Chapter 8

GEOTECHNICAL LRFD DESIGN

GEOTECHNICAL DESIGN MANUAL

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Table of Contents

Section **Page**

List of Tables

Title **Page**

CHAPTER 8

GEOTECHNICAL LRFD DESIGN

8.1 INTRODUCTION

Geotechnical engineering analyses and designs for transportation structures have traditionally been based on Allowable Stress Design (ASD), also known as Working Stress Design (WSD). Transportation structures that require geotechnical engineering are bridge foundations, sign and lighting foundations, Earth Retaining Structures (ERSs: MSE walls, reinforced concrete walls, cantilever walls, etc.), and embankments (both bridge and road). The primary guidance for the ASD design methodology has been the AASHTO Standard Specifications for Highway Bridges (17th edition – last edition published 2002) and various Federal Highway Administration (FHWA) geotechnical engineering publications. The ASD methodology is based on limiting the stresses induced by the applied loads (Q, which includes dead loads - DL and live loads - LL) on a component/member from exceeding the allowable (or working) stress of the material (R_{all}). The allowable stress of a material is computed by dividing the nominal strength of the material (R_n) by an appropriate factor of safety (FS) as indicated in the following equation.

$$\boldsymbol{Q = \sum DL + \sum LL \leq R_{all} = \frac{R_n}{FS}}$$ **Equation 8-1**

This design approach uses a single factor of safety to account for all of the geotechnical engineering uncertainties. The ASD factors of safety do not appropriately take into account variability associated with the predictive accuracy of dead loads, live loads, wind loads, and seismic loads or the different levels of uncertainty associated with design methodology, material properties, site variability, material sampling, and material testing. The assignment of ASD factors of safety has traditionally been based on experience and judgment. This methodology does not permit a consistent or rational method of accessing risk.

In 1986 an NCHRP study (20-7/31) concluded that the AASHTO Standard Specifications for Highway Bridges contained gaps and inconsistencies, and did not use the latest design philosophy and knowledge. In response, AASHTO adopted the Load and Resistance Factor Design (LRFD) Bridge Design Specification in 1994 and the Load and Resistance Factor Rating (LRFR) Guide Specification in 2002. The current AASHTO LRFD Specifications incorporate state-of-the-art analysis and design methodologies with load and resistance factors based on the known variability of applied loads and material properties. These load and resistance factors are calibrated from actual statistics to ensure a uniform level of safety. Because of LRFD's impact on the safety, reliability, and serviceability of the Nation's bridge inventory, AASHTO, in concurrence with the FHWA, set a transition deadline of 2007 for bridges and 2010 for culverts, retaining walls and other miscellaneous structures. After this date, States must design all new structures in accordance with the LRFD design methodology.

SCDOT is committed to using the LRFD design methodology on structures including all aspects of geotechnical engineering analysis and design. In this Manual the term AASHTO LRFD Specifications refers to the AASHTO LRFD Bridge Design Specifications, 9th Edition (2020), unless indicated otherwise. The LRFD geotechnical design approach is presented in Chapters 8, 9, and 10 of this Manual. All tables in this Chapter have been modified and adapted from the

AASHTO LRFD Specifications unless indicated otherwise. The geotechnical design methodology presented in this Manual provides guidance on how to apply the LRFD geotechnical design approach into geotechnical engineering analyses for SCDOT projects.

8.2 LRFD DESIGN PHILOSOPHY

Basic to all good engineering design methodologies (including ASD and LRFD) is that when a Load (Q or Demand) is placed on a component/member, there is sufficient Resistance (R or Capacity) to insure that an established performance criterion is not exceeded. This concept is illustrated by the following equation:

$$\boldsymbol{Load\ (Q) \leq RESISTANCE\ (R)}$$ **Equation 8-2**

The Load and Resistance quantities can be expressed as force, stress, strain, displacement, number of cycles, temperature, or some other parameter that results in structural or performance failure of a component/member. The level of inequality between the Load and Resistance side of Equation 8-2 represents the uncertainty. In order to have an acceptable design the uncertainties must be mitigated by applying an appropriate margin of safety in the design.

The LRFD design methodology mitigates the uncertainties by applying individual load factors (γ_i) and a load modifier (η_i) to each type of load (Q_i). On the resistance side of the equation a resistance factor (φ) is applied to the nominal resistance (R_n). The sum of the factored loads, Q, placed on the component/member must not exceed the factored resistance of the component/member in order to have satisfactory performance. The following equation illustrates the basic LRFD design concept.

$$\boldsymbol{Q = \sum \eta_i \gamma_i Q_i \leq \varphi R_n = R_r}$$ **Equation 8-3**

Where,

- Q = Factored Load
- Q_i = Force Effect
- η_i = Load modifier
- γ_i = Load factor
- R_r = Factored Resistance
- R_n = Nominal Resistance (i.e., ultimate capacity)
- φ = Resistance Factor

Equation 8-3 is applicable to more than 1 load combination as defined by the condition that defines the "Limit State".

