



Transmittal Number PT 11-065	Date August 2011
Publication Title / Publication Number <i>Geotechnical Design Manual M 46-03.05</i>	
Originating Organization Environmental and Engineering Programs	

**Remarks and Instructions**

The complete manual, revision packages, and individual chapters can be accessed at [www.wsdot.wa.gov/publications/manuals/m46-03.htm](http://www.wsdot.wa.gov/publications/manuals/m46-03.htm).

Please contact Tony Allen at 360-705-5450 or [allent@wsdot.wa.gov](mailto:allent@wsdot.wa.gov) with comments, questions, or suggestions for improvement to the manual.

For printed manuals, page numbers indicating portions of the manual that are to be removed and inserted are shown below.

Chapter	Remove Pages	Insert Pages
Title Page	i – ii	i–ii
Contents	ix – xvi	ix – xvi
Chapter 15 Abutments, Retaining Walls, and Reinforced Slopes	15-i – 15-84	15-i – 15-88
Appendix 15A Preapproved Proprietary Wall and Reinforced Slope General Design Requirements and Responsibilities	15-A-1 – 15-A-4	15-A-1 – 15-A-6

To get the latest information, please sign up for email updates for individual manuals at [www.wsdot.wa.gov/publications/manuals](http://www.wsdot.wa.gov/publications/manuals).

Washington State Department of Transportation  
Geotechnical Services  
1655 S 2nd Avenue  
Tumwater, WA 98512-6951





**Washington State  
Department of Transportation**

---

# **Geotechnical Design Manual**

M 46-03.05

August 2011

## **Americans with Disabilities Act (ADA) Information**

Materials can be provided in alternative formats by calling the ADA Compliance Manager at 360-705-7097. Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

## **Title VI Notice to the Public**

It is Washington State Department of Transportation (WSDOT) policy to ensure no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO's Title VI Coordinator at 360-705-7082 or 509-324-6018.

To get the latest information on WSDOT publications, sign up for individual email updates at [www.wsdot.wa.gov/publications/manuals](http://www.wsdot.wa.gov/publications/manuals).

Washington State Department of Transportation  
Environmental and Engineering Programs  
Geotechnical Services  
1655 S 2nd Avenue  
Tumwater, WA 98512-6951  
[www.wsdot.wa.gov/business/materialslab/geotechnicalservices.htm](http://www.wsdot.wa.gov/business/materialslab/geotechnicalservices.htm)

---

Appendix 9-A	Examples Illustrating Staged Fill Construction Design	9-43
	9-A.1 Problem Setup	9-43
	9-A.2 Determination of Maximum Stable First Stage Fill Height	9-44
	9-A.3 Total Stress Analysis Procedure Example	9-45
	9-A.4 Effective Stress Analysis Procedure Example	9-51

---

**Chapter 10 Soil Cut Design**

10.1	Overview and Data Acquisition	10-3
	10.1.1 Overview	10-3
	10.1.2 Site Reconnaissance	10-3
	10.1.3 Field Exploration	10-4
	10.1.3.1 Test Borings	10-4
	10.1.3.2 Sampling	10-4
	10.1.3.3 Groundwater Measurement	10-5
	10.1.4 Laboratory Testing	10-5
10.2	Overall Design Considerations	10-6
	10.2.1 Overview	10-6
	10.2.2 Design Parameters	10-7
10.3	Soil Cut Design	10-7
	10.3.1 Design Approach and Methodology	10-7
	10.3.2 Seepage Analysis and Impact on Design	10-9
	10.3.3 Drainage Considerations and Design	10-9
	10.3.4 Stability Improvement Techniques	10-10
	10.3.5 Erosion and Piping Considerations	10-11
10.4	Use of Excavated Materials	10-12
10.5	Special Considerations for Loess	10-13
10.6	PS&E Considerations	10-20
10.7	References	10-20
Appendix 10-A	Washington State Department of Transportation Loess Slope Design Checklist	10-23

---

**Chapter 11 Ground Improvement**

11.1	Overview	11-3
11.2	Development of Design Parameters and Other Input Data for Ground Improvement Analysis	11-3
11.3	Design Requirements	11-4
11.4	References	11-5

**Chapter 12 Rock Cut Design**

12.1	Overview	12-3
12.2	Development of Design Parameters and Other Input Data for Rock Cut Stability Analysis	12-3
12.3	Design Requirements	12-3
12.4	References	12-3

---

**Chapter 13 Landslide Analysis and Mitigation**

13.1	Overview	13-3
13.2	Development of Design Parameters and Other Input Data for Landslide Analysis	13-3
13.3	Design Requirements	13-3
13.4	References	13-3

---

**Chapter 14 Unstable Rockslope Analysis and Mitigation**

14.1	Overview	14-3
14.2	Development of Design Parameters and Other Input Data for Unstable Rockslope Analysis	14-3
14.3	Design Requirements	14-3
14.4	References	14-3

---

**Chapter 15 Abutments, Retaining Walls, and Reinforced Slopes**

15.1	Introduction and Design Standards	15-1
15.2	Overview of Wall Classifications and Design Process for Walls	15-2
15.3	Required Information	15-4
15.3.1	Site Data and Permits	15-4
15.3.2	Geotechnical Data Needed for Retaining Wall and Reinforced Slope Design	15-4
15.3.3	Site Reconnaissance	15-6
15.3.4	Field Exploration Requirements	15-6
15.3.4.1	Exploration Type, Depth, and Spacing	15-8
15.3.4.2	Walls and Slopes Requiring Additional Exploration	15-9
15.3.4.2.1	Soil Nail Walls	15-9
15.3.4.2.2	Walls With Ground Anchors or Deadmen Anchors	15-9
15.3.4.2.3	Wall or Slopes With Steep Back Slopes or Steep Toe Slopes	15-10
15.3.5	Field, Laboratory, and Geophysical Testing for Abutments, Retaining Walls, and Reinforced Slopes	15-10
15.3.6	Groundwater	15-11
15.3.7	Wall Backfill Testing and Design Properties	15-12

15.4	General Design Requirements	15-12
15.4.1	Design Methods	15-12
15.4.2	Tiered Walls	15-14
15.4.3	Back-to-Back Walls	15-14
15.4.4	Walls on Slopes	15-15
15.4.5	Minimum Embedment	15-16
15.4.6	Wall Height Limitations	15-16
15.4.7	Serviceability Requirements	15-17
15.4.8	Active, Passive, At-Rest Earth Pressures	15-18
15.4.9	Surcharge Loads	15-19
15.4.10	Seismic Earth Pressures	15-19
15.4.11	Liquefaction	15-23
15.4.12	Overall Stability	15-23
15.4.13	Wall Drainage	15-23
15.4.14	Utilities	15-24
15.4.15	Guardrail and Barrier	15-24
15.5	Wall Type Specific Design Requirements	15-26
15.5.1	Abutments	15-26
15.5.2	Nongravity Cantilever and Anchored Walls	15-26
15.5.2.1	Nongravity Cantilever Walls	15-26
15.5.2.2	Anchored/Braced Walls	15-27
15.5.2.3	Permanent Ground Anchors	15-28
15.5.2.4	Deadmen	15-32
15.5.3	Mechanically Stabilized Earth Walls	15-32
15.5.3.1	Live Load Considerations for MSE Walls	15-32
15.5.3.2	Backfill Considerations for MSE Walls	15-34
15.5.3.3	Compound Stability Assessment for MSE Walls	15-35
15.5.3.4	Design of MSE Walls Placed in Front of Existing Permanent Walls or Rock	15-36
15.5.3.5	MSE Wall Supported Abutments	15-38
15.5.3.6	Full Height Propped Precast Concrete Panel MSE Walls	15-40
15.5.3.7	Flexible Faced MSE Walls With Vegetation	15-41
15.5.3.8	Dry Cast Concrete Block Faced MSE Walls	15-41
15.5.3.9	Internal Stability Using K-Stiffness Method	15-43
15.5.3.9.1	K-Stiffness Method Loads and Load Factors	15-43
15.5.3.9.2	K-Stiffness Method Load Factors	15-51
15.5.3.9.3	K-Stiffness Method Resistance Factors	15-53
15.5.3.9.4	Safety Against Structural Failure (Internal Stability)	15-54
15.5.3.9.5	Strength Limit State Design for Internal Stability Using the K-Stiffness Method – Geosynthetic Walls	15-56
15.5.3.9.6	Strength Limit State Design for Internal Stability Using the K-Stiffness Method – Steel Reinforced Walls	15-60
15.5.3.9.7	Combining Other Loads With the K-Stiffness Method Estimate of $T_{max}$ for Internal Stability Design	15-64
15.5.3.9.8	Design Sequence Considerations for the K-Stiffness Method	15-64

15.5.4	Prefabricated Modular Walls	15-65
15.5.5	Rock Walls	15-65
15.5.6	Reinforced Slopes	15-66
15.5.7	Soil Nail Walls	15-67
15.6	Standard Plan Walls	15-68
15.7	Temporary Cut Slopes and Shoring	15-69
15.7.1	Overview	15-69
15.7.2	Geotechnical Data Needed for Design	15-71
15.7.3	General Design Requirements	15-71
15.7.3.1	Design Procedures	15-72
15.7.3.2	Safety Factors/Resistance Factors	15-72
15.7.3.3	Design Loads	15-73
15.7.3.4	Design Property Selection	15-74
15.7.4	Special Requirements for Temporary Cut Slopes	15-74
15.7.5	Performance Requirements for Temporary Shoring and Cut Slopes	15-76
15.7.6	Special Design Requirements for Temporary Retaining Systems	15-77
15.7.6.1	Fill Applications	15-77
15.7.6.1.1	MSE Walls	15-77
15.7.6.1.2	Prefabricated Modular Block Walls	15-78
15.7.6.2	Cut Applications	15-78
15.7.6.2.1	Trench Boxes	15-79
15.7.6.2.2	Sheet Piling, with or without Ground Anchors	15-79
15.7.6.2.3	Soldier Piles With or Without Ground Anchors	15-80
15.7.6.2.4	Prefabricated Modular Block Walls	15-80
15.7.6.2.5	Braced Cuts	15-80
15.7.6.2.6	Soil Nail Walls	15-80
15.7.6.3	Uncommon Shoring Systems for Cut Applications	15-81
15.7.7	Shoring and Excavation Design Submittal Review Guidelines	15-81
15.8	References	15-83
	Appendices	15-86
	Preapproved Wall Appendices	15-87
Appendix 15-A	Preapproved Proprietary Wall and Reinforced Slope General Design Requirements and Responsibilities	15-A-1
Appendix 15-B	Preapproved Proprietary Wall/Reinforced Slope Design and Construction Review Checklist	15-B-1
Appendix 15-C	HITEC Earth Retaining Systems Evaluation for MSE Wall and Reinforced Slope Systems, as Modified for WSDOT Use: Submittal Requirements	15-C-1
Appendix 15-D	Preapproved Proprietary Wall Systems	15-D-1
Appendix 15-E	Description of Typical Temporary Shoring Systems and Selection Considerations	15-E-1



---

Preapproved Wall Appendix: Specific Requirements and Details for LB Foster Retained Earth Concrete Panel Walls	1
Preapproved Wall Appendix: Specific Requirements and Details for Eureka Reinforced Soil Concrete Panel Walls	11
Preapproved Wall Appendix: Specific Requirements and Details for Hilfiker Welded Wire Faced Walls	15
Preapproved Wall Appendix: Specific Requirements and Details for KeySystem I Walls	21
Preapproved Wall Appendix: Specific Requirements and Details for Tensar MESA Walls	31
Preapproved Wall Appendix: Specific Requirements and Details for T-WALL® (The Neel Company)	51
Preapproved Wall Appendix: Specific Requirements and Details for Reinforced Earth (RECO) Concrete Panel Walls	67
Preapproved Wall Appendix: Specific Requirements and Details for SSL Concrete Panel Walls	117
Preapproved Wall Appendix: Specific Requirements and Details for Tensar ARES Walls	125
Preapproved Wall Appendix: Specific Requirements and Details for Nelson Walls	145
Preapproved Wall Appendix: Specific Requirements and Details for Tensar Welded Wire Form Walls	146

