Chapter 9

GEOTECHNICAL RESISTANCE FACTORS

GEOTECHNICAL DESIGN MANUAL

January 2022

Table of Contents

Section Page

List of Tables

CHAPTER 9

GEOTECHNICAL RESISTANCE FACTORS

9.1 INTRODUCTION

As described in Chapter 8, Resistance Factors (φ) are used in LRFD design to account for the variability associated with the resistance side of the basic LRFD Equation.

$$Q \leq \varphi R_n = R_r \qquad \textbf{Equation 9-1}$$

Where,

Q = Factored Load
R_r = Factored Resistance
R_n = Nominal Resistance (i.e., ultimate resistance)
φ = Resistance Factor

AASHTO and FHWA have conducted studies to develop geotechnical Resistance Factors (φ) based on reliability theory that accounts for the uncertainties presented below:

- Accuracy of Prediction Models (Design Methodology)
- Site Characterization
- Reliability of material property measurements
- Material properties relative to location, direction, and time
- Material Resistance
- Sufficiency and applicability of sampling
- Soil Behavior
- Construction Effects on Designs

When insufficient statistical data was available, the studies performed a back-analysis of the geotechnical designs to obtain a resistance factor that maintains the current level of reliability that is inferred by the ASD design methodology using the appropriate Factors of Safety.

The LRFD geotechnical design philosophy and load factors for geotechnical engineering are provided in Chapter 8. The Performance Limits for the Service and Extreme Event limit states are provided in Chapter 10. The design methodology used in the application of the design criteria (load factors, resistance factors, and performance limits) is based on AASHTO design methodology with modifications/deviations as indicated in the following Chapters of this Manual:

- Chapter 12 – Geotechnical Seismic Analysis
- Chapter 13 – Geotechnical Seismic Hazards
- Chapter 14 – Geotechnical Seismic Design
- Chapter 15 – Shallow Foundations
- Chapter 16 – Deep Foundations
- Chapter 17 – Embankments
- Chapter 18 – Earth Retaining Structures
- Chapter 19 – Ground Improvement
- Chapter 20 – Geosynthetic Design
- Appendix C – MSE Walls
- Appendix D – Reinforced Soil Slopes

9.2 SOIL PROPERTIES

The geotechnical Resistance Factors (φ) provided in this Chapter are only appropriate when soil material properties are based on sampling/testing frequency and testing methods as defined in this Manual. Geotechnical designs and/or analyses should be performed after establishing a "site" based on the site variability with respect to the soil properties that most affect the design or geotechnical analysis. A site variability of "Medium" or lower shall be selected based on the requirements of Chapter 7.

Engineering judgment is important in the selection of soil properties but must be used judiciously in a manner that is consistent with the method used to develop the resistance factors and should not be used as a method to account for insufficient geotechnical information due to an inadequate subsurface investigation. As indicated above, the AASHTO resistance factors were developed by either reliability theory or by ASD back-calculation. LRFD resistance factors that were based on reliability theory were developed based on using "average" soil shear properties for each identified geologic unit. LRFD resistance factors that were developed based on a back-analysis of ASD design methodology should use the same method of selecting soil properties (lower bound, average, etc.) as previously used in ASD design. For further information into how the resistance factors were developed the AASHTO LRFD Specifications and supporting reference documents should be consulted.

When sufficient subsurface information is available, soil properties should be rationally selected and substantiated by the use of statistical analyses of the geotechnical data. To arbitrarily select conservative soil properties may invalidate the assumptions made in the development of LRFD resistance factors by accounting for uncertainties multiple times; therefore, producing geotechnical designs which are more conservative and consequently have higher costs than the ASD design methodology previously used. When limited amounts of subsurface information is available or the subsurface information is highly variable, it may not be possible to select an "average" soil property for design and a conservative selection of soil properties may be required so as to reduce the risk of poor performance of the structure being designed.

9.3 RESISTANCE FACTORS FOR LRFD GEOTECHNICAL DESIGN

The geotechnical Resistance Factors (φ) that are provided in this Chapter are distinguished by the type of geotechnical structure being designed as listed below:

- Shallow Foundations
- Deep Foundations
- Embankments
- Earth Retaining Structures
- Reinforced Earth Internal Stability

Resistance factors for the determination of SSL induced geotechnical earthquake hazards are also provided.