8.3 LIMIT STATES

A "Limit State" is a condition beyond which a component/member of a foundation or other structure ceases to satisfy the provisions for which the component/member was designed. The AASHTO LRFD Specifications has defined the following limit states for use in design:

- Strength Limit State
- Service Limit State
- Extreme Event Limit State
- Fatigue Limit State

The Fatigue Limit State is the only limit state that is not used in geotechnical analyses or design. A description of the limit states that are used in geotechnical engineering are provided in the following table.

Table 8-1, Limit States
(Modified from Wilson, et al. (2007))

Limit State	Description
Strength	A design boundary condition considered to ensure that strength and stability are provided to resist specified load combinations, and avoid the total or partial collapse of the structure. Examples of Strength limit states in geotechnical engineering include bearing failure, sliding, and earth loadings for structural analysis.
Service	A design boundary condition for structure performance under intended service loads, and accounts for some acceptable measure of structure movement throughout the structure's performance life. Examples include vertical settlement of a foundation or lateral displacement of a retaining wall. Another example of a Service limit state condition is the rotation of a rocker bearing on an abutment caused by instability of the earth slope that supports the abutment.
Extreme Event (EE)	Evaluation of a structural member/component at this limit state considers a loading combination that represents an excessive or infrequent design boundary condition. Such conditions may include vessel impacts, vehicle impact, check flood (500-year flow event), and seismic events. Because the probability of these events occurring during the life of the structure is relatively small, a smaller margin of safety is appropriate when evaluating this limit state.

8.4 TYPES OF LOADS

AASHTO specifications classify loads as either permanent loads or transient loads.

8.4.1 Permanent Loads

Permanent loads are present for the life of the structure and do not change over time. Permanent loads are generally very predictable. The following is a list of all loads identified by AASHTO LRFD Specifications as permanent loads:

- Force Effects Due to Creep – CR
- Dead Load of Components – DC
- Downdrag – DD
- Dead Load of Wearing Surface and Utilities – DW
- Horizontal Earth Pressures – EH
- Locked-In Erection Stresses – EL
- Vertical Earth Pressure – EV
- Earth Load Surcharge – ES
- Secondary Forces from Post-tensioning – PS
- Force Effects Due to Shrinkage – SH

A brief description for each of these permanent loads is provided in Table 8-2. For a complete description and method of computing these loads see the AASHTO LRFD Specifications.

Table 8-2, Permanent Load Descriptions
(Modified from AASHTO LRFD Specifications (2020) and Wilson, et al. (2007))

AASHTO Designation	Definition	Description
CR	Creep	These loads are internal force effects that develop on structure components as a result of creep and shrinkage of materials. These forces should be considered for substructure design when applicable.
DC	Dead load of structural components and nonstructural attachments	These loads include the weight of both fabricated structure components (e.g., structural steel girders and prestressed concrete beams) and cast-in-place structure components (e.g., deck slabs, abutments, and footings). DC loads also include nonstructural attachments such as lighting and signs.
DD	Downdrag	When a deep foundation is installed to a firm bearing stratum (i.e. settlement of the deep foundation is inhibited) and through a soil layer that is subject to settlement of the surrounding soil to the deep foundation, downdrag forces are induced on the deep foundation. The magnitude of DD load may be computed in a similar manner as the positive shaft resistance calculation. Allowance may need to be made for the possible increase in undrained shear strength as consolidation occurs. For the strength limit state, the factored downdrag loads are added to the factored vertical dead load in the assessment of pile capacity. For the Service limit state, the downdrag loads are added to the vertical dead load in the assessment of settlement. Downdrag forces can also occur in the EE I limit state due to downdrag forces resulting from SSL of Sand-Like soils.
DW	Dead load of wearing surfaces and utilities	These loads include asphalt wearing surfaces, future overlays and planned widening, as well as miscellaneous items (e.g., scuppers, railings and supported utility services).
EH	Horizontal earth pressure load	These loads are the force effects of horizontal earth pressures due to partial or full embedment into soil. These horizontal earth pressures are those resulting from static load effects. The magnitude of horizontal earth pressure loads on a substructure are a function of: • Structure type (e.g., gravity, cantilever, anchored, or MSE wall) • Type, unit weight, and shear strength of the retained earth • Anticipated or permissible magnitude and direction of horizontal substructure movement • Compaction effort used during placement of soil backfill • Location of the ground water table within the retained soil