---

**Chapter 16 Geosynthetic Design**

16.1 Overview	16-3
16.2 Development of Design Parameters for Geosynthetic Application	16-3
16.3 Design Requirements	16-4
16.4 References	16-4

---

**Chapter 17 Foundation Design for Signals, Signs, Noise Barriers, Culverts, and Buildings**

17.1 General	17-3
17.1.1 Overview	17-3
17.1.2 Site Reconnaissance	17-3
17.1.3 Field Investigation	17-3
17.2 Foundation Design Requirements for Cantilever Signals, Strain Poles, Cantilever Signs, Sign Bridges, and Luminaires - General	17-6
17.2.1 Design by Correlation for Cantilever Signals, Strain Poles, Cantilever Signs, Sign Bridges, and Luminaires	17-6
17.2.2 Special Design for Cantilever Signals, Strain Poles, Cantilever Signs, Sign Bridges, and Luminaires	17-9
17.2.3 Cantilever Signals and Strain Pole Standards	17-9
17.2.3.1 Overview	17-9
17.2.3.2 Standard Foundation Designs	17-10
17.2.3.3 Construction Considerations	17-10

17.2.4	Cantilever and Sign Bridges	17-11
17.2.4.1	Overview	17-11
17.2.4.2	Standard Foundation Designs	17-11
17.2.4.3	Construction Considerations	17-11
17.2.5	Luminaires (Light Standards)	17-12
17.2.5.1	Overview	17-12
17.2.5.2	Standard Foundation Design	17-12
17.2.5.3	Construction Considerations	17-13
17.3	Noise Barriers	17-13
17.3.1	Overview	17-13
17.3.4	Foundation Design Requirements for Noise Barriers	17-14
17.3.4.1	Spread Footings	17-14
17.3.4.2	Shaft Foundations	17-15
17.3.4.3	Non-Standard Foundation Design	17-17
17.3.3	Construction Considerations	17-18
17.4	Culverts	17-18
17.4.1	Overview	17-18
17.4.2	Culvert Design and Construction Considerations	17-18
17.5	Buildings	17-19
17.5.1	Overview	17-19
17.5.2	Design Requirement for Buildings	17-19
17.6	References	17-22

---

**Chapter 18 Geotechnical Design for Marine Structure Foundations**

18.1	Overview	18-3
18.2	Design Philosophy	18-3
18.3	Load and Resistance Factors for Marine Structures Subject to Ship Impact	18-3
18.4	References	18-3

---

**Chapter 19 Infiltration Facility Design**

19.1	Overview	19-3
19.2	Geotechnical Investigation and Design for Infiltration Facilities	19-3
19.3	References	19-3

---

**Chapter 20 Unstable Slope Management**

20.1	Overview	20-3
20.2	References	20-3

**Chapter 21 Materials Source Investigation and Report**

21.1	Overview	21-3
21.2	Material Source Geotechnical Investigation	21-3
21.3	Materials Source Report	21-6

---

**Chapter 22 Vacant**

---

**Chapter 23 Geotechnical Reporting and Documentation**

23.1	Overview and General Requirements	23-1
23.2	Report Certification and General Format	23-2
23.2	Geotechnical Division Report Content Requirements	23-7
23.2.1	Conceptual or Preliminary Level Geotechnical Reports	23-7
23.2.2	Final Geotechnical Design Reports	23-9
23.2.3	Special Reporting Requirements for LRFD Foundation and Wall Designs	23-13
23.2.3.1	Footings	23-13
23.2.3.2	Drilled Shafts	23-15
23.2.3.3	Piles	23-17
23.2.3.4	Retaining Walls	23-19
23.3	Information to Be Provided in the Geotechnical Design File	23-24
23.3.1	Documentation for Conceptual Level Geotechnical Design	23-24
23.3.2	Documentation for Final Geotechnical Design	23-25
23.3.3	Geotechnical File Contents	23-26
23.4	Consultant Geotechnical Reports and Documentation Produced on Behalf of WSDOT	23-27
23.5	Summary of Geotechnical Conditions	23-28
Appendix 23-A PS&E Review Checklist		23-31
Appendix 23-B Typical Design Cross-Section for a Deep Foundation		23-37



# **Abutments, Retaining Walls, and Reinforced Slopes**

## **Chapter 15 Contents**

	<i>Page</i>
15.1 Introduction and Design Standards	15-1
15.2 Overview of Wall Classifications and Design Process for Walls	15-2
15.3 Required Information	15-4
15.3.1 Site Data and Permits	15-4
15.3.2 Geotechnical Data Needed for Retaining Wall and Reinforced Slope Design	15-4
15.3.3 Site Reconnaissance	15-6
15.3.4 Field Exploration Requirements	15-6
15.3.4.1 Exploration Type, Depth, and Spacing	15-8
15.3.4.2 Walls and Slopes Requiring Additional Exploration	15-9
15.3.4.2.1 Soil Nail Walls	15-9
15.3.4.2.2 Walls With Ground Anchors or Deadmen Anchors	15-9
15.3.4.2.3 Wall or Slopes With Steep Back Slopes or Steep Toe Slopes	15-10
15.3.5 Field, Laboratory, and Geophysical Testing for Abutments, Retaining Walls, and Reinforced Slopes	15-10
15.3.6 Groundwater	15-11
15.3.7 Wall Backfill Testing and Design Properties	15-12
15.4 General Design Requirements	15-12
15.4.1 Design Methods	15-12
15.4.2 Tiered Walls	15-14
15.4.3 Back-to-Back Walls	15-14
15.4.4 Walls on Slopes	15-15
15.4.5 Minimum Embedment	15-16
15.4.6 Wall Height Limitations	15-16
15.4.7 Serviceability Requirements	15-17
15.4.8 Active, Passive, At-Rest Earth Pressures	15-18
15.4.9 Surcharge Loads	15-19
15.4.10 Seismic Earth Pressures	15-19
15.4.11 Liquefaction	15-23
15.4.12 Overall Stability	15-23
15.4.13 Wall Drainage	15-23
15.4.14 Utilities	15-24
15.4.15 Guardrail and Barrier	15-24
15.5 Wall Type Specific Design Requirements	15-26
15.5.1 Abutments	15-26
15.5.2 Nongravity Cantilever and Anchored Walls	15-26
15.5.2.1 Nongravity Cantilever Walls	15-26
15.5.2.2 Anchored/Braced Walls	15-27
15.5.2.3 Permanent Ground Anchors	15-28
15.5.2.4 Deadmen	15-32

	<b>Page</b>
15.5.3 Mechanically Stabilized Earth Walls	15-32
15.5.3.1 Live Load Considerations for MSE Walls	15-32
15.5.3.2 Backfill Considerations for MSE Walls	15-34
15.5.3.3 Compound Stability Assessment for MSE Walls	15-35
15.5.3.4 Design of MSE Walls Placed in Front of Existing Permanent Walls or Rock	15-36
15.5.3.5 MSE Wall Supported Abutments	15-38
15.5.3.6 Full Height Propped Precast Concrete Panel MSE Walls	15-40
15.5.3.7 Flexible Faced MSE Walls With Vegetation	15-41
15.5.3.8 Dry Cast Concrete Block Faced MSE Walls	15-41
15.5.3.9 Internal Stability Using K-Stiffness Method	15-43
15.5.3.9.1 K-Stiffness Method Loads and Load Factors	15-43
15.5.3.9.2 K-Stiffness Method Load Factors	15-51
15.5.3.9.3 K-Stiffness Method Resistance Factors	15-53
15.5.3.9.4 Safety Against Structural Failure (Internal Stability)	15-54
15.5.3.9.5 Strength Limit State Design for Internal Stability Using the K-Stiffness Method – Geosynthetic Walls	15-56
15.5.3.9.6 Strength Limit State Design for Internal Stability Using the K-Stiffness Method – Steel Reinforced Walls	15-60
15.5.3.9.7 Combining Other Loads With the K-Stiffness Method Estimate of $T_{max}$ for Internal Stability Design	15-64
15.5.3.9.8 Design Sequence Considerations for the K-Stiffness Method	15-64
15.5.4 Prefabricated Modular Walls	15-65
15.5.5 Rock Walls	15-65
15.5.6 Reinforced Slopes	15-66
15.5.7 Soil Nail Walls	15-67
15.6 Standard Plan Walls	15-68
15.7 Temporary Cut Slopes and Shoring	15-69
15.7.1 Overview	15-69
15.7.2 Geotechnical Data Needed for Design	15-71
15.7.3 General Design Requirements	15-71
15.7.3.1 Design Procedures	15-72
15.7.3.2 Safety Factors/Resistance Factors	15-72
15.7.3.3 Design Loads	15-73
15.7.3.4 Design Property Selection	15-74
15.7.4 Special Requirements for Temporary Cut Slopes	15-74
15.7.5 Performance Requirements for Temporary Shoring and Cut Slopes	15-76
15.7.6 Special Design Requirements for Temporary Retaining Systems	15-77
15.7.6.1 Fill Applications	15-77
15.7.6.1.1 MSE Walls	15-77
15.7.6.1.2 Prefabricated Modular Block Walls	15-78

---

	<b>Page</b>
15.7.6.2 Cut Applications	15-78
15.7.6.2.1 Trench Boxes	15-79
15.7.6.2.2 Sheet Piling, with or without Ground Anchors	15-79
15.7.6.2.3 Soldier Piles With or Without Ground Anchors	15-80
15.7.6.2.4 Prefabricated Modular Block Walls	15-80
15.7.6.2.5 Braced Cuts	15-80
15.7.6.2.6 Soil Nail Walls	15-80
15.7.6.3 Uncommon Shoring Systems for Cut Applications	15-81
15.7.7 Shoring and Excavation Design Submittal Review Guidelines	15-81
15.8 References	15-83
Appendices	15-86
Preapproved Wall Appendices	15-87





### 15.1 Introduction and Design Standards

Abutments for bridges have components of both foundation design and wall design. This chapter addresses the earth pressures acting on the abutments as well as retaining walls and reinforced slopes. Retaining walls and reinforced slopes are typically included in projects to minimize construction in wetlands, to widen existing facilities, and to minimize the amount of right of way needed in urban environments. Projects modifying existing facilities often need to modify or replace existing retaining walls or widen abutments for bridges.

Retaining walls and reinforced slopes have many benefits associated with their use. Unfortunately, there also tends to be confusion regarding when they should be incorporated into a project, what types are appropriate, how they are designed, who designs them, and how they are constructed. The roles and responsibilities of the various WSDOT offices and those of the Department's consultants further confuse the issue of retaining walls and reinforced slopes, as many of the roles and responsibilities overlap or change depending on the wall type. All abutments, retaining walls, and reinforced slopes within WSDOT Right of Way or whose construction is administered by WSDOT shall be designed in accordance with the WSDOT *Geotechnical Design Manual* (GDM) and the following documents:

- WSDOT *Bridge Design Manual* M 23-50
- WSDOT *Design Manual* M 22-01
- AASHTO *LRFD Bridge Design Specifications*, U.S.

The most current versions or editions of the above referenced manuals including all interims or design memoranda modifying the manuals shall be used. In the case of conflict or discrepancy between manuals, the following hierarchy shall be used: Those manuals listed first shall supercede those listed below in the list.

The following manuals provide additional design and construction guidance for retaining walls and reinforced slopes and should be considered supplementary to the WSDOT GDM and the manuals and design specifications listed above:

- Lazarte, C. A., Elias, V., Espinoza, R. D., Sabatini, P. J., 2003. *Geotechnical Engineering Circular No. 7, Soil Nail Walls*, U.S. Department of Transportation, Federal Highway Administration, FHWA-IF-03-017, 305 pp.

