

**Chapter 8**  
**GEOTECHNICAL**  
**LRFD DESIGN**

Final

**SCDOT GEOTECHNICAL DESIGN MANUAL**

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# 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 (MSE walls, reinforced concrete walls, brick walls, cantilever walls, etc.), and roadway embankments (at bridge approaches and along roadways). The primary guidance for the ASD design methodology has been the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges (17<sup>th</sup> 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.

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

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 earthquake 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 design specification incorporates 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 Federal Highway Administration (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 specifications.

The 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 specifications refers to the AASHTO LRFD Bridge Specifications (latest edition), 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 AASHTO 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 the ASD method) with respect to structural or geotechnical engineering is that when a certain Load ( $Q$  or Demand) is placed on a component/member, there is sufficient Resistance ( $R$  or Supply) to insure that an established performance criterion is not exceeded as illustrated by the following equation:

$$\text{Load (Q) < RESISTANCE (R)} \qquad \text{Equation 8-2}$$

The Load and Resistance quantities can be expressed as a 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 ( $\gamma$ ) and a load modifier ( $\eta$ ) to each type of load ( $Q_i$ ). On the resistance side of the equation a resistance factor ( $\phi$ ) 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.

$$Q = \sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r \qquad \text{Equation 8-3}$$

Where,

- $Q$  = Factored Load
- $Q_i$  = Force Effect
- $\eta_i$  = Load modifier
- $\gamma_i$  = Load factor
- $R_r$  = Factored Resistance
- $R_n$  = Nominal Resistance (i.e. ultimate capacity)
- $\phi$  = Resistance Factor

Equation 8-3 is applicable to more than one 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. AASHTO 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 FHWA-NHI-05-094)**

Limit State	Description
<b>Strength</b>	The strength limit state is 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.
<b>Service</b>	The service limit state represents 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.
<b>Extreme Event</b>	Evaluation of a structural member/component at the extreme event limit state considers a loading combination that represents an excessive or infrequent design boundary condition. Such conditions may include ship impacts, vehicle impact, 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. 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 specifications as permanent loads:

- Dead Load of Components – DC
- DOWDRAG – 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

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 specifications.

**Table 8-2, Permanent Load Descriptions  
(Modified from FHWA-NHI-05-094)**

<b>AASHTO Designation</b>	<b>Definition</b>	<b>Description</b>
<b>DC</b>	Dead load of structural components and nonstructural attachments	The DC 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.
<b>DD</b>	Downdrag	When a deep foundation is installed through a soil layer that is subject to relative 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 Extreme Event I limit state due to downdrag forces resulting from soil liquefaction of loose sandy soil. Measures to mitigate downdrag are typically used by applying a thin coat of bitumen on the deep foundation surface or some other means of reducing surface friction on the pile may reduce downdrag forces.
<b>DW</b>	Dead load of wearing surfaces and utilities	The DW loads include asphalt wearing surfaces, future overlays and planned widening, as well as miscellaneous items (e.g., scuppers, railings and supported utility services).
<b>EH</b>	Horizontal earth pressure load	<p>The EH 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.</p> <p>The magnitude of horizontal earth pressure loads on a substructure are a function of:</p> <ul style="list-style-type: none"> <li>• Structure type (e.g., gravity, cantilever, anchored, or mechanically-stabilized earth wall)</li> <li>• Type, unit weight, and shear strength of the retained earth</li> <li>• Anticipated or permissible magnitude and direction of horizontal substructure movement</li> <li>• Compaction effort used during placement of soil backfill</li> <li>• Location of the ground water table within the retained soil</li> </ul>



**Table 8-2 (Continued), Permanent Load Descriptions  
(Modified from FHWA-NHI-05-094)**

<b>EL</b>	Locked-in erection stresses	The EL 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.
<b>EV</b>	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).
<b>ES</b>	Earth surcharge load	The ES loads are the force effects of surcharge loads on the backs of earth retaining structures. These effects must be considered in the design of walls and bridge abutments.

