread footings are thick, reinforced concrete members sized to meet the structural and geotechnical loading requirements for the proposed structural system. A factor affecting the size of the footing is the structural loading versus the ability of the soil to resist the applied loads.

Pile/shaft-supported footings distribute loads among two or more piles or drilled shafts that support a single column or group of columns.

19.5.2 Dynamic Load Allowance (IM)

Dynamic load allowance (IM), traditionally termed impact, shall be applied to the proportioning of footings to resist moment and shear, if any portion of the footing is above ground. Dynamic load allowance need not be applied to proportion spread footings to resist bearing, sliding, or overturning.

19.5.3 Minimum Dimensions/Materials

The following minimum criteria shall apply:

1. Footing Thickness:
   - Spread Footings: 2′-6″
   - Pile/Shaft-Supported Footings: 3′-6″
2. Compressive Strength: 28 day (for structural design): 4 ksi
3. Reinforcing Steel: f_y = 60 ksi

19.5.4 Footing Thickness and Shear Design

Reference: LRFD Articles 5.8.3, 5.13.3.6, and 5.13.3.8

The footing thickness may be governed by the development length of the footing dowels (footing to wall or column) or by concrete shear requirements. Generally, shear reinforcement in footings should be avoided. If concrete shear governs the thickness, it is usually more economical to use a thicker footing without shear reinforcement instead of a thinner footing with shear reinforcement.

19.5.5 Footing Elevation

The following will apply:

1. For grade-separation projects, the footing elevation shall be set to maintain a minimum of 2 ft of backfill above the top of the footing. When setting the footing elevation, consideration should also be given to future widenings.

2. For "waterline" footings, the bottom of the footing elevation shall be set a minimum of 1 ft below the mean low-water elevation.

3. At shallow stream crossings, the top of the footing should be set at or below the streambed elevation to minimize the potential for debris buildup.

4. For footings in navigable waters, the top of the footing shall be set either low enough to not present a hazard to the waterway traffic or high enough to be clearly visible to the waterway traffic.

19.5.6 Bearing Resistance and Eccentricity

Reference: LRFD Article 10.6.3

The required ultimate bearing and the geotechnical resistance factor shall be shown in the plans. See Section 6.3.

19.5.6.1 Soils Under Footings

Reference: LRFD Article 10.6.3.1.5

In contrast to the approach in the AASHTO *Standard Specifications*, a reduced effective footing area based upon the calculated eccentricity is used to include these effects. Uniform design bearing pressure is assumed over the effective area. This uniform-pressure model acknowledges the plastic nature of soil. An example is provided in Figure 19.5-2.

The location of the resultant of the center of pressure based upon factored loads should be within the middle ½ of the base.

19.5.6.2 Rock

Reference: LRFD Article 10.6.3.2.5

Following the traditional approach, a triangular or trapezoidal pressure distribution is assumed for footings on rock. This model acknowledges the linear-elastic response of rock.

The location of the resultant center of pressure based upon factored loads should be within the middle ¾ of the base.

19.5.7 <u>Sliding Resistance</u>

Reference: LRFD Article 10.6.3.3

Use the coefficients of friction in the *LRFD Specifications* for sliding resistance.

Keys in footings to develop passive pressure against sliding are not very effective, and their economic justification is often over estimated. However, when it becomes necessary to use a key, the designer shall prepare studies early in project design to evaluate this issue.

19.5.8 <u>Settlement</u>

Reference: LRFD Articles 3.12.6, 10.6.2.2, and 10.7.2.3

Differential settlement (SE) is considered a superstructure load in the *LRFD Specifications*. Generally, due to the methods used by SCDOT to proportion foundations, settlements are within a tolerable range and, therefore, force effects due to differential settlement need not be investigated. If varying conditions exist, settlement will be addressed in the Bridge Geotechnical Report, and the following effects should be considered:

1. <u>Structural</u>. The differential settlement of substructures causes the development of force effects in continuous superstructures. These force effects are directly proportional to structural depth and inversely proportional to span length, indicating a preference for shallow, long-span structures. They are normally smaller than expected and tend to be reduced in the inelastic phase. Nevertheless, they may be considered in design if deemed significant, especially those negative movements that may either cause or enlarge existing cracking in concrete deck slabs.

2. <u>Joint Movements</u>. A change in bridge geometry due to settlement causes movement in deck joints that should be considered in their detailing, especially for deep superstructures.

3. Profile Distortion. Excessive differential settlement may cause a distortion of the roadway profile that may be undesirable for vehicles traveling at high speed.

4. Appearance. Viewing excessive settlement may create a feeling of lack of safety.

Angular distortions between adjacent foundations greater than 0.008 radians in simple spans and 0.004 radians in continuous spans should not be ordinarily permitted.

19.5.9 Reinforcement

Reference: LRFD Articles 5.10.8 and 5.13.3

Unless other design considerations govern, the reinforcement in footings should be as follows:

1. Steel in Top of Footing. For pile/shaft-supported footings, the anchorage of piles or drilled shafts into footings requires tension reinforcement in the top of the footing to resist the potential negative bending under seismic action. The minimum reinforcement in the top of the footing in both directions shall be #6 bars at 12 in on center.

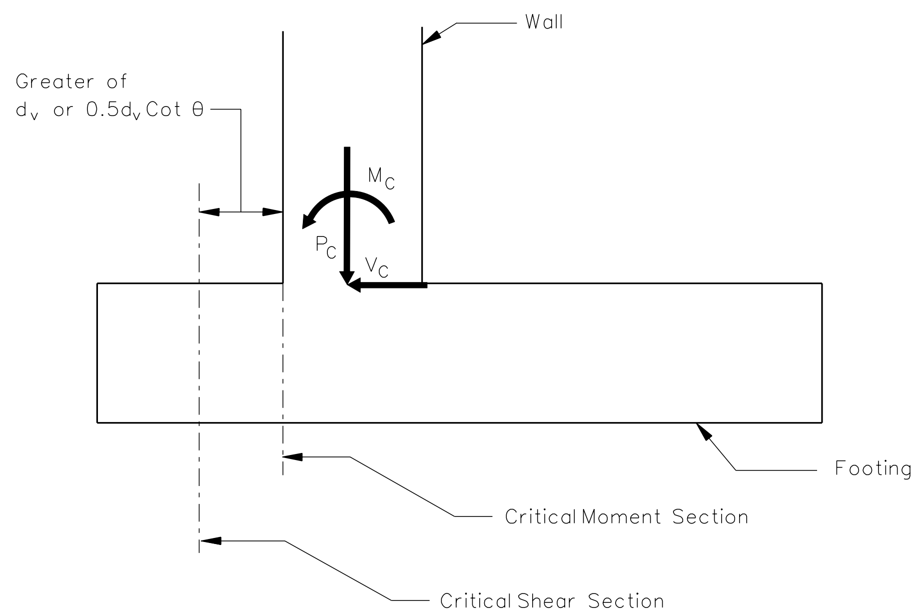
2. Embedment Length. Vertical steel extending upwards out of the footing shall also extend down to the bottom footing steel and shall be hooked on the bottom end regardless of the footing thickness. Bar embedment lengths shall be shown on the plans.

3. Spacing. The minimum spacing of reinforcing steel in either direction is 6 in on center; the maximum spacing is 12 in on center.

4. Other Reinforcement Considerations. LRFD Article 5.13.3 specifically addresses concrete footings. For items not included, the other relevant provisions of Section 5 should govern. For narrow footings, to which the load is transmitted by walls or wall-like bents, the critical moment section shall be taken at the face of the wall or bent stem; the critical shear section is a distance equal to the larger of "d_v" (d_v is the effective shear depth of the footing) or "$0.5d_v \cot \theta$" (θ is the angle of inclination of diagonal compressive stresses as defined in LRFD Article 5.8.3.4) from the face of the wall or bent stem where the load introduces compression in the top of the footing section. See Figure 19.5-1. For other cases, either LRFD Article 5.13.3 is followed, or a two-dimensional analysis may be used for greater economy of the footing.

19.5.10 Joints

Footings do not generally require construction joints. Where used, footing construction joints should be offset 2 ft from expansion joints or construction joints in walls and should be constructed with 3-in deep keyways placed in the joint.



CRITICAL SECTIONS FOR MOMENT AND SHEAR FOR WALLS OR WALL-LIKE PIERS

Figure 19.5-1

19.5.11 Stepped Footings

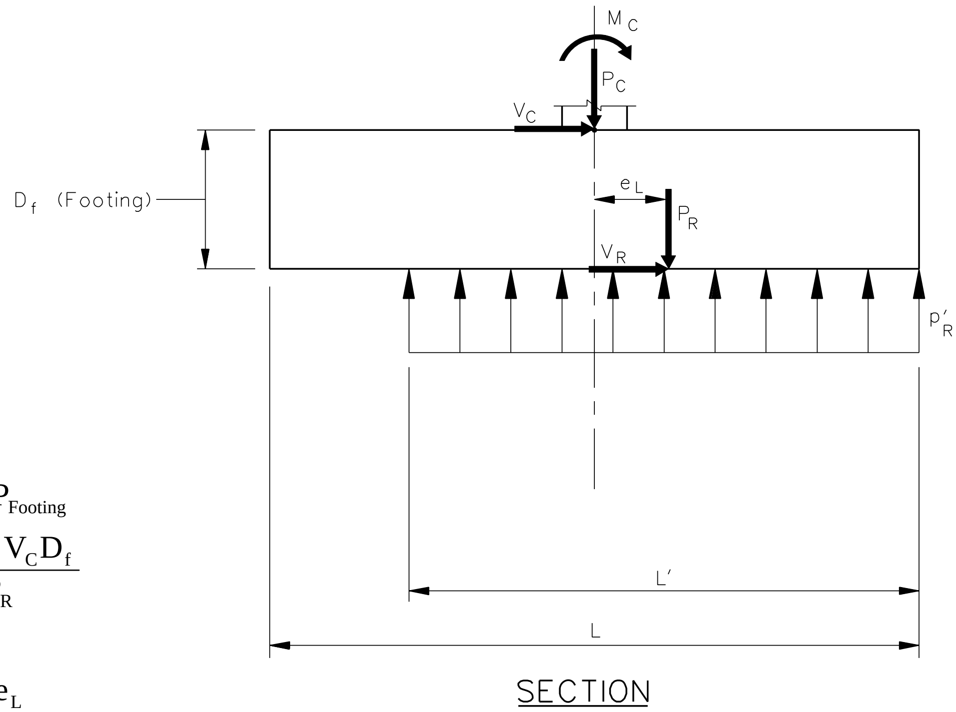
The difference in elevation of adjacent stepped footings should not be less than 6 in. The lower footing should extend at least 2 ft under the adjacent higher footing.

19.5.12 Example Analysis of a Spread Footing on Competent Soil

See Figure 19.5-2 for a schematic example of a spread footing on soil to support an interior bent at a grade separation.

19.5.13 Example Analysis of Pile-Supported Footings

See Figure 19.5-3 for a schematic example of the analysis of a pile-supported footing to support an interior bent at a stream crossing (fixed-pile connection). See Figure 19.5-4 for a similar footing assuming a pinned pile connection.



$$P_R = P_C + P_{Footing}$$

$$e_L = \frac{M_C + V_C D_f}{P_R}$$

$$V_R = V_C$$

$$L' = L - 2e_L$$

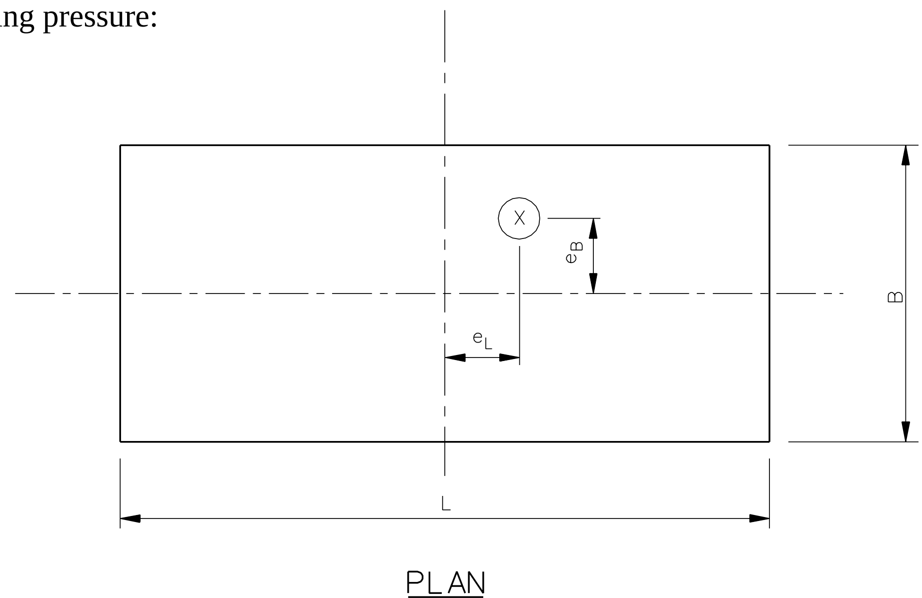
In two dimensions, bearing pressure:

$$p'_R = \frac{P_R}{(L')(B')}$$

Where:

$$L' = L - 2e_L$$

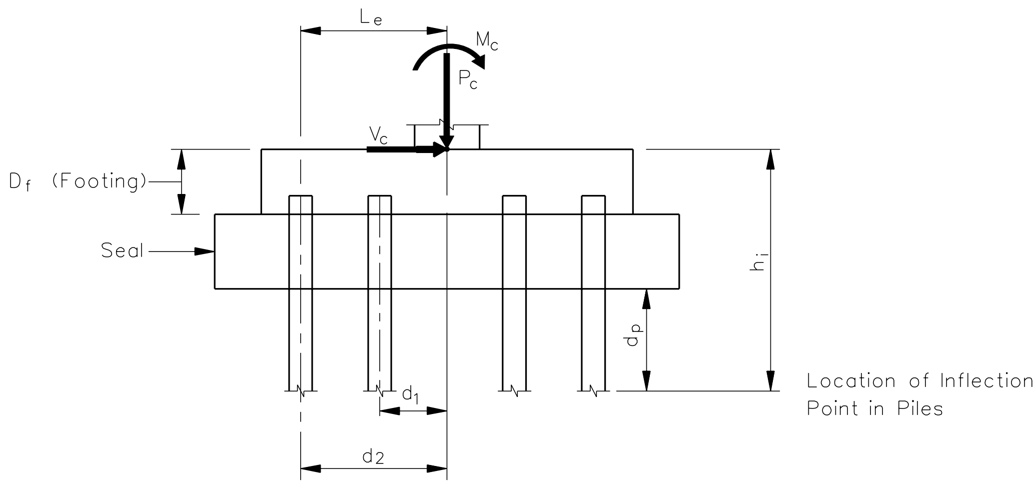
$$B' = B - 2e_B$$



Note: See LRFD Article 10.6.3.1.5.

EXAMPLE ANALYSIS OF SPREAD FOOTING ON COMPETENT SOIL

Figure 19.5-2



$P_R = P_c + P_{footing} + P_{seal} - \text{Buoyancy}$

Assumptions: Pile footing is rigid (footing is considered rigid if $L_e/D_f \leq 2.2$). Pile connections are fixed and shear forces per pile are significant.

To obtain forces in piles, sum moments about inflection point:

$$P_{max} = \frac{P_R}{\#\text{ of piles}} + \frac{(V_c h_i + M_c)\, d_2}{I_z}$$

$$P_{min} = \frac{P_R}{\#\text{ of piles}} - \frac{(V_c h_i + M_c)\, d_2}{I_z}$$

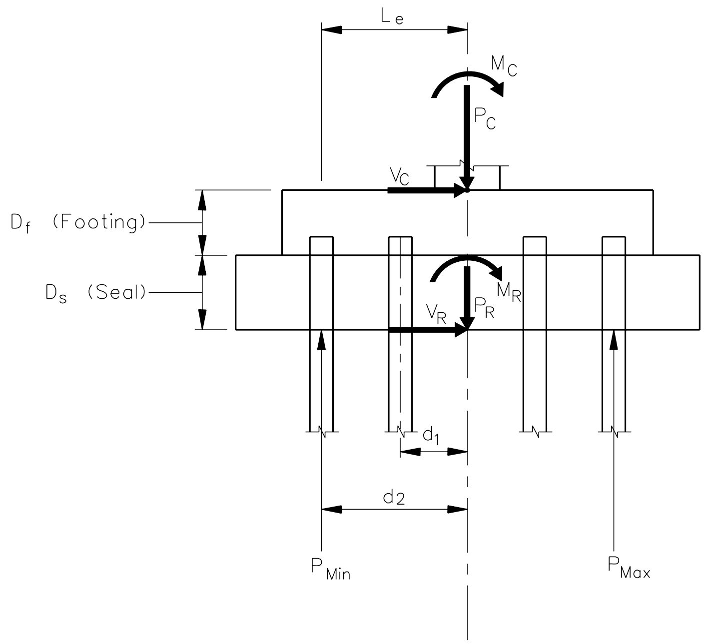
$$I_z = 2\left(d_1^2 + d_2^2\right)$$

$$V_{pile} = \frac{V_c}{\#\text{ of piles}}$$

$$M_{pile} = V_{pile}\, d_p$$

EXAMPLE ANALYSIS OF PILE-SUPPORTED FOOTING
(Fixed-Pile Connection)

Figure 19.5-3



$P_R = P_c + P_{footing} + P_{seal} - \text{Buoyancy}$

Assumptions: Pile footing is rigid (footing is considered rigid if $L_e/D_f \leq 2.2$). Pile connections are pinned, or shear force in pile is small.

$V_R = V_c - V_{\text{passive soil pressure on footing and seal}}$ *Note: Passive soil pressure is typically ignored.*

$M_R = M_c + V_c (D_f + D_s)$

Pile Loads:

$$P_{max} = \frac{P_R}{\#\text{ of piles}} + \frac{M_R\ d_2}{\Sigma d_i^2}$$

$$P_{min} = \frac{P_R}{\#\text{ of piles}} - \frac{M_R\ d_2}{\Sigma d_i^2}$$

EXAMPLE ANALYSIS OF PILE-SUPPORTED FOOTING
(Pinned-Pile Connection)

Figure 19.5-4

Chapter 20

SUBSTRUCTURES

SCDOT BRIDGE DESIGN MANUAL

April 2006

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(Continued)

CHAPTER 20

SUBSTRUCTURES

Section 11 of the *LRFD Bridge Design Specifications* discusses design and detailing requirements for abutments, piers, and walls. The *LRFD Specifications* uses the term "abutment" to designate bridge end supports; SCDOT's use of the term "end bent" is synonymous with the LRFD term "abutment." Similarly, the *LRFD Specifications* uses the term "pier" for intermediate supports while SCDOT uses "interior bent" synonymously. This Chapter presents SCDOT supplementary information on the design of these structural components. Section 12.4 of the *SCDOT Bridge Design Manual* presents Department criteria for the selection of substructure components within the context of structure type selection.

20.1 BENT CAPS

20.1.1 General

The provisions of Section 20.1 pertain to cast-in-place, reinforced concrete bent caps for end and interior bents. Provisions specific to the type of bent follow under the heading of that bent type. The following apply:

1. Precast. Precast bent caps shall not be used.

2. Post-Tensioning. In general, post-tensioning should be avoided. However, when necessary, post-tensioning may be used for bent caps. Over or adjacent to tidal waters, post-tensioning of bent caps is only permitted if the tendons are at least 20 ft above high tide.

20.1.2 Minimum Dimensions

The minimum cap widths and depths are given in Figures 20.1-1 and 20.1-2, respectively. Wider caps shall be used for bents having more than 1 row of piles. For pile sizes greater than 18 in, the minimum depths shall be increased as necessary to accommodate the pile embedment.

20.1.3 Minimum Clearances

20.1.3.1 Bent-Cap Width

For prestressed concrete beam or steel girder superstructures, the distance from the side face, step, or build-up of a concrete cap to the centerline of the anchor bolt shall not be less than 6 in, nor shall the distance to any edge or corner of the elastomeric bearing or masonry plate be less than 3 in.