As indicated in Chapter 8, the Fatigue limit state is the only limit state that is not used in geotechnical analyses or designs. Geotechnical resistance factors are provided for the following limit state load combinations:

- Strength – This includes Strength I, II, III, IV, and V; includes the design flood (100-year flow event)
- Service – This includes Service I; includes the design flood (100-yr flow event)
- Extreme Event – This includes Extreme Event I (Seismic loadings) and Extreme Event II (Impact loadings and check flood (500-yr flow event))

Resistance factors are provided based on the type of analysis being performed and the method of determination. When resistance factors are not applicable to the limit state the term "N/A" has been used in the resistance factor tables included in this Chapter. The method of determination shall either be based on the method of construction control or the analytical method used in the design. For details of the analytical methods used in the design see the appropriate Chapters in this Manual.

Geotechnical analyses that have not been calibrated for LRFD design methodology include, global stability analyses (static and seismic), and SSL induced geotechnical earthquake hazards. The resistance factors (φ) provided for these analyses are the inverse of the Factor of Safety (1/FS) and consequently have the same margin of safety as previously used in ASD designs. For global stability, Equation 9-1 can be written as indicated below.

$$\frac{R_n}{Q} = \frac{Resisting\ Forces}{Driving\ Forces} = FS \geq \frac{1}{\varphi}$$ **Equation 9-2**

or

$$\varphi \geq \frac{1}{FS} = \frac{Driving\ Forces}{Resisting\ Forces} = \frac{Q}{R_n}$$ **Equation 9-3**

Where,

R_n	=	Nominal Resistance (i.e., ultimate resistance)
Q	=	Factored Load (With load factor, γ = 1.0)
FS	=	Factor of Safety
φ	=	Resistance Factor

The geotechnical Resistance Factors (φ) provided in this Chapter have been selected by the SCDOT based on the standard-of-practice that is presented in this Manual, South Carolina geology, and local experience. Although statistical data combined with calibration have not been used to select regionally specific geotechnical resistance factors, the resistance factors presented in AASHTO and FHWA publications have been adjusted based on substantial successful experience to justify these values. The AASHTO LRFD Specifications should be consulted for any geotechnical resistance factors not provided in this Chapter. The OES/GDS shall review the AASHTO LRFD geotechnical resistance factors that are not included in this Manual prior to use and shall provide acceptance.

9.4 SHALLOW FOUNDATIONS

Geotechnical Resistance Factors (φ) for shallow foundations have been modified slightly from those specified in the AASHTO LRFD Specifications. Resistance factors for shallow foundations are shown in Table 9-1. Resistance factors for bearing resistance are specified for soil and rock. Resistance factors for sliding are based on the materials at the sliding interface.

Table 9-1, Resistance Factors for Shallow Foundations

Performance Limit	Limit States		
	Strength	Service	Extreme Event
Soil Bearing Resistance (Soil)	0.45	N/A	1.00
Soil Bearing Resistance (Rock)	0.45	N/A	1.00
Sliding Frictional Resistance (Cast-in-place Concrete on Sand)	0.80	N/A	1.00
Sliding Frictional Resistance (Cast-in-place or Precast Concrete on Clay)	0.85	N/A	1.00
Sliding Frictional Resistance (Precast Concrete on Sand)	0.90	N/A	1.00
Sliding (Soil on Soil)	0.90	N/A	1.00
Sliding Passive Resistance (Soil)	0.50	N/A	1.00
Lateral Displacement	N/A	1.00	1.00
Vertical Settlement	N/A	1.00	1.00

9.5 DEEP FOUNDATIONS

The design of deep foundations requires that foundations supporting bridge piers or abutments consider all limit state loading conditions applicable to the structure being designed. In addition, deep foundations may also be used to support ancillary transportation structures such as overhead signs, light fixtures, noise walls or ground improvement methods. Deep foundations consist of driven piles, drilled piles, drilled shafts, continuous flight auger piles and micro-piles. Continuous flight auger piles and micro-piles are not used to support SCDOT bridge structures. Contact the OES/GDS for permission to use either continuous flight auger (CFA) piles or micro-piles. If permission is granted to use either of these foundation types, then the OES/GDS will provide resistance factors for CFA piles. Obtain resistance factors for micro-piles from the latest edition of the AASHTO LRFD Specifications. The resistance factors provided in this Section shall be used for driven piles, drilled piles and drilled shafts regardless of the structure supported. See Chapter 16 for the design methodology for drilled piles. Drilled piles designed as driven piles shall use the driven pile resistance factors while drilled piles designed as drilled shafts shall use the drilled shaft resistance factors. SCDOT has deviated in its application of LRFD design of deep foundations as presented in the AASHTO LRFD Specifications. The deviations are a result of current design and construction practice, design policies, and experience obtained evaluating field load tests of driven piles and drilled shafts.