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:

- Vehicular braking force - BR
- Vehicular centrifugal force – CE
- Creep - CR
- 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
- Shrinkage - SH
- 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 specifications.

**Table 8-3, Transient Load Descriptions  
(Modified from FHWA-NHI-05-094)**

<b>AASHTO Designation</b>	<b>Definition</b>	<b>Description</b>
<b>BR</b>	Vehicular braking force	The BR loads are the force effects of vehicle braking that is represented as a horizontal force effect along the length of a bridge that is resisted by the structure foundations.
<b>CE</b>	Vehicular centrifugal force	The CE loads are the force effects of vehicles traveling on a bridge located along a horizontal curve and generate a centrifugal force effect that must be considered in design. For substructure design, centrifugal forces represent a horizontal force effect.

**Table 8-3 (Continued), Transient Load Descriptions  
(Modified from FHWA-NHI-05-094)**

<b>CR</b>	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.
<b>CT</b>	Vehicular collision force	The CT loads are the force effects of collisions by roadway and rail vehicles.
<b>CV</b>	Vessel collision force	The CV loads are the force effects of vessel collision by ships and barges due to their proximity to navigation 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.
<b>EQ</b>	Earthquake	<p><b><u>(DO NOT USE AASHTO FOR DETERMINATION OF EQ LOADS)</u></b> The EQ 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 <i>Seismic Design Specifications for Highway Bridges</i> specifies two design earthquakes to be used:</p> <ul style="list-style-type: none"> <li>• <i>Functional Evaluation Earthquake (FEE)</i>. The ground shaking having a 15% probability of exceedance in 75 years</li> <li>• <i>Safety Evaluation Earthquake (SEE)</i>. The ground shaking having a 3% probability of exceedance in 75 years</li> </ul> <p>For information on how to compute EQ loads for geotechnical earthquake engineering analyses see Chapters 11 and 12 of this Manual and the SCDOT <i>Seismic Design Specifications for Highway Bridges</i>.</p>
<b>FR</b>	Friction	Forces due to friction as a result of sliding or rotation of surfaces.
<b>IC</b>	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 will not be used.
<b>IM</b>	Vehicular dynamic load allowance	The IM 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 FHWA-NHI-05-094)**

<b>LL</b>	Vehicular live load	The LL 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 consists of a combination of a design truck HS20-44 and 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.
<b>LS</b>	Live load surcharge	The LS 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.
<b>PL</b>	Pedestrian live load	The PL loads are the force effects of pedestrian and/or bicycle traffic loads that are placed on bridge sidewalks or pedestrian bridges.
<b>SE</b>	Settlement	These loads are internal force effects that develop on structure components as a result of differential settlement between substructures and within substructure units.
<b>SH</b>	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.
<b>TG</b>	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.
<b>TU</b>	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.

**Table 8-3 (Continued), Transient Load Descriptions  
(Modified from FHWA-NHI-05-094)**

<b>WA</b>	Water load and stream pressure	The WA 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.
<b>WL</b>	Wind on live load	The WL 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.
<b>WS</b>	Wind load on structure	<p>The WS 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.</p> <p>Where wind loading is important, the wind pressure should be evaluated from two 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.</p>

**8.5 LOAD COMBINATION LIMIT STATES**

The limit states are further 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 FHWA-NHI-05-094)**

<b>Load Combination Limit State</b>	<b>Load Combination Considerations</b>
<b>Strength I</b>	Basic load combination relating to the normal vehicular use of the bridge without wind.
<b>Strength II</b>	Load combination relating to the use of the bridge by Owner-specified special design vehicles and/or evaluation permit vehicles, without wind.
<b>Strength III</b>	Load combination relating to the bridge exposed to wind velocity exceeding 55 mph without live loads.
<b>Strength IV</b>	Load combination relating to very high dead load to live load force effect ratios exceeding about 7.0 (e.g., for spans greater than 250 ft.).
<b>Strength V</b>	Load combination relating to normal vehicular use of the bridge with wind velocity of 55 mph.
<b>Extreme Event I</b>	Load combination including the effects of a design earthquake.
<b>Extreme Event II</b>	Load combination relating to collision by vessels and vehicles, and certain hydraulic events.
<b>Service I</b>	Load combination relating to the normal operational use of the bridge with 55 mph wind.

