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MEMORANDUM

To: John Caver P.E.
SCDOT Office of Alternative Delivery – Structural Engineer

From: John Hartland, P.E.

Date: July 8, 2024

Subject: Vessel Collision Loading
I-95 over Lake Marion Design Build Prep
Clarendon and Orangeburg Counties, South Carolina
SCDOT Project ID: P041130

Per our recent discussion, we have created a summary of recommended vessel collision loadings for the I-95 over Lake Marion Structural Design Criteria within the project's Request for Proposals. This memo addresses the following four aspects:

Adjacent Project Review: summarizes vessel collision forces for several adjacent projects and references a prior SCDOT D/B project located in Beaufort County.

Background: provides a concise summary of highway bridge design to mitigate vessel collisions.

Methodology and Analysis: defines the methodology for analyzing the vessel collision forces and presents analysis results specifically for the I-95 over Lake Marion project.

Recommendations: provides recommendations for the design forces applicable to the I-95 over Lake Marion project.

Adjacent Project Review

Adjacent D/B Bridge Vessel Force Summary (for reference):

Bridge Description	Location	Design Vessel	Eq. Static Force at CL Channel (Method 1)
US 601 over Congaree River	Upstream	AASHTO Minimum @ Unknown knots	275 kips*
SC 45 over Diversion Canal	Downstream	2000 Ton Barge @ 6.5 knots	2500 kips
Camp Hall over Diversion Canal	Downstream	860 Ton Barge @ 5 knots	1530 kips
US 21 over Harbor River (previous SCDOT Design-Build project)	Miscellaneous	400 Ton Barge w/ 100 Ton Tug @ 10 knots	1742 kips

* Assumed 2 knots velocity

Background

In recent decades, the design approach for highway bridges has evolved significantly to address the risks posed by vessel collisions. Following the Sunshine Skyway Bridge collapse in 1980, extensive research led to the adoption of the AASHTO Guide Specification for Vessel Collision Design of Highway Bridges, 1st Edition, 1991 (GS). This guide presented three alternative design methods for determining the design vessel for collision impact analysis defined as Method I, II, and III. The GS also introduced critical concepts such as the Probability of Aberrancy (PA), Geometric Probability (PG), and Probability of Collapse (PC). The GS provided a method, defined as Method II, for analyzing vessel collision risk considering these factors. The GS underwent revisions with the 2nd Edition published in 2009. However, it has since been superseded by the AASHTO LRFD Bridge Design Specifications (AASHTO LRFD BDS). The current edition, AASHTO LRFD BDS, 9th Edition, 2020, only provides for one design method (formerly known as Method II) which accounts for these factors resulting in a value-oriented design solution.

Following a review of the US 21 over Harbor River project RFP, Method I was utilized for calculating design vessel collision loads provided to the design-build teams for design. However, as stated above, this method is no longer part of the current editions of the AASHTO LRFD BDS and its use is not recommended.

Methodology and Analysis

AASHTO LRFD BDS, 9th Edition, was utilized for calculation of the design vessel loading. This method uses a statistical approach and utilizes multiple parameters, including channel width, probability of exceedance for different return periods, angle of approach, pier distance from the centerline of navigation channel, size of pier, etc. The I-95 over Lake Marion bridge is considered critical/essential; therefore the maximum annual frequency of collapse (AF), for the entire bridge, shall be taken as 0.0001.

The below assumptions are being made for the design/analysis:

- Annual Number of Vessels: 50
- Runaway barge velocity: 2 knots
- Barge with tow velocity: 7 knots
- Pier size = 8' (width/diameter)
- Design barge size is based on the vessel survey and navigation report, which is included in the Non-Programmatic Categorical Exclusion for the project
- Per AASHTO LRFD, the navigation zone is defined as 3*LOA on each side of the centerline of channel (LOA = Length overall of design vessel)

3.14.6—Design Collision Velocity

The design collision velocity may be determined as specified in Figure 3.14.6-1, for which:

V = design impact velocity (ft/s)
V_T = typical vessel transit velocity in the channel under normal environmental conditions but not taken to be less than V_{MIN} (ft/s)
V_{MIN} = minimum design impact velocity taken as not less than the yearly mean current velocity for the bridge location (ft/s)
X = distance to face of pier from centerline of channel (ft)
X_C = distance to edge of channel (ft)
X_L = distance equal to 3.0 times the length overall of the design vessel (ft)

The length overall, *LOA*, for barge tows shall be taken as the total length of the tow plus the length of the tug/tow boat.