The resistance factors used to determine the nominal resistance for single piles or drilled shafts in axial compression or uplift shall be based on the method of deep foundation load resistance verification during construction. The foundation resistance verification will typically be conducted at Test Pile (non-production pile) locations or at Index Pile (production pile) locations. Foundation resistance verification may be required at any foundation that does not meet foundation installation criteria or whose load carrying resistance is in question. A description of deep foundation load resistance verification methods (wave equation, static load testing, including the Osterberg® cell; rapid load testing (i.e., Statnamic® testing); high strain load testing (i.e., dynamic testing using either PDA or Apple® testing) are presented in Chapters 16 and 24. All other resistance factors are based on the design methodology used for deep foundations presented in Chapter 16. The frequency of deep foundation load resistance verification is dependent on the Site Variability as defined in Chapter 7.

A very widely accepted method to verify the axial load resistance of deep foundations is the use of the static load testing either uni-directional or bi-directional (i.e., Osterberg® Cell). The resistance factor for bi-directional load testing methods shall be the same as for conventional static load tests indicated in Tables 9-2 and 9-4.

The rapid load testing method has been included as a method of verifying pile resistance due to its regional popularity and its economic advantages. The rapid load testing methodology is a relatively new load testing method compared to static load testing or dynamic testing and has yet to be included in the AASHTO LRFD Specifications. The Statnamic® load test is regarded as a rapid load testing method that induces a “fast push” on the deep foundation element. The load applied to the top of the foundation is applied dynamically although at a much slower rate as compared to dynamic testing (PDA). The analysis of the rapid load test data requires that the dynamic resistance from the soil be subtracted from the total load applied to obtain the static resistance. Regional experience using rapid load testing has shown that dynamic resistance is greater for friction piles/drilled shafts in Clay-Like soils and consequently the reliability of this method is less for this type of foundation. For friction piles/drilled shafts in Sand-Like soils or end-bearing piles/drilled shafts on rock, IGM or dense sands the dynamic resistance is less and therefore the reliability of the rapid load testing method is better when compared to rapid load testing of friction piles/drilled shafts in cohesive soils. The method used to separate the dynamic resistance from the static resistance has not been nationally accepted (AASHTO) and the method’s reliability has not been independently verified.

SCDOT has conservatively assigned resistance factors for rapid load testing based on the limited regional practice. Since Clay-Like soils tend to produce higher dynamic resistances as compared to Sand-Like soils, a lower reliability has been assumed for friction piles/drilled shafts installed in Clay-Like soils. No increases in resistance factors will be allowed when performing multiple rapid load tests within a “Site” as indicated in Table 9-4. In order to increase the resistance factors indicated in this Section, a full-scale static load test per “Site” will be required to calibrate the rapid load test method of analysis, with the approval of the OES/GDS. The term “Site” is defined as indicated in Chapter 7.

For high strain load testing SCDOT uses (i.e., PDA or Apple®) to verify the capacity of either driven piles or drilled shafts. Typically the PDA is performed on driven piles, while the Apple® load test is performed on drilled shafts.

9.5.1 Driven Piles

AASHTO LRFD Specifications for driven piles differentiate between the predicted nominal axial capacities ($R_{nstatic}$) based on static analyses and the field verified pile capacities (R_n) by applying different geotechnical Resistance Factors (φ) for each of these axial capacities. Upon review of the AASHTO LRFD Specifications recommended geotechnical Resistance Factors (φ_{stat}) for the static resistance prediction, it was observed that the AASHTO geotechnical Resistance Factors (φ_{stat}) inherently presume a substantial amount of uncertainty in the predicted nominal axial resistance with respect to the field verified pile resistance using either dynamic formula, dynamic analysis, or static load tests. This presumption of greater uncertainty of predicted values vs. field verified values is logical and has merit for a national specification but it does not take into account the regional experience of predicting pile capacities. SCDOT has observed that when using the nominal axial compression pile resistance design methods presented in this Manual that there is rarely a need to extend the pile lengths in the field because the required pile resistance is achieved during pile driving. Driven piles are typically installed in Sand-Like soils where pile resistance is most likely underpredicted. It has been observed that the pile resistance methods predict fairly accurately when pile resistance verification is made using pile re-strikes with the Pile Driving Analyzer (PDA). Typically, pile lengths provided in the plans have sufficient length to achieve the required ultimate pile resistance at the end-of-driving or re-strikes when verified by wave equation, dynamic load testing (PDA), or static load tests.