**8.6 LOAD MODIFIERS**

AASHTO LRFD design methodology allows each factored load to be adjusted by a load modifier,  $\eta_i$ . This load modifier,  $\eta_i$ , accounts for the combined effects of ductility,  $\eta_D$ , redundancy,  $\eta_R$ , and operational importance,  $\eta_I$ . 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 is 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 specifications.

These load factors apply only to geotechnical structures. For bridges and roadway structures, the structural designers (Bridge and Roadway Structures) are responsible for evaluating the load combinations and load factors and provide the loads to the geotechnical engineers for analyses. For geotechnical structures where the engineer-of-record is the geotechnical engineer, the geotechnical engineer will be responsible for determining the load combinations and load factors for their geotechnical structure (embankments, MSE walls-external stability, reinforced slopes, etc.).

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

Load Combination Limit State	DC DD DW EH EV ES EL	LL IM CE BR PL LS	WA	WS	WL	FR	TU CR SH		<i>Note: Use Only One of These Load Types at a Time</i>					
							Min	Max	TG	SE	EQ	IC	CT	CV
<b>Strength I</b>	$\gamma_P$	1.75	1.00	----	----	1.00	0.50	1.20	$\gamma_{TG}$	$\gamma_{SE}$	----	----	----	----
<b>Strength II</b>	$\gamma_P$	1.35	1.00	----	----	1.00	0.50	1.20	$\gamma_{TG}$	$\gamma_{SE}$	----	----	----	----
<b>Strength III</b>	$\gamma_P$	----	1.00	1.40	----	1.00	0.50	1.20	$\gamma_{TG}$	$\gamma_{SE}$	----	----	----	----
<b>Strength IV</b>	$\gamma_P$	----	1.00	----	----	1.00	0.50	1.20	----	----	----	----	----	----
<b>Strength V</b>	$\gamma_P$	1.35	1.00	0.40	1.00	1.00	0.50	1.20	$\gamma_{TG}$	$\gamma_{SE}$	----	----	----	----
<b>Extreme Event I</b>	$\gamma_P$	$\gamma_{EQ}$	1.00	----	----	1.00	----	----	----	----	1.00	----	----	----
<b>Extreme Event II</b>	$\gamma_P$	0.50	1.00	----	----	1.00	----	----	----	----	----	1.00	1.00	1.00
<b>Service I</b>	1.00	1.00	1.00	0.30	1.00	1.00	1.00	1.20	$\gamma_{TG}$	$\gamma_{SE}$	----	----	----	----

The following observations about magnitude and relationship between various 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 load factor for wind load on structures for Strength III is greater than for Strength V (i.e., 1.40 versus 0.40) because the wind load represents the primary load for Strength III where structures are subjected to a wind velocity greater than 55 mph, compared to Strength V where wind velocity of 55 mph represents just a component of all loads on the structure.
- The live load factor for Strength III is zero because vehicular traffic is considered unstable and therefore unlikely under extreme wind conditions.
- The load factors for wind load for Strength V are less than 1.00 (i.e., 0.40) to account for the probability of the maximum value of these loads occurring simultaneously.

The load factor temperature gradient ( $\gamma_{TG}$ ) shall be selected by the structural designer in accordance with AASHTO specifications or other governing design specifications. The load settlement factor ( $\gamma_{SE}$ ) should be selected on a project-specific basis, typically it is taken as  $\gamma_{SE} = 1.0$ .