- Porterfield, J. A., Cotton, D. A., Byrne, R. J., 1994, *Soil Nail Walls-Demonstration Project 103, Soil Nailing Field Inspectors Manual*, U.S. Department of Transportation, Federal Highway Administration, FHWA-SA-93-068, 86 pp.
- Samtani, N. C., and Nowatzki, E. A., 2006, *Soils and Foundations, Reference Manual-Volumes I and II*, Washington, D.C., National Highway Institute Publication, FHWA-NHI-06-088/089, Federal Highway Administration.
- Berg, R. R., Christopher, B. R., and Samtani, N. C., 2009, *Design of Mechanically Stabilized Earth Walls and Reinforced Slopes*, No. FHWA-NHI-10-024, Federal Highway Administration, 306 pp.
- Sabatini, P. J., Pass, D. G., and Bachus, R. C., 1999, *Geotechnical Engineering Circular No. 4, Ground Anchors and Anchored Systems*, FHWA-IF-99-015, 281 pp.

## 15.2 Overview of Wall Classifications and Design Process for Walls

The various walls and wall systems can be categorized based on how they are incorporated into construction contracts. Standard Walls comprise the first category and are the easiest to implement. Standard walls are those walls for which standard designs are provided in the WSDOT *Standard Plans*. The internal stability design and the external stability design for overturning and sliding stability have already been addressed in the Standard Plan wall design, and bearing resistance, settlement, and overall stability must be determined for each standard-design wall location by the geotechnical designer. All other walls are nonstandard, as they are not included in the *Standard Plans*.

Nonstandard walls may be further subdivided into proprietary or nonproprietary. Nonstandard, proprietary walls are patented or trademarked wall systems designed and marketed by a wall manufacturer. The wall manufacturer is responsible for internal stability. Sliding stability, eccentricity, bearing resistance, settlement, compound stability, and overall slope stability are determined by the geotechnical designer. Nonstandard, nonproprietary walls are not patented or trade marked wall systems. However, they may contain proprietary elements. An example of this would be a gabion basket wall. The gabion baskets themselves are a proprietary item. However, the gabion manufacturer provides gabions to a consumer, but does not provide a designed wall. It is up to the consumer to design the wall and determine the stable stacking arrangement of the gabion baskets. Nonstandard, nonproprietary walls are fully designed by the geotechnical designer and, if structural design is required, by the structural designer. Reinforced slopes are similar to nonstandard, nonproprietary walls in that the geotechnical designer is responsible for the design, but the reinforcing may be a proprietary item.

A number of proprietary wall systems have been extensively reviewed by the Bridge and Structures Office and the HQ Geotechnical Division. This review has resulted in WSDOT preapproving some proprietary wall systems. The design procedures and wall details for these preapproved wall systems shall be in accordance with this manual (WSDOT GDM) and other manuals specifically referenced herein as applicable to the type of wall being designed, unless alternate design procedures have been agreed upon between WSDOT and the proprietary wall manufacturer. These preapproved design procedures and details allow the manufacturers to competitively bid a particular project without having a detailed wall design provided in the contract plans. Note that proprietary wall manufacturers may produce several retaining wall options, and not all options from a given manufacturer have been preapproved. The Bridge and Structures Office shall be contacted to obtain the current listing of preapproved proprietary systems prior to including such systems in WSDOT projects. A listing of the preapproved wall systems, as of the current publication date for this manual, is provided in WSDOT GDM Appendix 15-D. Specific preapproved details and system specific design requirements for each wall system are also included as appendices to WSDOT GDM Chapter 15. Incorporation of nonpreapproved systems requires the wall supplier to completely design the wall prior to advertisement for construction. All of the manufacturer's plans and details would need to be incorporated into the contract documents. Several manufacturers may need to be contacted to maintain competitive bidding. More information is available in Chapters 610 and 730 of the WSDOT *Design Manual* M 22-01.

If it is desired to use a non-preapproved proprietary retaining wall or reinforced slope system, review and approval for use of the wall or slope system on WSDOT projects shall be based on the submittal requirements provided in WSDOT GDM Appendix 15-C. The wall or reinforced slope system, and its design and construction, shall meet the requirements provided in this manual, including WSDOT GDM Appendix 15-A. For Mechanically Stabilized Earth (MSE) walls, the wall supplier shall demonstrate in the wall submittal that the proposed wall system can meet the facing performance tolerances provided in WSDOT GDM Appendix 15-A through calculation, construction technique, and actual measured full scale performance of the wall system proposed.

Note that MSE walls are termed Structural Earth (SE) walls in the WSDOT *Standard Specifications for Road, Bridge, and Municipal Construction* M 41-10 and associated General Special Provisions (GSPs). In the general literature, MSE walls are also termed reinforced soil walls. In this GDM, the term "MSE" is used to refer to this type of wall.

## 15.3 Required Information

### 15.3.1 Site Data and Permits

The WSDOT *Design Manual* discusses site data and permits required for design and construction. In addition, Chapters 610 and 730 provide specific information relating to geotechnical work and retaining walls.

### 15.3.2 Geotechnical Data Needed for Retaining Wall and Reinforced Slope Design

The project requirements, site, and subsurface conditions should be analyzed to determine the type and quantity of information to be developed during the geotechnical investigation. It is necessary to:

- Identify areas of concern, risk, or potential variability in subsurface conditions.
- Develop likely sequence and phases of construction as they may affect retaining wall and reinforced slope selection.
- Identify design and constructability requirements or issues such as:
  - *Surcharge loads from adjacent structures*      – *Easements*
  - *Backslope and toe slope geometries*              – *Excavation limits*
  - *Right of way restrictions*                              – *Wetlands*
  - *Materials sources*    – *Construction Staging*
- Identify performance criteria such as:
  - *Tolerable settlements for the retaining walls and reinforced slopes*
  - *Tolerable settlements of structures or property being retained*
  - *Impact of construction on adjacent structures or property*
  - *Long-term maintenance needs and access*
- Identify engineering analyses to be performed:
  - *Bearing resistance*    – *Global stability*
  - *Settlement*    – *Internal stability*
- Identify engineering properties and parameters required for these analyses.
- Identify the number of tests/samples needed to estimate engineering properties.

Table 15-1 provides a summary of information needs and testing considerations for retaining walls and reinforced slope design.

Geotechnical Issues	Engineering Evaluations	Required Information for Analyses	Field Testing	Laboratory Testing
<p><b>Fill Walls/ Reinforced Soil Slopes</b></p> <ul style="list-style-type: none"> <li>• internal stability</li> <li>• external stability</li> <li>• <u>global and compound stability</u></li> <li>• limitations on rate of construction</li> <li>• settlement</li> <li>• horizontal deformation?</li> <li>• lateral earth pressures?</li> <li>• bearing capacity?</li> <li>• chemical compatibility with soil, groundwater, and wall materials?</li> <li>• pore pressures behind wall</li> <li>• borrow source evaluation (available quantity and quality of borrow soil)</li> <li>• liquefaction</li> <li>• potential for subsidence (karst, mining, etc.)</li> <li>• constructability</li> <li>• scour</li> </ul>	<ul style="list-style-type: none"> <li>• subsurface profile (soil, ground water, rock)</li> <li>• horizontal earth pressure coefficients</li> <li>• interface shear strengths</li> <li>• foundation soil/wall fill shear strengths?</li> <li>• compressibility parameters? (including consolidation, shrink/swell potential, and elastic modulus)</li> <li>• chemical composition of fill/ foundation soils?</li> <li>• hydraulic conductivity of soils directly behind wall?</li> <li>• time-rate consolidation parameters?</li> <li>• geologic mapping including orientation and characteristics of rock discontinuities?</li> <li>• design flood elevations</li> <li>• seismicity</li> </ul>	<ul style="list-style-type: none"> <li>• SPT</li> <li>• CPT</li> <li>• dilatometer</li> <li>• vane shear</li> <li>• piezometers</li> <li>• test fill?</li> <li>• nuclear density?</li> <li>• pullout test (MSEW/RSS)</li> <li>• rock coring (RQD)</li> <li>• geophysical testing</li> </ul>	<ul style="list-style-type: none"> <li>• 1-D Oedometer</li> <li>• triaxial tests</li> <li>• unconfined compression</li> <li>• direct shear tests</li> <li>• grain size distribution</li> <li>• Atterberg Limits</li> <li>• specific gravity</li> <li>• pH, resistivity, chloride, and sulfate tests?</li> <li>• moisture content?</li> <li>• organic content</li> <li>• moisture-density relationships</li> <li>• hydraulic conductivity</li> </ul>	
<p><b>Cut Walls</b></p> <ul style="list-style-type: none"> <li>• internal stability</li> <li>• external stability</li> <li>• excavation stability</li> <li>• <u>global and compound stability</u></li> <li>• dewatering</li> <li>• chemical compatibility of wall/soil</li> <li>• lateral earth pressure</li> <li>• down-drag on wall</li> <li>• pore pressures behind wall</li> <li>• obstructions in retained soil</li> <li>• liquefaction</li> <li>• see page</li> <li>• potential for subsidence (karst, mining, etc.)</li> <li>• constructability</li> </ul>	<ul style="list-style-type: none"> <li>• subsurface profile (soil, ground water, rock)</li> <li>• shear strength of soil</li> <li>• horizontal earth pressure coefficients</li> <li>• interface shear strength (soil and reinforcement)</li> <li>• hydraulic conductivity of soil</li> <li>• geologic mapping including orientation and characteristics of rock discontinuities</li> <li>• seismicity</li> </ul>	<ul style="list-style-type: none"> <li>• test cut to evaluate stand-up time</li> <li>• well pumping tests</li> <li>• piezometers</li> <li>• SPT</li> <li>• CPT</li> <li>• vane shear</li> <li>• dilatometer</li> <li>• pullout tests (anchors, nails)</li> <li>• geophysical testing</li> </ul>	<ul style="list-style-type: none"> <li>• triaxial tests</li> <li>• unconfined compression</li> <li>• direct shear</li> <li>• grain size distribution</li> <li>• Atterberg Limits</li> <li>• specific gravity</li> <li>• pH, resistivity tests</li> <li>• organic content</li> <li>• hydraulic conductivity</li> <li>• moisture content</li> <li>• unit weight</li> </ul>	

**Summary of Information Needs and Testing Considerations**  
Table 15-1

WSDOT GDM Chapter 5 covers requirements for how the results from the field investigation, the field testing, and laboratory testing are to be used to establish properties for design. The specific tests and field investigation requirements needed for foundation design are described in the following sections.

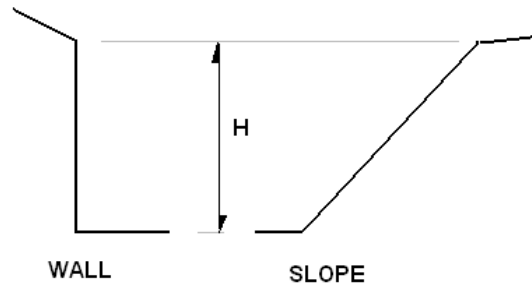
### **15.3.3 Site Reconnaissance**

For each abutment, retaining wall, and reinforced slope, the geotechnical designer should perform a site review and field reconnaissance. The geotechnical designer should be looking for specific site conditions that could influence design, construction, and performance of the retaining walls and reinforced slopes on the project. This type of review is best performed once survey data has been collected for the site and digital terrain models, cross-sections, and preliminary wall profiles have been generated by the civil engineer (e.g., region project engineer). In addition, the geotechnical designer should have access to detailed plan views showing existing site features, utilities, proposed construction, and right of way limits. With this information, the geotechnical designer can review the wall/slope locations making sure that survey information agrees reasonably well with observed site topography. The geotechnical designer should observe where utilities are located, as they will influence where field exploration can occur and they may affect design or constructability. The geotechnical designer should look for indications of soft soils or unstable ground. Items such as hummocky topography, seeps or springs, pistol butted trees, and scarps, either old or new, need to be investigated further. Vegetative indicators such as equisetum (horsetails), cat tails, black berry, or alder can be used to identify soils that are wet or unstable. A lack of vegetation can also be an indicator of recent slope movement. In addition to performing a basic assessment of site conditions, the geotechnical designer should also be looking for existing features that could influence design and construction such as nearby structures, surcharge loads, and steep back or toe slopes. This early in design, it is easy to overlook items such as construction access, materials sources, and limits of excavation. The geotechnical designer needs to be cognizant of these issues and should be identifying access and excavation issues early, as they can affect permits and may dictate what wall type may or may not be used.