SCDOT has elected to use resistance factors (φ) based on the construction pile resistance verification method required in the plans to predict the nominal axial capacities (static determination of ultimate pile resistance) during design, which is used to select the number of piles and pile plan lengths.

Additional considerations that have gone into the selection of SCDOT geotechnical resistance factors are as follows:

- The definition of a "Site" is the same as presented in the AASHTO LRFD specifications with the exception that a "Site" cannot have a variability greater than "Medium". If a "Site" classifies as a "High" variability, the "Site" shall be reduced in size to maintain a variability of "Low" or "Medium." The Site Variability shall be determined as indicated in Chapter 7.
- Resistance factors are based on a Site Variability of "Low" or "Medium"
- When field load testing is used, a minimum of 1 test pile is required per "Site" and it is typically placed at the weakest location based on the subsurface soil investigation and design methodology.
- The Contractor's pile installation plan is reviewed by SCDOT and the pile driving installation equipment is evaluated using the Wave Equation.
- At a minimum, Wave Equation Analysis is used to verify the field pile resistance during pile driving.
- If a Pile Driving Analyzer test is performed, the Wave Equation is calibrated using signal matching (CAPWAP) with the dynamic testing results.
- Determine the length of piling using the appropriate φ factor for the Wave Equation (only) or using the Wave Equation and PDA together. Use the Pile Cost-PDAvsNo-PDA spreadsheet to determine the cost benefit of using the PDA versus not using the PDA. The spreadsheet is available on the Geotechnical Design Webpage of the SCDOT Website.
- If not using PDA testing has been determined previously, then the Pile Cost-PDAvsNo-PDA spreadsheet does not need to be used.
- When load tests are performed, the test pile installation is monitored with the Pile Driving Analyzer (PDA).

- All bridges, regardless of the OC, will be designed using the same geotechnical Resistance Factors to maintain the same level of variability.

Load modifiers presented in Chapter 8 are not used to account for the influence of redundancy in geotechnical foundation design. Redundancy in deep foundation design is taken into account by the selection of the geotechnical resistance factor. Non-redundant pile foundations are those foundations that have pile footings with less than 5 piles supporting a single column, or less than 5 piles in a pile bent. Otherwise the foundations are redundant.

A resistance factor of 1.0 should be used for soils encountered in scour zones or zones neglected in design when performing pile driveability evaluations or when determining the required driving resistance. A resistance factor 10 percent greater than that shown in Table 9-3 can be used for the pile tested, but shall not exceed a resistance factor of 0.80. Except for redundant piles in low and medium site variability conditions when 2 or more piles are statically tested, the resistance factors provided in Table 9-2 shall be used.

When dynamic testing is used, dynamic testing controls the construction of pile foundations by verifying pile resistance (signal matching required - CAPWAP), calibrating wave equation inspector charts based on signal matching, and monitoring the pile driving hammer performance throughout the project.

All test and index piles should require dynamic testing to monitor pile installation. The number of dynamic tests shall conform to the requirements of Note 2 to Table 9-3. Include an equal number of additional dynamic tests if restrikes are required for test piles or index piles. For bridges with more than 200 piles, a minimum 3.0 percent of the piles for “Sites” with “Low” variability or 6.0 percent of the piles for “Sites” with “Medium” variability should be included in the contract as test piles to allow for evaluation of poor or highly variable hammer performance or pile restrikes to verify pile resistance throughout the project. The additional dynamic testing of production piles shall be used uniformly throughout the “Site” for QC of the Contractor’s pile driving operations.

Table 9-2, Number of Static Load Tests per Site

Number of Static Load Tests per Site	**Resistance Factor (φ)**			
	Low Site Variability		**Medium Site Variability**	
	Redundant	**Non-Redundant**	**Redundant**	**Non-Redundant**
1	0.80	0.65	0.70	0.60
2	0.90	0.70	0.75	0.65
3 or more	0.90	0.70	0.85	0.70