Table 8-2 (Continued), Permanent Load Descriptions
(Modified from AASHTO LRFD Specifications (2020) and Wilson, et al. (2007))

EL	Locked-in erection stresses	These loads are accumulated locked-in force effects resulting from the construction process, typically resulting from segmental superstructure construction. These would include precast prestressed or post-tensioned concrete structures. For substructure designs, these force effects are small enough and can be ignored.
EV	Vertical pressure from dead load of earth fill	The vertical pressure of earth fill dead load acts on the top of footings and on the back face of battered wall and abutment stems. The load is determined by multiplying the volume of fill by the density and the gravitational acceleration (unit weight).
ES	Earth surcharge load	Surcharge loads are the force effects on the backs of ERSs. These effects must be considered in the design of walls and bridge abutments.
PS	Post-tensioning forces	The post-tensioning forces imposed on a continuous structure supports and any internal forces.
SH	Shrinkage	These loads are internal force effects that develop on structure components as a result of shrinkage of materials. These forces should be considered for substructure design when applicable.

8.4.2 Transient Loads

Transient loads may only be present for a short amount of time, may change direction, and are generally less predictable than permanent loads. Transient loads include the following:

- Blast Loading – BL
- Vehicular braking force – BR
- Vehicular centrifugal force – CE
- Vehicular collision force – CT
- Vessel collision force – CV
- Earthquake – EQ
- Friction – FR
- Ice load – IC
- Vehicular dynamic load allowance – IM
- Vehicular live load – LL
- Live load surcharge – LS
- Pedestrian live load – PL
- Settlement – SE
- Temperature gradient – TG
- Uniform temperature – TU
- Water load and stream pressure – WA
- Wind on live load – WL
- Wind load on structure – WS

A brief description for each of these transient loads is provided in Table 8-3. For a complete description and method of computing these loads see the AASHTO LRFD Specifications.

Table 8-3, Transient Load Descriptions
(Modified from AASHTO LRFD Specifications (2020) and Wilson, et al. (2007))

AASHTO Designation	Definition	Description
BL	Blast Loading	The force effects of a blast loading, either intentional or unintentional, on either a bridge or bridge component.
BR	Vehicular braking force	The force effects of vehicle braking that are represented as a horizontal force effect along the length of a bridge that is resisted by the structure foundations.

Table 8-3 (Continued), Transient Load Descriptions
(Modified from AASHTO LRFD Specifications (2020) and Wilson, et al. (2007))

CE	Vehicular centrifugal force	These loads are the force effects of vehicles traveling on a bridge located along a horizontal curve and that generate a centrifugal force effect that must be considered in design. For substructure design, centrifugal forces represent a horizontal force effect.
CT	Vehicular collision force	These loads are the force effects of collisions by roadway and rail vehicles.
CV	Vessel collision force	These loads are the force effects of vessel collision by ships and barges due to their proximity to navigable waterways. The principal factors affecting the risk and consequences of vessel collisions with substructures in a waterway are related to vessel, waterway, and bridge characteristics.
EQ	Earthquake	**(DO NOT USE AASHTO FOR DETERMINATION OF EQ LOADS)** These loads are the earthquake force effects that are predominately horizontal and act through the center of mass of the structure. Because most of the weight of a bridge is in the superstructure, seismic loads are assumed to act through the bridge deck. These loads are due to inertial effects and therefore are proportional to the weight and acceleration of the superstructure. The effects of vertical components of earthquake ground motions are typically small and are usually neglected except for complex bridges. The SCDOT Seismic Specs specifies 2 design earthquakes to be used: • Functional Evaluation Earthquake (FEE). The ground shaking having a 15% probability of exceedance in 75 years • Safety Evaluation Earthquake (SEE). The ground shaking having a 3% probability of exceedance in 75 years For information on how to compute EQ loads for geotechnical earthquake engineering analyses see Chapters 11, 12, 13 and 14 of this Manual and the SCDOT Seismic Specs.
FR	Friction	Forces due to friction as a result of sliding or rotation of surfaces.
IC	Ice Load	Ice force effects on piers as a result of ice flows, thickness of ice, and geometry of piers. In South Carolina this factor is typically not used on bridges. Ice force effects (i.e., the weight of ice) should be considered in the design of overhead signs, signals and sound walls.
IM	Vehicular dynamic load allowance	These loads are the force effects of dynamic vehicle loading on structures. For foundations and abutments supporting bridges, these force effects are incorporated into the loads used for superstructure design. For retaining walls not subject to vertical superstructure reactions and for foundation components completely below ground level, the dynamic load allowance is not applicable.