### **15.3.4 Field Exploration Requirements**

A soil investigation and geotechnical reconnaissance is critical for the design of all abutments, retaining walls, or reinforced slopes. The stability of the underlying soils, their potential to settle under the imposed loads, the usability of any existing excavated soils for wall/reinforced slope backfill, and the location of the ground water table are determined through the geotechnical investigation. All abutments, retaining, walls and reinforced slopes regardless of their height require an investigation of the underlying soil/rock that supports the structure. Abutments shall be investigated like other bridge piers in accordance with WSDOT GDM Chapter 8.

Retaining walls and reinforced slopes that are equal to or less than 10 ft in exposed height as measured vertically from wall bottom to top or from slope toe to crest, as shown in Figure 15-1, shall be investigated in accordance with this manual. For all retaining walls and reinforced slopes greater than 10 ft in exposed height, the field exploration shall be completed in accordance with the AASHTO *LRFD Bridge Design Specifications* and this manual.



### Exposed Height (H) for a Retaining Wall or Slope

Figure 15-1

Explorations consisting of geotechnical borings, test pits, hand holes, or a combination thereof shall be performed at each wall or slope location. Geophysical testing may be used to supplement the subsurface exploration and reduce the requirements for borings. If the geophysical testing is done as a first phase in the exploration program, it can also be used to help develop the detailed plan for second phase exploration. As a minimum, the subsurface exploration and testing program should obtain information to analyze foundation stability and settlement with respect to:

- Geological formation(s).
- Location and thickness of soil and rock units.
- Engineering properties of soil and rock units, such as unit weight, shear strength and compressibility.
- Ground water conditions.
- Ground surface topography.
- Local considerations (e.g., liquefiable, expansive or dispersive soil deposits, underground voids from solution weathering or mining activity, or slope instability potential).

In areas underlain by heterogeneous soil deposits and/or rock formations, it will probably be necessary to perform more investigation to capture variations in soil and/or rock type and to assess consistency across the site area. In a laterally homogeneous area, drilling or advancing a large number of borings may be redundant, since each sample tested would exhibit similar engineering properties. In all cases, it is necessary to understand how the design and construction of the geotechnical feature will affect the soil and/or rock mass in order to optimize the exploration. The following minimum guidelines for

frequency and depth of exploration shall be used. Additional exploration may be required depending on the variability in site conditions, wall/slope geometry, wall/slope type, and the consequences should a failure occur.

#### 15.3.4.1 Exploration Type, Depth, and Spacing

Generally, walls 10 ft or less in height, constructed over average to good soil conditions (e.g., non-liquefiable, medium dense to very dense sand, silt or gravel, with no signs of previous instability) will require only a basic level of site investigation. A geologic site reconnaissance (see WSDOT GDM Chapter 2), combined with widely spaced test pits, hand holes, or a few shallow borings to verify field observations and the anticipated site geology may be sufficient, especially if the geology of the area is well known, or if there is some prior experience in the area.

The geotechnical designer should investigate to a depth below bottom of wall or reinforced slope at least to a depth where stress increase due to estimated foundation load is less than 10 percent of the existing effective overburden stress and between one and two times the exposed height of the wall or slope. Exploration depth should be great enough to fully penetrate soft highly compressible soils (e.g., peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g., stiff to hard cohesive soil, compact dense cohesionless soil, or bedrock). Hand holes and test pits should be used only where medium dense to dense granular soil conditions are expected to be encountered within limits that can be reasonably explored using these methods, approximately 10 ft for hand holes and 15 ft for test pits, and that based on the site geology there is little risk of an unstable soft or weak layer being present that could affect wall stability.

For retaining walls and reinforced slopes less than 100 ft in length, the exploration should occur approximately midpoint along the alignment or where the maximum height occurs. Explorations should be completed on the alignment of the wall face or approximately midpoint along the reinforced slope, i.e., where the height, as defined in Figure 15-1, is  $0.5H$ . Additional borings to investigate the toe slope for walls or the toe catch for reinforced slopes may be required to assess overall stability issues.

For retaining walls and slopes more than 100 ft in length, exploration points should in general be spaced at 100 to 200 ft, but may be spaced at up to 500 ft in uniform, dense soil conditions. Even closer spacing than 100 to 200 ft should be used in highly variable and potentially unstable soil conditions. Where possible, locate at least one boring where the maximum height occurs. Explorations should be completed on the alignment of the wall face or approximately midpoint along the reinforced slope, i.e., where the height is  $0.5H$ . Additional borings to investigate the toe slope for walls or the toe catch for reinforced slopes may be required to assess overall stability issues.



A key to the establishment of exploration frequency for walls is the potential for the subsurface conditions to impact the construction of the wall, the construction contract in general, and the long-term performance of the finished project. The exploration program should be developed and conducted in a manner that these potential problems, in terms of cost, time, and performance, are reduced to an acceptable level. The boring frequency described above may need to be adjusted by the geotechnical designer to address the risk of such problems for the specific project.

### 15.3.4.2 Walls and Slopes Requiring Additional Exploration

#### 15.3.4.2.1 Soil Nail Walls

Soil nail walls should have additional geotechnical borings completed to explore the soil conditions within the soil nail zone. The additional exploration points shall be at a distance of 1.0 to 1.5 times the height of the wall behind the wall to investigate the soils in the nail zone. For retaining walls and slopes more than 100 ft in length, exploration points should in general be spaced at 100 to 200 ft, but may be spaced at up to 500 ft in uniform, dense soil conditions. Even closer spacing than 100 to 200 ft should be used in highly variable and potentially unstable soil conditions. The depth of the borings shall be sufficient to explore the full depth of soils where nails are likely to be installed, and deep enough to address overall stability issues.

In addition, each soil nail wall should have at least one test pit excavated to evaluate stand-up time of the excavation face. The test pit shall be completed outside the nail pattern, but as close as practical to the wall face to investigate the stand-up time of the soils that will be exposed at the wall face during construction. The test pit shall remain open at least 24 hours and shall be monitored for sloughing, caving, and groundwater see page. A test pit log shall be prepared and photographs should be taken immediately after excavation and at 24 hours. If variable soil conditions are present along the wall face, a test pit in each soil type should be completed. The depth of the test pits should be at least twice the vertical nail spacing and the length along the trench bottom should be at least one and a half times the excavation depth to minimize soil-arching effects. For example, a wall with a vertical nail spacing of 4 ft would have a test pit 8 ft deep and at least 12 ft in length at the bottom of the pit.

#### 15.3.4.2.2 Walls With Ground Anchors or Deadmen Anchors

Walls with ground anchors or deadman anchors should have additional geotechnical borings completed to explore the soil conditions within the anchor/deadman zone. For retaining walls more than 100 ft in length, exploration points should in general be spaced at 100 to 200 ft, but may be spaced at up to 500 ft in uniform, dense soil conditions. Even closer spacing than 100 to 200 ft should be used in highly variable and potentially unstable soil conditions. The borings should be completed outside the no-load zone

of the wall in the bond zone of the anchors or at the deadman locations. The depth of the borings shall be sufficient to explore the full depth of soils where anchors or deadmen are likely to be installed, and deep enough to address overall stability issues.

#### **15.3.4.2.3 Wall or Slopes With Steep Back Slopes or Steep Toe Slopes**

Walls or slopes that have a back slopes or toe slopes that exceed 10 ft in slope length and that are steeper than 2H:1V should have at least one hand hole, test pit, or geotechnical boring in the backslope or toe slope to define stratigraphy for overall stability analysis and evaluate bearing resistance. The exploration should be deep enough to address overall stability issues. Hand holes and test pits should be used only where medium dense to dense granular soil conditions are expected to be encountered within limits that can be reasonably explored using these methods, approximately 10 ft for hand holes and 20 ft for test pits.

#### **15.3.5 Field, Laboratory, and Geophysical Testing for Abutments, Retaining Walls, and Reinforced Slopes**

The purpose of field and laboratory testing is to provide the basic data with which to classify soils and to estimate their engineering properties for design. Often for abutments, retaining walls, and reinforced slopes, the backfill material sources are not known or identified during the design process. For example, mechanically stabilized earth walls are commonly constructed of backfill material that is provided by the Contractor during construction. During design, the material source is not known and hence materials cannot be tested. In this case, it is necessary to design using commonly accepted values for regionally available materials and ensure that the contract will require the use of materials meeting or exceeding these assumed properties.

For abutments, the collection of soil samples and field testing shall be in accordance with WSDOT GDM Chapters 2, 5, and 8.

For retaining walls and reinforced slopes, the collection of soil samples and field testing are closely related. WSDOT GDM Chapter 5 provides the minimum requirements for frequency of field tests that are to be performed in an exploration point. As a minimum, the following field tests shall be performed and soil samples shall be collected:

In geotechnical borings, soil samples shall be taken during the Standard Penetration Test (SPT). Fine grained soils or peat shall be sampled with 3-in Shelby tubes or WSDOT Undisturbed Samplers if the soils are too stiff to push 3-in Shelby tubes. All samples in geotechnical borings shall be in accordance with WSDOT GDM Chapters 2 and 3.

In hand holes, sack soil samples shall be taken of each soil type encountered, and WSDOT Portable Penetrometer tests shall be taken in lieu of SPT tests. The maximum vertical spacing between portable penetrometer tests should be 5 ft.

In test pits, sack soil samples shall be taken from the bucket of the excavator, or from the spoil pile for each soil type encountered once the soil is removed from the pit. WSDOT Portable Penetrometer tests may be taken in the test pit. However, no person shall enter a test pit to sample or perform portable penetrometer tests unless there is a protective system in place in accordance with Washington Administrative Code (WAC) 296-155-657.

In soft soils, CPT tests or insitu vane shear tests may be completed to investigate soil stratigraphy, shear strength, and drainage characteristics.

All soil samples obtained shall be reviewed by a geotechnical engineer or engineering geologist. The geotechnical designer shall group the samples into stratigraphic units based on consistency, color, moisture content, engineering properties, and depositional environment. At least one sample from each stratigraphic unit should be tested in the laboratory for Grain Size Distribution, Moisture Content, and Atterberg Limits (fine grained soils only). Additional tests, such as Loss on Ignition, pH, Resistivity, Sand Equivalent, or Hydrometer may be performed.

Walls that will be constructed on compressible or fine grained soils should have undisturbed soil samples available for laboratory testing, e.g., shelly tubes or WSDOT undisturbed samples. Consolidation tests and Unconsolidated Undrained (UU) triaxial tests should be performed on fine grained or compressible soil units. Additional tests such as Consolidated Undrained (CU), Direct Shear, or Lab Vane Shear may be performed to estimate shear strength parameters and compressibility characteristics of the soils.

Geophysical testing may be used for establishing stratification of the subsurface materials, the profile of the top of bedrock, depth to groundwater, limits of types of soil deposits, the presence of voids, anomalous deposits, buried pipes, and depths of existing foundations. Data from Geophysical testing shall always be correlated with information from direct methods of exploration, such as SPT, CPT, etc.

### **15.3.6 Groundwater**

One of the principal goals of a good field reconnaissance and field exploration is to accurately characterize the groundwater in the project area. Groundwater affects the design, performance, and constructability of project elements. Installation of piezometer(s) and monitoring is usually necessary to define groundwater elevations. Groundwater measurements shall be conducted in accordance with WSDOT GDM Chapter 2, and shall be assessed for each wall. In general, this will require at least one groundwater measurement point for each wall. If groundwater has the potential to affect wall performance or to require special measures to address drainage to be implemented, more than one measurement point per wall will be required.

### 15.3.7 Wall Backfill Testing and Design Properties

The soil used as wall backfill may be tested for shear strength in lieu of using a lower bound value based on previous experience with the type of soil used as backfill (e.g., gravel borrow). See WSDOT GDM Chapter 5 (specifically Table 5-2) for guidance on selecting a shear strength value for design if soil specific testing is not conducted. A design shear strength value of  $36^\circ$  to  $38^\circ$  has been routinely used as a lower bound value for gravel borrow backfill for WSDOT wall projects. Triaxial tests conducted in accordance with AASHTO T296-95 (2000), but conducted on remolded specimens of the backfill compacted at optimum moisture content, plus or minus 3 percent, to 95 percent of maximum density per WSDOT Test Method T606, may be used to justify higher design friction angles for wall backfill, if the backfill source is known at the time of design. This degree of compaction is approximately equal to 90 to 95 percent of modified proctor density (ASTM D1557). The specimens are not saturated during shearing, but are left at the moisture content used during specimen preparation, to simulate the soil as it is actually placed in the wall. Note that this type of testing can also be conducted as part of the wall construction contract to verify a soil friction assumed for design.