Table 9-3, Geotechnical Resistance Factors for Driven Piles

Analysis and Method of Determination	Limit States			
	Strength		Service	Extreme Event
	Redundant	Non-Redundant		
Nominal Resistance Single Pile in Axial Compression (soil) with Wave Equation (1)	0.50	0.40	N/A	1.00
Nominal Resistance Single Pile in Axial Compression (rock) with Wave Equation (1, 4)	0.60	0.50	N/A	1.00
Nominal Resistance Single Pile in Axial Compression with High Strain Load Testing (PDA) and calibrated Wave Equation (2)	0.65	0.55	N/A	1.00
Nominal Resistance Single Pile in Axial Compression with Static Load Testing. Dynamic Monitoring (PDA) of test pile installation and calibrated Wave Equation (2, 3).	See Table 9-2		N/A	1.00
Nominal Resistance Single Pile in Axial Compression with Rapid Load Testing For Friction Piles. Dynamic Monitoring (PDA) of test pile installation and calibrated Wave Equation (2)	0.65	0.55	N/A	1.00
Nominal Resistance Single Pile in Axial Compression with Rapid Load Testing For End Bearing Piles in Rock or Very Dense Sand. Dynamic Monitoring (PDA) of test pile installation and calibrated Wave Equation (2).	0.70	0.55	N/A	1.00
Pile Group Block Failure (Clay)	0.60	N/A	N/A	1.00
Nominal Resistance Single Pile in Axial Uplift Load with High Strain Load Testing (PDA) and calibrated Wave Equation (2)	0.50	0.40	N/A	0.80
Nominal Resistance Single Pile in Axial Uplift Load with Static Load Testing	0.60	0.50	N/A	0.80
Group Uplift Resistance	0.50	N/A	N/A	N/A
Single or Group Pile Lateral Load Geotechnical Analysis (Lateral Displacements)	1.00	1.00	1.00	1.00
Single or Group Pile Vertical Settlement	1.00	1.00	1.00	1.00
Pile Driveability – Geotechnical Analysis	1.00	1.00	N/A	N/A

(1) Applies only to factored loads less than or equal to 600 kips, load testing (i.e., dynamic, rapid or static) is required for piles with factored loads greater than 600 kips.
(2) Dynamic testing is required on at least 2 piles per pile type and per “site”, but no less than 2 percent of the total production piles per pile type for each approved hammer type used.
(3) See Table 9-3 for number of static load testing required.
(4) Use this resistance factor if the N-value is greater than or equal to 50 blows per 2 inches of penetration.

9.5.2 Drilled Shafts

Drilled shaft geotechnical resistance factors (φ) have been provided in Table 9-4. Resistance factors are provided for Clay, Sand, Rock, and IGM as well as dynamic, static and rapid load testing.

Additional considerations that have gone into the selection of SCDOT geotechnical resistance factors are as follows:

- The definition of a “Site” is provided in Chapter 7 of this Manual. A “Site” cannot have a variability greater than “Medium”. If a “Site” classifies as a “High” variability, the “Site” shall be reduced in size to maintain a variability of “Low” or “Medium.”
- Resistance factors are based on a site variability of “Low” or “Medium.”
- When field load testing is used, a minimum of 1 test shaft is required per “Site” and it is typically placed at the weakest location based on the subsurface soil investigation and design methodology.

As discussed in Chapter 8, load modifiers will not be used to account for the influence of redundancy in geotechnical foundation design. Redundancy in deep foundations is taken into account by the selection of the geotechnical resistance factor. Non-redundant foundations are those drilled shaft footings with 4 or less drilled shafts supporting a single column or individual drilled shafts supporting individual columns in a bent regardless of the number of columns in the bent. Drilled shaft footings with 5 or more drilled shafts are classified as redundant drilled shaft foundations. If the foundation is a hammerhead (1 shaft and 1 column per bent) reduce the non-redundant resistance factor by 20 percent.

Because drilled shaft capacities cannot be verified individually during construction (only drilled shaft installation monitoring), a single resistance factor will be provided on the plans for both redundant and non-redundant drilled shafts. No increases in resistance factors will be allowed when performing multiple load tests within a “Site” as indicated in Table 9-2. A resistance factor 10 percent greater than that shown in Table 9-4 can be used for the drilled shaft tested, but shall not exceed a resistance factor of 0.80.