AASHTO requires that certain permanent loads and transient loads be factored using maximum and minimum load factors, as shown in Table 8-6 and 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 ( $\gamma_p$ ,  $\gamma_{EQ}$ ) 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 one 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 8-6.
- 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 8-6, Load Factors for Permanent Loads,  $\gamma_p$**

Type of Load		Load Factor	
		Maximum	Minimum
<b>DC:</b> Component and Attachment		1.25	0.90
<b>DC:</b> Strength IV Only		1.50	0.90
<b>DD:</b> Downdrag on Deep Foundations	Driven Piles ( $\alpha$ - Tomlinson Method)	1.40	0.25
	Driven Piles ( $\lambda$ - Method)	1.05	0.30
	Drilled Shafts (O'Neill & Reese 1999 Method)	1.25	0.35
<b>DW:</b> Wearing Surface and Utilities		1.50	0.65
<b>EH:</b> 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
<b>EL:</b> Locked-in Erection Stresses		1.00	1.00
<b>EV:</b> Vertical Earth Pressures	Overall Stability	1.00	N/A
	Retaining Walls and Abutments	1.35	1.00
	Rigid Buried Structure	1.30	0.90
	Rigid Frames	1.35	0.90
	Flexible Buried Structures other than Metal Box Culvert	1.95	0.90
	Flexible Metal Box Culvert	1.50	0.90
<b>ES:</b> 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 ( $\gamma_p$ ) 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 downdrag load should be considered a resistance and an appropriate uplift resistance factor should be applied.

Earthquake load factors ( $\gamma_{EQ}$ ) used in Extreme Event I load combinations should be factored using maximum and minimum load factors, as shown in Table 8-7. These factors are provided for guidance in the design of geotechnical structures where the geotechnical engineer is the engineer-of-record. For the design of bridges, hydraulic structures, and other road structures the SCDOT *Bridge Design Manual* and AASHTO specifications shall be used.

**Table 8-7, Load Factors for Earthquake Loads,  $\gamma_{EQ}$**

Type of Load	Load Factor	
	Maximum	Minimum
<b>LL:</b> Live Load	0.50	0.00
<b>IM:</b> Impact	---	---
<b>CE:</b> Vehicular Centrifugal Force	---	---
<b>BR:</b> Vehicular Breaking Force	---	---
<b>PL:</b> Pedestrian Live Load	0.50	0.00
<b>LS:</b> Live Load Surcharge	0.50	0.00

**Table 8-8, Uniform Surcharge Pressures**

Material Description	Uniform Pressure (psf)	
<b>PL:</b> Pedestrian Live Load	Sidewalk widths 2.0 ft or wider	75
	Bridge walkways or bicycle pathways	85
<b>LS<sup>(1)</sup>:</b> Live load uniform surcharge at bridge abutments perpendicular to traffic Where $H_{abut}$ = Abutment Height	$H_{abut} \leq 5$ ft.	500
	$5$ ft. $< H_{abut} \leq 20$ ft.	375
	$H_{abut} \geq 20$ ft.	250
<b>LS<sup>(1,2)</sup>:</b> 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
	$H_{wall} \geq 20$ ft.	250
<b>LS<sup>(1,2)</sup>:</b> Live Load Surcharge on Retaining Walls Parallel To Traffic Where $H_{wall}$ = Wall Height and distance from back of wall $\geq 1.0$ ft	$H_{wall} \leq 5$ ft.	250
	$5$ ft. $< H_{wall} \leq 20$ ft.	250
	$H_{wall} \geq 20$ ft.	250
<b>LS<sup>(1)</sup>:</b> Live Load Surcharge on embankments	250	

<sup>(1)</sup> Uniform Pressure equal to  $\gamma_s h_{eq}$  as per AASHTO specifications distributed over the traffic lanes. Where the unit weight of the soil,  $\gamma_s$ , is taken as 125 pcf and the surcharge equivalent height is  $h_{eq}$ .

<sup>(2)</sup> 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.

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 specifications shall be used.