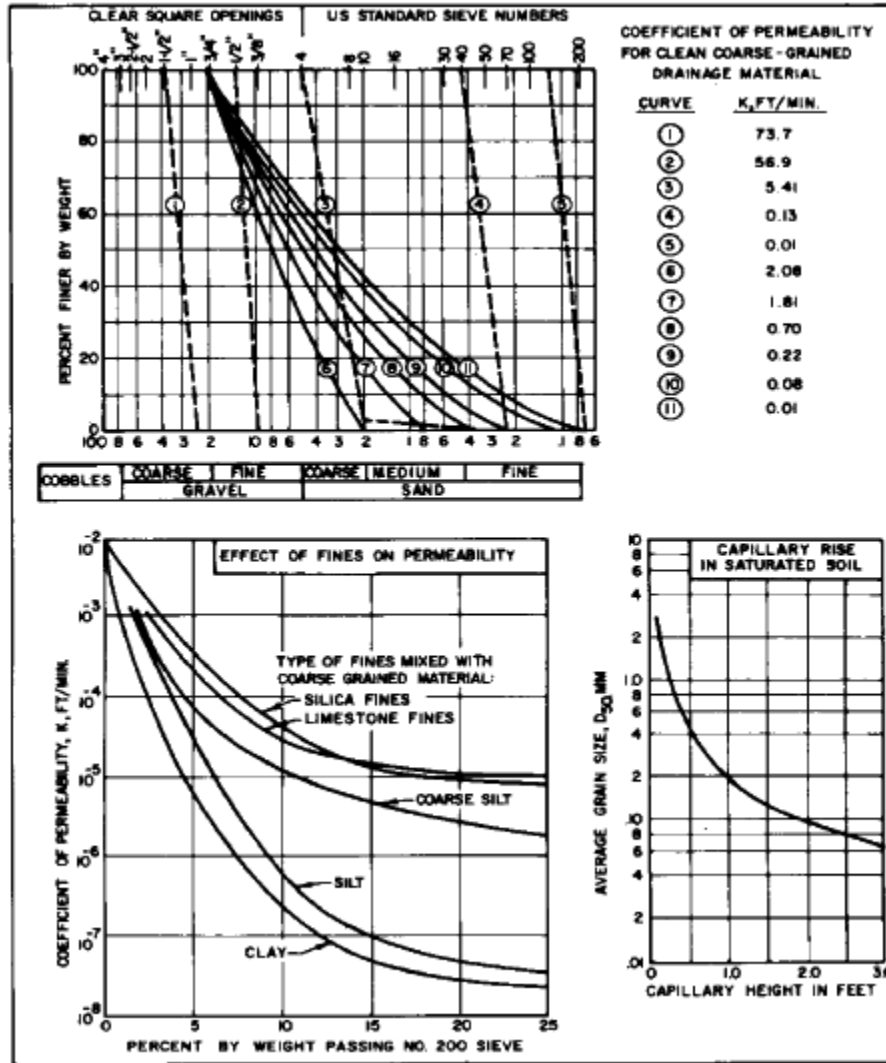
Other typical soil design properties for various types of backfill and native soil units are provided in WSDOT GDM Chapter 5.

The ability of the wall backfill to drain water that infiltrates it from rain, snow melt, or ground water shall be considered in the design of the wall and its stability. Figure 15-2 illustrates the effect the percentage of fines can have on the permeability of the soil. In general, for a soil to be considered free draining, the fines content (i.e., particles passing the No. 200 sieve) should be less than 5 percent by weight. If the fines content is greater than this, the reinforced wall backfill cannot be fully depended upon to keep the reinforced wall backfill drained, and other drainage measures may be needed.

## 15.4 General Design Requirements

### 15.4.1 Design Methods

The AASHTO *LRFD Bridge Design Specifications* shall be used for all abutments and retaining walls addressed therein. The walls shall be designed to address all applicable limit states (strength, service, and extreme event). Rock walls, reinforced slopes, and soil nail walls are not specifically addressed in the AASHTO specifications, and shall be designed in accordance with this manual. Many of the FHWA manuals used as WSDOT design references were not developed for LRFD design. For those wall types (and including reinforced slopes) for which LRFD procedures are not available, allowable stress design procedures included in this manual, either in full or by reference, shall be used, again addressing all applicable limit states.



Permeability and Capillarity of Drainage Materials (after NAVFAC, 1986)  
 Figure 15-2

The load and resistance factors provided in the AASHTO LRFD Specifications have been developed in consideration of the inherent uncertainty and bias of the specified design methods and material properties, and the level of safety used to successfully construct thousands of walls over many years. These load and resistance factors shall only be applied to the design methods and material resistance estimation methods for which they are intended, if an option is provided in this manual or the AASHTO LRFD specifications to use methods other than those specified herein or in the AASHTO LRFD specifications. For estimation of soil reinforcement pullout in reinforced soil (MSE) walls, the resistance factors provided are to be used only for the default pullout methods provided in the AASHTO LRFD specifications. If wall system specific pullout resistance estimation methods are used, resistance factors shall be developed statistically using reliability theory to produce a probability of failure  $P_f$  of

approximately 1 in 100 or smaller. Note that in some cases, Section 11 of the AASHTO *LRFD Bridge Design Specifications* refers to AASHTO LRFD Section 10 for wall foundation design and the resistance factors for foundation design. In such cases, the design methodology and resistance factors provided in the WSDOT GDM Chapter 8 shall be used instead of the resistance factors in AASHTO LRFD Section 10, where the GDM and the AASHTO Specifications differ.

For reinforced soil slopes, the FHWA manual entitled “Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design & Construction Guidelines” by Berg, et al. (2009), or most current version of that manual, shall be used as the basis for design. The LRFD approach has not been developed as yet for reinforced soil slopes. Therefore, allowable stress design shall be used for design of reinforced soil slopes.

All walls shall meet the requirements in the *Design Manual* for layout and geometry. All walls shall be designed and constructed in accordance with the Standard Specifications, General Special Provisions, and *Standard Plans*. Specific design requirements for tiered walls, back-to-back walls, and MSE wall supported abutments are provided in the WSDOT GDM as well as in the AASHTO *LRFD Bridge Design Specifications*, and by reference in those design specifications to FHWA manuals (Berg, et al. 2009).

#### 15.4.2 Tiered Walls

Walls that retain other walls or have walls as surcharges require special design to account for the surcharge loads from the upper wall. Proprietary wall systems may be used for the lower wall, but proprietary walls shall not be considered preapproved in this case. Chapter 730 of the WSDOT *Design Manual* discusses the requirements for utilizing non-preapproved proprietary walls on WSDOT projects. If the upper wall is proprietary, a preapproved system may be used provided it meets the requirements for preapproval and does not contain significant structures or surcharges within the wall reinforcing.

For tiered walls, the FHWA manual entitled “Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes” by Berg, et al. (2009), shall be used as the basis for design for those aspects of the design not covered in the AASHTO LRFD Bridge Design Specifications and the GDM.

#### 15.4.3 Back-to-Back Walls

The face-to-face dimension for back-to-back sheetpile walls used as bulkheads for waterfront structures must exceed the maximum exposed height of the walls. Bulkhead walls may be cross braced or tied together provided the tie rods and connections are designed to carry twice the applied loads.

The face to face dimension for back to back Mechanically Stabilized Earth (MSE) walls should be 1.1 times the average height of the MSE walls or greater. Back-to-back MSE walls with a width/height ratio of less than 1.1 shall not be used unless approved by the State Geotechnical Engineer and the State Bridge Design Engineer. The maximum height for back-to-back MSE wall installations (i.e., average of the maximum heights of the two parallel walls) is 30 ft, again, unless a greater height is approved by the State Geotechnical Engineer and the State Bridge Design Engineer. Justification to be submitted to the State Geotechnical Engineer and the State Bridge Design Engineer for approval should include rigorous analyses such as would be conducted using a calibrated numerical model, addressing the force distribution in the walls for all limit states, and the potential deformations in the wall for service and extreme event limit states, including the potential for rocking of the back-to-back wall system.

The soil reinforcement for back-to-back MSE walls may be connected to both faces, i.e., continuous from one wall to the other, provided the reinforcing is designed for at least double the loading, if approved or required by the State Geotechnical Engineer. Reinforcement may overlap, provided the reinforcement from one wall does not contact the reinforcement from the other wall. Reinforcement overlaps of more than 3 ft are generally not desirable due to the increased cost of materials. Preapproved proprietary wall systems may be used for back-to-back MSE walls provided they meet the height, height/width ratio and overlap requirements specified herein. For seismic design of back-to-back walls in which the reinforcement layers are tied to both wall faces, the walls shall be considered unable to slide to reduce the acceleration to be applied. Therefore, the full ground acceleration shall be used in the walls in that case.

For back-to-back walls, the FHWA manual entitled “Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes” by Berg, et al. (2009), shall be used as the basis for design for those aspects of the design not covered in the AASHTO LRFD Bridge Design Specifications and the GDM.

#### **15.4.4 Walls on Slopes**

Standard Plan walls founded on slopes shall meet the requirements in the *Standard Plans*. All other walls shall have a near horizontal bench at the wall face at least 4 ft wide to provide access for maintenance. Bearing resistance for footings in slopes and overall stability requirements in the AASHTO *LRFD Bridge Design Specifications* shall be met. Table C11.10.2.2-1 in the AASHTO *LRFD Bridge Design Specifications* should be used as a starting point for determining the minimum wall face embedment when the wall is located on a slope. Use of a smaller embedment must be justified based on slope geometry, potential for removal of soil in front of the wall due to erosion, future construction activity, etc., and external and global wall stability considerations.

### 15.4.5 Minimum Embedment

All walls and abutments should meet the minimum embedment criteria in AASHTO. The final embedment depth required shall be based on geotechnical bearing and stability requirements provided in the AASHTO LRFD specifications, as determined by the geotechnical designer (see also WSDOT GDM Section 15.4.4). Walls that have a sloping ground line at the face of wall may need to have a sloping or stepped foundation to optimize the wall embedment. Sloping foundations (i.e., not stepped) shall be 6H:1V or flatter. Stepped foundations shall be 1.5H:1V or flatter determined by a line through the corners of the steps. The maximum feasible slope of stepped foundations for walls is controlled by the maximum acceptable stable slope for the soil in which the wall footing is placed. Concrete leveling pads constructed for MSE walls shall be sloped at 6H:1V or flatter or stepped at 1.5H:1V or flatter determined by a line through the corners of the steps. As MSE wall facing units are typically rectangular shapes, stepped leveling pads are preferred.

In situations where scour (e.g., due to wave or stream erosion) can occur in front of the wall, the wall foundation (e.g., MSE walls, footing supported walls), the pile cap for pile supported walls, and for walls that include some form of lagging or panel supported between vertical wall elements (e.g., soldier pile walls, tieback walls), the bottom of the footing, pile cap, panel, or lagging shall meet the minimum embedment requirements relative to the scour elevation in front of the wall. A minimum embedment below scour of 2 ft, unless a greater depth is otherwise specified, shall be used.

### 15.4.6 Wall Height Limitations

Proprietary wall systems that are preapproved through the WSDOT Bridge and Structures Office are in general preapproved to 33 ft or less in total height. Greater wall heights may be used and for many wall systems are feasible, but a special design (i.e., not preapproved) may be required. The 33 ft preapproved maximum wall height can be extended if approved by the State Geotechnical and Bridge Design Engineers.