Type of Pile	**Minimum Cap Width (Single Row of Vertical Piles)**
HP 12 x 53	2′-6″
HP 14 x 73	2′-8″
18-in square prestressed concrete	3′-0″
20-in square prestressed concrete	3′-2″
24-in square prestressed concrete	3′-6″

MINIMUM CAP WIDTHS FOR PILE-SUPPORTED BENTS

Figure 20.1-1

Type of Pile	**Minimum Cap Depth**
Single Row of Piles	2′-6″
Double Row of Piles	3′-0″

MINIMUM CAP DEPTHS FOR PILE-SUPPORTED BENTS

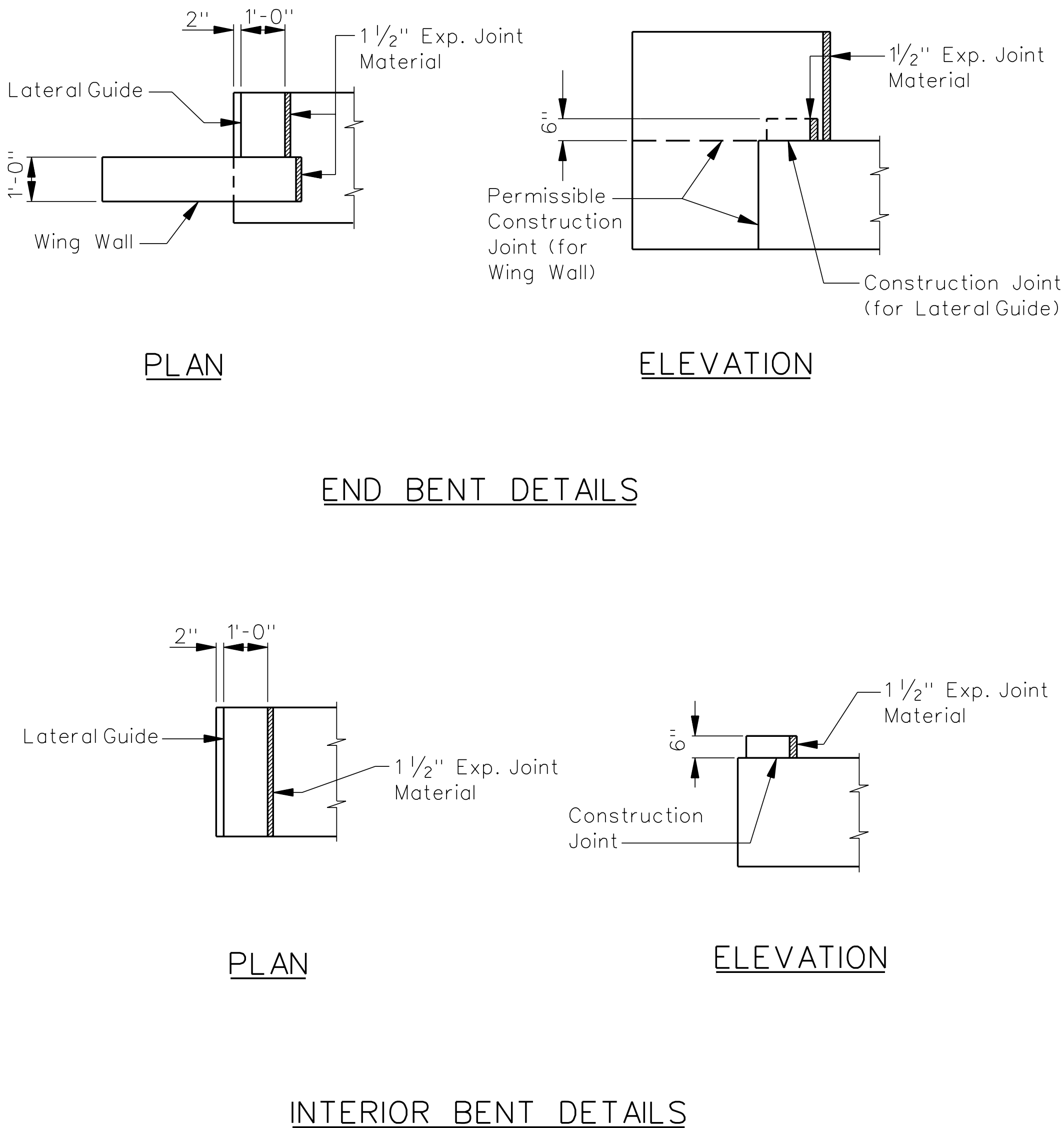
Figure 20.1-2

For bents, the width of caps shall project beyond the sides of the columns. The added width of the cap shall be a minimum of 3 in on each side of the column. This width reduces the reinforcement interference between the column and cap. The cap width shall be adequate to accommodate the joint shear requirements of the *SCDOT Seismic Design Specifications* for *Highway Bridges*.

20.1.3.2 Bent-Cap Length

The length of interior bent caps should provide a minimum of 9 in from the centerline of the anchor bolt to the end of the bent cap. The length of interior bent caps should also provide a minimum of 9 in from the edge or corner of the elastomeric bearing or masonry plate to the end of the bent cap.

For cored slab structures, bent caps shall be detailed with a concrete lateral guide at the outside face of the exterior slab units; see Figure 20.1-3. Provide 1½-in expansion joint material between the cored slab and lateral guide and, if approach slabs are detailed, provide 1½-in expansion joint material between the approach slab and wing wall.



LATERAL GUIDE FOR CORED SLAB BRIDGES

Figure 20.1-3

20.1.4 Construction Joints

In general, use a construction joint where the cap length exceeds 70 ft. Locate this construction joint near the middle of the cap at the one-quarter point between supporting elements.

20.1.5 Beam Seat Elevations

If the elevation difference between any two adjacent beam seats is:

- less than $^3/_{16}$ in, detail the build-up level and use the lower elevation for both beam seats;
- $^3/_{16}$ in to less than 1 in, use the lower elevation for both beam seats, detail a booster plate with the bearing plate, and allow the Contractor the option to combine the booster plate with the bearing plate; or
- 1 in or greater, detail a split level build-up.

20.1.6 Cap Reinforcement

20.1.6.1 Longitudinal Reinforcement

The minimum number and size of main reinforcing bars for both top and bottom mats of the bent cap shall be as shown in Figure 20.1-4. The main reinforcing bars shall be designed or detailed in no more than two layers. The designer shall not use bundled reinforcing bars. In addition to these detailing requirements, the longitudinal reinforcement shall also meet the design requirements of Chapter 15 and LRFD Section 5.

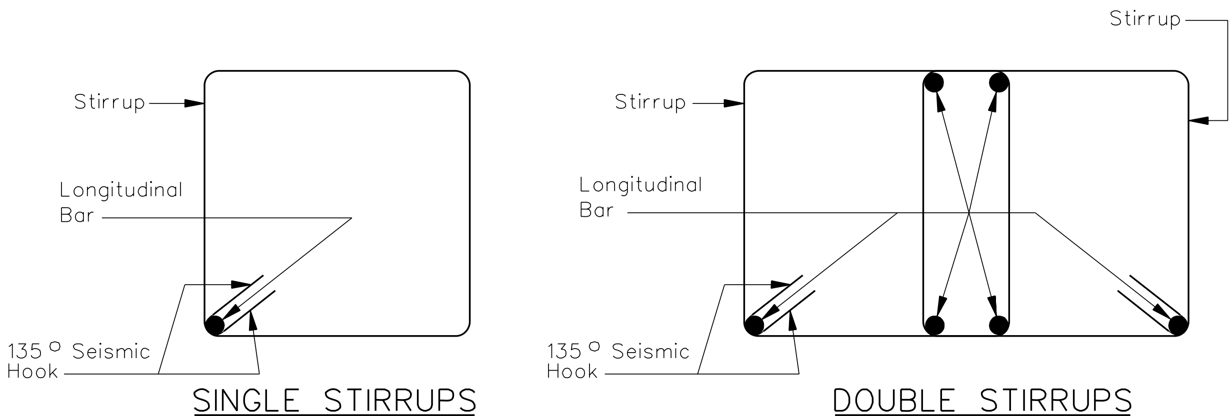
Cap Width	Reinforcing Steel
≤ 3′-0″	4 #9 bars or equivalent
3′-0″ - 4′-0″	5 #9 bars or equivalent
4′-0″ - 5′-0″	6 #9 bars or equivalent
5′-0″ - 5′-8″	7 #9 bars or equivalent

MINIMUM LONGITUDINAL REINFORCEMENT

Figure 20.1-4

20.1.6.2 Transverse Reinforcement

All cap stirrups located between columns or piles shall be one piece, using enclosed hoops with 135° seismic hooks at one corner as shown in Figure 20.1-5. The 135° seismic hooks shall have extensions no less than the larger of 10 bar diameters or 6 in. The size and spacing of the stirrups shall be according to the *LRFD Specifications*. The minimum transverse reinforcement shall be #5 stirrups. The maximum spacing of stirrups shall be 12 in. For cap widths of 4′-6″ or greater, double stirrups should be used. When double stirrups are used, provide a minimum of four longitudinal bars between the overlapping stirrups as shown in Figure 20.1-5.



CAP STIRRUPS

Figure 20.1-5

20.1.6.3 Caps with Build-ups

In level caps where build-ups are detailed to accommodate superelevation or roadway crown, provide additional reinforcement in build-ups greater than 4 in tall. The additional reinforcement shall consist of a minimum of #4 U-shaped reinforcing bars spaced at a maximum of 12 in each way. These reinforcing bars shall be properly developed into the bent cap.

20.1.7 <u>Sloped Caps</u>

The designer may consider sloping the cap following the superelevation or crown in the roadway surface. If the required build-up to accommodate the superelevation or roadway crown on a level cap exceeds 12 in, the cap shall be sloped.

20.1.8 <u>Design Procedures</u>

The strut-and-tie model of LRFD Article 5.6.3 should be considered where the distance between the centers of applied load and/or the supporting reactions is less than approximately twice the cap depth. Otherwise, the sectional models for moment and shear are appropriate.

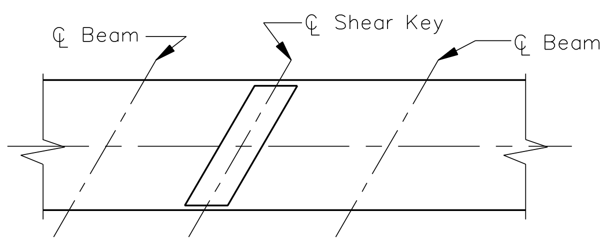
20.1.9 Shear Restraints

To accommodate seismic and other lateral loads, beam or girder spans may be detailed with shear keys cast on the cap to provide a shear transfer between the superstructure and the substructure. Shear keys shall be skewed parallel to the girders as shown in Figure 20.1-6. The substructure shall be checked for the loading transferred by the shear key. If other types of connections are proposed, the detail shall be approved by the State Bridge Design Engineer before use, and the structure shall be analyzed and designed accordingly.

A minimum of 20% of the superstructure dead load shall be used for designing the shear restraints.

20.1.10 Beam and Girder Anchorage

All beam or girder spans, including both steel and concrete, shall be anchored to the substructure on both ends with anchor bolts or dowels. The design of the anchor system shall address both horizontal and vertical loads. Connections between slabs and caps on flat slab bridges shall also be designed for seismic loads. See the *SCDOT Seismic Design Specifications for Highway Bridges*.



SHEAR KEY PLAN VIEW

Figure 20.1-6

20.2 END BENTS/WING WALLS

20.2.1 General

See Section 12.4 for a general discussion on end bents.

20.2.2 Loads

Reference: LRFD Articles 3.11, 11.6.1.1, and 11.6.1.3

The static earth pressure shall be determined in accordance with Article 3.11 of the *LRFD Specifications*.

Load effects from the approach slabs shall be included in the design of end bents. One half of the total dead load of the approach slab shall be applied as a concentrated transverse line load on the end bent. For the determination of live-load effects from the approach slab, the approach slab may be considered to be simply supported.

20.2.3 General End Bent Design and Detailing Criteria

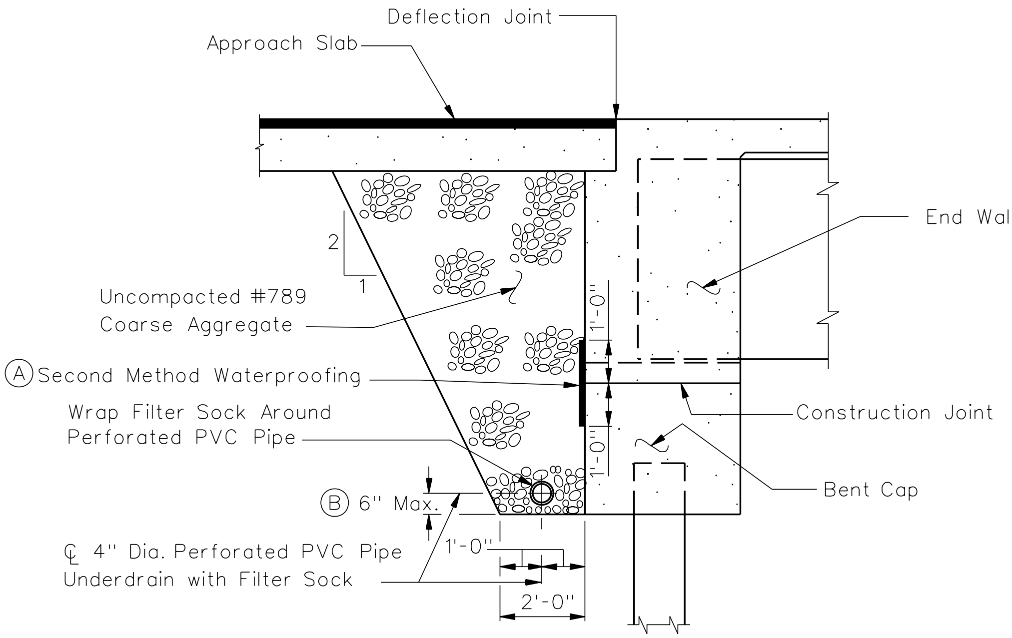
The following applies to the design and detailing of end bents:

1. End Bent Elevation. The top of the bent cap shall be a minimum of 12 in above the surrounding grade. The bottom of the bent cap shall be a minimum of 12 in below the surrounding grade. See Figure 20.2-2.

2. Expansion Joints. Vertical expansion joints should be considered for wall lengths exceeding 90 ft. In this case, a water stop or other means of control shall be used to prevent leakage.

3. Backfill. The embankment adjacent to the end bents of all prestressed and structural steel end spans shall be detailed with backfill material and underdrain as shown in Figure 20.2-1. Additionally, the construction joint between the end wall and the bent cap shall be waterproofed.

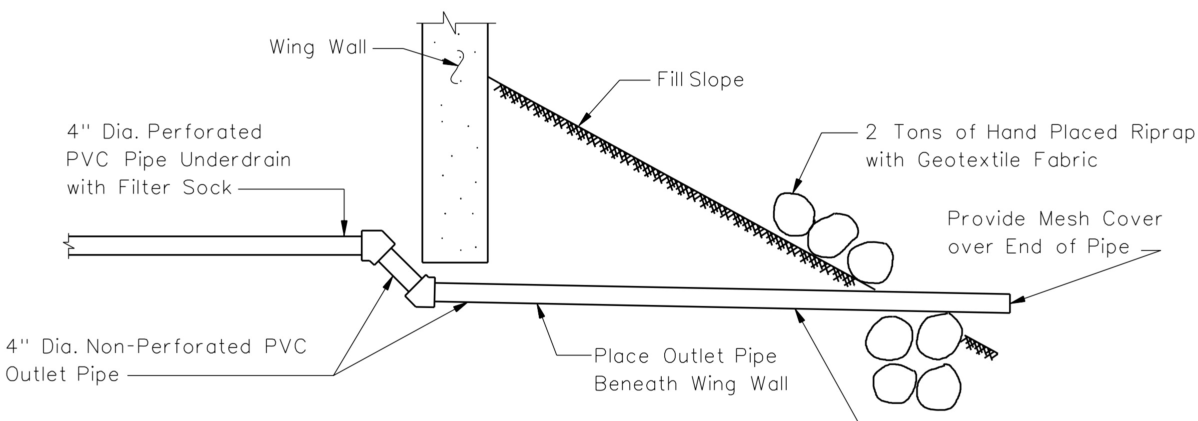
   The 4-in diameter perforated PVC pipe underdrain shall comply with the *SCDOT Standard Specifications*. Filter sock shall be geotextile for drainage filtration, Class I fabric (protected). The unit price bid for the underdrain shall include all costs of furnishing and installing the 4-in diameter perforated PVC pipe underdrain, filter sock, uncompacted #789 coarse aggregate, 4-in diameter non-perforated PVC outlet pipe, riprap, and geotextile fabric for riprap. Measurement of the underdrain shall be based on the weight of the aggregate, and all costs associated with the construction of the outlets shall be considered incidental and included in the unit price bid for the underdrain. For estimating the weight of the aggregate, a unit weight of 1½ tons per cubic yard shall be assumed. The weight shall be rounded to the nearest ton.



PIPE UNDERDRAIN DETAIL

Ⓐ Second Method Waterproofing shall extend the full length of the End Wall and Wing Wall. See the Standard Specifications.

Ⓑ Slope Pipe a minimum of 0.5% to drain.



PIPE OUTLET DETAIL

END WALL DETAILS

Figure 20.2-1

4. End Bent Top Surfaces. Beam seats shall be level. For free-standing end bent caps, the remaining exposed top surfaces shall be transversely sloped away from the fill face.

5. Pavement Rest. Provide a minimum pavement rest width of 8 in.

6. Bridge Approach Joints. Provide a terminal joint or pavement relief joint at the end of the roadway at the bridge approach slab if the roadway pavement is concrete.

7. Skewed Bridges. For skew angles greater than 20°, detail a 3-in minimum chamfer at acute corners.

8. Soil Reinforcements. Soil reinforcements (such as steel strips, bar mats, and geosynthetics commonly used in mechanically stabilized earth (MSE) wall construction) shall not be used as attachments to end bent caps or end walls in an attempt to resist lateral loads applied to these components.

20.2.4 Integral End Bents

Reference: LRFD Article 11.6.2.1

Integral end bents are typically constructed using the following method. The superstructure girders are set in place and anchored to the previously cast-in-place bent cap. The concrete above the previously cast-in-place cap is cast at the same time as the superstructure deck.

Integral end bent details shall meet the following requirements:

1. End Walls. For integral end bents, the end wall shall be detailed the full width of the end bent, and the end wall concrete shall be cast as the last portion of the deck pour of the end span. See Figure 20.2-1.

2. Concrete Cover. Concrete cover beyond the edge of the girder at the rear face of the end wall shall be at least 4 in. The minimum cover shall also apply to the pavement rest area. The top flange of steel girders may be clipped, and the top flange of prestressed I-beams may be cast to meet this requirement.

3. Girder Anchorage. A 12-in maximum spacing shall be provided through the webs of steel girders and through prestressed I-beams to allow reinforcing bars to be inserted to further anchor the girder to the end wall. Position the holes so that, when the reinforcing bars are inserted, they will be within the end wall reinforcing cage.

4. Deck Slab Bars. Use L-shaped bars extending from the end wall into the top of the slab at 12-in spacing or less.

20.2.5 Semi-Integral End Bents

In semi-integral end bents, the end wall is cast around the girder ends, attached to the slab, but separated from the bent cap. Parallel wing walls shall be used, and the wings can either be monolithic with the end wall and isolated from the bent cap or attached to the bent cap with only the end wall left free to move. In concept, this freedom of movement minimizes the displacement of the piles.

For SCDOT projects, end wall movement and rotation are allowed through the detailing of the connection of the end wall and the cap as either:

- dowel bars/anchor bolts forming a hinge,
- dowel bars/anchor bolts and shear keys forming a hinge, or
- a bond-breaker between the end wall and the bent cap allowing longitudinal translation.

With the exception of the hinge or bond-breaker detailed between the bent cap and the end wall, the design and detailing requirements of an integral end bent in Section 20.2.4 also apply to semi-integral end bents.

20.2.6 Free-Standing End Bents

The minimum backwall thickness for a free-standing end bent is 12 in. Walls are of constant thickness; battered walls shall not be used.

20.2.7 Piles

Reference: LRFD Article 10.7

20.2.7.1 General

The following criteria apply to piles for all bents:

1. <u>Pile Spacing</u>. Pile spacing should not normally exceed 10 ft. One pile shall preferably be placed beneath each girder. To reduce force effects for a large beam spacing, consider using twin piles under the beam, spaced at not less than 30 in or 2½ times the pile width. Where not possible to place a pile beneath each girder, the piles shall be uniformly spaced across the length of the bent. See Section 19.2 for minimum pile spacings.

2. <u>Number</u>. The number of piles supporting a bent shall not be less than four.

3. <u>Overhang</u>. The minimum overhang for a cap supported by piles shall be 18 in.

4. Pile-Cap Connections. To allow for constructibility, the pile embedment shall have a tolerance of ±6 in. Unless approved otherwise by the State Bridge Design Engineer, the pile embedment into the cap shall not be less than 12 in.

   Prestressed concrete piles may be connected to the caps by being embedded into the cap an equivalent of one pile width. No roughening of the pile is required. The pile surface to be embedded shall be clean and free of any laitance prior to placement of the cap concrete.

   For pile bents supporting flat slab superstructures, the minimum bent cap depth shall be 30 in for 18-in square prestressed concrete piles.

   For pile bents with piles larger than 18-in square, maximum pile embedment may dictate that deeper pile caps be used for constructibility and due to the effects of punching shear. For pile bents supporting beams, regardless of pile size, the effects of punching shear shall be investigated.

   The end and side clearances from piles to the surface of the cap should also be considered during design to ensure that design forces will not cause the pile to break out of the sides or ends of the pile cap.

5. Batter. Vertical piles shall be used at integral end bents and are preferred at semi-integral and free-standing end bents. If battered piles are used, a refined analysis is required.

20.2.7.2 Piles for Integral/Semi-Integral End Bents

The following criteria apply specifically to piles and loads at integral and semi-integral end bents:

1. Configuration. A single row of piles shall be used for an integral end bent.

2. Loads/Forces. For jointless bridges satisfying the requirements provided in Section 12.2, the designer may neglect force effects in the end bent piles due to temperature, shrinkage, creep, and horizontal earth pressures.

   An alternative analysis must be used if the criteria in Section 12.2 are not met. The following steps should be considered in this analysis:

   - Establish the point of zero superstructure movement by considering the elastic resistance of all substructures and bearing devices.

   - Consider the effects of creep, shrinkage, and temperature.

   - Assume that the longitudinal movement at any point along the superstructure is proportional to its distance to the point of zero superstructure movement. For example, the longitudinal movement at a point 50 ft from the point of zero movement should be considered to be one-half of the horizontal movement at a point 100 ft from the point of zero movement.

- Neglect the lateral curvature of the superstructure if it satisfies the provisions of LRFD Article 4.6.1.2.
- Distribute the vertical force effects in the end bents among the piles based upon static equilibrium as axial loads.
- Consider the lateral soil resistance in establishing the force effects and buckling resistance of piles.
- Combine the force effects in accordance with the provisions of LRFD Article 3.4.1.

For in-house-designed projects, the Department uses LPILE for evaluating loads and forces on piles at end bents.

3. Pile Type. Typically, steel H-piles or steel pipe piles are used, but prestressed concrete piles may be used if they are detailed at interior bents. The orientation of steel H-piles (strong versus weak axis) is a design consideration, and it is preferable that all piles be oriented the same. For integral end bents, all end bent piling shall be driven vertically, and only one row of piling is permitted.