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**

Material Description		Unit Weight (pcf)
<b>Bituminous (AC) Wearing Surfaces</b>		140
<b>Steel</b>		490
<b>Wood</b>	Hard	60
	Soft	50
<b>Unreinforced Concrete<sup>(1)</sup></b>	Lightweight	110
	Sand-Lightweight	120
	Normal Weight ( $f_c \leq 5.0$ ksi)	145
	Normal Weight ( $5.0 \text{ ksi} < f_c \leq 15.0 \text{ ksi}$ ) ( $f_c - \text{ksi}$ )	$140 + f_c$
<b>Soils</b>	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
<b>Rock</b>	Rolled Gravel or ballast	140
	Crushed Stone	95
	Gravel	100
	Weathered Rock (PWR)	155
	Basement Metamorphic or Igneous Rock	165
<b>Water</b>	Fresh	62.4
	Salt	64.0

<sup>1</sup> For reinforced concrete, add 5 pcf

## 8.8 LOAD COMBINATIONS AND FACTORS FOR CONSTRUCTION LOADS

In the design of geotechnical structures the geotechnical engineer 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 stage construction, and specialty ground improvement (wick drains, surcharges, geosynthetic reinforcement, stone 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 ( $\gamma_P$ ) 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**

Operational classifications have been developed for standard bridges and typical roadway structures. Standard bridges are those bridges whose design is governed by the *Bridge Design Manual*. These classifications have been developed specifically for the South Carolina transportation system. The operational classifications serve to assist in providing guidance as to the operational requirements of the structure being designed. Resistance factors and performance limits in Chapters 9 and 10, respectively, have been established for the various structures based on the operational classification. This is particularly evident when evaluating earthquake engineering analyses/designs. In some cases the degree of analysis or design requirements has been related to the operational classification of the structure. Bridges in the South Carolina transportation system can be classified based on the Bridge Operational Classification (OC) presented in Section 8.9.1 of this Manual. Roadway embankments, retaining structures, and other miscellaneous structures located along the roadways can be classified based on the Roadway Structure Operational Classification (ROC) presented in Section 8.9.2 of this Manual.

**8.9.1 Bridge Operational Classification (IC)**

The Bridge Operational Classification (OC) presented in Table 8-10 is the same as that used in the SCDOT *Seismic Design Specifications for Highway Bridges*.

**Table 8-10, Bridge Operational Classification (OC)**

<b>Bridge Operational Classification (OC)</b>	<b>Description</b>
<b>I</b>	These are standard bridges that are located on the Interstate system and along the following roads: <ul style="list-style-type: none"> <li>▪ US 17</li> <li>▪ US 378 from SC 441 east to I-95</li> <li>▪ I-20 Spur from I-95 east to US 76</li> <li>▪ US 76 from I-20 Spur east to North Carolina</li> </ul> Additional bridges that fall in this category are those structures that meet any of the following criteria: <ul style="list-style-type: none"> <li>▪ Structures that do not have detours</li> <li>▪ Structures with detours greater than 25 miles</li> <li>▪ Structures with a design life greater than 75 years</li> </ul>
<b>II</b>	All bridges that do not have a bridge OC = I and meet any of the following criteria: <ul style="list-style-type: none"> <li>▪ A projected (20 years) ADT <math>\geq</math> 500</li> <li>▪ A projected (20 years) ADT <math>&lt;</math> 500, with a bridge length of 180 feet or longer or individual span lengths of 60 feet or longer</li> </ul>
<b>III</b>	All bridges that do not have a bridge OC = I or II classification.

**8.9.2 Roadway Structure Operational Classification (ROC)**

The Roadway Structure Operational Classification (ROC) was developed specifically for the Geotechnical Manual to assist in the design of roadway embankments and structures located along the highways. The classification of roadway structures is directly related to the Bridge Operational Classification (OC) by associating proximity to bridges and their respective classification.

**Table 8-11, Roadway Structure Operational Classification (ROC)**

<b>Roadway Structure Operational Classification (ROC)</b>	<b>Description</b>
<b>I</b>	Roadway embankments or structures located within 150 feet of a bridge with OC = I. Rigid walls with heights greater than 15 feet. Flexible walls with heights greater than 50 feet.
<b>II</b>	Roadway embankments or structures located within 150 feet of a bridge with OC = II.
<b>III</b>	Roadway embankments or structures (retaining walls, etc.) located within 150 feet of a bridge with OC=III or located more than 150 feet from the bridge regardless of the bridge classification.