Some types of walls may have more stringent height limitations. Walls that have more stringent height limitations include full height propped precast concrete panel MSE walls (WSDOT GDM Section 15.5.3.5), flexible faced MSE walls with a vegetated face (WSDOT GDM Section 15.5.3.6), and MSE wall supported bridge abutments (WSDOT GDM Section 15.5.3.4), and modular dry cast concrete block faced systems (WSDOT GDM Section 15.5.3.8). Other specific wall systems may also have more stringent height limitations due to specific aspects of their design or the materials used in their construction.



### 15.4.7 Serviceability Requirements

Walls shall be designed to structurally withstand the effects of total and differential settlement estimated for the project site, both longitudinally and in cross-section, as prescribed in the AASHTO LRFD Specifications. In addition to the requirements for serviceability provided above, the following criteria (Tables 15-2, 15-3, and 15-4) shall be used to establish acceptable settlement criteria:

Total Settlement	Differential Settlement Over 100 ft	Action
$\Delta H \leq 1$ in	$\Delta H_{100} \leq 0.75$ in	Design and Construct
$1 \text{ in} < \Delta H \leq 2.5$ in	$0.75 \text{ in} < \Delta H_{100} \leq 2$ in	Ensure structure can tolerate settlement
$\Delta H > 2.5$ in	$\Delta H_{100} > 2$ in	Obtain Approval <sup>1</sup> prior to proceeding with design and Construction

<sup>1</sup>Approval of WSDOT State Geotechnical Engineer and WSDOT Bridge Design Engineer required.

#### **Settlement Criteria for Reinforced Concrete Walls, Nongravity Cantilever Walls, Anchored/Braced Walls, and MSE Walls With Full Height Precast Concrete Panels (Soil is Place Directly Against Panel)**

*Table 15-2*

Total Settlement	Differential Settlement Over 100 ft	Action
$\Delta H \leq 2$ in	$\Delta H_{100} \leq 1.5$ in	Design and Construct
$2 \text{ in} < \Delta H \leq 4$ in	$1.5 \text{ in} < \Delta H_{100} \leq 3$ in	Ensure structure can tolerate settlement
$\Delta H > 4$ in	$\Delta H_{100} > 3$ in	Obtain Approval <sup>1</sup> prior to proceeding with design and Construction

<sup>1</sup>Approval of WSDOT State Geotechnical Engineer and WSDOT Bridge Design Engineer required.

#### **Settlement Criteria for MSE Walls With Modular (Segmental) Block Facings, Prefabricated Modular Walls, and Rock Walls**

*Table 15-3*

Total Settlement	Differential Settlement Over 50 ft	Action
$\Delta H \leq 4$ in	$\Delta H_{50} \leq 3$ in	Design and Construct
$4 \text{ in} < \Delta H \leq 12$ in	$3 \text{ in} < \Delta H_{50} \leq 9$ in	Ensure structure can tolerate settlement
$\Delta H > 12$ in	$\Delta H_{50} > 9$ in	Obtain Approval <sup>1</sup> prior to proceeding with design and Construction

<sup>1</sup>Approval of WSDOT State Geotechnical Engineer and WSDOT Bridge Design Engineer required.

### Settlement Criteria for MSE Walls with Flexible Facings and Reinforced Slopes

Table 15-4

For MSE walls with precast panel facings up to 75 ft<sup>2</sup> in area, limiting differential settlements shall be as defined in the AASHTO LRFD Specifications, Article C11.10.4.1.

Note that more stringent tolerances may be necessary to meet aesthetic requirements for the walls.

#### 15.4.8 Active, Passive, At-Rest Earth Pressures

The geotechnical designer shall assess soil conditions and shall develop earth pressure diagrams for all walls except standard plan walls in accordance with the AASHTO *LRFD Bridge Design Specifications*. Earth pressures may be based on either Coulomb or Rankine theories. The type of earth pressure used for design depends on the ability of the wall to yield in response to the earth loads. For walls that free to translate or rotate (i.e., flexible walls), active pressures shall be used in the retained soil. Flexible walls are further defined as being able to displace laterally at least 0.001H, where H is the height of the wall. Standard concrete walls, MSE walls, soil nail walls, soldier pile walls and anchored walls are generally considered as flexible retaining walls. Non-yielding walls shall use at-rest earth pressure parameters. Nonyielding walls include, for example, integral abutment walls, wall corners, cut and cover tunnel walls, and braced walls (i.e., walls that are cross-braced to another wall or structure). Where bridge wing and curtain walls join the bridge abutment, at rest earth pressures should be used. At distances away from the bridge abutment equal to or greater than the height of the abutment wall, active earth pressures may be used. This assumes that at such distances away from the bridge abutment, the wing or curtain wall can deflect enough to allow active conditions to develop.

If external bracing is used, active pressure may be used for design. For walls used to stabilize landslides, the applied earth pressure acting on the wall shall be estimated from limit equilibrium stability analysis of the slide and

wall (external and global stability only). The earth pressure force shall be the force necessary to achieve stability in the slope, which may exceed at-rest or passive pressure.

Regarding the use of passive pressure for wall design and the establishment of its magnitude, the effect of wall deformation and soil creep should be considered, as described in the *AASHTO LRFD Bridge Design Specifications*, Article 3.11.1 and associated commentary. For passive pressure in front of the wall, the potential removal of soil due to scour, erosion, or future excavation in front of the wall shall be considered when estimating passive resistance.

#### 15.4.9 Surcharge Loads

Article 3.11.6 in the *AASHTO LRFD Bridge Design Specifications* shall be used for surcharge loads acting on all retaining walls and abutments for walls in which the ground surface behind the wall is 4H:IV or flatter, the wall shall be designed for the possible presence of construction equipment loads immediately behind the wall. These construction loads shall be taken into account by applying a 250 psf live load surcharge to the ground surface immediately behind the wall. Since this is a temporary construction load, seismic loads should not be considered for this load case.

#### 15.4.10 Seismic Earth Pressures

For all walls and abutments, the Mononobe-Okabe method described in the *AASHTO LRFD Bridge Design Specifications*, Chapter 11 and Appendix A11.1.1.1, should be used. In addition, for this approach it is assumed that the wall backfill is completely drained and cohesionless (i.e., not susceptible to liquefaction).

Walls and abutments that are free to translate or move during a seismic event may use a reduced horizontal acceleration coefficient  $k_h$  of approximately one-half effective peak ground acceleration coefficient  $A_s$ . Vertical acceleration coefficient,  $k_v$ , should be set equal to 0.

Walls and abutments that are not free to translate or move during a seismic event shall use a horizontal acceleration coefficient of 1.5 times effective peak ground acceleration coefficient,  $A_s$ . Vertical acceleration coefficient should be set equal to 0.

For free standing walls that are free to move during seismic loading, if it is desired to use a value of  $k_h$  that is less than 50 percent of  $A_s$ , such walls may be designed for a reduced seismic acceleration (i.e., yield acceleration) as specifically calculated in Article C11.6.5 of the *AASHTO LRFD Bridge Design Specifications*, or by using a Newmark time history analysis (see WSDOT GDM Section 6.4.3.2) to calculate a yield acceleration that corresponds to the amount of horizontal wall displacement allowed. The reduced (yield) acceleration, as described above, should be calculated using a wall displacement that is less than or equal to the following displacements:

- Structural gravity or semi-gravity walls – maximum horizontal displacement of 4 in.
- MSE walls – maximum horizontal displacement of 8 in.

These maximum allowed displacements do not apply to walls that support other structures, unless it is determined that the supported structures have the ability to tolerate the design displacement without compromising the required performance of the supported structure. These maximum allowed displacements also do not apply to walls that support utilities that cannot tolerate such movements and must function after the design seismic event or that support utilities that could pose a significant danger to the public if the utility ruptured. For walls that do support other structures, the maximum wall horizontal displacement allowed shall be no greater than the displacement that is acceptable for the structure supported by the wall.

These maximum allowed wall displacements also do not apply to non-gravity walls (e.g., soldier pile, anchored walls). A detailed structural analysis of non-gravity walls is required to assess how much they can deform laterally during the design seismic event, so that the appropriate value of  $k_h$  can be determined.

The current AASHTO specifications are not consistent regarding the location of the resultant of the earth pressure when seismic loading occurs, nor are they consistent regarding the separation of the static earth pressure from the seismic earth pressure (i.e., the use of  $\Delta K_{ae}$  to represent the seismic portion of the earth pressure versus the use of  $K_{ae}$  to represent the total of the seismic and static earth pressure). Until this issue is resolved, the following policy shall be implemented regarding seismic earth pressure calculation:

- The seismic “component” of the Mononobe-Okabe earth pressure may be separated from the static earth pressure acting on the wall as shown in Article 11.10.7.1 in the AASHTO *LRFD Bridge Design Specifications*. If this is done, the seismic component,  $\Delta K_{ae}$ , shall be calculated as  $K_{ae} - K_a$  for walls that are free to move and develop active earth pressure conditions, and as  $K_{ae} - K_0$  for walls that are not free to move (i.e., at rest earth pressure conditions prevail, and  $K_{ae}$  is calculated using a horizontal acceleration coefficient of 1.5 times the effective peak ground acceleration coefficient). Note that in this case, to complete the seismic design of the wall, the static earth pressure resulting from  $K_a$  or  $K_0$  **must be added** to the seismic component of the earth pressure resulting from  $\Delta K_{ae}$  to obtain the total earth pressure acting in the extreme event limit state. The load factor for EQ in Section 3 of the AASHTO *LRFD Bridge Design Specifications* (i.e., a load factor of 1.0) shall be applied to the static and seismic earth pressure loads, since in Mononobe-Okabe earth pressure analysis, a total static plus seismic earth pressure is calculated as one force initially, and then separated into the static and seismic components as a second step.

- The resultant force of the Mononobe-Okabe earth pressure distribution, as represented by  $\Delta K_{ae}$  should be applied at  $0.6H$  from the bottom of the pressure distribution. Note that the distribution is an inverted trapezoid if the resultant is applied at  $0.6H$ , with the pressure at the top of the distribution equal to  $0.8\Delta K_{ae}\gamma H$ , and the pressure at the bottom equal to  $0.2\Delta K_{ae}\gamma H$ .
- If the seismic earth pressure force is calculated and distributed as a single force as specified in Appendix A11.1.1.1 of the AASHTO *LRFD Bridge Design Specifications*, the combined earth pressure force shall be applied at  $0.5H$  from the bottom of the pressure distribution, resulting in a uniform pressure distribution in which the pressure is equal to  $0.5 K_{ae}\gamma H$ . Note that since this uniform pressure distribution includes both the static and seismic component of lateral earth pressure, this uniform earth pressure **must not be added** to the earth pressure resulting from  $K_a$  or  $K_0$ . Note that this is the preferred approach to estimating earth pressures for the Extreme Event I (seismic) limit state.
- For all walls, the pressure distribution should be applied from the bottom of wall to the top of wall except cantilever walls, anchored walls, or braced walls. For these walls, the pressure should be applied from the top of wall to the elevation of finished ground line at the face of wall.

The Mononobe-Okabe seismic earth pressure theory was developed for a single layer cohesionless soil with no water present. For most gravity walls, this assumption is applicable in most cases. However, for cut walls such as anchored walls or non-gravity cantilever walls, it is possible and even likely that these assumptions may not be applicable. In such cases where these assumptions are not fully applicable, a weighted average (weighted based on the thickness of each layer) of the soil properties (e.g., effective stress  $\phi$  and  $\gamma$ ) should be used to calculate  $K_{ae}$ . Only the soil above the dredge line or finished grade in front of the wall should be included in the weighted average. If water behind the wall cannot be fully drained, the lateral pressure due to the difference in head must be added to the pressure resulting from  $K_{ae}$  to obtain the total lateral force acting in the Extreme Event I limit state (note  $K_{ae}$  includes the total of seismic and active earth pressure, as described previously).

As an alternative to the Mononobe-Okabe method, especially for those cases where the Mononobe-Okabe method is not applicable, limit equilibrium slope stability analysis may be used to estimate the total force (static plus seismic) behind the wall, using  $k_h$  (the acceleration coefficient used to calculate  $K_{ae}$ ) to include seismic force in the slope stability analysis (Chugh, 1995). Steps to accomplish this are as follows:

1. Set up slope/wall model geometry, soil properties, and ground water as would normally be done when conducting a slope stability analysis. The internal face of the wall should be modeled as a free boundary.