20.2.7.3 Piles for Free-Standing End Bents

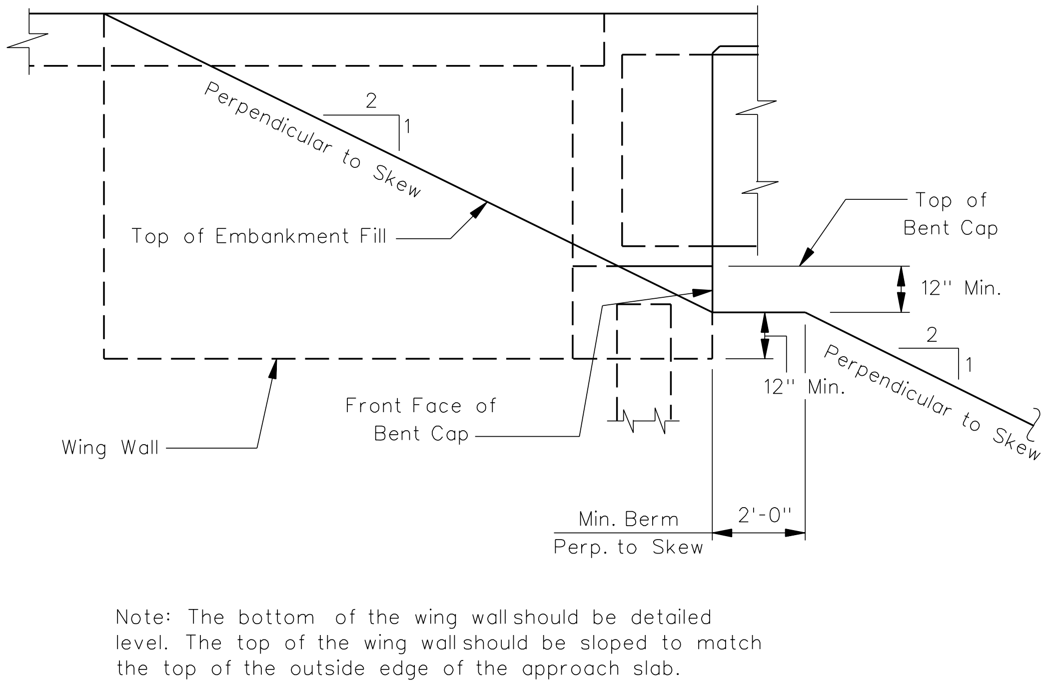
The following criteria apply to piles for free-standing end bents:

1. Pile Spacing. Consider using two rows of piles to achieve the necessary longitudinal stiffness. The minimum pile spacing is 30 in or 2½ times the pile width.
2. Movement. The designer shall investigate the effects of the movements due to overturning pressures or lateral pressures (e.g., ensure that the closing of joints does not occur).

20.2.8 Wing Walls

Reference: LRFD Article 11.6.1.4

Wing walls shall be of sufficient length to retain the roadway embankment and to furnish protection against erosion. The designer shall design all wing walls so that the embankment is at least 1 ft below the top of the end bent cap at the front face of the cap. The wing walls shall also be designed to allow for a minimum berm width of 2 ft (measured perpendicular to the bent cap). See Figure 20.2-2. Generally, the slope of the fill should not be steeper than 2H:1V, and the wing wall lengths should be established on this basis.



WING WALL SCHEMATIC

Figure 20.2-2

With respect to end bents, the following applies to wing walls:

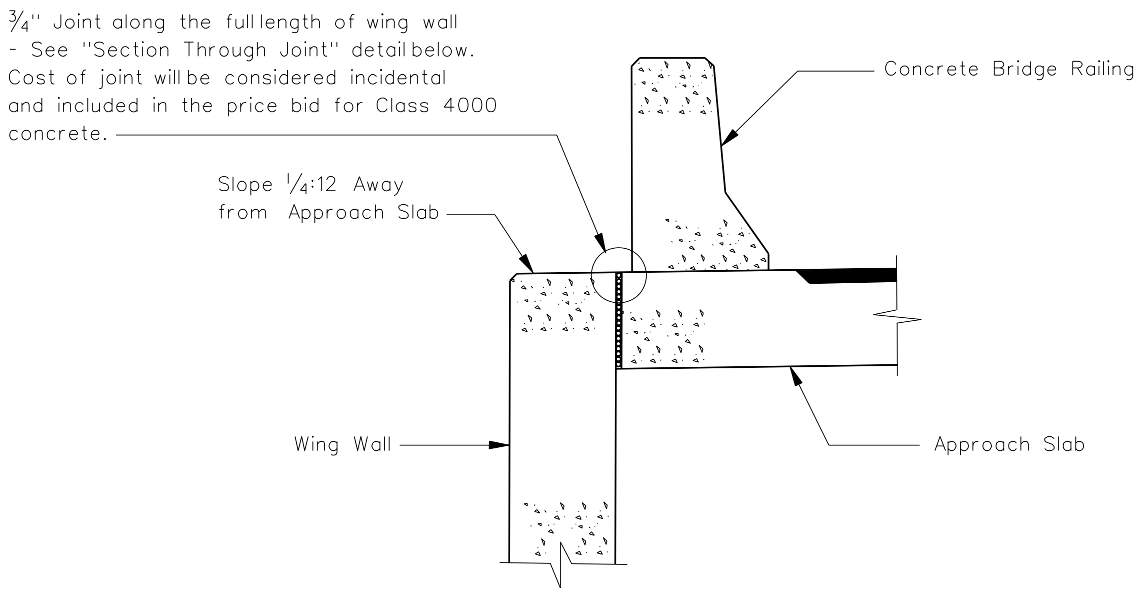
1. Geometry. For structure types other than flat slabs or cored slabs, the designer shall use parallel wing walls (i.e., wing walls that are parallel to the centerline of bridge). For flat slab or cored slab structures, straight wing walls (i.e., wing walls that are parallel to the centerline of bent) are preferred. Parallel wing walls may be used for these shallow-depth structures if necessary:

   - to restrict transverse seismic displacements,
   - when a certain type of aesthetics is desired,
   - when there is interference between the existing and proposed structures, or
   - when some other type of restriction exists.

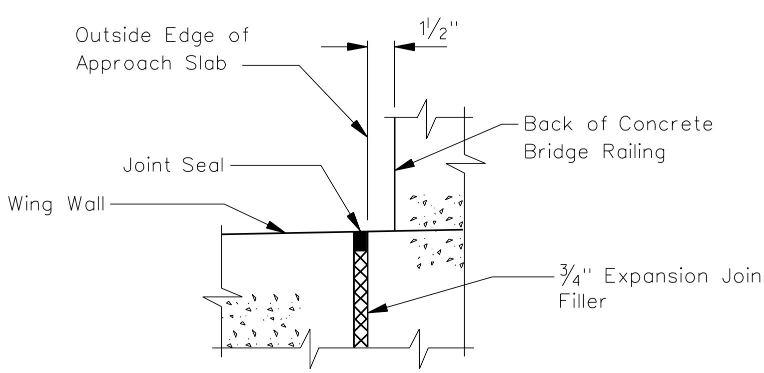
2. Thickness. The minimum thickness of any wing wall shall be 12 in.

3. Approach Slabs. For bridges having parallel wing walls, the designer shall use approach slabs, and the wing walls shall be detailed adjacent to the outside edge of the approach slab. See Figure 20.2-3.

4. Longer Parallel Wing Walls. In general, parallel wing walls should not extend more than 10 ft behind the rear face of the end bent. If parallel wing walls on rigid end bents have a total length of more than 10 ft, investigate the use of auxiliary pile footings for wing wall support. Avoid pile-supported wings at flexible end bents.



SECTION THROUGH WING WALL/APPROACH SLAB



SECTION THROUGH JOINT

WING WALLS AND APPROACH SLABS

Figure 20.2-3

In addition, for wing walls longer than 10 ft, the designer shall investigate the force effects in the connection between the wing wall and end bent, and in the wing wall itself, and shall provide adequate reinforcing steel. The junction of the end bent and wing wall is a critical design element, requiring special considerations. If the wing wall is tied to the end bent (i.e., there is no joint), design for at-rest pressure. All reinforcement must be developed into both elements such that full moment resistance can be obtained.

For rigid free-standing end bents, the forces are merely due to permanent loads and live-load surcharge. For flexible end bents, other transient loads must be considered in addition to the permanent loads.

5. Unattached Wing Walls. Unattached wing walls shall be designed as retaining walls.

20.2.9 End-Bent Construction Joints

To accommodate normal construction practices, the designer should detail the following horizontal construction joints in the plans:

1. In semi-integral end bents, a horizontal construction joint should be permitted between the bottom of slab fillet and the top of the end wall.

2. In integral end bents, a horizontal construction joint shall be detailed at the top of the bent cap.

3. In free-standing end bents, a horizontal construction joint shall be detailed between the top of the bent cap and the bottom of the backwall. Some expansion joint types may require another construction joint at the pavement rest. Use a shear key for any horizontal construction joints.

4. In parallel wing walls, a permissible horizontal construction joint shall be detailed at an elevation that is the same as the top of the bent cap.

Planned vertical construction joints are normally associated with staged construction issues. Make provisions for splicing or mechanical reinforcing couplers on horizontal reinforcing steel. Vertical reinforcing steel should be at least 3 in from the construction joint.

20.3 INTERIOR BENTS

Reference: LRFD Article 11.7

20.3.1 General

SCDOT uses the multi-column, hammerhead, and pile bent for its three basic types of interior bents, which are discussed below. See Section 12.4 for more information. The bridge designer must consider the mass concrete placement requirements of the *SCDOT Standard Specifications* when determining the sizes of structural components of the bent.

In tidal water, no construction joints shall be located in the zone between extreme low tide and extreme high tide. This requirement also applies to the pile-to-footing connection.

20.3.2 Reinforced Concrete Columns

20.3.2.1 Column Cross Sections

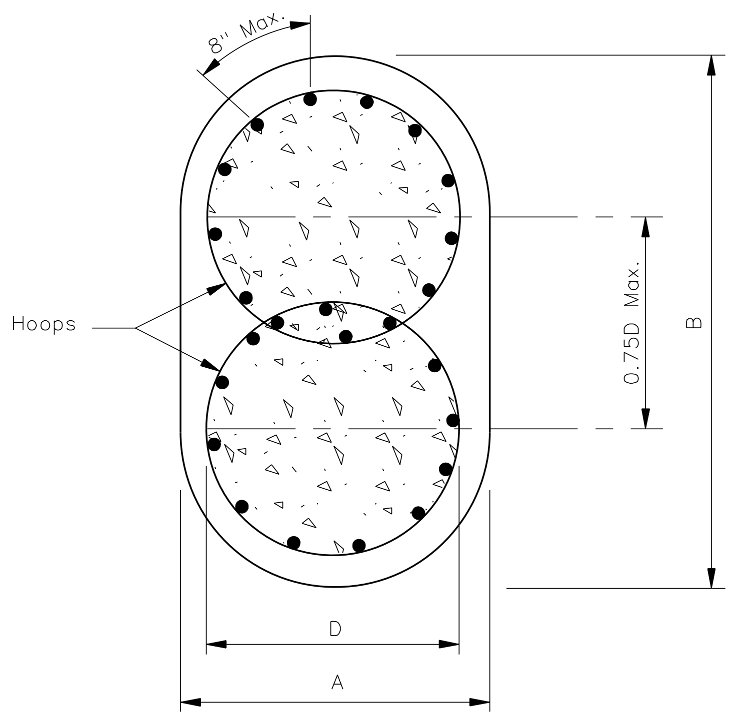
Reinforced concrete columns for multi-column bents and single-column bents with hammerhead caps should have circular cross sections. If a circular column cannot be designed for the required loading, use a column with an oblong cross section. The minimum diameter for circular columns or the circular ends of oblong columns shall be 3 ft.

Where supported on drilled shafts, detail a minimum of 3 in from the edge of shaft to the edge of column at the column/shaft interface. If the column supported on a drilled shaft would be less than 5 ft tall, extend the shaft to the bent cap.

20.3.2.2 Column Reinforcement

Mechanical butt-welded spliced hoops shall be used as transverse reinforcing steel. Reinforce columns with oblong cross sections with interlocking hoops with a center-to-center spacing not to exceed ¾ times the diameter of the cage. The overlaps shall be interlocked by a minimum of four bars. Figure 20.3-1 illustrates the detailing of an oblong column.

Vertical column reinforcing bars shall be #8 or larger, with #10 bars being the preferred minimum. Detail the longitudinal reinforcing steel continuous with a maximum spacing of 8 in center-to-center. The vertical column reinforcing bars must be fully developed where these bars enter into the bent cap and the spread footing or pile cap. The use of biased vertical column reinforcement is prohibited.



OBLONG COLUMNS WITH INTERLOCKING HOOPS

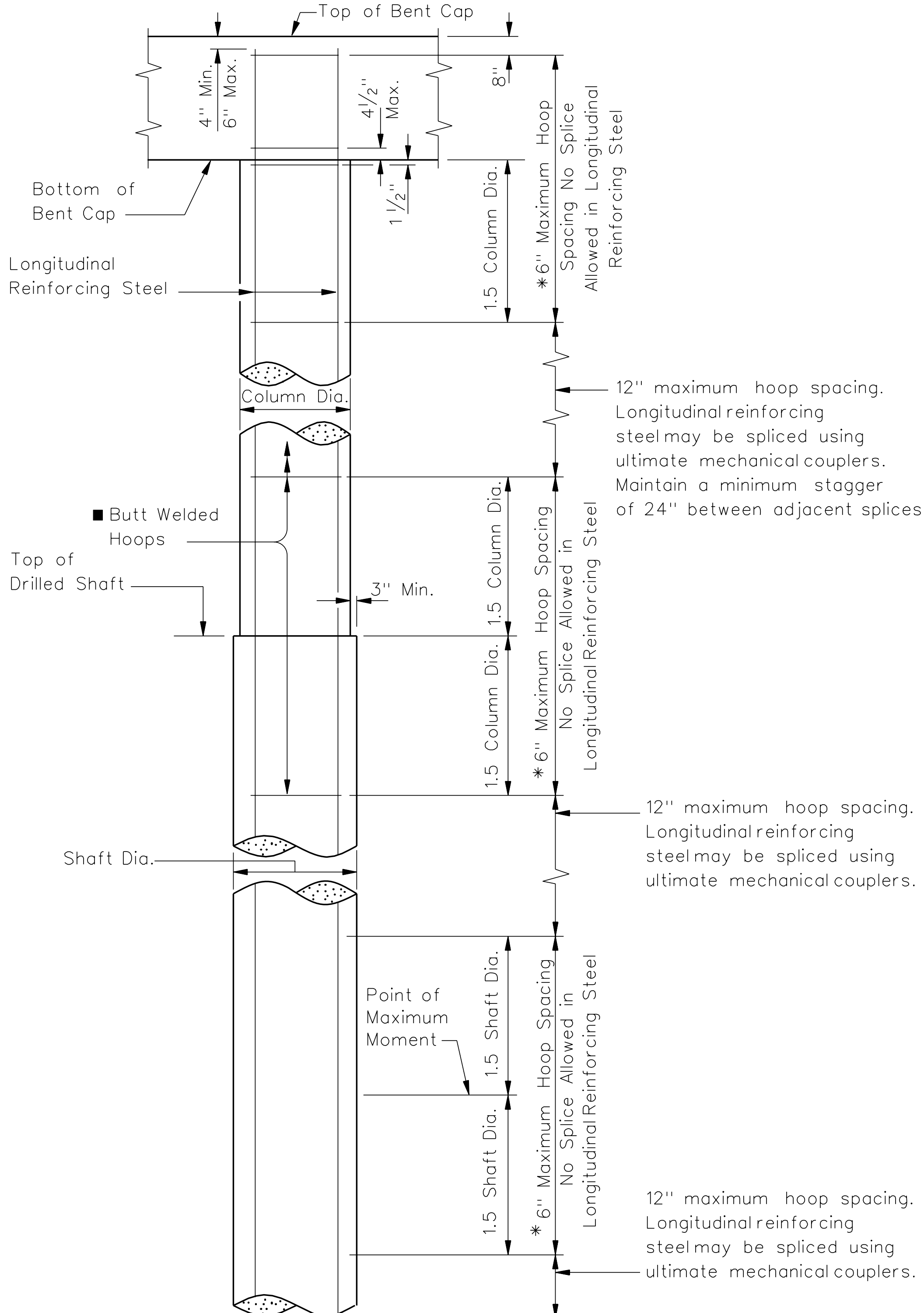
Figure 20.3-1

The column-reinforcing details shown in Figures 20.3-2 and 20.3-3 shall be the minimum requirements for all projects, regardless of site location. The maximum spacing of the transverse column reinforcement shall be decreased as necessary to comply with applicable design specifications.

Mechanical couplers shall be used for splicing the vertical steel. Do not locate splices within the plastic-hinge zones of the column. The designer shall clearly identify these regions as a “No-Splice Zone,” and these regions shall be detailed and shown in the plans. Outside the “No-Splice Zone,” mechanical splices are permitted. A minimum stagger of 2′-0″ between adjacent splices shall be required and the locations shown in the drawings. Splices in bundled bars shall also be staggered at a minimum of 2′-0″. If coated bars are used, the couplers shall be tested with reinforcing bars coated as required for the bridge, and the couplers shall be coated with a compatible coating.

If a column is less than 10 ft in height, do not splice the steel extending out of the footing or shaft.

Post-tensioning shall not be used for columns.

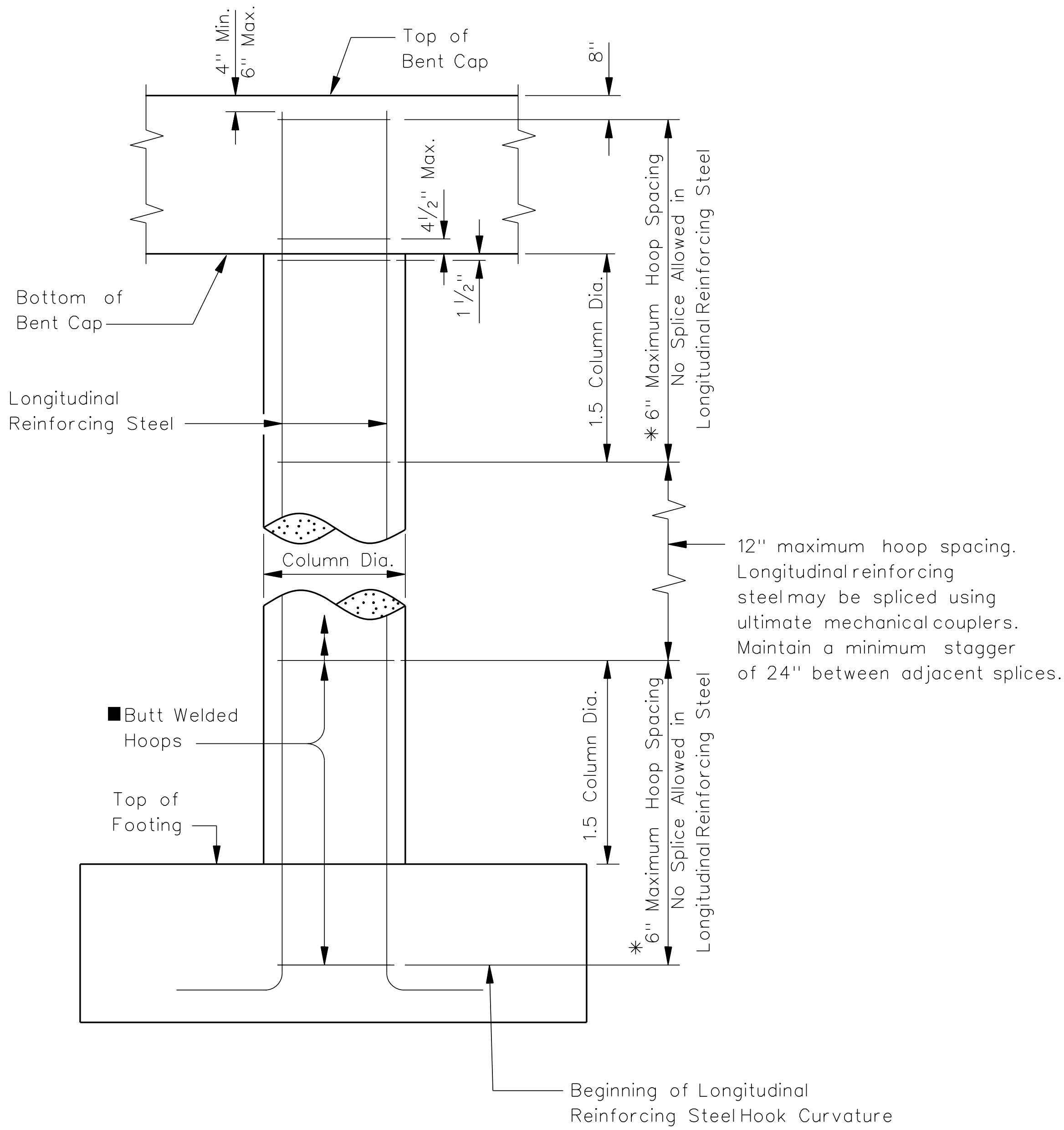


■ Hoops shall have butt welded splices and the minimum size shall be #6. To prevent the hoop weld splices from being located on the same vertical plane, the locations of the splices shall be staggered around the perimeter of the column by a minimum distance of 1/3 of the hoop circumference.

∗8" maximum spacing if bundled hoops are used.

MINIMUM COLUMN REINFORCING
(Supported by Drilled Shafts)

Figure 20.3-2



■ Hoops shall have butt welded splices and the minimum size shall be #6. To prevent the hoop weld splices from being located on the same vertical plane, the locations of the splices shall be staggered around the perimeter of the column by a minimum distance of 1/3 of the hoop circumference.

* 8" maximum spacing if bundled hoops are used.

MINIMUM COLUMN REINFORCING
(Supported by Footings)

Figure 20.3-3

20.3.2.3 Column Construction Joints

In general, construction joints shall be used at the top and bottom of the column. Where columns exceed 25 ft in height, construction joints shall be shown such that concrete pours do not exceed 25 ft in height. Locate all construction joints at least 12 in above the water elevation expected during construction.