Table 9-4, Resistance Factor for Drilled Shafts

Performance Limit			Limit States			
			Strength		Service	Extreme Event
			Redundant	Non-Redundant[1]		
Nominal Resistance Single Drilled Shaft in Axial Compression	Clay	Side	0.55	0.45	N/A	1.00
		Tip	0.50	0.40	N/A	1.00
	Sand	Side	0.65	0.55	N/A	1.00
		Tip	0.60	0.50	N/A	1.00
	IGM	Side	0.70	0.60	N/A	1.00
		Tip	0.65	0.55	N/A	1.00
	Rock	Side	0.60	0.50	N/A	1.00
		Tip	0.60	0.50	N/A	1.00
Nominal Resistance Single Drilled Shaft in Axial Compression with High Strain Load Testing			0.65	0.65	N/A	1.00
Nominal Resistance Single Drilled Shaft in Axial Compression with Static Load Testing			0.70	0.70	N/A	1.00
Nominal Resistance Single Drilled Shaft in Axial Compression with Rapid Load Testing.			0.65	0.65	N/A	1.00
Nominal Resistance Single Drilled Shaft in Axial Uplift Load (Side Resistance)	Clay		0.45	0.35	N/A	1.00
	Sand		0.55	0.45	N/A	1.00
	IGM		0.55	0.45	N/A	1.00
	Rock		0.50	0.40	N/A	1.00
Nominal Resistance Single Drilled Shaft in Axial Uplift with Static Load Testing			0.60	0.60	N/A	1.00
Drilled Shaft Group Block Failure (Clay)			0.55	N/A	N/A	1.00
Drilled Shaft Group Uplift Resistance			0.45	N/A	N/A	1.00
Single or Group Drilled Shaft Lateral Load Geotechnical Analysis (Structural Resistance)			1.00	1.00	1.00	1.00
Single or Group Drilled Shaft Lateral Load Geotechnical Analysis (Lateral Displacements)			1.00	1.00	1.00	1.00
Single or Group Drilled Shaft Vertical Settlement			1.00	1.00	1.00	1.00

(1) If foundation is a hammerhead (1 shaft and 1 column per bent) reduce the non-redundant resistance factor by 20 percent.

9.6 EMBANKMENTS

Geotechnical Resistance Factors (φ) for both bridge and roadway embankments (both unreinforced and reinforced) have been modified slightly from those specified in the AASHTO LRFD Specifications. Resistance factors for embankments (fill) sections and cut-sections are shown in Table 9-5. The φ for temporary embankments is indicated in Table 9-5. The global stability resistance factors for the EE I limit state check includes the inertial effects (i.e., PGA) of the seismic event as determined in Chapter 12. Should the presence of soils that will undergo SSL be encountered on a site, see Section 9.9 for the required resistance factors. The GEOR should use engineering judgment to possibly lower the resistance factor for the possible consequences of failure.

Table 9-5, Resistance Factors for Embankments (Fill / Cut Section)

Performance Limit	**Limit States**				
	Strength		**Service**		**Extreme Event**
	Temporary[1]	**Perm.**	**Temporary**[1]	**Perm.**	
Lateral Squeeze	0.90	0.75	N/A	N/A	1.00
Lateral Displacement	N/A	N/A	1.00	1.00	1.00
Vertical Settlement	N/A	N/A	1.00	1.00	1.00
Global Stability Embankment (Fill)	0.90	0.75	N/A	N/A	1.00[2]
Global Stability Cut Section	0.90	0.75	N/A	N/A	1.00[2]

[1]Use if vertical staging is required or if temporary condition will exist.

[2]Global stability analyses for Extreme Event I limit state that have resistance factors greater than specified require a displacement analysis to determine if it meets the performance limits presented in Chapter 10.

9.7 EARTH RETAINING STRUCTURES

Geotechnical Resistance Factors (φ) for ERSs have been modified slightly from those specified in the AASHTO LRFD Specifications by varying resistance factors based on the retaining wall system type. Resistance factors are provided for external stability of the structure with respect to bearing, sliding, and passive resistance. Resistance factors for bearing resistance are specified for soil and rock. Resistance factors for sliding are based on the materials at the sliding interface. The φ provide in Tables 9-6 and 9-7 may require modification downward for both the Service and the EE limit states depending on what the ERS is supporting (i.e., a building or bridge (supported on shallow foundations)). For φ due to internal stability of Mechanically Stabilized Earth (MSE) walls see Section 9.8. Resistance factors for Rigid Gravity Retaining Walls are provided in Table 9-6; Flexible Gravity Retaining Walls are provided in Table 9-7 and Cantilever Retaining Walls with or without anchors are provided in Table 9-8. The φ provided in these tables apply to both permanent and temporary ERSs. The use of rigid gravity ERSs as temporary ERSs is not anticipated; therefore, φ has not be provided. The global stability resistance factors for the EE I limit state check include the inertial effects (i.e., PGA) of the seismic event as determined in Chapter 12. Should the presence of soils that will undergo SSL be encountered on a site, see Section 9.9 for the required resistance factors. The GEOR should use engineering judgment to lower the resistance factor for the possible consequences of failure.

Rigid gravity retaining walls include cast-in-place concrete walls typically used in roadway projects. Flexible gravity retaining wall systems include bin walls; panel and block face MSE walls. Cantilever walls include sheet pile walls and soldier pile walls.