2. Select an appropriate slope stability analysis method. Spencer's method is preferred because it satisfies equilibrium of forces and moments, but other analysis methods may be used, subject to approval by the WSDOT State Geotechnical Engineer.
3. Be sure that the failure surface search parameters are appropriate for the site and subsurface geometry so that the most critical surface is obtained.
4. Apply the earth pressure to be calculated as a boundary force on the face of the wall. In general, this force should be applied at a resultant location of  $0.5 H$  on the boundary, though the resultant location can be adjusted up or down to investigate the sensitivity of the location of the force, if desired. The angle of the applied force depends on the friction angle between the wall and the soil. An assumption of  $0$  to  $0.67\phi$  below the horizontal is typical, though a value up to  $\phi$  may be used if the wall/backfill soil interface is very rough.
5. Adjust the magnitude of the applied load until the calculated safety factor is 1.0. The force determined in this manner can be assumed to be equal to the total earth pressure acting on the wall during seismic loading.

If cohesive soils are present behind the wall, the residual drained friction angle rather than the peak friction angle (see WSDOT GDM Chapter 5) should be used to determine the seismic lateral earth pressure.

For anchored walls, since an empirically based Apparent Earth Pressure (AEP) based on the active, or in some cases at rest, earth pressure coefficient is used for static design,  $K_{ae}$  should replace  $K_a$  or  $K_0$  in the AEP for seismic design.

Note also that the slope of the active failure plane flattens as the earthquake acceleration increases. For anchored walls, the anchors should be located behind the active failure wedge. The methodology provided in FHWA Geotechnical Engineering Circular No. 4 (Sabatini, et al., 1999) should be used to locate the active failure plane for the purpose of anchored zone location for anchored walls.

Since the load factor used for the seismic lateral earth pressure for EQ is currently 1.0, to obtain the same level of safety for sliding and bearing obtained from the AASHTO Standard Specification design requirements, a resistance factor of slightly less than 1.0 is required. For bearing resistance during seismic loading, a resistance factor of 0.9 should be used.

For walls that support other structures that are located over the active zone of the wall, the inertial force due to the mass of the supported structure should be considered in the design of the wall if that structure can displace laterally with the wall during the seismic event. For supported structures that are only partially supported by the active zone of the wall, numerical modeling of the wall and supported structure should be considered to assess the impact of the supported structure inertial force on the wall stability.

### 15.4.11 Liquefaction

Under extreme event loading, liquefaction and lateral spreading may occur. The geotechnical designer shall assess liquefaction and lateral spreading for the site and identify these geologic hazards. Design to assess and to mitigate these geologic hazards shall be conducted in accordance with the provisions in WSDOT GDM Chapter 6.

### 15.4.12 Overall Stability

All retaining walls and reinforced slopes shall have a resistance factor for overall stability of 0.75 (i.e., a safety factor of 1.3 as calculated using a limit equilibrium slope stability method). This resistance factor is not to be applied directly to the soil properties used to assess this mode of failure. All abutments and those retaining walls and reinforced slopes deemed critical shall have a resistance factor of 0.65 (i.e., a safety factor of 1.5). Critical walls and slopes are those that support important structures like bridges and other retaining walls. Critical walls and slopes would also be those whose failure would result in a life threatening safety hazard for the public, or whose failure and subsequent replacement or repair would be an intolerable financial burden to the citizens of Washington State. See WSDOT GDM Section 8.6.5.2 for additional background and guidance regarding the assessment of overall stability.

It is important to check overall stability for surfaces that include the wall mass, as well as surfaces that check for stability of the soil below the wall, if the wall is located well above the toe of the slope. If the slope below the wall is determined to be potentially unstable, the wall stability should be evaluated assuming that the unstable slope material has moved away from the toe of the wall, if the slope below the wall is not stabilized. The slope above the wall, if one is present, should also be checked for overall stability.

Stability shall be assessed using limiting equilibrium methods in accordance with WSDOT GDM Chapter 7.

### 15.4.13 Wall Drainage

Drainage should be provided for all walls. In instances where wall drainage cannot be provided, the hydrostatic pressure from the water shall be included in the design of the wall. In general, wall drainage shall be in accordance with the *Standard Plans*, General Special Provisions, and the WSDOT *Design Manual*. Figure 730-2 in the *Design Manual* shall be used for drain details and drain placement for all walls not covered by WSDOT Standard Plan D-4 except as follows:

- Gabion walls and rock walls are generally considered permeable and do not typically require wall drains, provided construction geotextile is placed against the native soil or fill.

- Soil nail walls shall use composite drainage material centered between each column of nails. The drainage material shall be connected to weep holes using a drain gate or shall be wrapped around an underdrain.
- Cantilever and Anchored wall systems using lagging shall have composite drainage material attached to the lagging face prior to casting the permanent facing. Walls without facing or walls using precast panels are not required to use composite drainage material provided the water can pass through the lagging unhindered.

#### 15.4.14 Utilities

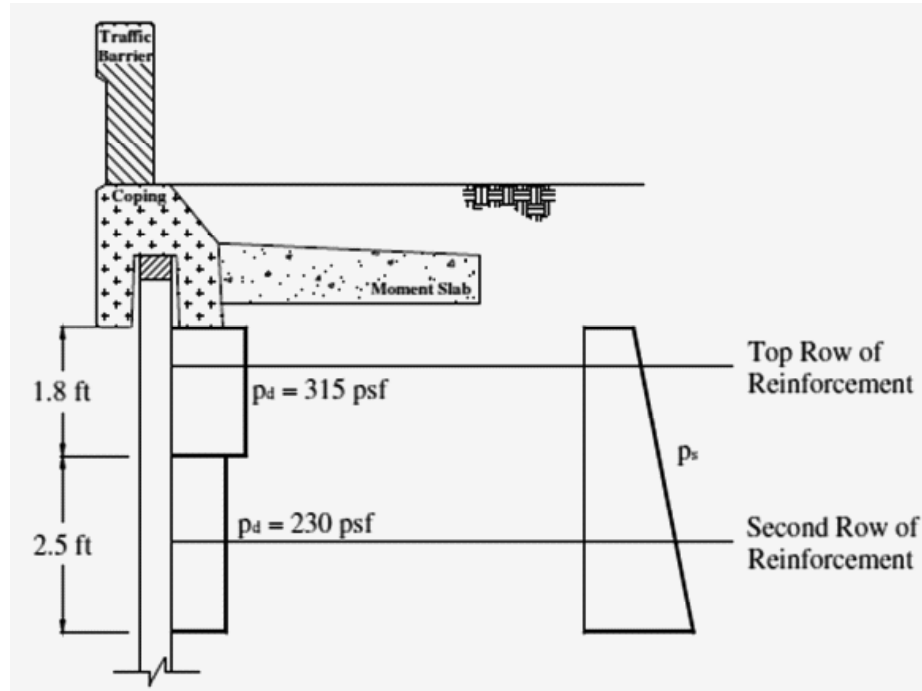
Walls that have or may have future utilities in the backfill should minimize the use of soil reinforcement. MSE, soil nail, and anchored walls commonly have conflicts with utilities and should not be used when utilities must remain in the reinforced soil zone unless there is no other wall option. Utilities that are encapsulated by wall reinforcement may not be accessible for replacement or maintenance. Utility agreements should specifically address future access if wall reinforcing will affect access.

#### 15.4.15 Guardrail and Barrier

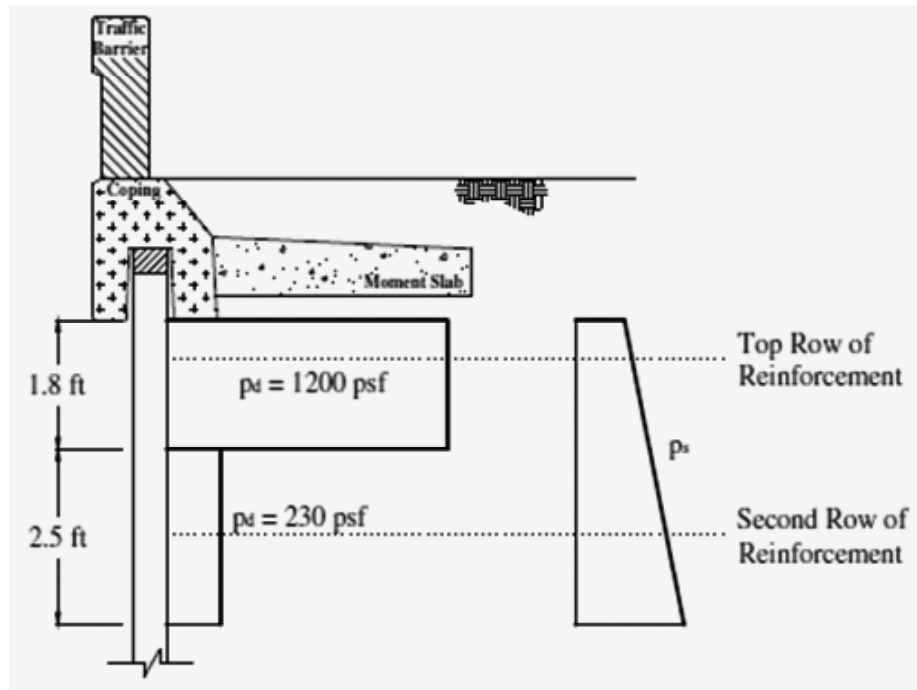
Guardrail and barrier shall meet the requirements of the WSDOT *Design Manual*, *Bridge Design Manual*, *Standard Plans*, and the AASHTO *LRFD Bridge Design Specifications*. In no case shall guardrail be placed through MSE wall or reinforced slope soil reinforcement closer than 3 ft from the back of the wall facing elements. Furthermore, the guard rail posts shall be installed through the soil reinforcement in a manner that prevents ripping and distortion of the soil reinforcement, and the soil reinforcement shall be designed to account for the reduced cross-section resulting from the guardrail post holes.

For walls with a traffic barrier, the distribution of the applied impact load to the wall top shall be as described in the AASHTO *LRFD Bridge Design Specifications* Article 11.10.10.2 for LRFD designs unless otherwise specified in the WSDOT *Bridge Design Manual*, except that for MSE walls, the impact load should be distributed into the soil reinforcement considering only the top two reinforcement layers below the traffic barrier to take the distributed impact load as described in NCHRP Report 663, Appendix I (Bligh, et al., 2010). See Figure 15-3 for an illustration of soil reinforcement load distributions. In that figure,  $p_d$  is the dynamic pressure distribution due to the traffic impact load that is to be resisted by the soil reinforcement, and  $p_s$  is the static earth pressure distribution, which is to be added to the dynamic pressure to determine the total soil reinforcement loading.





(a) Pressure distribution for reinforcement pullout.



(b) Pressure distribution for reinforcement rupture.

**MSE Wall Soil Reinforcement Design for Traffic Barrier Impact for TL-3 and TL-4 Loading (after Bligh, et al., 2010)**

*Figure 15-3*

## 15.5 Wall Type Specific Design Requirements

### 15.5.1 Abutments

Abutment foundations shall be designed in accordance with WSDOT GDM Chapter 8. Abutment walls, wingwalls, and curtain walls shall be designed in accordance with AASHTO *LRFD Bridge Design Specifications* and as specifically required in this GDM. Abutments that are backfilled prior to constructing the superstructure shall be designed using active earth pressures. Active earth pressures shall be used for abutments that are backfilled after construction of the superstructure, if the abutment can move sufficiently to develop active pressures. If the abutment is restrained, at-rest earth pressure shall be used. Abutments that are “U” shaped or that have curtain/wing walls should be designed to resist at-rest pressures in the corners, as the walls are constrained (see WSDOT GDM Section 15.4.8).

### 15.5.2 Nongravity Cantilever and Anchored Walls

WSDOT typically does not utilize sheet pile walls for permanent applications, except at Washington State Ferries (WSF) facilities. Sheet pile walls may be used at WSF facilities but shall not be used elsewhere without approval of the WSDOT Bridge Design Engineer. Sheet pile walls utilized for shoring or cofferdams shall be the responsibility of the Contractor and shall be approved on construction, unless the construction contract special provisions or plans state otherwise.