Table 8-3 (Continued), Transient Load Descriptions
(Modified from AASHTO LRFD Specifications (2020) and Wilson, et al. (2007))

LL	Vehicular live load	These loads are the force effects of vehicular live load (truck traffic). The force effects of truck traffic are in part modeled using a highway design “umbrella” vehicle designated HL-93 to represent typical variations in axle loads and spacing. The HL-93 vehicular live load includes a design lane loading that simulates a truck train combined with a concentrated load to generate a maximum moment or shear effect for the component being designed, and an impact load (not used on lane loadings) to account for the sudden application of the truck loading to the structure.
LS	Live load surcharge	These loads are the force effects of traffic loads on backfills that must be considered in the design of walls and abutments. These force effects are considered as an equivalent surcharge. Live load surcharge effects produce a horizontal pressure component on a wall in addition to horizontal earth loads. If traffic is expected within a distance behind a wall equal to about half of the wall height, the live load traffic surcharge is assumed to act on the retained earth surface.
PL	Pedestrian live load	These loads are the force effects of pedestrian and/or bicycle traffic loads that are placed on bridge sidewalks or pedestrian bridges.
SE	Settlement	These loads are internal force effects that develop on structure components as a result of differential settlement between substructures and within substructure units.
TG	Temperature gradient	These loads are internal force effects and deformations that develop on structure components as a result of positive and negative temperature gradients with depth in component’s cross-section. These forces should be considered for substructure design when applicable.
TU	Uniform temperature	These loads are internal force effects that develop on structure components as a result of thermal movement associated with uniform temperature changes in the materials. These forces should be considered for substructure design when applicable.
WA	Water load and stream pressure	These loads are the force effects on structures due to water loading and include static pressure, buoyancy, and stream pressure. Static water and the effects of buoyancy need to be considered whenever substructures are constructed below a temporary or permanent ground water level. Buoyancy effects must be considered during the design of a spread footing or pile cap located below the water elevation. Stream pressure effects include stream currents and waves, and floating debris.
WL	Wind on live load	These loads are the wind force effects on live loads. The WL force should only be applied to portions of the structure that add to the force effect being investigated.

Table 8-3 (Continued), Transient Load Descriptions
(Modified from AASHTO LRFD Specifications (2020) and Wilson, et al. (2007))

WS	Wind load on structure	These loads are the wind force effects of horizontal wind pressure on the structure. The effects of vertical wind pressure on the underside of bridges due to an interruption of the horizontal flow of air and the effects of aero-elastic instability represent special load conditions that are typically taken into account for long-span bridges. For small and/or low structures, wind loading does not usually govern the design. However, for large and/or tall bridges, wind loading can govern the design and should be investigated. Where wind loading is important, the wind pressure should be evaluated from 2 or more different directions for the windward (facing the wind), leeward (facing away from the wind), and side pressures to determine which produce the most critical loads on the structure.

8.5 LOAD COMBINATION LIMIT STATES

The limit states are subdivided based on consideration of applicable load. The design of foundations supporting bridge piers or abutments should consider all limit state loading conditions applicable to the structure being designed. A description of the load combination limit states that are used in geotechnical engineering is provided in Table 8-4. Most substructure designs will require the evaluation of foundation and structure performance at the Strength I and Service I limit states. These limit states are generally similar to evaluations of ultimate capacity and deformation behavior in ASD, respectively.

Table 8-4, Load Combination Limit State Considerations
(Modified from Wilson, et al. (2007))

Load Combination Limit State	Load Combination Considerations
Strength I	Basic load combination relating to the normal vehicular use of the bridge without wind.
Strength II	Load combination relating to the use of the bridge by Owner-specified special design vehicles and/or evaluation permit vehicles, without wind.
Strength III	Load combination relating to the bridge exposed to wind velocity exceeding 55 mph without live loads.
Strength IV	Load combination relating to very high dead load to live load force effect ratios in the bridge substructures exceeding about 7.0 (e.g., for spans greater than 250 ft.).
Strength V	Load combination relating to normal vehicular use of the bridge with wind velocity of 55 mph.
Extreme Event I	Load combination including the effects of the design earthquakes. South Carolina uses 2 design earthquakes (SEE and FEE).
Extreme Event II	Load combination relating to collision by vessels and vehicles, check flood (500-year flow event), and certain hydraulic events.
Service I	Load combination relating to the normal operational use of the bridge with 55 mph wind.

8.6 LOAD MODIFIERS

AASHTO LRFD methodology allows each factored load to be adjusted by a load modifier, η_i. This load modifier, η_i, accounts for the combined effects of ductility, η_D, redundancy, η_R, and operational importance, η_I. In geotechnical design load modifiers are not used to account for the influence of ductility, redundancy, and operational importance on structure performance. The influences of redundancy and operational importance have been incorporated into the selection of the geotechnical resistance factors. Therefore, a load modifier of 1.0 shall be used by the SCDOT for all geotechnical engineering analyses.