20.3.3 Multi-Column Bents

Concrete frame bents may be used to support a variety of superstructures. The columns of the bent are round in cross section. The columns may be directly supported by the footing or by a drilled shaft.

The following applies to the design and detailing of multi-column bents:

1. Column Size. The minimum size column diameter shall be 3′-0″. Standard column sizes include 3′-0″, 3′-6″, 4′-0″, 4′-6″, and 5′-0″. For column diameters greater than 5′-0″, increase the column diameter in 6-in increments.

2. Column Spacing. In general, column spacing should not exceed approximately 25 ft center to center of columns.

3. Footings. Bents founded on spread footings have typically been designed with separate footings under each column. Existing analytical techniques provide tools for the analysis of a common footing for all columns, and this configuration may result in a more economical footing.

4. Compressive Reinforcing Steel in Cap or Footing. Compressive reinforcing steel tends to buckle when the cover is gone or when the concrete around the steel is weakened by compression. If the initial design indicates the need for compressive steel, the interior bent shall be redesigned to eliminate this need.

20.3.4 Single-Column Bents with Hammerhead Caps

For aesthetic considerations, single-column bents with hammerhead caps may be more suitable. The following applies to the design of single-column bents with hammerhead caps:

1. Cap Location. The bottom of a hammerhead cap should preferably be a minimum of 6 ft above the finished ground line on stream crossings to help prevent debris accumulation.

2. Cantilevers. The design of the cantilever is affected by the cantilever depth-versus-length geometry. Where the distance between the centerline of the bearing and the column is less than approximately twice the depth of the cantilever, the strut-and-tie model in LRFD Article 5.6.3 should be considered for the design of the cantilever.

3. Cap Reinforcement. The longitudinal reinforcement is limited by the requirements of Section 20.1. These requirements also effectively limit the length of the cantilever.

20.3.5 Pile Bents

Under the appropriate conditions (e.g., shallow water, environmental considerations), pile bents may provide the most economical substructure. Exposed steel piles shall not be used in standing water or marsh.

SCDOT prefers that pile bents have a single row of vertical piles. The following applies to the design and detailing of pile bents:

1. Limitations. Pile bents have a relatively low resistance to longitudinal forces. This support should not be used if the stream carries large debris flow, because debris accumulation can increase stream forces significantly.

2. Buckling and Slenderness Considerations. Buckling due to the unsupported length of the pile should be checked using LRFD Articles 5.7.4.3 and 6.9 for concrete and steel piles, respectively.

20.3.6 Dynamic Load Allowance (IM) for Bents

Reference: LRFD Article 3.6.2.1

The *LRFD Specifications* allows the Dynamic Load Allowance (IM), traditionally called impact, to only be omitted on "foundation components that are entirely below ground level." Therefore, SCDOT requires the dynamic load allowance to be considered in the structural design of bent caps, interior bent columns, and all piles, drilled shafts, and footings, if any portion of these elements are above ground.

20.3.7 Moment-Magnification

Reference: LRFD Article 5.7.4

Bents, bent columns, and piles are referred to as compressive members, although their design is normally controlled by flexure. In most cases, the use of the moment-magnification approach in LRFD Article 5.7.4.3 is warranted. For exceptionally tall or slender columns/shafts where the slenderness ratio (Kl/r) is greater than 100, a refined analysis, as outlined in LRFD Article 5.7.4.1, should be performed. Where P-Delta design procedures are used, consideration shall be given in the design to the initial out-of-straightness of columns and the sustained dead load.

Chapter 21

JOINTS AND BEARINGS

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 21

JOINTS AND BEARINGS

Section 14 of the *LRFD Bridge Design Specifications* discusses the design and detailing requirements for joints and bearings. This Chapter presents SCDOT supplementary information on the design of these bridge components.

21.1 JOINTS

21.1.1 Expansion Joints

Reference: LRFD Articles 14.4 and 14.5

LRFD Article 14.4 discusses the movements and loads on bridge joints, and LRFD Article 14.5 provides requirements for joints and considerations for specific joint types. This Section presents SCDOT criteria for the use of expansion joints in bridge decks.

Expansion length equals the distance from the expansion joint to the point of assumed zero movement. The point of assumed zero expansion is the point along the bridge that is assumed to remain stationary when expansion or contraction of the bridge occurs.

21.1.1.1 General

Expansion joints in bridge decks are often necessary to accommodate the expansion and contraction of bridges due to temperature variations. The following general criteria apply to all expansion joints in bridge decks:

1. Jointless Bridges. Because of their inherent operational and maintenance problems, the objective is to eliminate expansion joints. See Section 12.2 for design requirements of jointless bridges.

2. Maintenance Problems. Many of the maintenance problems on bridges result from failed joints. Therefore, the proper selection, design, and detailing of expansion joints are critical issues.

3. Temperature Range. The bridge designer shall use Procedure B of LRFD Article 3.12.2 where applicable to determine the appropriate design thermal range. For bridge types not covered by Procedure B, Procedure A shall be used.

4. Expansion-Joint Support. For finger and modular joints supported from the top of the beam, a detail of the supporting device shall be shown in the plans.

5. Armor-Plate Recess. The top of armor plates at deflection joints, at expansion joints, and at the top of steel extrusions at strip seal joints shall be recessed ¼ in from finished grade. This LRFD requirement (Article 14.5.3.3) allows milling of the concrete, if needed, adjacent to the joints.

6. Effects of Skew. The thermal movements of skewed bridges are such that racking can occur at the expansion joints. The movement is not solely in the longitudinal direction. The acute corners of a bridge with parallel skewed supports tend to expand and contract more than the obtuse corners, causing the joint to rack.

21.1.1.2 Estimation of Design Thermal Movement, Δ_T

The design thermal movement in inches shall be estimated by the following equation:

$$\Delta_T = \alpha L \left(T_{MaxDesign} - T_{MinDesign}\right) \quad \text{(LRFD Equation 3.12.2.3-1)}$$

where:

α = coefficient of thermal expansion, 6 x 10^{-6} for concrete beams and 6.5 x 10^{-6} for steel girders, in/in/°F

L = expansion length, in

$T_{MaxDesign}$ = maximum design temperature from LRFD Figure 3.12.2.2-1 for concrete beam bridges, from LRFD Figure 3.12.2.2-3 for steel girder bridges, or from LRFD Table 3.12.2.1-1 for other type bridges

$T_{MinDesign}$ = minimum design temperature from LRFD Figure 3.12.2.2-2 for concrete beam bridges, from LRFD Figure 3.12.2.2-4 for steel girder bridges, or from LRFD Table 3.12.2.1-1 for other type bridges

21.1.1.3 Estimation of Total Movement

In addition to the thermal movement, the effects of creep (CR) and shrinkage (SH) should be included in the total movement for concrete bridges. In lieu of a more detailed calculation, the total movement can be estimated as 115% of the design thermal movement, Δ_T.

21.1.1.4 Expansion Joint Selection

Figure 21.1-1 presents the typical application for several types of expansion joints used by SCDOT. This figure also provides the maximum joint opening and recommended usage.

Joint Type	Maximum Joint Opening (in)	Usage
Compression Seal (Elastomeric or Evazote Seal)	3½	Preferred joint where skew ≤ 30°
Strip Seal	4	Where compression seals are not applicable
Open Finger Plate	> 4	Where large movements are anticipated
Modular Expansion	> 4	Where large movements are anticipated and the drainage requirements of finger joints are undesirable
Asphaltic Plug	< 2	Bridge rehabilitation projects only
Silicone Rubber Sealant	< 2	Cored Slab Bridges and Sleeper Slabs

EXPANSION JOINT SELECTION

Figure 21.1-1

21.1.1.5 Compression Seal Joint

Reference: LRFD Article 14.5.6.6

On bridges with 30° or less skew, SCDOT prefers the compression seal joint for joint openings up to 3½ in.

21.1.1.6 Strip Seal Joint

Reference: LRFD Article 14.5.6.7

Where compression seal joints are not applicable, the strip seal expansion joint is the preferred deck expansion joint system for estimated total design thermal movements from 1 in to 3 in. The bridge designer shall select a strip seal joint from the manufacturer's information that provides the estimated total design thermal movement for the joint being considered.

21.1.1.7 Open Finger Plate Joint

Reference: LRFD Articles 14.5.6.1 and 14.5.6.3

Open finger plate joints are applicable to anticipated movements of 3 in or greater.

Finger plates allow debris to pass through; therefore, a collector trough is required underneath to catch the debris. Almost every collector trough detail is a high-maintenance item with marginal effectiveness. However, despite its problems, a well-designed finger plate is perhaps the best design for large-movement joints.

21.1.1.8 Modular Expansion Joint

Reference: LRFD Article 14.5.6.9

Modular joints may require significant maintenance. Leakage, gland tears, and broken welds in modular joints are common. Therefore, in the selection of modular seals, consideration should be given to those that have been verified by long-term performance and designed to facilitate repair and replacement of components.

SCDOT only uses modular expansion joints when absolutely necessary, such as where large movements are anticipated and the drainage requirements of finger joints are undesirable. The proposed use of modular expansion joints must be approved by the State Bridge Design Engineer. The following will apply to the design of modular-type expansion joints:

1. Expansion Movement. Modular joints may only be considered where the anticipated expansion movements exceed 3 in.

2. Splices. Where practical, modular joints should be full length with no field splices across the roadway width. If a field splice is required for traffic continuity, the support beams should be spaced at a maximum of 2 ft from the splice location, which should be outside of the wheel path. The splice will be designed according to the manufacturer's recommendations.

3. Elastomeric Seal. The elastomeric seal, in a modular joint, will be one piece across the roadway width, regardless of traffic continuity considerations and the presence of a field splice.

21.1.1.9 Asphaltic Plug Joint

Reference: LRFD Article 14.5.6.5

SCDOT only uses an asphaltic plug on bridge rehabilitation projects. This joint system is a smooth, durable, load-bearing surface that uses a combination of polymer-modified asphaltic binder and selected aggregate that provides estimated total design thermal movement ranges up to 2 in. Its advantages include the elimination of the mechanical anchorage systems, ease of placement, low maintenance, and rideability. Its disadvantages include its non-flexibility in cold temperatures and its tendency to rut under heavy traffic in hot temperatures.

21.1.1.10 Silicone Rubber Sealant Joint

Reference: LRFD Article 14.5.6.5

The silicone rubber sealant system can be used in joints that have estimated total design thermal movements up to 2 in. SCDOT practice is to use this system where anticipated movements are small such as on cored slab bridges and at sleeper slabs. The movement capacity of this type of joint is dictated by the joint width at the time of installation. The movement capacity is a function of the installation width plus or minus some percent of original gap size. The silicone rubber sealant joint is easily maintained because local joint failures can be easily repaired. This system can be bonded to concrete, steel, or polymeric elastic cement.

21.1.1.11 Cover Plates

Cover plates shall be used over expansion joints at sidewalks. Where bicycles are anticipated in the roadway, the use of cover plates in the shoulder area shall be considered.

21.1.1.12 Example Problems

The following presents two example problems for the design of expansion joints.

Example 21.1-1 — <u>Prestressed Concrete Beam Bridge with Concrete Deck</u>

Given: Prestressed concrete beams supporting reinforced concrete bridge deck.
L = expansion length = 240 ft
θ = skew angle = 0°

Problem: Determine expansion joint movement requirements.

Solution: Estimated design thermal movement:

$$\Delta_T = \alpha L (T_{MaxDesign} - T_{MinDesign}) \qquad \text{(LRFD Equation 3.12.2.3-1)}$$

For a concrete superstructure:

$\alpha = 6.0 \times 10^{-6}$ in/in/°F

$T_{MaxDesign}$ = 105°F based upon the bridge location and LRFD Figure 3.12.2.2-1

$T_{MinDesign}$ = 30°F based upon the bridge location and LRFD Figure 3.12.2.2-2

$\Delta_T = (6.0 \times 10^{-6} \text{ in/in/°F})(240 \text{ ft})(12 \text{ in/ft})(105° - 30°)$

$\Delta_T = 1.3 \text{ in}$

$\Delta_{total} = 1.15 (1.3 \text{ in}) = 1.5 \text{ in}$ (See Section 21.1.1.3)

A compression seal joint is acceptable because the estimated total design movement is within the range for compression seals.

Movements from mean temperature of 70°F:

1.3 in/(105°F – 30°F) = 0.01733 in/°F
Contraction (from 70°F to 30°F) = 0.7 in
Expansion (from 70°F to 105°F) = 0.6 in

Joint opening @ 105°F = 1.5 in (assumed minimum gap)
@ 70°F = 1.5 in + (0.01733 in/°F)(105°F – 30°F) + ½(0.15)(1.3) = 2.2 in
@ 30°F = 1.5 in (assumed minimum gap) + 1.3 in (estimated design thermal movement) + (0.15)(1.3) = 3.0 in

Example 21.1-2 — <u>Steel Girder Bridge with Concrete Deck</u>

Given: Steel plate girders supporting reinforced concrete bridge deck.
L = expansion length = 250 ft
θ = skew angle = 30°

Problem: Determine expansion joint movement requirements.

Solution: Estimated design thermal movement:

$$\Delta_T = \alpha L \left(T_{MaxDesign} - T_{MinDesign}\right)$$ (LRFD Equation 3.12.2.3-1)

For a steel superstructure:

$\alpha = 6.5 \text{ x } 10^{-6} \text{ in/in/°F}$

$T_{MaxDesign}$ = 110°F based upon the bridge location and LRFD Figure 3.12.2.2-3

$T_{MinDesign}$ = 20°F based upon the bridge location and LRFD Figure 3.12.2.2-4

$\Delta_T = (6.5 \text{x} 10^{-6} \text{ in/in/°F}) (250 \text{ ft}) (12 \text{ in/ft}) (110° - 20°)$

$\Delta_T = 1.8 \text{ in}$

A compression seal joint is acceptable because the estimated design thermal movement times the cosine of the skew angle (1.8 in (cos 30°) = 1.6 in) is within the range for compression seals.

Movements from mean temperature of 70°F:

1.8 in/(110°F – 20°F) = 0.01955 in/°F
Contraction (from 70°F to 20°F) = 1.0 in
Expansion (from 70°F to 110°F) = 0.8 in

Joint openings (normal to the joint) @110°F = 1.75 in (assumed minimum gap)
@ 70°F = 1.75 in + (0.01955 in/°F)(110°F – 70°F)(cos 30°) = 2.4 in
@ 30°F = 1.75 in (assumed minimum gap) + 1.8 in (estimated design thermal movement) x (cos 30°) = 3.3 in

Minimum nominal seal width to accommodate racking:

Estimate design thermal movement parallel to joint = 1.8 x sin 30° = 0.9 in

Allow a maximum racking of 20% of the nominal seal width.

$$\text{Minimum nominal seal width} = \frac{0.9 \text{ in}}{0.20} = 4.5 \text{ in}$$

21.1.2 Longitudinal Open Joints

Reference: LRFD Article 14.5.1.1

Longitudinal open joints are not required in concrete bridge decks with widths of 90 ft or less. For decks wider than 90 ft, a longitudinal open joint may be used or a longitudinal closure pour, preferably not less than 3 ft wide, may be used. See Section 17.3 for information on longitudinal closure pours for decks. No longitudinal expansion joints should be detailed, except for locations where concrete barrier rail or raised concrete median is placed on each side of the joint.

21.2 BEARINGS

21.2.1 General

Reference: LRFD Articles 14.4 and 14.6

Bearings ensure the functionality of a bridge by allowing translation and rotation to occur consistent with the assumed boundary conditions, while supporting the vertical loads. In all cases, bearings shall be aligned normal to the centerlines of beams and girders.

21.2.1.1 Movements

The consideration of movement is important for bearing design. Movements include both translations and rotations. The sources of movement include initial camber or curvature, construction loads, misalignment, construction tolerances, settlement of supports, thermal effects, creep, shrinkage, and traffic loading.

21.2.1.2 Effect of Camber and Construction Procedures

The initial camber of bridge girders induces bearing rotation. Initial camber may cause a larger initial rotation on the bearing, but this rotation may decrease as construction of the bridge progresses. Rotation due to camber and the initial construction tolerances is sometimes the largest component of the total bearing rotation. Both the initial rotation and its short duration should be considered. At an intermediate state of construction, deflections and rotations due to the weight of the deck slab and construction equipment must be added to the effects of live load and temperature. Construction loads and movements due to tolerances should be included. The direction of loads, movements, and rotations must also be considered, because it is inappropriate to simply add the absolute maximum magnitudes of these design requirements. The designer should anticipate the worst possible (but realistic) condition. Combinations of absolute maximums that can not realistically occur should not be considered. In special cases, it may be economical to install the bearing with an initial offset, or to adjust the position of the bearing after construction has started, to minimize the adverse effect of these temporary initial conditions.

21.2.1.3 Design Thermal Movements

Reference: LRFD Article 3.12.2

A change in temperature causes a translation in the bridge component. The design thermal movement shall be estimated by the following equation:

$$\Delta_T = \alpha L \left(T_{MaxDesign} - T_{MinDesign}\right) \quad \text{(LRFD Equation 3.12.2.3-1)}$$

where: α = the coefficient of thermal expansion given in Section 21.1

L = expansion length, in

$T_{MaxDesign}$ = maximum design temperature from LRFD Figure 3.12.2.2-1 for concrete beam bridges, from LRFD Figure 3.12.2.2-3 for steel girder bridges, or from LRFD Table 3.12.2.1-1 for other type bridges

$T_{MinDesign}$ = minimum design temperature from LRFD Figure 3.12.2.2-2 for concrete beam bridges, from LRFD Figure 3.12.2.2-4 for steel girder bridges, or from LRFD Table 3.12.2.1-1 for other type bridges

A change in the temperature gradient induces bending and deflections. It should be further noted that a given temperature change causes thermal movement in all directions. Because the thermal movement is a function of the expansion length as shown in LRFD Equation 3.12.2.3-1, a short, wide bridge may experience greater transverse movement than longitudinal movement.

21.2.1.4 Loads and Restraint

Restraint forces occur when any part of a movement is prevented. Forces due to direct loads include the dead load of the bridge and loads due to traffic, earthquakes, water, and wind. Temporary loads due to construction equipment and staging also occur. It should be noted that the majority of the direct design loads are reactions of the bridge superstructure on the bearing, and they can be estimated from the structural analysis. The applicable AASHTO load combinations must be considered.

21.2.1.5 Serviceability, Maintenance, and Protection Requirements

Reference: LRFD Article 2.5.2.3

Bearings under deck joints may be exposed to large amounts of dirt, debris, and moisture that promote corrosion and deterioration. As a result, these bearings should be designed and installed to minimize environmental damage and to allow easy access for inspection.

The service demands on bridge bearings are very severe and result in a service life that is typically shorter than that of other bridge elements. Therefore, allowances for bearing replacement should be part of the design process. Lifting locations should be provided to facilitate removal and replacement of bearings without damaging the structure. In most cases, additional hardware is not needed for this purpose. The primary requirements are to allow space suitable for lifting jacks during the original design and to employ details that permit quick removal and replacement of the bearing.

21.2.1.6 Bearing Selection

Bearing selection is influenced by many factors such as loads, geometry, maintenance, available clearance, displacement, rotation, deflection, availability, policy, designer preference, construction tolerances, and cost. In general, vertical displacements are restrained, rotations are allowed to occur as freely as possible, and horizontal displacements may be either accommodated or restrained. The loads should be distributed among the bearings in accordance with the superstructure analysis.

The following summarizes typical SCDOT practices for the selection of a bearing type:

1. Steel-Reinforced Elastomeric Bearings. Where possible, steel-reinforced elastomeric bearings should be used for all girder bridges. A steel-reinforced elastomeric bearing assembly is shown in Figure 21.2-5 at the end of Section 21.2.

2. Plain Elastomeric Bearing Pads. Plain elastomeric bearings should be used for all cored slab bridges and flat slab bridges. They are also used as leveling pads at integral bents.

3. Pot Bearings. Pot bearings shall be avoided due to their cost. Pot bearings may be appropriate at bridges with large vertical loads, in excess of 750 kips. Figures 21.2-6 and 21.2-7 at the end of Section 21.2 show typical pot bearing assemblies.

4. PTFE. For expansion pot bearings and where the maximum movements of elastomeric bearings are exceeded, the designer should consider using flat PTFE (Polytetrafluorethylene) slider plates. An example of a PTFE slider plate used in conjunction with a pot bearing is given in Figure 21.2-6 at the end of Section 21.2.

5. Seismic Isolation Bearings. The use of seismic isolation bearings is discussed in the AASHTO *Guide Specifications for Seismic Isolation Design*. The use of seismic isolation bearings requires the approval of the State Bridge Design Engineer.

See Figure 21.2-1 for a general summary of bearing capabilities. The values shown in the table are for preliminary guidance only.

The final step in the selection process consists of completing a design of the bearing in accordance with the *LRFD Specifications*. The resulting design will provide the geometry and other pertinent specifications for the bearing.

Bridges without integral end bents must have at least one bearing line fixed in the longitudinal direction. All of the bearings at this bearing line shall be fixed in the longitudinal direction.

Where transverse fixity is required, all of the bearings at a bearing line need not be fixed transversely. Only the number required to resist the transverse loads (e.g., wind) must be fixed transversely.