Table 9-6, Resistance Factors for Rigid Gravity Retaining Walls

Performance Limit		Limit States		
		Strength	**Service**	**Extreme Event**
Soil Bearing Resistance (Soil)		0.55	N/A	1.00
Soil Bearing Resistance (Rock)		0.55	N/A	1.00
Sliding Resistance	Shear Component	1.00	N/A	1.00
	Passive Component	0.50	N/A	1.00
Lateral Squeeze		0.75	N/A	1.00
Lateral Displacement		N/A	1.00	1.00
Vertical Settlement		N/A	1.00	1.00
Global Stability Fill Walls		0.75	N/A	1.00[1]
Global Stability Cut Walls		0.75	N/A	1.00[1]

[1]Global stability analyses for Extreme Event I limit state that have resistance factors greater than specified require a displacement analysis to determine if it meets the performance limits presented in Chapter 10.

Table 9-7, Resistance Factors for Flexible Gravity Retaining Walls

Performance Limit	Limit States				
	Strength		**Service**		**Extreme Event**
	Temporary[1]	**Perm.**	**Temporary**[1]	**Perm.**	
Soil Bearing Resistance (Soil)	0.85	0.65	N/A	N/A	1.00
Soil Bearing Resistance (Rock)	0.85	0.65	N/A	N/A	1.00
Sliding Frictional Resistance	1.00	1.00	N/A	N/A	1.00
Lateral Squeeze	0.80	0.75	N/A	N/A	1.00
Lateral Displacement	N/A	N/A	1.00	1.00	1.00
Vertical Settlement	N/A	N/A	1.00	1.00	1.00
Global Stability Fill Walls	0.80	0.75	N/A	N/A	1.00[2]
Global Stability Cut Walls	0.80	0.75	N/A	N/A	1.00[2]

[1]Use if vertical staging is required or if temporary condition will exist.

[2]Global stability analyses for Extreme Event I limit state that have resistance factors greater than specified require a displacement analysis to determine if it meets the performance limits presented in Chapter 10.

Table 9-8, Resistance Factors for Cantilever Retaining Walls

<table>
<tr><th colspan="2" rowspan="2">Performance Limit</th><th colspan="5">Limit States</th></tr>
<tr><th colspan="2">Strength</th><th colspan="2">Service</th><th>Extreme Event</th></tr>
<tr><td colspan="2">Axial Compressive Resistance of Vertical Elements</td><td colspan="5">Sections 9.4 and 9.5 Apply</td></tr>
<tr><td colspan="2">Passive Resistance of Vertical Element</td><td colspan="2">0.75</td><td colspan="2">N/A</td><td>0.85</td></tr>
<tr><td colspan="2">Flexural Resistance of Vertical Element</td><td colspan="2">0.90</td><td colspan="2">N/A</td><td>0.90</td></tr>
<tr><td rowspan="2">Tensile Resistance of Anchor (1)</td><td>Mild Steel (ASTM A615)</td><td colspan="2" rowspan="2">N/A</td><td colspan="2">0.900[1]</td><td>0.90[1]</td></tr>
<tr><td>High Strength Steel (ASTM A722)</td><td colspan="2">0.80[1]</td><td>0.80[1]</td></tr>
<tr><td rowspan="3">Pullout Resistance of Anchors (2)</td><td>Sand and Silts</td><td colspan="2" rowspan="3">N/A</td><td colspan="2">0.65[2]</td><td>0.90[2]</td></tr>
<tr><td>Clay</td><td colspan="2">0.70[2]</td><td>1.00[2]</td></tr>
<tr><td>Rock</td><td colspan="2">0.50[2]</td><td>1.00[2]</td></tr>
<tr><td colspan="2">Anchor Pullout Resistance Test (3)
(With proof test of every production anchor)</td><td colspan="2">N/A</td><td colspan="2">1.00[3]</td><td>1.00[3]</td></tr>
<tr><td colspan="2"></td><td>Temporary[4]</td><td>Perm.</td><td>Temporary[4]</td><td>Perm.</td><td></td></tr>
<tr><td colspan="2">Lateral Displacement</td><td>N/A</td><td>N/A</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td colspan="2">Vertical Settlement</td><td>N/A</td><td>N/A</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td colspan="2">Global Stability Fill Walls</td><td>0.80</td><td>0.75</td><td>N/A</td><td>N/A</td><td>1.00[5]</td></tr>
<tr><td colspan="2">Global Stability Cut Walls</td><td>0.80</td><td>0.75</td><td>N/A</td><td>N/A</td><td>1.00[5]</td></tr>
</table>

[1]Apply to maximum proof test load for the anchor. For mild steel apply resistance factor to F_y. For high-strength steel apply the resistance factor to guaranteed ultimate tensile strength.