8.7 LOAD COMBINATION AND LOAD FACTORS

Load factors vary for different load types and limit states to reflect either the certainty with which the load can be estimated or the importance of each load category for a particular limit state. Table 8-5 provides load combinations and appropriate load factors to be used on SCDOT geotechnical designs. This table is based on the AASHTO LRFD Specifications.

These load factors apply only to geotechnical structures. For bridges and structures located along roadways, the SEOR is responsible for evaluating the load combinations and load factors and providing the loads to the geotechnical engineers for analyses. For geotechnical structures, the GEOR will be responsible for determining the load combinations and load factors for their geotechnical structure (embankments, MSE walls-external stability, reinforced slopes, etc.). Some analytical methods have not been calibrated for LRFD design methodology. Geotechnical analyses that have not been calibrated include, global stability analyses (static and seismic), and liquefaction induced geotechnical seismic hazards. For these analyses a load factor (γ) of unity (1.0) shall be used.

Table 8-5, Load Combination and Load Factors (Modified from AASHTO LRFD Specifications (2020))

Load Combination Limit State	DC DD DW EH EV ES EL PS CR SH	LL IM CE BR PL LS	WA	WS	WL	FR	TU		TG	SE	*Note: Use Only One of These Load Types at a Time*				
							Min	Max			EQ	BL	IC	CT	CV
Strength I	γ_P	1.75	1.00	----	----	1.00	0.50	1.20	γ_{TG}	γ_{SE}	----	----	----	----	----
Strength II	γ_P	1.35	1.00	----	----	1.00	0.50	1.20	γ_{TG}	γ_{SE}	----	----	----	----	----
Strength III	γ_P	----	1.00	1.00	----	1.00	0.50	1.20	γ_{TG}	γ_{SE}	----	----	----	----	----
Strength IV	γ_P	----	1.00	----	----	1.00	0.50	1.20	----	----	----	----	----	----	----
Strength V	γ_P	1.35	1.00	1.00	1.00	1.00	0.50	1.20	γ_{TG}	γ_{SE}	----	----	----	----	----
Extreme Event I	1.00	γ_{EQ}	1.00	----	----	1.00	----	----	----	----	1.00	----	----	----	----
Extreme Event II	1.00	0.50	1.00	----	----	1.00	----	----	----	----	----	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.20	γ_{TG}	γ_{SE}	----	----	----	----	----

Observations about the magnitude and relationship between various the load factors indicated in Table 8-5 are listed below:

- A load factor of 1.00 is used for all permanent and most transient loads for Service I.
- The live load factor for Strength I is greater than that for Strength II (i.e., 1.75 versus 1.35) because variability of live load is greater for normal vehicular traffic than for a permit vehicle.
- The live load factor for Strength I is greater than that for Strength V (i.e., 1.75 versus 1.35) because variability of live load is greater for normal vehicular use without wind than for a bridge subjected to a wind of 55 mph, and because less traffic is anticipated during design wind conditions.
- The live load factor for Strength III is zero because vehicular traffic is considered unstable and therefore unlikely under extreme wind conditions.

The load factor temperature gradient (γ_{TG}) shall be selected by the SEOR in accordance with AASHTO LRFD Specifications or other governing design specifications. The load settlement factor (γ_{SE}) is used to account for the effects of foundation movement on the bridge and shall be selected based on the method used to determine the amount of settlement as provided in Table 8-6. The blast load factor (γ_{BL}) shall only be used as directed by the Department and is not anticipated being required in geotechnical design.

Table 8-6, Load Factors for Permanent Loads Due to Foundation Movements, γ_{SE} (Modified from AASHTO LRFD Specifications (2020))

Foundation Movement and Movement Estimation Method		γ_{SE}
Immediate Settlement		
	Hough Method	1.00
	Schmertmann Method	1.40
	Local Owner Approved Method	*
Consolidation Settlement		1.00
Lateral Movement		
	Soil-structure Interaction Method (P-y or Strain Wedge)	1.00
	Local Owner Approved Method	*

*To be determined by SCDOT based on local geologic conditions

AASHTO requires that certain permanent loads and transient loads be factored using maximum and minimum load factors, as shown in Table 8-7. The concept of using maximum and minimum factored loads in geotechnical engineering can be associated with using these load factors (max. and min.) to achieve a load combination that produces the largest driving force and the smallest resisting force. Criteria for the application of the permanent load factors (γ_P, γ_{EQ}) are presented below:

- Load factors should be selected to produce the largest total factored force effect under investigation.
- Both maximum and minimum extremes should be investigated for each load combination.
- For load combinations where a force effect decreases the effect of another force, the minimum value should be applied to the load that reduces the force effect.
- The load factor that produces the more critical combination of permanent force effects should be selected from Table 8-7.
- If a permanent load increases the stability or load-carrying capacity of a structural component (e.g., load from soil backfill on the heel of a wall), the minimum value for that permanent load must also be investigated.