Type	Load (kips)	Translation (in)		Rotation Limit (Rad)	Cost	
	[1]Optimal Design Range	Min	Max		Initial	Maintenance
Plain Elastomeric Pad	0 to 150	0	¾	0.0175	low	low
Steel-Reinforced Elastomeric Bearing	50 to 650	0	4	0.04	low	low
Flat PTFE Slider	0 to > 2250	1	> 4	0	low	moderate
Pot Bearing	270 to 2250	[2]0	[2]0	0.02	high	high

1 *Higher and lower values may be available if needed.*

2 *Pot bearings themselves have no translational capability. Expansion pot bearings are achieved by using them in conjunction with flat PTFE sliders.*

SUMMARY OF BEARING CAPABILITIES

Figure 21.2-1

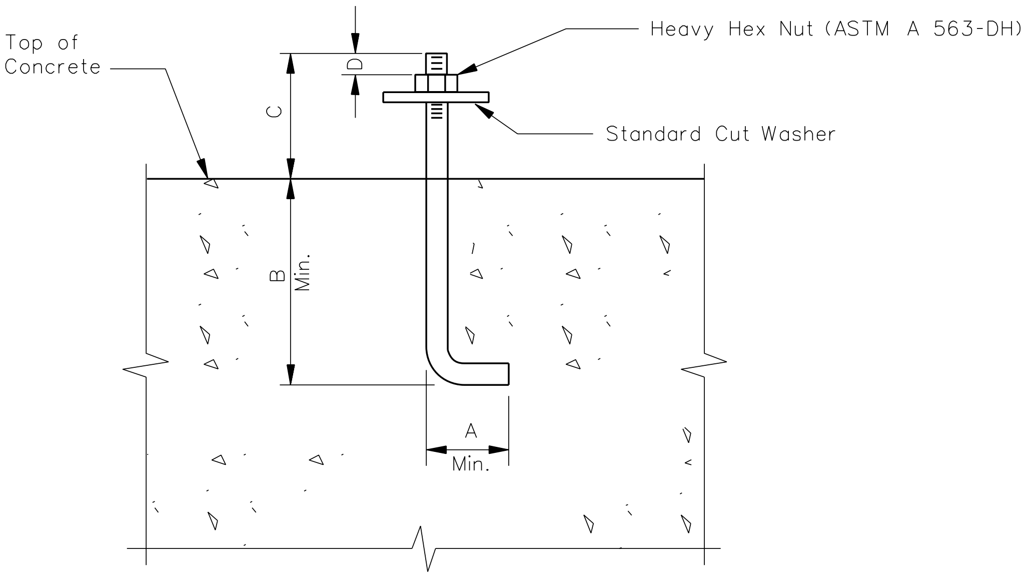
21.2.1.7 Anchor Bolts

Anchor bolts shall be used to connect all bearings to the concrete beam seat.

Figure 21.2-2 illustrates minimum requirements for anchor bolt details that shall be used. Holes for anchor bolts shall be ¼ in larger in diameter than the diameter of the anchor bolt. The centerlines of anchor bolts shall be a minimum of 2 in from the edge of the beam or girder. Maintain ½ in of clearance from the edge of the elastomeric bearing pad to the edge of the anchor bolt.

21.2.1.8 Bearing Plate Details

The bearing plate shall be at least 1 in wider than the elastomeric bearing on which the plate rests. Bearing plates shall satisfy the edge distances given in Figure 21.2-3.



Span Length	Minimum No. of Bolts	Minimum Bolt Diameter	A	B	C	D
< 50 ft	2	1 in	4 in	10 in	*	1 in
51 ft to 100 ft	2	1¼ in	5 in	12 in	*	1¼ in
101 ft to 150 ft	2	1½ in	5½ in	15 in	*	1½ in
> 150 ft	4	1½ in	5½ in	15 in	*	1½ in

**Dimension to be determined by the bridge designer.*

ANCHOR BOLT DETAILS

Figure 21.2-2

Anchor Bolt Hole Diameter or Slot Width	Minimum Edge Distance from Centerline of Hole
1¼ in	1½ in
1½ in	2 in
1¾ in	2½ in

MINIMUM BEARING PLATE/ANCHOR BOLT EDGE DISTANCES

Figure 21.2-3

Use a minimum bearing plate thickness of 1½ in. When the instantaneous slope of the grade plus the final in-place camber exceeds 1%, bevel the bearing plate to match the grade plus final camber. For beveled bearing plates, maintain a minimum of 1 in thickness at the edge of the bearing plate.

At expansion bearings, slotted bearing plates shall be provided. The minimum slot size should be determined according to the amount of movement and end rotation calculated. The slot length, L, should be the larger of:

L = (diameter of anchor bolt) + 2¼ (total movement) + TOL
L = (diameter of anchor bolt) + 2.0 (total end rotation) + ⅔ (total movement) + TOL

where:

TOL = the construction tolerance = 1.0 in

The slot length should be rounded to the next higher ¼ in. The width of the slot shall be as shown Figure 21.2-3. To account for the possibility of different setting temperatures at each stage, offset dimensions shall be provided in the plans for stage-constructed projects. For all other projects, the designer shall consider the need to provide offset dimensions.

21.2.1.9 Leveling Pad at Integral Bents

An elastomeric pad shall be detailed under the bearing plate of beams at integral bents to provide a level and uniform bearing surface. Structural grout is not an acceptable substitute.

21.2.2 Elastomeric Bearing Pads and Steel-Reinforced Elastomeric Bearings

Reference: LRFD Articles 14.7.5 and 14.7.6

21.2.2.1 General

Elastomeric bearing pads and steel-reinforced elastomeric bearings have fundamentally different behaviors and, therefore, they are discussed separately. It is usually desirable to orient elastomeric pads and bearings so that the long side is parallel to the principal axis of rotation, because this orientation better accommodates the rotations.

Elastomeric bearing pads and steel-reinforced elastomeric bearings have many desirable attributes. They are usually a low-cost option, and they require minimal maintenance.

21.2.2.2 Shape Factor

Elastomers are used in both elastomeric bearing pads and steel-reinforced elastomeric bearings. The behavior of both pads and bearings is influenced by the shape factor (S) where:

$$S = \frac{\text{Plan Area}}{\text{Area of Perimeter Free to Bulge}}$$

21.2.2.3 Holes

SCDOT prohibits the use of holes in steel-reinforced elastomeric bearings.

21.2.2.4 Edge Distance

For elastomeric pads and bearings resting directly on the concrete bridge seat, the minimum edge distance shall be 3 in.

21.2.2.5 Elastomer

Reference: LRFD Articles 14.7.5.2 and 14.7.6.2

SCDOT only uses neoprene for its elastomeric bearing pads and steel-reinforced elastomeric bearings.

All elastomers are visco-elastic, nonlinear materials and, therefore, their properties vary with strain level, rate of loading, and temperature. Bearing manufacturers evaluate the materials on the basis of Shore A Durometer hardness, but this parameter is not a good indicator of the shear modulus, G. A Shore A Durometer hardness of 50 or 60 will be used, and this leads to shear modulus values in the range of 0.095 to 0.200 (use least favorable value for design) ksi @73°F. The shear stiffness of the bearing is its most important property because it affects the forces transmitted between the superstructure and substructure.

Elastomers are flexible under shear and uniaxial deformation, but they are very stiff against volume changes. This feature makes possible the design of a bearing that is flexible in shear but stiff in compression.

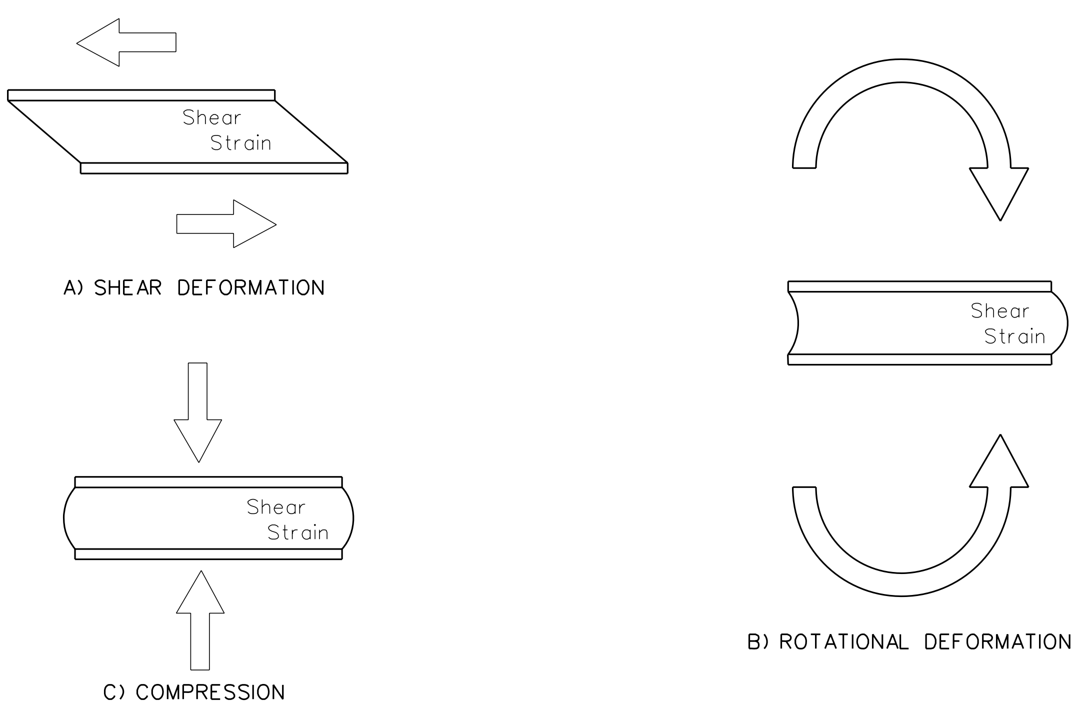
Elastomers stiffen at low temperatures. The low-temperature stiffening effect is very sensitive to elastomer compound, and the increase in shear resistance can be controlled by selection of an elastomer compound that is appropriate for the climatic conditions. The minimum low-temperature elastomer shall be Grade 2. The designer shall indicate the elastomer grade in the plans.

21.2.2.6 Steel-Reinforced Elastomeric Bearing Pads

The use of steel-reinforced elastomeric pads in combination with steel bearing plates is preferred for slab on girder bridges. Use 1-in minimum clearance between the edge of the elastomeric bearing and the edge of the bearing plate in the direction parallel to the beam or girder. Use ½-in minimum clearance between the edge of the elastomeric bearing pad and the anchor bolt in the direction perpendicular to the beam or girder. A typical steel-reinforced elastomeric bearing assembly is shown in Figure 21.2-5 at the end of Section 21.2.

Steel-reinforced elastomeric bearings behave differently than plain elastomeric bearing pads. Steel-reinforced elastomeric bearings have uniformly spaced layers of steel and elastomer. The bearing accommodates translation and rotation by deformation of the elastomer. The elastomer is flexible under shear stress but stiff against volumetric changes. Under uniaxial compression without steel reinforcement, the flexible elastomer would shorten significantly and sustain large increases in its plan dimension; but with the stiff steel layers, lateral expansion is restrained. This restraint induces a bulging pattern as shown in Figure 21.2-4 and provides a large increase in stiffness under compressive load. This permits a steel-reinforced elastomeric bearing to support relatively large compressive loads while accommodating large translations and rotations.

The design of steel-reinforced elastomeric bearings requires an appropriate balance of compressive, shear, and rotational stiffnesses. The shape factor affects the bearing's ability to compress and rotate, but it has no impact on the bearing's ability to translate horizontally.



STRAINS IN A STEEL-REINFORCED ELASTOMERIC BEARING

Figure 21.2-4

A bearing pad must be designed to control the stress in the steel reinforcement and the strain in the elastomer. This is accomplished by controlling the elastomer layer thickness and the shape factor of the bearing. Fatigue, stability, delamination, yield, and rupture of the steel reinforcement; stiffness of the elastomer; and geometric constraints must be satisfied.

Large rotations and translations require thicker bearing pads. Translations and rotations may occur about the longitudinal or transverse axis of a steel-reinforced elastomeric bearing.

Steel-reinforced elastomeric bearing pads become large if they are designed for loads greater than approximately 650 kips. The maximum practical load capacity of a steel-reinforced elastomeric bearing pad is approximately 750 kips. Uniform heating and curing during vulcanization of such a large mass of elastomer becomes difficult, because elastomers are poor heat conductors. Manufacturing constraints thus impose a practical upper limit on the size of most steel-reinforced elastomeric bearing pads. If the design loads exceed 650 kips, the designer should check with the manufacturer for availability.

21.2.2.7 Plain Elastomeric Bearing Pads

Plain elastomeric bearing pads can support modest gravity loads, but they can only accommodate limited rotation or translation. Hence, they are best suited for bridges with small expansion lengths or specialty situations.

Plain elastomeric pads (PEP) rely on friction at their top and bottom surfaces to restrain bulging due to the Poisson effect. Friction is unreliable, and local slip results in a larger elastomer strain than that which occurs in reinforced elastomeric pads and bearings. The increased elastomer strain limits the load capacity of the PEP. The PEP must be relatively thin if it will carry the maximum allowable compressive load. A maximum friction coefficient of 0.20 should be used for the design of elastomeric pads that are in contact with clean concrete or steel surfaces. If the shear force is greater than 0.20 of the simultaneously occurring compressive force, then the bearing should be secured against horizontal movement. If the designer is checking the maximum seismic forces that can be transferred to the substructure through the pad, then a friction coefficient of 0.40 should be used.

Plain elastomeric pads are restricted for practical reasons to lighter bearing loads, in the order of 150 kips or less. Translations of ¾ in and rotations of 0.0175 radians or less are possible with PEP bearings.

Plain elastomeric pads shall be designed and detailed in accordance with Method A of LRFD Article 14.7.6.

21.2.3 <u>Design of Steel-Reinforced Elastomeric Bearing Pads</u>

Reference: LRFD Articles 14.7.5 and 14.7.6

The Method A procedure found in LFRD Article 14.7.6 shall be used for steel-reinforced elastomeric bearings. The Method B procedure found in LRFD Article 14.7.5 may be used for high-capacity bearings. The approval of the State Bridge Design Engineer is required to use the Method B design.

The Method B design procedure allows significantly higher average compressive stresses. These higher allowable stress levels are justified by an additional acceptance test, specifically a long-duration compression test. Designers must prepare a unique Special Provision for inclusion in the contract documents if a high-capacity elastomeric bearing is used. High-capacity elastomeric bearings (AASHTO Method B Design) should be used only where very tight geometric constraints, extremely high loads, or special conditions or circumstances require the use of higher grade material.

Design criteria for both methods are based upon satisfying fatigue, stability, delamination, steel reinforcement yield/rupture, and elastomer stiffness requirements.

The minimum elastomeric bearing length or width shall be 6 in. Generally, all pads shall be 50 or 60 durometer hardness. A minimum of ⅛ in of cover shall be provided at the edges of the steel shims. The top and bottom cover layers shall be no more than 70% of the thickness of the interior layers.

In determining bearing pad thicknesses, it should be assumed that slippage will not occur. The total elastomer thickness shall be no less than twice the maximum longitudinal or transverse deflection. The designer shall check the bearing against horizontal walking in accordance with LRFD Article 14.7.6.4.

A setting temperature of 70°F shall be used for the installation of the bearings. The formulas for determining the total elastomer thickness are shown below:

1. For precast, prestressed concrete beam spans, an allowance must be made for half of the shrinkage. The design thermal movement (Δ_T) shall be based upon $T_{MaxDesign}$ from LRFD Figure 3.12.2.2-1 and $T_{MinDesign}$ from LRFD Figure 3.12.2.2-2.

2. Minimum Total Elastomer Thickness for Precast Girders = 2 (Δ_T + ½ Δ Shrinkage).

3. For steel girder spans, the design thermal movement (Δ_T) shall be based upon $T_{MaxDesign}$ from LRFD Figure 3.12.2.2-3 and $T_{MinDesign}$ from LRFD Figure 3.12.2.2-4. No allowance is needed for shrinkage.

4. Minimum Total Elastomer Thickness for Steel Girders = 2 (Δ_T).

5. Creep is not typically considered when determining the total elastomer thickness for precast concrete beams.

6. For cast-in-place and post-tensioned concrete spans, the full shrinkage, elastic shortening, and creep shall be considered in addition to the thermal movement.

21.2.4 Seismic Design

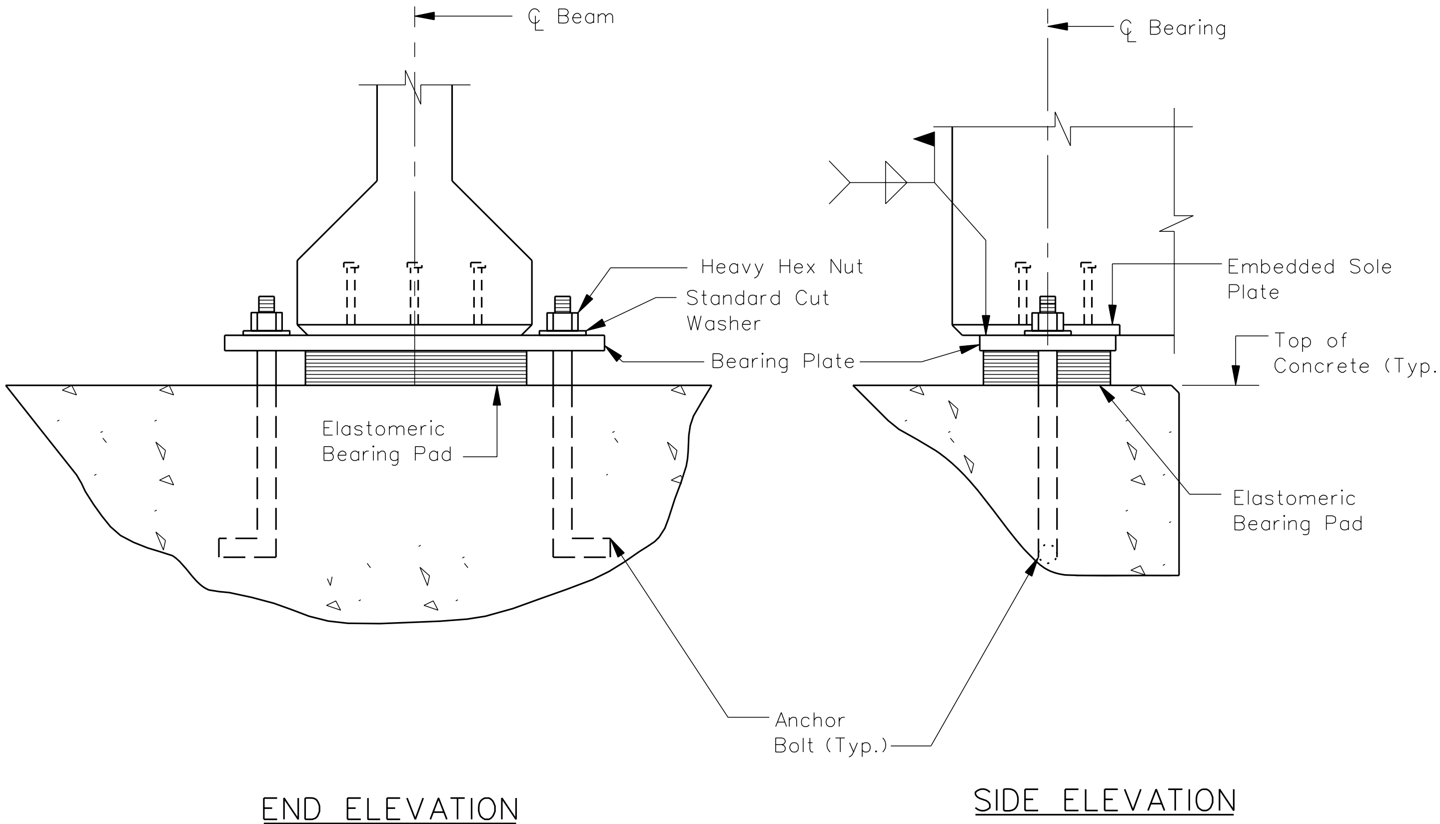
The bearing details must be consistent with the design assumptions used in the seismic analysis of the bridge.

21.2.5 Bearing Assembly Details

The following figures provide typical details for acceptable connections for bearing assemblies:

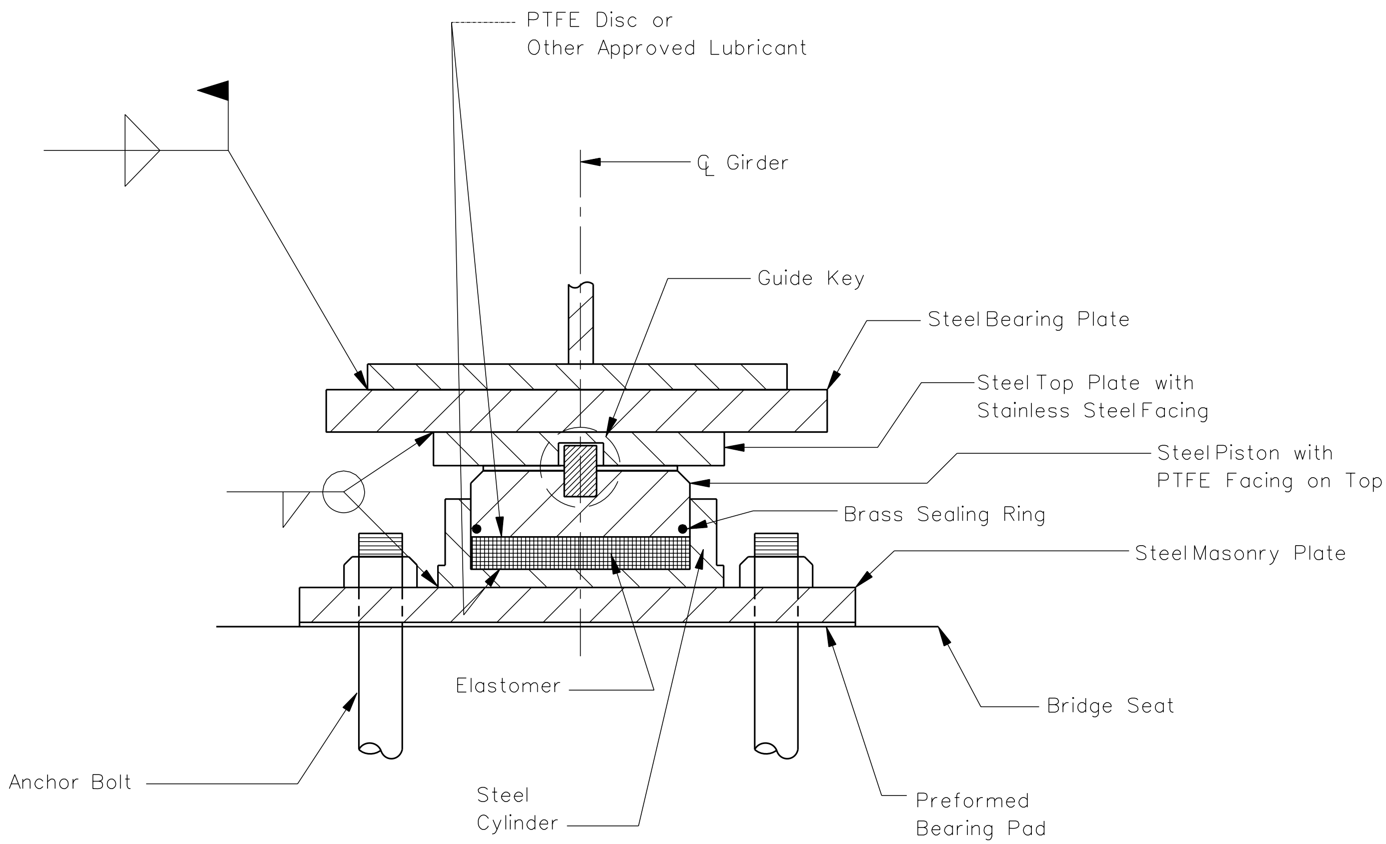
1. Elastomeric Bearing Assembly. See Figure 21.2-5.
2. Pot Bearings. See Figures 21.2-6 and 21.2-7.