[2]Apply to presumptive ultimate unit bond stresses for preliminary design only. See AASHTO LRFD (C11.9.4.2) specifications for additional information.

[3]Apply where proof tests are conducted on every production anchor to load of 1.0 or greater times the factored load on the anchor.

[4]Use if vertical staging is required or if temporary condition will exist.

[5]Global stability analyses for Extreme Event I limit state that have resistance factors greater than specified require a displacement analysis to determine if it meets the performance limits presented in Chapter 10.

9.8 REINFORCED SOIL (INTERNAL STABILITY)

Geotechnical Resistance Factors (φ) for analysis of internal stability of reinforced soils are based on AASHTO LRFD Specifications. Resistance factors for internal stability of reinforced soils are shown in Table 9-9. Resistance factors may be used in reinforced soil slopes or MSE walls. The external stability of MSE walls shall be governed by the resistance factors provided for flexible walls in Table 9-7. The external stability of RSSs with slopes less than 70° shall be governed by the resistance factors provided for flexible gravity retaining walls in Table 9-7.

Table 9-9, Resistance Factors for Reinforced Soils (Internal)

Performance Limit			Limit States		
			Strength	**Service**	**Extreme Event**
Tensile Resistance of Reinforcement and Connectors	Metallic Reinforcement[1]	Strip Reinforcement	0.75	N/A	1.00
		Grid Reinforcement [2]	0.65		0.85
	Geosynthetic Reinforcement	Geotextiles and Geogrid Reinforcement	0.80	N/A	1.00
		Geostrip Reinforcement	0.55		1.00
Pullout Resistance	Metallic Reinforcement[1]	Strip and Grid Reinforcement	0.90	N/A	1.20
	Geosynthetic Reinforcement	Geotextiles, Geogrid and Geostrip Reinforcement	0.70	N/A	1.00

[1]Apply to gross cross-section less sacrificial area. For sections with holes, reduce the gross area and apply to net section less sacrificial area.

[2]Applies to grid reinforcements connected to a rigid facing element (concrete panel or block). For grid reinforcements connected to a flexible facing mat or which are continuous with the facing mat, use the resistance factor for strip reinforcements.

9.9 SSL INDUCED GEOTECHNICAL SEISMIC HAZARDS

Geotechnical Resistance Factors (φ) for SSL and SSL induced geotechnical seismic hazards are provided in Tables 9-10 and 9-11. Resistance factors for other seismic hazards that are not SSL induced (i.e., seismic slope stability, lateral foundation displacements, downdrag on deep foundations, etc.) are addressed under the Extreme Event limit state for each specific structure. These resistance factors apply only to the EE I limit state and either SSL (Table 9-10) or SSL induced geotechnical seismic hazards (Table 9-11).

Table 9-10, Resistance Factors for Soil Shear Strength Loss

Seismic Hazard Description	**Resistance Factor Symbol φ**	**Extreme Event I**
Sand-Like Soil Shear Strength Loss (Liquefaction) (Triggering)	$\varphi_{SL\text{-}Sand}$	0.90
Clay-Like Soil Shear Strength Loss (Triggering)	$\varphi_{SL\text{-}Clay}$	0.90

Flow failure is the global instability induced by SSL beneath an embankment or ERS without the effect of the inertial loading. Seismic instability is the combination of SSL beneath an embankment or ERS with the effect of inertial loading. Both of these checks are for sites that have undergone SSL.

Table 9-11, Resistance Factors for Soil SSL Induced Seismic Hazards

Seismic Hazard Description	Resistance Factor Symbol φ	Extreme Event I
Flow Failure (Triggering)	φ_{Flow}	1.00
Lateral Spread (Triggering)	φ_{Spread}	1.00
Seismic Instability	$\varphi_{EQ\text{-}Stability}$	1.00

9.10 REFERENCES

American Association of State Highway and Transportation Officials, (2020), AASHTO LRFD Bridge Design Specifications Customary U.S. Units, 9th Edition, American Association of State Highway and Transportation Officials, Washington, D.C.

South Carolina Department of Transportation, (2006), Bridge Design Manual, South Carolina Department of Transportation, https://www.scdot.org/business/structural-design.aspx.

South Carolina Department of Transportation, (2008), Seismic Design Specifications for Highway Bridges, South Carolina Department of Transportation, https://www.scdot.org/business/structural-design.aspx.