Table 8-7, Load Factors for Permanent Loads, γ_P
(Modified from AASHTO LRFD Specifications (2020))

Type of Load		Load Factor	
		Maximum	Minimum
DC: Component and Attachment		1.25	0.90
DC: Strength IV Only		1.50	0.90
DD: Downdrag on Deep Foundations	Driven Piles (α (Tomlinson) Method)	1.40	0.25
	Driven Piles (λ Method)	1.05	0.30
	Drilled Shafts (O'Neill & Reese 2010 Method)	1.25	0.35
DW: Wearing Surface and Utilities		1.50	0.65
EH: Horizontal Earth Pressure	Active	1.50	0.90
	At-Rest	1.35	0.90
	Apparent Earth Pressure (AEP) for Anchored Walls	1.35	N/A
EL: Locked-in Erection Stresses		1.00	1.00
EV: Vertical Earth Pressures	Overall Stability	1.00	N/A
	Retaining Walls and Abutments	1.35	1.00
	MSE Wall internal stability soil reinforcements		
	• Stiffness Method		
	o Reinforcement and connection rupture	1.35	N/A
	o Soil failure – geosynthetics (Service I)	1.20	N/A
	• Coherent Gravity Method	1.35	N/A
	Rigid Buried Structure	1.30	0.90
	Rigid Frames	1.35	0.90
	Flexible Buried Structures		
	• Metal Box Culverts, Structural Plate Culverts with Deep Corrugations, and Fiberglass Culverts	1.50	0.90
	• Thermoplastic Culverts	1.30	0.90
	• All Others	1.95	0.90
	Internal and Compound Stability for Soil Failure in Soil Nail Walls	1.00	N/A
ES: Earth Surcharge		1.50	0.75

The load factors for downdrag loads (DD) are specific to the method used to compute the load. Only maximum load factors for permanent loads (γ_P) are applicable for downdrag loads (DD), these represent the uncertainty in accurately estimating downdrag loads on piles. If the downdrag load acts to resist a permanent uplift force effect, the minimum load factor will be utilized.

Typically in South Carolina the earthquake load factor (γ_{EQ}) used in Extreme Event I (EE I) live load combinations is 0.0, unless otherwise determined by the Department.

Typical transient loads used to design geotechnical structures for pedestrian live loads (PL), and live load surcharge (LS) shall be computed using the values indicated in Table 8-8. When traffic live loads (LL) are necessary, the AASHTO LRFD Specifications shall be used.

Table 8-8, Uniform Surcharge Pressures

Material Description		Uniform Pressure (psf)
PL: Pedestrian Live Load	Sidewalk widths 2.0 ft or wider	75
	Bridge walkways or bicycle pathways	90
LS[1] : Live load uniform surcharge at bridge abutments perpendicular to traffic Where H_{abut} = Abutment Height	$H_{abut} \leq 5$ ft.	500
	$H_{abut} = 10$ ft.[3]	375
	$H_{abut} \geq 20$ ft.	250
LS[1, 2] : Live Load Surcharge on Retaining Walls Parallel To Traffic Where H_{wall} = Wall Height and distance from back of wall = 0.0 ft.	$H_{wall} \leq 5$ ft.	625
	5 ft. < $H_{wall} \leq 20$ ft.	440
	$H_{wall} > 20$ ft.	250
LS[1, 2] : Live Load Surcharge on Retaining Walls Parallel To Traffic Where H_{wall} = Wall Height and distance from back of wall ≥ 1.0 ft	$H_{wall} \leq 5$ ft.	250
	5 ft. < $H_{wall} \leq 20$ ft.	250
	$H_{wall} > 20$ ft.	250
LS[1] : Live Load Surcharge on embankments		250

(1) Uniform Pressure equal to $\gamma_s h_{eq}$ as per AASHTO specifications distributed over the traffic lanes. Where the unit weight of the soil, γ_s, is taken as 125 pcf and the surcharge equivalent height is h_{eq}.
(2) Traffic lanes shall be assumed to extend up to the location of a physical barrier such as a guardrail. If no guardrail or other type of barrier exists, traffic shall be assumed to extend to the back of the wall.
(3) For abutment heights between 5 and 10 feet and 10 and 20 feet linearly interpolate uniform pressure.