These figures represent suggested details. The details may be revised as needed on a project-by-project basis.



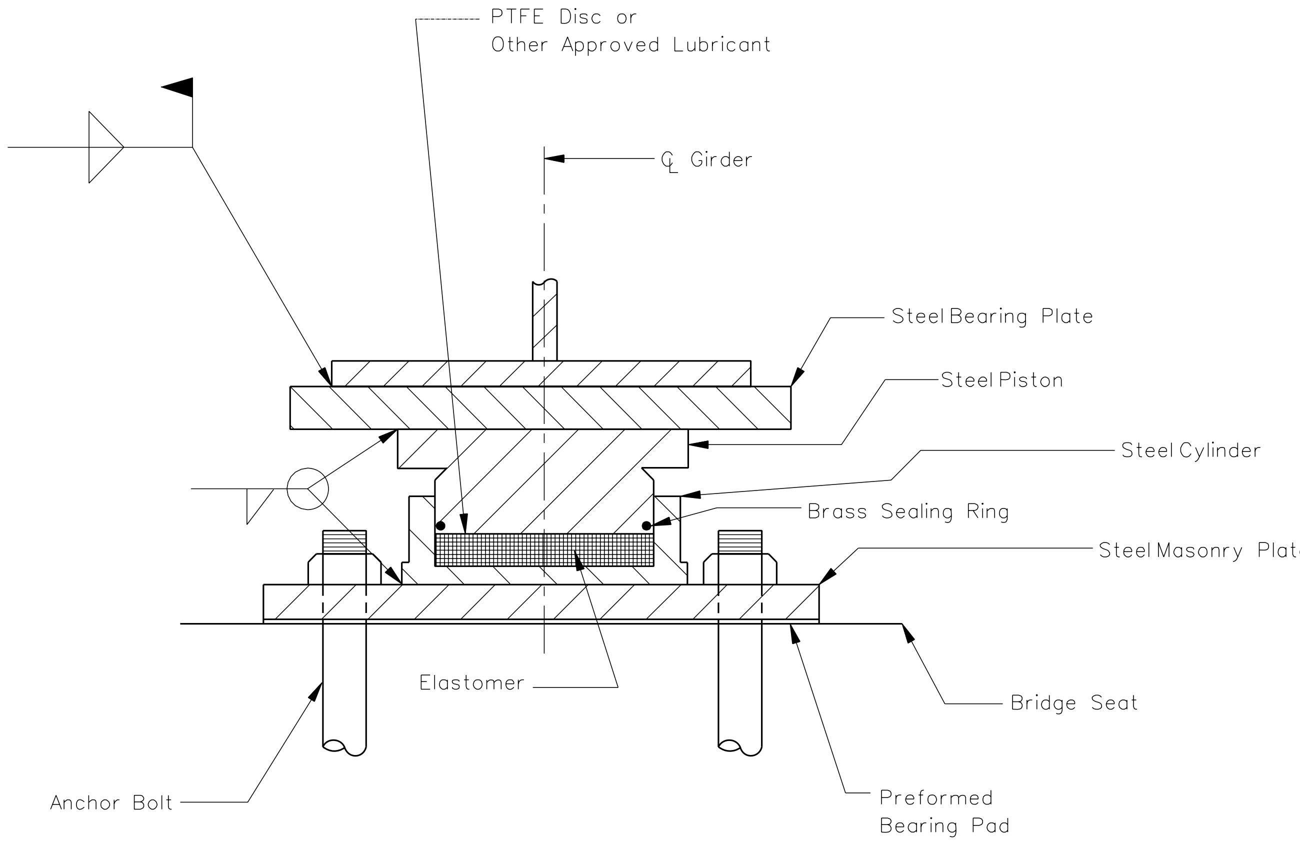
ELASTOMERIC BEARING ASSEMBLY

Figure 21.2-5



GUIDED EXPANSION POT BEARINGS

Figure 21.2-6



FIXED POT BEARINGS

Figure 21.2-7

Chapter 22

HIGHWAY BRIDGES OVER RAILROADS

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 22

HIGHWAY BRIDGES OVER RAILROADS

22.1 PROCEDURES

These procedures apply to projects being designed in-house. For Consultant-designed projects, the Consultant will be responsible for coordination with all railroad companies that may be affected.

22.1.1 Utilities Office

The Utilities Office is responsible for coordinating with the railroad companies where SCDOT projects impact railroads. The Utilities Office's responsibilities include obtaining cost estimates for securing agreements with railroad companies for the relocation and adjustment of their facilities, as required for highway construction, and conducting direct negotiations with railroad companies, when necessary.

22.1.2 Project Development

Because of the unique nature of highway-railroad grade separations, special coordination must occur when a railroad alignment and a highway alignment intersect or when these alignments are in close proximity to each other. A conceptual layout is developed considering the minimum horizontal and vertical clearances in this Chapter. The Project Manager will submit the conceptual bridge plans to the Utilities Office. The Utilities Office will coordinate with representatives from the impacted railroad company and evaluate the following:

- construction of future tracks;
- off-track maintenance roadways;
- drainage requirements, from both the railroad's perspective and SCDOT's perspective; and
- bent locations.

The Utilities Office will advise the Project Manager if the conceptual plans are acceptable or if revisions are needed to the conceptual layout. Preliminary bridge and road plans will be developed and then forwarded to the Utilities Office through the Project Manager. In addition, the Project Manager shall also provide an explanation of the proposed project. The Utilities Office will forward the plans to the railroad company for review and approval.

See Chapter 2 for a discussion on how the coordination with railroad companies is incorporated into the project development process for a bridge project.

22.2 DESIGN CRITERIA

22.2.1 General

Highway bridges constructed over or near railroads must be designed to be consistent with the geometric requirements of railroads. This includes criteria for lateral clearances, vertical clearances, and the width of the railroad roadbed section. These criteria are based on:

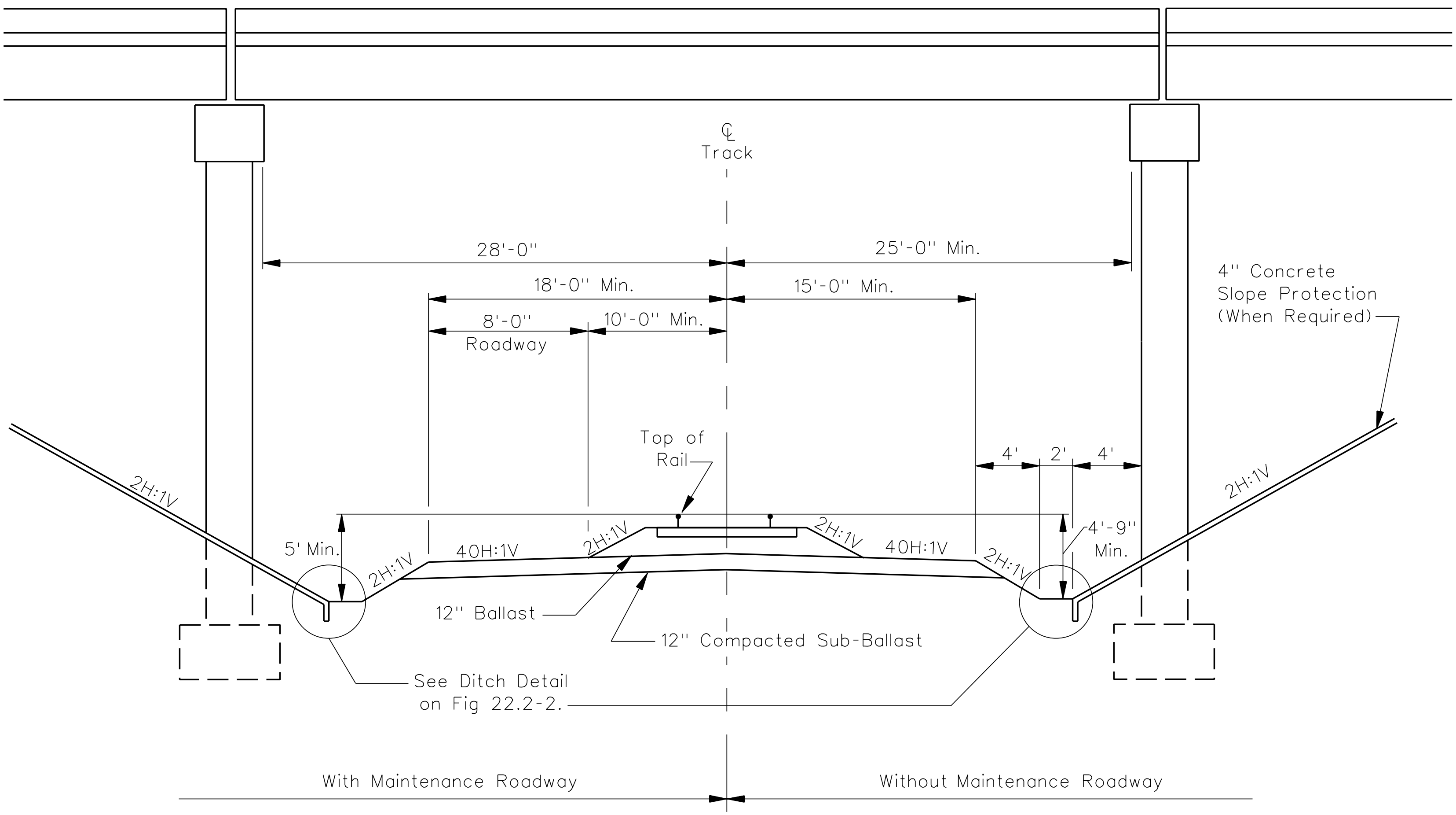
- the Federal Highway Administration participation limits for railroad geometrics;
- the requirements of the State of South Carolina;
- the specifications of the American Railroad Engineering and Maintenance-of-Way Association (AREMA); and
- the criteria established by individual railroad companies (i.e., CSX Transportation and Norfolk Southern Corporation).

22.2.2 Basic Geometric Configuration

The basic geometric configuration of the railroad cross section passing under a highway bridge is primarily based on the following factors:

- number and type of tracks,
- drainage treatments,
- maintenance roadway,
- specific requirements of individual railroad companies, and
- end slope. (Note: This will be 2H:1V maximum unless it is specifically engineered for stability at a steeper slope and slope protection is provided).

Figures 22.2-1 and 22.2-2 present the basic railroad cross sections based on these variables. Sections 22.2.3 and 22.2.4 present additional information that must be considered. Meeting the clearance requirements in Figures 22.2-1 and 22.2-2 typically determines the bridge length.

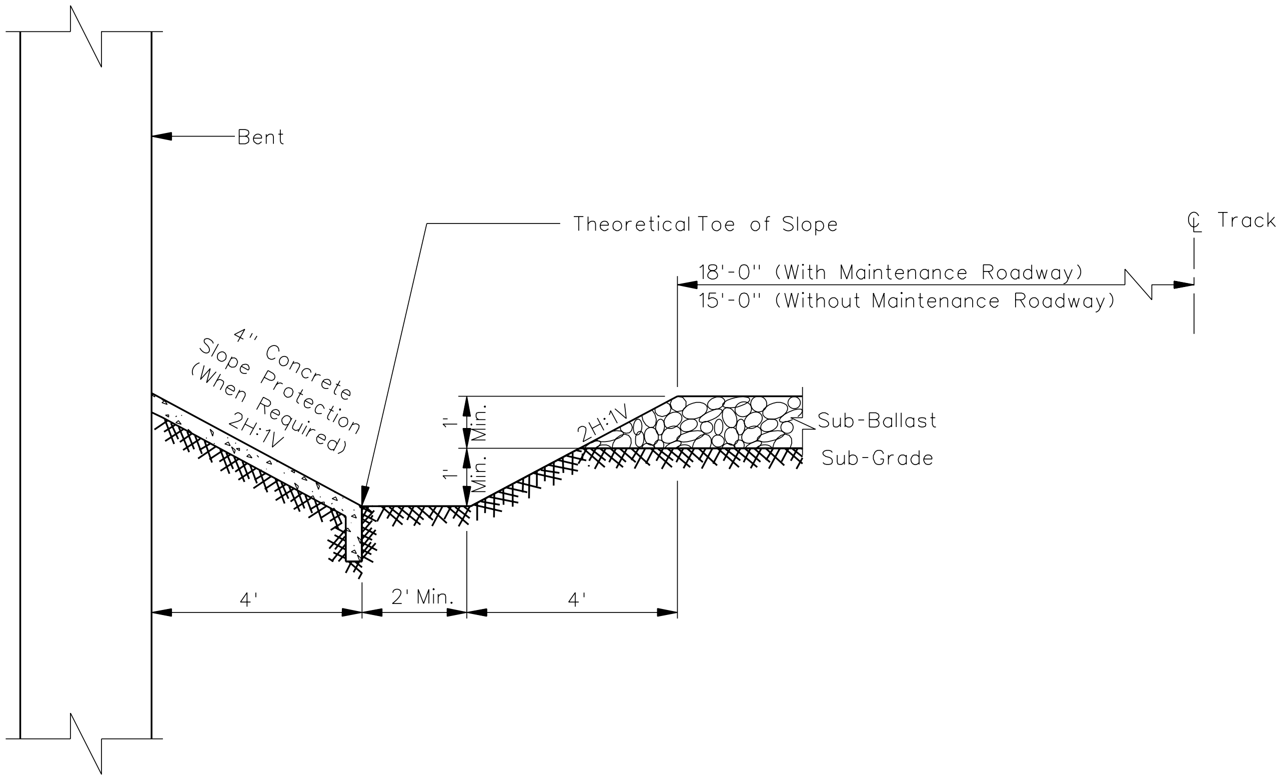


Notes:

1. *Horizontal dimensions shown are perpendicular to centerline of track.*
2. *Horizontal dimensions shown are the minimum distances to construct a standard railroad roadbed section. Actual required horizontal clearances may need to be increased due to the existing roadbed section and alignment, location of parallel ditches, and hydrologic conditions.*
3. *See Figure 22.2-3 for vertical clearances.*

RAILROAD CLEARANCES

Figure 22.2-1



Notes:

1. *Theoretical toe of slope is based on the standard railroad roadbed section. Actual toe of slope may vary due to existing ground line.*
2. *The ditch section shown is the minimum acceptable section.*
3. *The ditch section must be increased as required by local conditions, location of parallel ditches, and hydrologic condition.*

RAILROAD CLEARANCES
(Ditch Detail)

Figure 22.2-2

22.2.3 SCDOT/AREMA Recommendations

The American Railroad Engineering and Maintenance-of-Way Association (AREMA) publishes the *AREMA Manual*, which provides design standards for railroads. In addition to the *AREMA Manual,* SCDOT, in conjunction with CSX Transportation and Norfolk Southern Corporation, has developed specifications and design recommendations that will apply to the railroad cross section under a highway bridge.

22.2.3.1 Regulatory Template for Tangent Sections of Track

Figure 22.2-3 is the railroad template for permanent construction.

22.2.3.2 Clearances Under Bridges

The clearances shown in Figures 22.2-1 and 22.2-2 are for tangent track. In addition, consider the following:

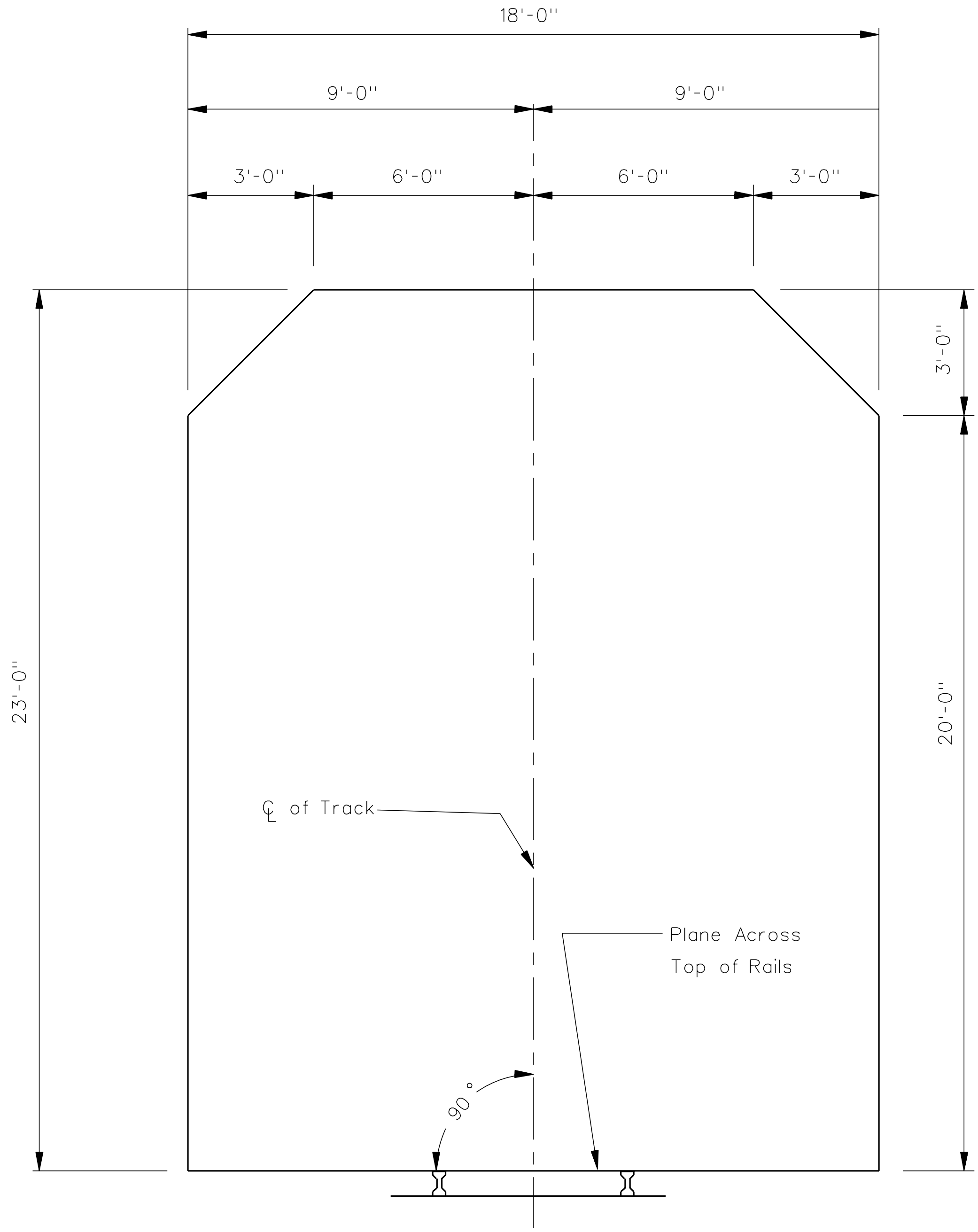
1. Horizontal Clearances (Tangent Track). End bents and/or interior bents for overhead bridge structures shall be located to clear the ditches of a typical track roadbed section and, where possible, be set with a minimum of 25.0 ft from the face of bent to the centerline of track. Edges of the footing should not be closer than 15.0 ft from the centerline of the track.

2. Horizontal Clearances (Curved Track). On curved track, the lateral clearances on each side of the track centerline shall be increased 1.5 in per degree of curvature on the railroad alignment. When the fixed obstruction is adjacent to the tangent track but the track is curved within 80 ft of the obstruction, the lateral clearances on each side of track centerline shall be increased as shown in Figure 22.2-4.

   On superelevated track, the track centerline remains perpendicular to a plane across the top of rails. Where the track is superelevated, clearances on the inside of the curve shall be increased by 3½ in for each inch of elevation differential between the inside and outside edges of the superelevated section.

3. Vertical Clearances. Vertical clearances shall be set between a minimum of 23.0 ft and a maximum of 23.4 ft from the top of rail to the bottom of the superstructure. If the minimum finished grade elevation is not controlled by the vertical clearance, the 23.4 ft maximum does not apply.

4. Temporary Clearances. Temporary horizontal construction clearances shall be noted on the plans as a minimum of 13.0 ft for tangent tracks and 14.0 ft for curved tracks measured from the centerline of track. Temporary vertical construction clearance shall be noted as 22.0 ft above the top of high rail. The railroad company may request increased temporary clearances after review of the preliminary plans.