**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, Earth Retaining Structures, and Embankments 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 Extreme Event I limit state is used to evaluate seismic loadings and its effect on the bridge. The Extreme Event II limit state is used for the evaluation of vessel impact or vehicle impact on the bridge structure. The Extreme Event I limit state may control the design of foundations in seismically active areas. The Extreme Event II limit state may control the design of foundations of piers that may be exposed to vehicle or vessel impacts.

The service limit state is typically evaluated in terms of excessive deformation in the forms of settlement, lateral displacement, or rotation. The Service II and Service III limit states are used to evaluate specific critical structural components and are not generally applicable to foundation design. With respect to deformation, (i.e., horizontal deflection or settlement), the Service I limit state or the Extreme Event limit states will control the design. Performance limits and corresponding limit states for design of shallow foundations and deep foundations are provided in Tables 8-12 and 8-13, respectively.

Bridge foundation design shall take into account the change in foundation condition resulting from scour analyses. The design flood scour (100-year event) shall be used for the strength and service limit states. The scour resulting from a check flood (500-year event) and from hurricanes shall be used for the Extreme Event limit states.

**Table 8-12, Shallow Foundation Limit States**

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

**Table 8-13, Deep Foundation Limit States**

Performance Limit	Limit States		
	Strength	Service	Extreme Event
Axial Compression Load	√		√
Axial Uplift Load	√		√
Structural Capacity	√		√
Lateral Displacements		√	√
Settlement		√	√

### 8.10.2 Embankments

The predominant loads influencing the stability of an embankment are dead weight, earth pressure, and live load surcharge. The Strength I limit state load combinations will therefore control the design soil bearing resistance and stability at the Strength limit state. The Service I limit state and the Extreme Event limit states will control the deformation and overall stability of the embankment design. When evaluating the embankment with respect to seismic loads, Extreme Event I limit state is used. The Extreme Event I limit state may control the design in seismically active areas. Performance limits and corresponding limit state for design of embankments are provided in Table 8-14.

**Table 8-14, Embankment Limit States**

Performance Limit	Limit States		
	Strength	Service	Extreme Event
Soil Bearing Resistance	√		√
Lateral Spread	√		√
Lateral Squeeze	√		√
Lateral Displacements		√	√
Vertical Settlement		√	√
Overall Stability		√	√

### 8.10.3 Earth Retaining Structures

The predominant loads influencing the stability of earth retaining structures 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 bearing, sliding, and overturning. The Service I limit state and the Extreme Event limit states will control the deformation performance limits for retaining walls. When evaluating the earth retaining structures with respect to seismic loads, the Extreme Event I limit state is used. The Extreme Event I limit state may control the design in seismically active areas. Performance limits and corresponding limit states for design of earth retaining structures are provided in Table 8-15.

**Table 8-15, Earth Retaining Structures Limit States**

Performance Limit	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

The geotechnical information contained in this Manual must be used in conjunction with the SCDOT *Seismic Design Specifications for Highway Bridges*, SCDOT *Bridge Design Manual*, and AASHTO LRFD Bridge Design Specifications with precedence in order indicated. The geotechnical manual will take precedence over all references with respect to geotechnical engineering design.

AASHTO LRFD Bridge Design Specifications, U.S. Customary Units, 4<sup>th</sup> Edition, (2007), American Association of State Highway and Transportation Officials.

FHWA-NHI-05-094, (2005). "LRFD for Highway Bridge Substructures and Earth Retaining Structures," National Highway Institute (NHI), NHI Course No. 130082A, Reference Manual, June 2005.

NCHRP Project 20-7/31, (1986). "Development of Comprehensive Bridge Specifications and Commentary," National Cooperative Highway Research Program (NCHRP), August 1986.

SCDOT *Bridge Design Manual* (2006), South Carolina Department of Transportation, [http://www.scdot.org/doing/bridge/06design\\_manual.shtml](http://www.scdot.org/doing/bridge/06design_manual.shtml)

SCDOT *Seismic Design Specifications for Highway Bridges* (2008), South Carolina Department of Transportation, <http://www.scdot.org/doing/bridge/bridgeseismic.shtml>