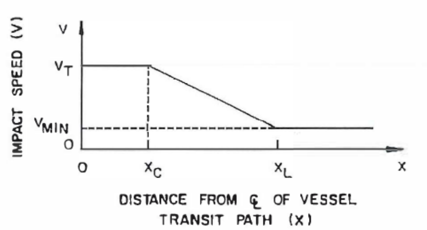
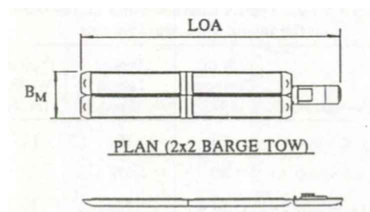


Figure 3.14.6-1—Design Collision Velocity Distribution



Example LOA with barge tow

Summary of Events:

A summary of the Vessel events which have been analyzed is presented below:

- Event 1 = 120'x45' x 250 Ton Runaway Barge (velocity = 2 knots)
- Event 2 = 120'x45' x 400 Ton Barge with 70'x35' x 100 Ton Tow Boat (velocity = 7 knots)
- Minimum AASHTO Event = 195'x35' x 200 Ton Barge (velocity = 2 knots)

LOA = Length overall of design vessel = 120' (barge) + 70' (tow) = 190'
Navigation Zone = 6 LOA = 1140' (570' each side of CL Channel)

Event 1 does not control the analysis within the navigation zone; therefore, we recommend that this event is not included within the RFP.

Analysis of Bents Outside the Navigational Zone:

We recommend utilizing the minimum AASHTO barge with a 2 knot velocity, as discussed during our recent conversation. The minimum AASHTO barge (35' x 195' x 200 Tons) with a 2 knot velocity results in a minimum loading of 275 kips on each interior bent outside of the navigation zone.

Analysis of Bents Within the Navigational Zone:

The following three span arrangements within the navigational zone were analyzed to provide an assessment of the influence of the span lengths on the vessel impact design force requirements:

1. 120' channel and approach spans
2. 170' channel span with 140' approach spans
3. 300' channel and approach spans

For the first two span arrangements, the following two conditions were evaluated to determine the required vessel impact design force of the piers within the navigation zone:

A. Maximizing the vessel impact design resistance required for the two adjacent interior bents on each side of the CL channel, with the minimum AASHTO vessel impact design loading on the remainder of bents within the navigation zone
B. Provide the same design resistance for all of the bents within the navigation zone

For the third span arrangement, only two bents are located within the navigation zone on either side of the channel, so only the Condition A was evaluated.

The required vessel impact design force required for each span arrangement and condition are provided in the following tables.

- Span Arrangement 1 (Condition A)

CL Bent distance from CL Channel (ft)	60	180	300	420	540
Bent Width (ft)	8	8	8	8	8
Bent Vessel Impact Design Loading (kips)	1244	1244	275	275	275

Return Period = 10,018 years

- Span Arrangement 1 (Condition B)

CL Bent distance from CL Channel (ft)	60	180	300	420	540
Bent Width (ft)	8	8	8	8	8
Bent Vessel Impact Design Loading (kips)	1026	1026	1026	1026	1026

Return Period = 10,019 years

- Span Arrangement 2 (Condition A)

CL Bent distance from CL Channel (ft)	85	225	365	505
Bent Width (ft)	8	8	8	8
Bent Vessel Impact Design Loading (kips)	1031	1031	275	275

Return Period = 10,001 years

- Span Arrangement 2 (Condition B)

CL Bent distance from CL Channel (ft)	85	225	365	505
Bent Width (ft)	8	8	8	8
Bent Vessel Impact Design Loading (kips)	928	928	928	928

Return Period = 10,007 years

- Span Arrangement 3 (Condition A)

CL Bent distance from CL Channel (ft)	150	450
Bent Width (ft)	8	8
Bent Vessel Impact Design Loading (kips)	403	403

Return Period = 10,003 years

As demonstrated by the analysis, the design vessel impact force of the bents reduces with the increase in the span length and distribution of the design loading to the bents within the navigation zone. This is primarily a result of the reduced likelihood of a vessel impacting a bridge pier or superstructure component if it is aberrant in the vicinity of the bridge. This concept is reflected in the probabilistic design approach and defined as the Geometric Probability (PG) in AASHTO LRFD BDS Section 3.14.5.

Recommendations:

Our recommendations regarding the vessel collision design criteria to be implemented for the project are as follows:

- Analysis and design shall be in accordance with AASHTO LRFD Bridge Design Specifications, 9th Edition, 2020, Section 3.14. (AASHTO LRFD BDS)

- Proposed bridge operational classification shall be Critical and or Essential in accordance with AASHTO LRFD BDS Section 3.14.3. Proposed bridge shall satisfy AASHTO requirements for critical bridges and continue to function after an impact. The bridge may be damaged but should not collapse and should remain serviceable, even though repairs are needed.

- Minimum span length of 120' within the navigation zone defined above.

- If a minimum vessel impact design force is prescribed in the RFP, we recommend requiring a minimum design force of 1,245 kips for the two bents on each side adjacent to the navigational channel and 275 kips for all other bents.

- If the Department chooses to allow the design build teams to determine the required vessel design forces based on their proposed span arrangements, we recommend the following design events be provided for the analysis:
    - 120'x45' x 400 Ton Barge with 70'x35' x 100 Ton Tow Boat (velocity = 7 knots)
    - 195'x35' x 200 Ton Barge (velocity = 2 knots) (AAHSTO minimum barge)

- The application of the vessel impact forces shall be in accordance with AASHTO LRFD Bridge Design Specifications (LRFD) 3.14.14.

- For the investigation of the local collision forces outlined in LRFD 3.14.14, the barge impact load shall be applied 5' above the Max Pool Elevation of Lake Marion

Please let us know if you have any questions.