Dead loads computed for components (DC), wearing surfaces and utilities (DW), and vertical earth pressures (EV) shall be computed using the unit weights of the materials. In the absence of specific unit weights of materials, the values indicated in Table 8-9 should be used.

Table 8-9, Unit Weights of Common Materials
(Modified from AASHTO LRFD Specifications (2020))

Material Description		Unit Weight (pcf)
Bituminous (AC) Wearing Surfaces		140
Steel		490
Wood	Hard	60
	Soft	50
Unreinforced Concrete[(1)]	Lightweight	110 - 135
	Normal Weight ($f'_c \leq 5.0$ ksi)	145
	Normal Weight ($5.0 \text{ ksi} < f'_c \leq 15.0$ ksi) (f'_c - ksi)	$140 + 0.001 * f'_c$
Soils (moist)	Compacted Soils	120
	Very Loose to Loose Sand	100
	Medium to Dense Sand	125
	Dense to Very Dense Sand	130
	Very Soft to Soft Clay	110
	Medium Clay	118
	Stiff to Very Stiff Clay	125
Rock	Rolled Gravel or ballast	140
	Crushed Stone	95
	Gravel	100
	Intermediate Geomaterials (IGM)	155
	Basement Metamorphic or Igneous Rock	165
Water	Fresh	62.4
	Salt	64.0

[1] For reinforced concrete, add 5 pcf

8.8 LOAD COMBINATIONS AND FACTORS FOR CONSTRUCTION LOADS

In the design of geotechnical structures the GEOR must take into consideration potential construction loadings and sequence of construction into the design of geotechnical structures. When a construction method is specified, such as staged construction, and specialty ground improvement (prefabricated vertical drains (PVDs), surcharges, geosynthetic reinforcement, aggregate columns, etc.), or when temporary structures such as temporary MSE walls, sheet piling, etc. are designed, the Strength I limit state shall be used with the following modifications to the load factors. The maximum permanent load factor (γ_P) for permanent loads DC and DW shall be at least 1.25 and the maximum load factor for transient loads LL, PL, and LS shall be at least 1.30. Construction plans and specifications of construction methods and temporary construction structures must include construction limitations and sequence of construction used in developing the design.

8.9 OPERATIONAL CLASSIFICATION

An Operational classification (OC) has been developed for all "typical" bridges on the South Carolina transportation system. "Typical" bridges are those bridges whose design is governed by the Seismic Specs. These classifications have been developed specifically for the South Carolina transportation system and are defined in the Seismic Specs. OC serves to assist in providing guidance as to the operational (i.e., the post-seismic event Service and Damage Level) requirements of the structure being designed as well as the design effort that will be required. The Performance Limits in Chapter 10 have been established for the various structures based on the OC. This is particularly evident when evaluating geotechnical earthquake engineering analyses/designs.

8.10 LRFD GEOTECHNICAL DESIGN AND ANALYSIS

The limit state that is selected for geotechnical engineering analyses/designs is dependent on the performance limit state and the probability of the loading condition. Guidance in selecting limit states for geotechnical analyses of Bridge Foundations, Embankments, and ERSs are provided in the following subsections.

8.10.1 Bridge Foundations

The design of foundations supporting bridge piers or abutments should consider all limit state loading conditions applicable. Strength limit states are used to evaluate a condition of total or partial collapse. The Strength limit state is typically evaluated in terms of shear or bending stress failure.

The Service limit state is typically evaluated in terms of excessive deformation in the forms of settlement, lateral displacement, or rotation. The Service II, III and IV limit states are used to evaluate specific critical structural components and are not generally applicable to foundation design.

The EE I limit state is used to evaluate seismic loadings and its effect on the bridge. The EE II limit state is used for the evaluation of vessel impact or vehicle impact and for the effect of the check flood on the bridge structure. The EE I limit state may control the design of foundations in seismically active areas. The EE II limit state may control the design of foundations or piers that may be exposed to vehicle or vessel impacts or may be exposed to the check flood (500-year (0.2 percent Annual Exceedance Probability (AEP))flood event).

With respect to deformation, (i.e., horizontal deflection or settlement), the Service I limit state or the EE I limit state will control the design. Performance measures and the corresponding limit states for design of shallow foundations and deep foundations are provided in Tables 8-10 and 8-11 respectively.

Bridge foundation design for a given limit state shall take into account the change in foundation condition as indicated below:

- Strength – used to determine nominal resistance for axial stability and critical penetration depth for lateral stability (includes design (100-yr (1.0 percent AEP)) flood scour);
- Service – used to determine displacements (includes design (100-yr) flood scour);
- Extreme Event I – used to determine axial resistance and lateral stability in seismic;

- Extreme Event II – 1) used to determine axial resistance and lateral stability for impact (vessel/vehicle) load, and/or 2) used to determine axial resistance and lateral stability for the check (500-yr) flood scour.