REGULATORY TEMPLATE FOR TANGENT TRACK
(Clearance Box)

Figure 22.2-3

Distance from Obstruction to Curved Track (ft)	Increase Per Degree of Curvature (in)
20	1½
40	1⅛
60	¾
80	⅜

Note: To convert radius of curve (R, in ft) to degree of curvature (D, based on the chord definition), $D = 2(\sin^{-1}(50/R))$.

LATERAL CLEARANCE INCREASE
(For Tracks on Horizontal Curves)

Figure 22.2-4

22.2.3.3 Track Center Distances

The minimum distance between track centers is 15.0 ft. Individual railroad companies may have different requirements. These requirements, and any plans the railroad companies may have for future additional tracks, must be determined early in the project.

22.2.3.4 Bridge Length

The length of the bridge shall be established by locating the toes of the end fill slopes to accommodate the standard railroad road bed profile with open ditches as shown in Figures 22.2-1 and 22.2-2. End fills shall be sloped at 2H:1V taken perpendicular to the tracks. Slopes flatter than 2H:1V may be used when required by a geotechnical analysis. Piping of railroad ditches shall not be allowed.

The Project Manager should note that the above method of establishing the bridge length conflicts with the current FHWA criteria, which allows a 20-ft maximum distance from the centerline of track to the face of the fill slope. Therefore, it will be necessary for the Department to request FHWA to grant an exception on an individual project basis.

22.2.3.5 Bent Protection

To limit damage by the redirection and deflection of railroad equipment, bents supporting bridges over railways and with a clear distance of less than 25.0 ft from the centerline of a railroad track shall be of heavy construction (defined below) or shall be protected by a reinforced concrete crash wall. The following will apply:

1. Single-Column Bents. Crashwalls for single-column bents shall be a minimum of 2.5 ft thick and shall extend a minimum of 10.0 ft above the top of high rail. The wall shall extend a minimum of 6.0 ft beyond the column on each side in the direction parallel to the track.

2. Multiple-Column Bents. The columns shall be connected with a wall of the same thickness as the columns or 2.5 ft, whichever is greater. The wall shall extend a minimum of 2.5 ft beyond the end of outside columns in a direction parallel to the track and shall extend at least 4 ft below the lowest surrounding grade.

3. Reinforcing Steel. Reinforcing steel to adequately anchor the crashwalls to the column and footing shall be provided.

4. Heavy Construction. For bents of heavy construction, crashwalls may be omitted. Heavy construction is considered as solid bents with a minimum thickness of 2.5 ft and a length of 20.0 ft; single-column bents of a minimum of 4.0 ft by 12.5 ft dimensions; or any other solid bent sections with equivalent cross sections and a minimum of 2.5 ft thickness.

22.2.3.6 Side Slopes

Concrete slope protection pavement should be provided where practical. Generally, concrete slope protection will not be provided where the tracks are located in a cut section having steep slopes. When concrete slope protection is not provided, consider providing a low retaining wall attached to the bents adjacent to the track to prevent the fill from sloughing into the railroad ditches.

22.2.3.7 Bridge Widenings

Existing horizontal and vertical clearances should be maintained for widening projects. If the existing vertical clearance is greater than 23 ft, it may be reduced to a minimum of 23 ft. Clearances for reconstruction work or for alteration of existing tracks are dependent on existing physical conditions and, where reasonably practical, should be improved to meet the requirements for new construction.

22.2.4 Railroad Company Design Criteria

Each railroad company operating within the State of South Carolina requests or requires that SCDOT comply with its design criteria for highway bridges over railroads. These may apply to restrictions during construction, fencing, drainage, erosion control, etc. The Project Manager must ensure that the Department coordinates early with the railroad companies, through the Utilities Office, to identify these site-specific design criteria.

22.2.5 FHWA Participation

The Appendix to Subpart B of 23 CFR 646 presents the limits of FHWA participation for the costs of highway bridges over railroads. For convenience, Figure 22.2-5 reproduces those portions of the FHWA regulations that are applicable in South Carolina. The Appendix to Subpart B of 23 CFR 646 implements provisions of 23 CFR 646.212(a)(3). Note that SCDOT practices may differ from the criteria in the FHWA regulations.

22.2.6 Fencing

A protective fence will be provided if requested by the railroad company.

22.2.7 Construction Requirements

For information on shoring for construction excavations, demolition of existing structures, and erection procedures, see the *SCDOT Standard Specifications* and Supplemental Specifications.

Construction casing shall be specified for drilled shafts that are located within 30 ft of the centerline of an existing railroad track. For drilled shaft locations greater than 30 ft from the centerline of a track, consideration shall be given to requiring construction casing.

22.2.8 Control of Drainage from Highway Bridge Deck

Deck drains shall not be allowed to discharge onto railroad right-of-way. Chapter 18 discusses bridge deck drainage. When drains are required within the railroad right-of-way, a closed drainage system shall be used, and the drainage shall be directed away from the railroad right-of-way.

Lateral Geometrics

A cross section with a horizontal distance of 6.1 meters, measured at right angles from the centerline of track at the top of rails, to the face of the embankment slope, may be approved. The 6.1-meters distance may be increased at individual structure locations as appropriate to provide for drainage if justified by a hydraulic analysis or to allow adequate room to accommodate special conditions, such as where heavy and drifting snow is a problem. The railroad must demonstrate that this is its normal practice to address these special conditions in the manner proposed. Additionally, this distance may also be increased up to 2.5 meters as may be necessary for off-track maintenance equipment, provided adequate horizontal clearance is not available in adjacent spans and where justified by the presence of an existing maintenance road or by evidence of future need for such equipment. All piers should be placed at least 2.8 meters horizontally from the centerline of the track and preferably beyond the drainage ditch. For multiple track facilities, all dimensions apply to the centerline of the outside track.

Any increase above the 6.1-meters horizontal clearance distance must be required by specific site conditions and be justified by the railroad to the satisfaction of the State highway agency (SHA) and the FHWA.

Vertical Clearance

A vertical clearance of 7.1 meters above the top of rails, which includes an allowance for future ballasting of the railroad tracks, may be approved. Vertical clearance greater than 7.1 meters may be approved when the State regulatory agency having jurisdiction over such matters requires a vertical clearance in excess of 7.1 meters or on a site by site basis where justified by the railroad to the satisfaction of the SHA and the FHWA. A railroad's justification for increased vertical clearance should be based on an analysis of engineering, operational and/or economic conditions at a specific structure location.

EXCERPT FROM
APPENDIX TO SUBPART B OF PART 646—HORIZONTAL AND VERTICAL CLEARANCE PROVISIONS FOR OVERPASS AND UNDERPASS STRUCTURES

Figure 22.2-5

Chapter 23

BRIDGE WIDENING AND REHABILITATION

SCDOT BRIDGE DESIGN MANUAL

April 2006

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CHAPTER 23

BRIDGE WIDENING AND REHABILITATION

23.1 BRIDGE WIDENING

23.1.1 Introduction

It may be necessary to widen existing bridges for a variety of reasons:

1. The existing bridge may provide an inadequate roadway width.

2. The project may be adding lanes to a highway segment to increase the traffic-carrying capacity of the facility.

3. A bridge may be widened to add an auxiliary lane across the structure (e.g., increasing the length of an acceleration lane for a freeway entrance, adding a weaving segment at the interior of a cloverleaf interchange).

A bridge widening can present a multitude of difficult issues during the design stage, during construction, and throughout its service life. Special attention is required to both the overall design and the details of the widening to minimize construction and maintenance problems. The widening of a structure should also be designed in coordination with the appearance and function of the existing bridge.

This Section presents Department guidelines for widening existing bridges. The following briefly summarizes the basic objectives in bridge widening:

1. Do not perpetuate details that have proven to be fatigue prone. Examples include welded cover plate ends and other details with a fatigue resistance lower than Detail Category C or C′ (i.e., Detail Categories D through E′).

2. Match the structural components of the existing structure, including splice locations, as practical.

3. With respect to fixity, match the existing bearing function. The rotational and deflection characteristics of the existing bearing type should be considered when selecting new bearings.

It is not normally warranted to modify the existing structure solely because it was designed to earlier Specifications and does not satisfy the provisions of the *LRFD Bridge Design Specifications*. Bridges designed to the earlier AASHTO *Standard Specifications* are usually acceptable with respect to the adequacy of their structural design. However, the bridge designer shall evaluate the need to seismically retrofit the existing bridge. The degree of knowledge for seismic design increases with each subsequent seismic event; therefore, reviewing existing bridges within the context of the latest seismic requirements may be justified.

23.1.2 Existing Structures with Substandard Capacity

Typically, existing bridges to be widened should be designed based on the original design. The SCDOT Bridge Maintenance Office, which has the responsibility for inspecting all in-service bridges and maintaining all State-owned in-service bridges, should always be consulted on the condition and the load capacity of the existing structure. Based on this information, the designer may determine that the existing structure should be strengthened to the same load-carrying capacity as the widened portion. For the evaluation, the following should be considered, as appropriate:

- cost of strengthening existing structure;
- physical condition, operating characteristics, and remaining service life of the structure;
- seismic resistance of structure;
- other site-specific conditions;
- width of widening; and
- traffic accommodation during construction.

23.1.3 Girder Type Selection

In selecting the type of girder for a structure widening, the widened portion of the structure should be a construction type and material type consistent with the existing structure, as practical. Materials used in the construction of the widening should have the same thermal and elastic properties as the existing structure. Avoid mixing concrete and steel beams in the same span. One exception to this is for an existing conventionally reinforced concrete T-beam structure. In this case, it is preferable to use prestressed concrete I-beams or steel rolled beams for the widened portion.

23.1.4 Attaching Bridge Decks

23.1.4.1 Existing Bridge Deck

The designer must evaluate the need to rehabilitate or replace the existing bridge deck as part of the bridge widening project. Section 23.2 discusses the evaluation of an existing bridge deck.

23.1.4.2 Longitudinal Expansion Joints

Longitudinal expansion joints in bridge decks between a bridge widening and an existing bridge are often a continuous source of bridge maintenance problems and are a potential safety hazard if they are located within the riding surface of the deck. Therefore, as a general policy, no longitudinal expansion joints should be detailed, except for locations where concrete barrier rail or raised concrete median is placed on each side of the joint.

23.1.4.3 Lapping Reinforcing Steel

A positive attachment of the widened and existing decks by lapping reinforcing steel usually provides a better riding deck, presents a better appearance, and reduces maintenance problems in comparison to longitudinal expansion joints. A positive attachment of the old and the new decks should be made for the entire length of the structure.

In some cases, it may be desirable to use mechanical couplers or an epoxy-resin anchorage system instead of lapping reinforcing steel. Lapped reinforcing steel may be more expensive than other options because of the need to provide adequate bond length. For example, mechanical couplers may be more cost effective than removing additional existing concrete to expose more length of reinforcing bar to obtain the necessary lap splice length.

23.1.4.4 Requirements

The following requirements should be considered when widening an existing girder/beam and deck-type structure:

1. Large Overhangs. Structures with large overhangs, where adequate room exists between the outside edge of deck and the exterior edge of the top flange, should be widened by removing the concrete from the overhang to a width sufficient to develop adequate length for lapping the original transverse deck reinforcing steel to that of the widening.

2. Small Overhangs. Structures with small overhangs, where removal of the overhang to the exterior edge of the top flange will not provide sufficient bond length, should be either doweled to the widening or have transverse reinforcing steel exposed and extended by mechanical lap splice.

3. Existing Barrier. Where the existing deck will not be overlaid with concrete, the deck should be removed to at least the existing gutter line.

4. Longitudinal Construction Joints. Longitudinal construction joints should not be located over the beam flanges. Longitudinal construction joints should preferably be aligned with the permanent lane lines or located in the shoulder area of the deck. These joints tend to be more visible than the pavement markings during adverse weather conditions.

5. Deck Loading. Removal of the deck past the outside beam line (i.e., to somewhere between the fascia girder and the first interior girder) will result in a temporary cantilever slab condition. The designer must ensure that the temporary cantilever deck can resist the loadings anticipated during construction.

6. Deck Removal. A 1-in vertical saw cut shall be made in the existing slab where the slab is to be removed.

23.1.5 Closure Pours to Counteract the Effects of Dead-Load Deflection

Typical SCDOT practice is to use a closure pour between the existing bridge and the widened portion.

Unless the widened structure is completely prefabricated, deflection of the girders or beams will occur due to superimposed dead loads, such as the deck slab, diaphragms, barriers, etc. If proper provisions are not made to accommodate the dead load deflection, construction and maintenance problems will ensue. Where the deflection from the deck slab weight exceeds ½ in, a closure pour shall be used to complete the attachment to the existing structure. When a closure pour is used:

- stay-in-place forms shall not be used under the closure pour,
- diaphragms between new and existing construction shall not be rigidly connected until after the new deck is poured, and
- reinforcing steel shall not be tied or coupled to the existing reinforcing steel until after the new deck is poured.

A closure pour serves two useful purposes: It defers final connection to the existing structure until after the deflection from the deck slab weight has occurred; and it provides the width needed to make a smooth transition between differences in final grades that result from theoretical versus actual deflections or construction tolerances.

Considering the effects of dead-load deflection, two general groups of superstructure types can be distinguished:

- precast concrete beam or steel girder construction, where the largest percentage of deflection occurs when the deck concrete is placed; and
- cast-in-place construction (e.g., flat slab bridges), where the deflection occurs after the falsework is released.

In the first group, dead-load deflection after placing the deck is usually insignificant but, in the second group, the dead-load deflection continues for a lengthy time after the falsework is released. In conventionally reinforced concrete structures, approximately ⅔ to ¾ of the total deflection occurs over a four-year period after the falsework is released due to shrinkage and creep. A theoretical analysis of differential deflection that occurs between the new and existing structures after closure will usually demonstrate that it is difficult to design for this condition. Past performance indicates, however, that theoretical overstress in the connection reinforcing has not resulted in maintenance problems, and it is generally assumed that some of the additional load is distributed to the existing structure with no difficulty, or its effects are dissipated by inelastic relaxation. Good engineering practice dictates that the closure width should relate to the amount of dead load deflection that is expected to occur after the closure is placed. A minimum closure width of 3 ft is recommended.

23.1.6 Vehicular Vibration During Construction

All structures deflect when subjected to live loading, and many bridge widenings are constructed with traffic on the existing structure. Fresh concrete in the deck is subjected to deflections and vibrations caused by traffic. Studies such as NCHRP 86 *Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs* have shown that:

- reinforced concrete is not adversely affected by jarring and vibrations of low frequency and amplitude during the period of setting and early strength development;
- traffic-induced vibrations do not cause relative movement between fresh concrete and embedded reinforcement; and
- investigations of the condition of widened bridges have shown the performance of attached widenings, with and without the use of a closure pour, to be satisfactory.

Therefore, no special measures other than those described in Section 23.1.5 must be taken to prevent movement and vibration during concrete pouring or curing.

23.1.7 Substructure

Generally, new interior bent substructure units required to support the bridge widening are not connected to the existing substructure. Not connecting the new substructure to the old avoids damage to the substructure components due to differential settlement. However, if the new substructure unit consists of one column, the new substructure may be connected to the existing substructure, provided that suitable provisions are made in the design and details to prevent differential settlement. The effects of excavation adjacent to existing substructures shall be considered. The existing substructure shall be cleaned and textured if it is visible to the public. Consult with the Bridge Maintenance Office on any needed repair to exposed reinforcing steel and spalls.

23.1.8 Superstructure

The spacing between the existing exterior girder and the adjacent new girder shall be equal to or less than the girder spacing of the existing span. New diaphragm spacing for widenings shall be consistent with the existing diaphragm spacing. For widenings using a single girder system, a minimum of one interior diaphragm is required. With the exception of end diaphragm connections to existing beams at simply supported spans, field welding to the existing beams is prohibited. On the existing deck, detail the same expansion joint type as that used on the new deck.

23.1.9 Design Criteria (Historical Background)

For bridge widenings, the designer should be aware of the historical perspective of design criteria, such as live loads, allowable stresses, etc., when analyzing an existing structure. For information on specific structures, see the as-built plans, old special provisions, any documentation of modifications made after original construction, and the appropriate editions of the AASHTO *Standard Specifications*.

Throughout the years, modifications to steel beam sections have occurred. Designers should refer to the construction year AISC steel tables for beam properties, steel strength, and other data.

23.1.10 Clearances

Existing horizontal and vertical clearances shall be maintained unless the existing clearance is greater than the minimum clearance required for a new structure.

23.2 BRIDGE REHABILITATION

23.2.1 Responsibilities

Typically, the SCDOT Bridge Maintenance Office and Bridge Design Section coordinate on the design of bridge rehabilitation projects depending on the workload of each Unit. Where the Bridge Design Section is responsible for the bridge rehabilitation project, the bridge designer should seek input from the Bridge Maintenance Office for assistance.

23.2.2 Project Identification Process

The Bridge Maintenance Office identifies bridge rehabilitation and replacement projects.

23.2.2.1 SCDOT Bridge Management System

The SCDOT Bridge Maintenance Office has the responsibility for running the SCDOT Bridge Management System (BMS). It uses both the National Bridge Inspection (NBI) data and additional detailed bridge data. This system is used as a tool along with input from Department management and the Districts in making decisions regarding:

- preservation,
- rehabilitation, and
- replacements.

23.2.2.2 National Bridge Inspection Standards (NBIS)

The National Bridge Inspection Standards (NBIS), a nationwide inspection and inventory program, is intended to detect structural problems. The Federal Highway Administration has promulgated regulations that each State Department of Transportation must meet. The following presents a brief discussion on the operational requirements of the NBIS:

1. Frequency of Inspections. Each bridge must be inspected at periodic intervals based on its condition and type.

2. Qualifications of Personnel. The Federal regulation lists the minimum qualifications for all bridge inspection personnel.

3. Inspection Procedures and Reports. Each State must have a systematic method for conducting field inspections and reporting its findings.

4. Records. Each State must have a systematic means of entering, storing, and retrieving all bridge inspection data.

5. Ratings. All bridges are rated according to their load-carrying capacity. This includes both the Operating and Inventory Ratings. This information assists in the posting, the issuing of special overload permits, and the scheduling for rehabilitation or replacement.

23.2.2.3 SCDOT Bridge Inspection Program

The Bridge Maintenance Office is responsible for collecting, maintaining, and reporting bridge inspection information and for ensuring that the SCDOT Bridge Inspection Program complies with the requirements of the NBIS. The South Carolina Bridge Inspection Program provides the data that, through the use of the Sufficiency Rating, identifies the overall sufficiency of every bridge open to the public in the State of South Carolina.

23.2.2.4 Sufficiency Rating

The Sufficiency Rating formula is a method of evaluating highway bridge data by calculating several factors (structural adequacy, safety, serviceability, functional obsolescence, and special reductions) to obtain a numeric value that is indicative of the bridge's sufficiency to remain in service and its funding eligibility. The result of the Sufficiency Rating formula is a percentage in which 100 is an entirely sufficient bridge and 0 is an entirely deficient bridge.

23.2.3 Rehabilitation Strategy

Bridge rehabilitation design involves the following basic steps:

1. Perform a field investigation of the existing bridge.
2. Collect the available data on the existing bridge (e.g., as-built plans, bridge inspection data, traffic volumes).
3. Identify the necessary condition surveys and tests (e.g., coring, chain drag, chloride analysis, identifying fracture-critical members).
4. Evaluate the data from the condition surveys and tests.
5. Select the appropriate bridge rehabilitation technique(s) to upgrade the bridge to meet the necessary structural and functional objectives.

For those bridge rehabilitation projects designed by the Bridge Design Section, the bridge designer should seek input from the Bridge Maintenance Office to implement the bridge rehabilitation strategy.

23.2.4 Bridge Decks

23.2.4.1 Evaluation

Certain factors are symptomatic indicators that a bridge deck may need to be rehabilitated or replaced. Some examples are:

- extensive delamination,
- exposed reinforcing steel, and
- spalls.

When considering a bridge deck for replacement or rehabilitation, the Bridge Design Section requests a number of tests to gather information on the deck's condition. The gathered information allows the designer to determine whether deck rehabilitation or deck replacement would be more effective and, if the choice is rehabilitation, the information allows the determination of the appropriate level of treatment.

The Bridge Design Section requests the following information to perform a deck evaluation:

- a plot locating existing delaminations, spalls, and cracks;
- measurement of the depth of cover on the top mat of reinforcing steel on a grid pattern;
- sampling and laboratory analysis to determine the existing levels of chloride contamination; and
- deck concrete compressive strength assessed through destructive testing of deck core samples.

23.2.4.2 Condition Assessment Tests

23.2.4.2.1 Visual Inspection

The following applies to visual inspections:

1. Description. A visual inspection of the bridge deck should establish:
    - the approximate extent of cracking, delamination, spalling, and joint opening;
    - evidence of any corrosion;
    - evidence of pattern cracking, efflorescence, or dampness on the deck underside;
    - rutting of the riding surface and/or ponding of water;

- operation of deck joints;
- functionality of deck drainage system; and
- bridge rails and guardrail-to-bridge-rail transitions meeting current SCDOT standards.

2. Purpose. The visual inspection of the bridge deck will achieve the following:

   - By establishing the approximate extent of cracking, corrosion, delamination, and spalling (and by having evidence of other deterioration), the bridge designer can determine if a more extensive inspection is warranted.
   - The inspector will identify substandard safety appurtenances.

3. When to Use. Use for all bridge deck evaluations.

4. Analysis of Data. Pattern cracking, efflorescence, or dampness on the deck underside suggest that this portion of the deck is likely to be highly contaminated. In addition, the designer should consider:

   - traffic control,
   - timing of repair,
   - age of structure,
   - average daily traffic,
   - slab depth,
   - structure type,
   - depth of cover to reinforcement, and
   - seismic factors.

23.2.4.2.2 Delamination Testing or Sounding

The following applies to delamination testing or sounding:

1. Description. Establishes the presence of delamination, based on audible observation, by chain drag or hammer. Based on the observation that delaminated concrete responds with a “hollow sound” when struck by a metal object.

2. Purpose. To determine the location and areas of delamination.

3. When to Use. Use for all bridge deck evaluations, except where asphalt overlays prevent performance of the test.

4. Analysis of Data. Based on the extent of the bridge deck spalling, the following will apply:

- 5% delamination of surface area is a general guide for considering remedial action, and
- 10% delamination is a general guide for considering bridge deck replacement.

23.2.4.2.3 Coring

The following applies to coring:

1. Description. 2-in or 4-in diameter cylindrical cores are taken. In decks with large amounts of reinforcement, it is difficult to avoid cutting steel if 4-in diameter cores are used.

2. Purpose. To establish strength, composition of concrete, crack depth, position of reinforcing steel.

3. When to Use. Use for all bridge deck evaluations.

4. Analysis of Data. Less than 2 in of concrete cover is considered inadequate for corrosion protection. Less than 3 ksi compressive strength of concrete is considered inadequate. If compressive strengths are less than 3 ksi, the designer must obtain a determination from the State Bridge Design Engineer whether to proceed with the deck rehabilitation or to proceed with a deck replacement. The choice of core locations can have a significant impact on the findings.

23.2.4.2.4 Chloride Analysis

The following applies to chloride analysis:

1. Description. A chemical analysis of pulverized samples of the bridge deck concrete extracted from the deck or by in-place drilling.

2. Purpose. To determine the chloride content profile from the deck surface to a depth of about 3 in or more.

3. When to Use. Use for all bridge deck evaluations. Take chloride samples at three to five locations per span from each span 100 ft or less in length. Increase the number of samples for longer spans.

4. Analysis of Data. The “threshold” or minimum level of water-soluble chloride contamination in concrete necessary to corrode reinforcing steel is 1.2 lbs/yd^3 or 0.03% chloride by weight. Chloride concentrations equal to or greater than this value above the top reinforcing mat require the removal of at least enough concrete so that the remaining concrete contamination is below the threshold.

Threshold or greater chloride concentrations at the level of the top reinforcing mat require either 1) hydro-demolition to remove enough concrete to ensure that the remaining concrete is below the threshold values, or 2) deck replacement.

Threshold contamination or worse at or near the level of the bottom mat of reinforcing steel requires deck replacement.

23.2.5 Bearing Replacement

Often, the existing bearings may only need to be cleaned and/or repositioned. Extensive deterioration, or frozen bearings, may indicate that the design should be modified. A variety of elastomeric devices may be substituted for sliding and roller bearing assemblies. If the reason for deterioration is a leak in the deck joint, then the deck joint should be resealed or rehabilitated.

Rocker bearings and elastomeric bearings should not be mixed on the same interior bent, due to differences in movement.

If the bearings are seriously dislocated, their anchor bolts are badly bent or damaged, or the beam seats or pedestals are structurally cracked, then the bridge may have a system-wide problem, which is usually caused by temperature or settlement. All of these items should be investigated and evaluated.

The bearing design may require alteration if warranted by seismic vulnerability. Damaged or malfunctioning bearings can fail during an earthquake. In addition, steel rocker and roller bearings perform poorly because rocker bearings can easily tip over when their limits are exceeded during a seismic event and rollers roll freely. One option is to replace these bearings with prefabricated steel-reinforced elastomeric bearings. To maintain the existing beam elevation, either a steel assembly is inserted between the beam seat and the elastomeric bearing, or the elastomeric bearing is seated on a new concrete pedestal. Construction of new concrete pedestals may create significant additional traffic control costs. Existing anchor bolts that extend into a new pedestal from the top of the bent may be considered to assist in resisting the horizontal interface shear between the new pedestal and the existing interior bent. In both cases, the beam should be positively connected to the substructure by anchor bolts, either directly or indirectly.

See Chapter 21 for more information on bearings.

23.2.6 Seismic Retrofit

Bridges that are selected for seismic retrofitting shall be investigated for the same basic criteria that are required for all new bridges, including minimum support length and minimum bearing force demands. This evaluation will be based on the *SCDOT Seismic Design Specifications for Highway Bridges*. Specific details for seismic retrofitting may be found in the *Seismic Design and Retrofit Manual for Highway Bridges*, FHWA, latest edition.

Minor seismic retrofit will usually be limited to seismic restrainers, isolation bearings, and increasing the support length of beam seats. For the most part, the minor work will be limited to work at or above the beam seats.

Major seismic retrofit includes such items as strengthening columns, interior bents, bent caps, etc. It will generally include work below the level of the beam seats and may include work that requires cofferdams. SCDOT prepares cost estimates that compare the costs of a retrofit versus total replacement (including life-cycle costs). SCDOT then coordinates with FHWA to determine the project approach.

Chapter 24

CONSTRUCTION OPERATIONS

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CHAPTER 24

CONSTRUCTION OPERATIONS

24.1 SHOP PLANS/WORKING DRAWINGS

24.1.1 Definitions

"Shop plans" are plans prepared by the Contractor that contain manufacturing details of an item that will become a permanent part of the project and its appurtenances, such as structural steel fabrication drawings, prestressing concrete beam drawings, or any other supplementary plans or similar data that the Contractor is required to submit to the Engineer for review before fabrication.

"Working drawings" are sketches, calculations, etc., prepared by the Contractor for temporary structural features that may include erection plans, falsework plans, cofferdam plans, temporary structure plans, or any other supplementary plans or similar data that the Contractor is required to submit to the Engineer for review before assembly of the subject of the drawings on the project site.

24.1.2 Policies and Procedures

SCDOT policies and procedures for shop plans and working drawings reviews are documented in the *SCDOT Standard Specifications for Highway Construction.* The following provides information supplementary to that in the *SCDOT Standard Specifications*:

1. Shop Plans (In-House-Designed Projects). The Contractor shall submit six sets of the shop plans to the SCDOT State Bridge Design Engineer, which are reviewed by the Bridge Design Section. The basic objective of the review is to ensure that the intended design performance and durability of the structural element will not be compromised by the construction and/or fabrication procedures or by problems with materials. After review, the State Bridge Design Engineer retains one set of the shop plans for the bridge design file and distributes:

    - one set to the Contractor,
    - two sets to the SCDOT Resident Engineer, and
    - two sets to the SCDOT Office of Materials and Research.

2. Shop Plans (Consultant-Designed Projects). The Contractor shall submit seven sets of the shop plans directly to the Consultant. If the plans need to be revised and resubmitted, the Consultant sends the plans back to the Contractor. SCDOT shall be provided copies of all transmittal letters. After the Consultant reviews and accepts the shop plans, the Consultant submits six sets of the shop plans to the SCDOT State Bridge Design

Engineer, not the Contractor. The State Bridge Design Engineer retains one set for the bridge design file and distributes:

- one set to the Contractor,
- two sets to the SCDOT Resident Engineer, and
- two sets to the SCDOT Office of Materials and Research.

3. Working Drawings. The Contractor shall submit working drawings and design calculations to the SCDOT Bridge Construction Engineer for the following temporary falsework/form system elements:

- cofferdams,
- temporary shoring walls,
- new falsework/form systems, and
- other falsework/form systems as required in the Special Provisions.

The Contractor shall submit seven copies for review and acceptance on all projects except railroad projects. On railroad projects, the Contractor shall submit nine copies for review and acceptance.

When working drawings are for items of work that are included as bid items (e.g., cofferdams, temporary shoring wall), the Bridge Construction Engineer will forward the drawings to the designer (Bridge Design Team or Consultant) for review. For all other working drawing submittals, the designer will assist the Bridge Construction Engineer with the review when requested.

24.2 CONSTRUCTION PLANS

24.2.1 Construction Plans Storage

The Final Construction Plans are filed within the Bridge Design Section and remain in permanent storage. These plans are only revised to reflect major changes that occurred during construction.

24.2.2 Final As-Built Plans

During construction of the project, the Resident Construction Engineer maintains a separate set of drawings on which all revisions to the plans on the project are recorded. These plans, when checked and completed, are transmitted to the Final Construction Plans Manager in the Headquarters where they are retained for permanent record.

24.2.3 Plan Revisions and Construction Changes

24.2.3.1 Revised Plan Sheets

Use the following procedures to make revisions to the plan sheets after they have been submitted to the Engineering Reproduction Manager.

1. Changes Prior to Award. Changes to plan sheets that are made available to the bidders prior to the award of a contract will be reviewed by the Bridge Design Section, which will verify that all changes have been made in the CADD files. Revised plan sheets will be provided to the Engineering Reproduction Manager, who will incorporate the revised sheets into the plans after the award of the contract.

2. Changes After Award. Revised plan sheets that are not available to the bidders prior to the letting will not be added to the bid plans. This procedure is for all revisions made after the award or when the revisions are not made available to the prospective bidders prior to letting. The bridge designer labels any additional or revised plan sheets provided with the indication CONSTRUCTION CHANGE. These sheets will be inserted into the plans, and the original sheets will be placed face down in the back of the stored plans for reference. A note will be added to the Title Sheet describing which plan sheets are affected by the change or additional work. Revised and added plan sheets during the construction phase will be incorporated into the Final As-Built Plans after construction is completed. Revised plan sheets are provided to the Bridge Design Section for distribution.

24.2.3.2 Working Plans

Working Plans requested by District personnel include all revised sheets in the proper order with the old sheets removed. The Engineering Reproduction Manager will maintain a complete electronic copy of the Working Plans and will provide copies to Department employees when specifically requested. The Engineering Reproduction Manager in the Road Design Section will archive all plan sheets, original and revised, on the appropriate Department server.

24.3 OTHER CONSTRUCTION INVOLVEMENT

24.3.1 Change Orders

Construction personnel may seek input from the Bridge Design Section on change orders related to structural items. Details on the procedures for construction change orders may be found in Section 101.6 of the *SCDOT Construction Manual*.

24.3.2 Value Engineering Proposals

The Department allows Contractors to submit Value Engineering Proposals. Upon receipt, the Resident Construction Engineer will contact the appropriate SCDOT personnel to discuss the original design intent and the potential merits and cost savings of accepting the Proposal. The Bridge Design Section will be contacted for structural features. More information on Value Engineering Proposals may be found in the *SCDOT Standard Specifications*.

Chapter 25

COMPUTER PROGRAMS

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CHAPTER 25

COMPUTER PROGRAMS

25.1 GENERAL

The Bridge Design Section uses many computer programs for structural analysis and design, which can provide significant benefits. These include the capability of quickly analyzing several alternative designs (i.e., simulation capabilities), of reducing the probability of mathematical errors, and for saving time by avoiding laborious hand calculations. However, the user of any computer program must consider the following:

1. Judgment and experience are critical to the proper interpretation of the computer output.
2. The user should, after the computer run, recheck the input for accuracy.
3. The user should carefully check all output to ensure that answers are reasonable and logical and that there are no obvious errors. The check should include an equilibrium check in structural applications, for example, verifying that the sum of the applied loads equals the sum of the reactions. In addition, simple free-body diagrams can also be checked by cutting the structure at a section where a free body can easily be taken.
4. The user should be familiar with the advantages and limitations of each program.

This Chapter presents some of the commercially available computer programs used by the Bridge Design Section. The Chapter provides a brief description of each program's applications.

25.2 COMMERCIALLY AVAILABLE PROGRAMS

25.2.1 CAPP

25.2.1.1 Description

CAPP (Capacity Analysis Pushover Program) is a fully functional 2-D pushover program with analytical and modeling capabilities. CAPP is applicable to the nonlinear analysis of bridges with output results generated and reported in an engineering report format.

CAPP is available from Imbsen Software Systems.

25.2.1.2 Input

The CAPP user interface generates nodes and members. The Input File editor allows the user to change the input file directly and update it graphically, or change items within the interface and observe the automatic updating within the input file. All material, sections, hinges, elements, reports, and data are available in Project Manager for access, manipulation, and extraction. The interface allows the user to view the force diagrams, reactions, displaced shapes, locations of nonlinearity, and trace element/hinge nonlinear behavior at any load step, from application of dead load to collapse.

25.2.1.3 Output

CAPP uses an event-to-event load incrementation strategy coupled with an equilibrium error correcting Newton-Raphson algorithm to ensure the accuracy of a calculated response. Load combinations allow for combining the non-push-load cases together with load factors before the push analysis is performed to capture the effects of the structure's initial state of stress. CAPP allows the user to analyze various push-load patterns in the same model file to envelope overall structure behavior. Graphically, during analysis, the user can observe structure nonlinear deformations, the location of nonlinearity, and various limit states of yielding components.

25.2.2 CONSPAN™

25.2.2.1 Description

CONSPAN™ is a comprehensive program for the design and analysis of prestressed, precast concrete beams using either the AASHTO LFD or LRFD design methodologies. The program accommodates simple spans and multiple simple spans made continuous for live loads. CONSPAN™ incorporates both LFD and LRFD AASHTO Specifications into one interface.

Simple-span static analysis is performed for dead loads resisted by the precast sections. Continuous static analysis is performed for dead loads acting upon the composite structure. A continuous moving load analysis is performed for the live load.

CONSPAN™ is available from LEAP Software, Inc.

25.2.2.2 Input

CONSPAN™ simplifies the entry of project data with a system of tab screens, dialog boxes, graphical button, menus, and wizards. Designs are completed with either the CONSPAN™ automated features or the user-specified input.

25.2.2.3 Output

CONSPAN™ presents analysis results in a variety of easy-to-view formats, from a one-page design summary to comprehensive project reports. Analysis results and graphical sketches can be exported to spreadsheets and .dxf formats.

During individual beam designs, various design parameters such as distribution factors, impact/dynamic allowance factors, and allowable stresses are established. The strand and debonding/shielding patterns can be automatically generated by CONSPAN™ or specified by the user. Debonding constraints limiting the number of debonded strands can also be user-specified. Service load stress envelopes, generated by combining the results of the analysis, are checked against allowable limits. Factored positive moments and shears are checked against the ultimate strength capacity of the effective section. Mild reinforcement in the deck, at the interior bents, is computed for factored negative and positive moments. Many other code criteria such as cracking moments, horizontal shear, stresses at limit states, etc., are also automatically checked.

25.2.3 <u>FB-MultiPier</u>

25.2.3.1 Description

FB-MultiPier, the successor to the Florida Pier analysis program, is a nonlinear, finite-element analysis program designed for analyzing bridge interior bent structures composed of nonlinear interior bent columns and caps supported on a linear pile cap and nonlinear piles/shafts with nonlinear soil. This analysis program couples nonlinear structural finite-element analysis with nonlinear static soil models for axial, lateral, and torsional soil behavior to provide a robust system of analysis for coupled bridge interior bent structures and foundation systems.

FB-MultiPier is available from the Bridge Software Institute.

25.2.3.2 Input

FB-MultiPier performs the generation of the finite-element model internally, given the geometric definition of the structure and foundation system as input graphically by the designer. This feature allows the engineer to work directly with the design parameters and decreases the data management necessary to create and interpret a model.

25.2.3.3 Output

FB-MultiPier contains an analysis program that is coupled with a graphical pre-processor and post-processor. These programs allow the user of FB-MultiPier to view the structure while generating the model and to view the resulting deflections, bi-axial and uni-axial interaction diagrams, and internal forces in a graphical environment.

25.2.4 <u>LPILE</u>

25.2.4.1 Description

LPILE is a special purpose program based on rational procedures for analyzing a pile under lateral loading. Soil behavior is modeled with p-y curves internally generated by the computer program. Alternatively, the user can manually introduce other p-y curves. Special procedures are programmed for developing p-y curves for layered soils and for rocks.

A single, user-friendly interface written for the Microsoft Windows© environment is provided for the preparation of input and subsequent analytical run and for the graphical observation of data contained in the output file. The program produces plain-text input and output files that may be observed and/or edited for their inclusion in project reports.

LPILE is available from Ensoft, Inc.

25.2.4.2 Input

Several types of pile-head boundary conditions may be selected, and the properties of the pile can also vary as a function of depth.

25.2.4.3 Output

The program computes deflection, shear, bending moment, and soil response with respect to depth in nonlinear soils. Components of the stiffness matrix at the pile head may be computed internally by the program to assist the users in superstructure and substructure analysis. Several pile lengths may be automatically checked by the program to help the user produce a design with an optimum pile penetration. LPILE has capabilities to compute the ultimate-moment capacity of a pile section and can provide design information for the reinforcing arrangement. The user may optionally command the program to generate and consider nonlinear values of flexural stiffness (EI) that are generated internally based on specified pile dimensions, material properties, and cracked/uncracked concrete behavior.

25.2.5 MERLIN-DASH

25.2.5.1 Description

MERLIN-DASH was developed for use by bridge design engineers. MERLIN-DASH offers a wide range of features and options to meet the demands of universal usage in the analysis, design, and rating of steel and reinforced concrete bridges.

The structural analysis is performed via a series of modular subroutines based on the stiffness method.

MERLIN-DASH is available from the BEST Center of the University of Maryland.

25.2.5.2 Input

A mesh generation capability allows for the incorporation of fully automated AASHTO Dead Load (DL) and Live Load (LL) sequences.

25.2.5.3 Output

MERLIN-DASH incorporates a flexible sequence of operations initiated with analysis and proceeding, at the user's option, to perform various combinations of the following functions for the AASHTO WSD, LFD, or LRFD methods:

- Analysis — A complete analysis for all AASHTO DL and LL conditions with the capability to reiterate for changes in sections due to design changes.
- Design — Determination of the size of steel structural components based on a user-controlled design sequence leading to either minimum cost or weight.
- Code Check — Complete and detailed code check of all steel or reinforced concrete beam components, which reference specific AASHTO equation numbers and applicable coefficients.
- Rating — Detailed inventory and operating rating of all beam components using either the AASHTO live-load provisions or special user-specified vehicles.
- Staging — Dead-load pouring sequence stage analysis.

25.2.6 RC-PIER®

25.2.6.1 Description

RC-PIER® is an integrated tool for both the AASHTO *Standard Specifications* and *LRFD Specifications* analysis and design of reinforced concrete bridge substructures and foundations. RC-PIER® allows users to design multi-column and hammerhead bents, straight, tapered or variable caps, and circular, rectangular (tapered and non-tapered) or drilled-shaft columns. Footing types include isolated or combined, supported on either soil or piles. The number of loads, bearings, and piles that may be included in the design are limited by the user's computer hardware capabilities. Analysis results are presented in a variety of easy-to-view formats.

RC-PIER® is available from LEAP Software, Inc.

25.2.6.2 Input

RC-PIER® makes the entry of project data convenient with a system of tabbed screens, dialog boxes, graphic buttons, and menus. 3-D design representations are created based on the parametric data entered, allowing users to confirm the accuracy of the input.

25.2.6.3 Output

RC-PIER® allows users to design cap beams, biaxial columns, and footings. Users can apply strut-and-tie modeling. Specifically, the program performs the following:

1. Cap Design. RC-PIER® can generate a reinforcing pattern that will satisfy the design criteria. Alternatively, customized patterns may be entered. RC-PIER® conducts ultimate capacity checks for positive and negative moments at every check point along the length, and it alerts the user if the section capacity or provided reinforcement at any point(s) is not adequate. RC-PIER® also checks to verify that the provided reinforcing pattern is sufficient for cracking and fatigue. For shear and torsion design, RC-PIER® will compute the required stirrup area.

2. Column Design. Column design in RC-PIER® may be conducted with or without consideration for slenderness effects. Users may choose from P-delta analysis, unbraced moment magnification, or braced moment magnification. RC-PIER® considers the minimum and maximum reinforcement ratios in the design process. Optional interaction diagrams are available for both the top and bottom of column.

3. Footing Design. RC-PIER® can accommodate footings supported on soil or piles. RC-PIER® supports isolated, combined, and strap footings. The comprehensive design of the footing includes pile force/soil pressure calculations, flexure design, and cracking and fatigue checks on all faces of the column. RC-PIER® also calculates one-way shear at a distance equal to the footing depth "d" from the column face and two-way (punching)

shear at the critical perimeter around the column. Users may select a maximum pile force/soil pressure computed by the program or input their own value for the design.

RC-PIER® provides output in a number of comprehensive and detailed formats. The program generates analysis-result plot diagrams that may be exported to a spreadsheet format.

25.2.7 WinSEISAB

25.2.7.1 Description

WinSEISAB was specifically developed to perform the seismic analysis of bridges. The overall objectives in developing WinSEISAB are to provide the practicing bridge engineer with a usable design tool and mechanism for implementing the latest seismic design methodologies into the bridge engineering profession.

WinSEISAB is available from Imbsen Software Systems.

25.2.7.2 Input

Horizontal alignments composed of a combination of tangent and curved segments are described using alignment data taken directly from roadway plans. WinSEISAB has generating capabilities that will, with a minimum amount of input data, automatically provide a model consistent with the model currently being used to conduct dynamic analyses. The central theme underlying the development of WinSEISAB is to provide the bridge designer with an effective means of user-program communication using a problem-oriented language developed specifically for the bridge engineer. User input data is thoroughly checked for syntax and consistency prior to conducting an analysis, and numerous default values are assumed for the data not entered by the user.

25.2.7.3 Output

WinSEISAB can be used to analyze simply supported or continuous deck, girder-type bridges with no practical limitation on the number of spans or the number of columns at a bent. In addition, seismic restrainer units may be placed between adjacent structural segments.

25.2.8 XTRACT

25.2.8.1 Description

XTRACT features a fully interactive program for the analysis of structural cross sections. Using nonlinear analysis algorithms, XTRACT can generate moment curvatures, axial force-moment interactions, and moment-moment interactions for unconfined and confined concrete, steel, prestressed, and composite structural elements. The program can accommodate the input and analysis of any arbitrary cross section (even with holes removed from the cross section) made up of any material input from the available nonlinear material models.

XTRACT is available from Imbsen Software Systems.

25.2.8.2 Input

The program input consists of the specification of a standard cross section, or the geometry of a non-standard cross section, and the material type.

25.2.8.3 Output

XTRACT performs a section analysis and can produce moment curvatures at various performance levels, axial force-moment interactions at user-defined target strains, and moment-moment interactions under applied axial loads.