Table 8-10, Shallow Foundation Limit States

Performance Measure	Limit States		
	Strength	Service	Extreme Event
Soil Bearing Resistance	√		√
Sliding Frictional Resistance	√		√
Sliding Passive Resistance	√		√
Structural Capacity	√		√
Lateral Displacement		√	√
Vertical Settlement		√	√

Table 8-11, Deep Foundation Limit States

Performance Measure	Limit States		
	Strength	Service	Extreme Event
Axial Compression Load	√		√
Axial Uplift Load	√		√
Structural Capacity	√		√
Lateral Displacements		√	√
Settlement		√	√
Critical Penetration (Soil Failure only)	√		

8.10.2 Embankments

The predominant loads influencing the stability of an embankment are dead weight, earth pressure, and live load surcharge.

AASHTO LRFD Specifications (2020) states:

> The overall stability of the retaining wall, retained slope and foundation soil or rock shall be evaluated for all walls using limiting equilibrium methods of analysis. The overall stability of temporary cut slopes to facilitate construction shall also be evaluated.…
>
> The evaluation of overall stability of earth slopes *(embankments)* with or without a foundation unit should be investigated at the Strength I Load Combination and an appropriate resistance factor.

The Service I limit state and the EE limit states will control the deformation, while the Strength I limit state will control the overall stability of the embankment design. When evaluating the embankment with respect to seismic loads, the EE I limit state is used; however, see Chapter 17 for no analysis condition requirements. The EE I limit state may control the design in seismically active areas. All bridge embankments shall be designed for Strength, Service and EE limit states. Roadway embankments shall be designed for the Strength and Service limit states only. It is noted the vessel/vehicle impact loading of EE II shall not be used in the design of embankments.

- Strength – used to determine the nominal stability of the slope (includes design (100-yr) flood scour);
- Service – used to determine displacements (includes design (100-yr) flood scour);
- Extreme Event I – used to determine the stability of the slope in seismic events;
- Extreme Event II – used to determine the stability of the slope including the check (500-yr) flood scour

Both the SEE and FEE events shall be used in EE I design; however, if adequate resistance factors and displacements are achieved using the SEE EE I loads, then the GEOR may elect not to use the FEE event. The report shall indicate that the FEE event was not used and shall indicate why this event was not used. Performance measures and corresponding limit state for design of embankments are provided in Table 8-12.

Table 8-12, Embankment Limit States

Performance Measure	Limit States		
	Strength	Service	Extreme Event
Lateral Squeeze	√		√
Lateral Displacements		√	√
Vertical Settlement		√	√
Overall Stability	√		√

8.10.3 Earth Retaining Structures

The predominant loads influencing the stability of ERSs are dead weight, earth pressure, and live load surcharge. The Strength I and IV limit state load combinations have the largest dead, earth and live load factors and therefore control the design at the Strength limit state. The Strength limit state is evaluated for overall stability, bearing, sliding, and overturning (eccentricity). The Service I limit state and the EE limit states will control the deformation performance limits for ERSs. When evaluating the ERSs with respect to seismic loads, the EE I limit state is used. The EE I limit state may control the design in more seismically active areas. All ERSs shall be designed for Strength, Service and EE limit states.

- Strength – used to determine nominal resistance for overall stability, bearing, sliding (including frictional and passive) as well as structural capacity (includes design (100-yr) flood scour);
- Service – used to determine the nominal stability, the vertical and horizontal displacements (includes design (100-yr) flood scour);

- Extreme Event I – used to determine resistance for bearing, sliding (including frictional and passive), eccentricity as well as structural capacity and the nominal stability, the vertical and horizontal displacements during seismic events
- Extreme Event II – used to determine the stability of the slope including the check (500-yr) flood scour

Both the SEE and FEE events shall be used in EE I design of ERSs located within the bridge embankment. The EE I design of ERSs located within the roadway embankment shall use the SEE only. It is noted that vehicular impact on ERSs is not used in slope stability analysis. Performance measures and corresponding limit states for design of earth retaining structures are provided in Table 8-13.

Table 8-13, Earth Retaining Structures Limit States

Performance Measure	Limit States		
	Strength	Service	Extreme Event
Soil Bearing Resistance	√		√
Sliding Frictional Resistance	√		√
Sliding Passive Resistance	√		√
Structural Capacity	√		√
Lateral Load Analysis (Lateral Displacements)		√	√
Settlement		√	√
Overall Stability	√		√

8.11 REFERENCES

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

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