Permanent soldier piles for soldier pile and anchored walls should be installed in drilled holes. Impact or vibratory methods may be used to install temporary soldier piles, but installation in drilled holes is preferred.

Nongravity and Anchored walls shall be designed using the latest edition of the AASHTO *LRFD Bridge Design Specifications*. Key geotechnical design requirements for these types of walls are found in Sections 3 and 11 of the AASHTO LRFD specifications. Instead of the resistance factor for passive resistance of the vertical wall elements provided in the AASHTO LRFD specifications, a resistance factor for passive resistance of 0.75 shall be used.

#### 15.5.2.1 Nongravity Cantilever Walls

The exposed height of nongravity cantilever walls is generally controlled by acceptable deflections at the top of wall. In “good” soils, cantilever walls are generally 12 to 15 ft or less in height. Greater exposed heights can be achieved with increased section modulus or the use of secant/tangent piles. Nongravity cantilever walls using a single row of ground anchors or deadmen anchors shall be considered an anchored wall.

In general, the drilled hole for the soldier piles for nongravity cantilever walls will be filled with a relatively low strength flowable material such as controlled density fill (CDF), provided that water is not present in the

drilled hole. Since CDF has a relatively low cement content, the cementitious material in the CDF has a tendency to wash out when placed through water. If the CDF becomes too weak because of this, the design assumption that the full width of the drilled hole, rather than the width of the soldier pile by itself, governs the development of the passive resistance in front of the wall will become invalid. The presence of groundwater will affect the choice of material specified by the structural designer to backfill the soldier pile holes, e.g., CDF if the hole is not wet, or higher strength concrete designed for tremie applications. Therefore, it is important that the geotechnical designer identify the potential for ground water in the drilled holes during design, as the geotechnical stability of a nongravity cantilever soldier pile wall is governed by the passive resistance available in front of the wall.

Typically, when discrete vertical elements are used to form the wall, it is assumed that due to soil arching, the passive resistance in front of the wall acts over three pile/shaft diameters. For typical site conditions, this assumption is reasonable. However, in very soft soils, that degree of soil arching may not occur, and a smaller number of pile diameters (e.g., 1 to 2 diameters) should be assumed for this passive resistance arching effect. For soldier piles placed in very dense soils, such as glacially consolidated till, when CDF is used, the strength of the CDF may be similar enough to the soil that the full shaft diameter may not be effective in mobilizing passive resistance. In that case, either full strength concrete should be used to fill the drilled hole, or only the width of the soldier pile should be considered effective in mobilizing passive resistance.

If the wall is being used to stabilize a deep seated landslide, in general, it should be assumed that full strength concrete will be used to backfill the soldier pile holes, as the shearing resistance of the concrete will be used to help resist the lateral forces caused by the landslide.

### 15.5.2.2 Anchored/Braced Walls

Anchored/braced walls generally consist of a vertical structural elements such as soldier piles or drilled shafts and lateral anchorage elements placed beside or through the vertical structural elements. Design of these walls shall be in accordance with the AASHTO *LRFD Bridge Design Specifications*.

In general, the drilled hole for the soldier piles for anchored/braced walls will be filled with a relatively low strength flowable material such as controlled density fill (CDF). For anchored walls, the passive resistance in front of the wall toe is not as critical for wall stability as is the case for nongravity cantilever walls. For anchored walls, resistance at the wall toe to prevent “kickout” is primarily a function of the structural bending resistance of the soldier pile itself. Therefore, it is not as critical that the CDF maintain its full shear strength during and after placement if the hole is wet. For anchored/braced walls, the only time full strength concrete would be used to fill the soldier pile holes in the buried portion of the wall is when the anchors are

steeply dipping, resulting in relatively high vertical loads, or for the case when additional shear strength is needed to resist high lateral kickout loads resulting from deep seated landslides. In the case of walls used to stabilize deep seated landslides, the geotechnical designer must clearly indicate to the structural designer whether or not the shear resistance of the soldier pile and cementitious backfill material (i.e., full strength concrete) must be considered as part of the resistance needed to help stabilize the landslide.

### 15.5.2.3 Permanent Ground Anchors

The geotechnical designer shall define the no-load zone for anchors in accordance with the AASHTO *LRFD Bridge Design Specifications*. If the ground anchors are installed through landslide material or material that could potentially be unstable, the no load zone shall include the entire unstable zone as defined by the actual or potential failure surface plus 5 ft minimum. The contract documents should require the drill hole in the no load zone to be backfilled with a non-structural filler. Contractors may request to fill the drill hole in the no load zone with grout prior to testing and acceptance of the anchor. This is usually acceptable provided bond breakers are present on the strands, the anchor unbonded length is increased by 8 ft minimum, and the grout in the unbonded zone is not placed by pressure grouting methods.

The geotechnical designer shall determine the factored anchor pullout resistance that can be reasonably used in the structural design given the soil conditions. The ground anchors used on the projects shall be designed by the Contractor. Compression anchors (see Sabatini, et al., 1999) may be used, but conventional anchors are preferred by WSDOT.

The geotechnical designer shall estimate the nominal anchor bond stress ( $\tau_n$ ) for the soil conditions and common anchor grouting methods. AASHTO *LRFD Bridge Design Specifications* and the FHWA publications listed at the beginning of this chapter provide guidance on acceptable values to use for various types of soil and rock. The geotechnical designer shall then apply a resistance factor to the nominal bond stress to determine a feasible factored pullout resistance (FPR) for anchors to be used in the wall. In general, a 5-in diameter low pressure grouted anchor with a bond length of 15 to 30 ft should be assumed when estimating the feasible anchor resistance. FHWA research has indicated that anchor bond lengths greater than 40 ft are not fully effective. Anchor bond lengths greater than 50 ft shall be approved by the State Geotechnical Engineer.

The structural designer shall use the factored pullout resistance to determine the number of anchors required to resist the factored loads. The structural designer shall also use this value in the contract documents as the required anchor resistance that Contractor needs to achieve. The Contractor will design the anchor bond zone to provide the specified resistance. The Contractor will be responsible for determining the actual length of the bond zone, hole diameter, drilling methods, and grouting method used for the anchors.

All ground anchors shall be proof tested, except for anchors that are subjected to performance tests. A minimum of 5 percent of the wall's anchors shall be performance tested. For ground anchors in clays, or other soils that are known to be potentially problematic, especially with regard to creep, at least one verification test shall be performed in each soil type within the anchor zone. Past WSDOT practice has been to perform verification tests at two times the design load with proof and performance tests done to 1.5 times the design load. National practice has been to test to 1.33 times the design load for proof and performance tests. Historically, WSDOT has utilized a higher safety factor in its anchored wall designs (FS=1.5) principally due to past performance with anchors constructed in Seattle Clay. For anchors that are installed in Seattle Clay, other similar formations, or clays in general, the level of safety obtained in past WSDOT practice shall continue to be used (i.e., FS = 1.5). For anchors in other soils (e.g., sands, gravels, glacial tills), the level of safety obtained when applying the national practice (i.e., FS = 1.33) should be used.

The AASHTO *LRFD Bridge Design Specifications* specifically addresses anchor testing. However, to be consistent with previous WSDOT practice, verification tests, if conducted, shall be performed to 1.5 times the factored design load (FDL) for the anchor. Proof and performance tests shall be performed to 1.15 times the factored design load (FDL) for anchors installed in clays, and to 1.00 times the factored design load (FDL) for anchors in other soils and rock. The geotechnical designer should make the decision during design as to whether or not a higher test load is required for anchors in a portion of, or all of, the wall due to the presence of clays or other problematic soils. These proof, performance, and verification test loads assume that a load factor,  $\gamma_{EH}$ , of 1.35 is applied to the apparent earth pressure used to design the anchored wall.

The following shall be used for verification tests:

Load	Hold Time
AL	1 Min.
0.25FDL	10 Min.
0.50FDL	10 Min.
0.75FDL	10 Min.
1.00FDL	10 Min.
<b>1.15FDL</b>	<b>60 Min.</b>
1.25FDL	10 Min.
1.50FDL	10 Min.
AL	1 Min.

AL is the alignment load. The test load shall be applied in increments of 25 percent of the factored design load. Each load increment shall be held for at least 10 minutes. Measurement of anchor movement shall be obtained at each load increment. The load-hold period shall start as soon as the test load is applied and the anchor movement, with respect to a fixed reference, shall be measured and recorded at 1 minute, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30, 45, and 60 minutes.

The following shall be used for proof tests, for anchors in clay or other creep susceptible or otherwise problematic soils or rock:

Load	Hold Time
AL	1 Min.
0.25FDL	1 Min.
0.50FDL	1 Min.
0.75FDL	1 Min.
1.00FDL	1 Min.
<b>1.15FDL</b>	<b>10 Min.</b>
AL	1 Min.

The following shall be used for proof tests, for anchors in sands, gravels, glacial tills, rock, or other materials where creep is not likely to be a significant issue:

Load	Hold Time
AL	1 Min.
0.25FDL	1 Min.
0.50FDL	1 Min.
0.75FDL	1 Min.
<b>1.00FDL</b>	<b>10 Min.</b>
AL	1 Min.

The maximum test load in a proof test shall be held for ten minutes, and shall be measured and recorded at 1 minute, 2, 3, 4, 5, 6, and 10 minutes. If the anchor movement between one minute and ten minutes exceeds 0.04 in, the maximum test load shall be held for an additional 50 minutes. If the load hold is extended, the anchor movements shall be recorded at 15, 20, 25, 30, 45, and 60 minutes.

Performance tests cycle the load applied to the anchor. Between load cycles, the anchor is returned to the alignment load (AL) before beginning the next load cycle. The following shall be used for performance tests:

Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5*	Cycle 6
AL	AL	AL	AL	AL	AL
0.25FDL	0.25FDL	0.25FDL	0.25FDL	0.25FDL	Lock-off
	0.50FDL	0.50FDL	0.50FDL	0.50FDL	
		0.75FDL	0.75FDL	0.75FDL	
			1.00FDL	1.00FDL	
				<b>1.15FDL</b>	

\*The fifth cycle shall be conducted if the anchor is installed in clay or other problematic soils. Otherwise, the load hold is conducted at 1.00FDL and the fifth cycle is eliminated.

The load shall be raised from one increment to another immediately after a deflection reading. The maximum test load in a performance test shall be held for 10 minutes. If the anchor movement between one minute and 10 minutes exceeds 0.04 in, the maximum test load shall be held for an additional 50 minutes. If the load hold is extended, the anchor movements shall be recorded at 15, 20, 25, 30, 45, and 60 minutes. After the final load hold, the anchor shall be unstressed to the alignment load then jacked to the lock-off load.

The structural designer should specify the lock-off load in the contract. Past WSDOT practice has been to lock-off at 80 percent of the anchor design load. Because the factored design load for the anchor is higher than the “design load” used in past practice, locking off at 80 percent would result in higher tendon loads. To match previous practice, the lock-off load for all permanent ground anchors shall be 60 percent of the factored design load for the anchor.

Since the contractor designs and installs the anchor, the contract documents should require the following:

1. Lock off shall not exceed 70 percent of the specified minimum tensile strength for the anchor.
2. Test loads shall not exceed 80 percent of the specified minimum tensile strength for the anchor.
3. All anchors shall be double corrosion protected (encapsulated). Epoxy coated or bare strands shall not be used unless the wall is temporary.
4. Ground anchor installation angle should be 15 to 30 degrees from horizontal, but may be as steep as 45 degrees to install anchors in competent materials or below failure planes.

The geotechnical designer and the structural designer should develop the construction plans and special provisions to ensure that the contractor complies with these requirements.

#### 15.5.2.4 Deadmen

The geotechnical designer shall develop earth pressures and passive resistance for deadmen in accordance with AASHTO *LRFD Bridge Design Specifications*. Deadmen shall be located in accordance with Figure 20 from NAVFAC DM-7.2, Foundations and Earth Structures, May 1982 (reproduced below for convenience in Figure 15-4).

#### 15.5.3 Mechanically Stabilized Earth Walls

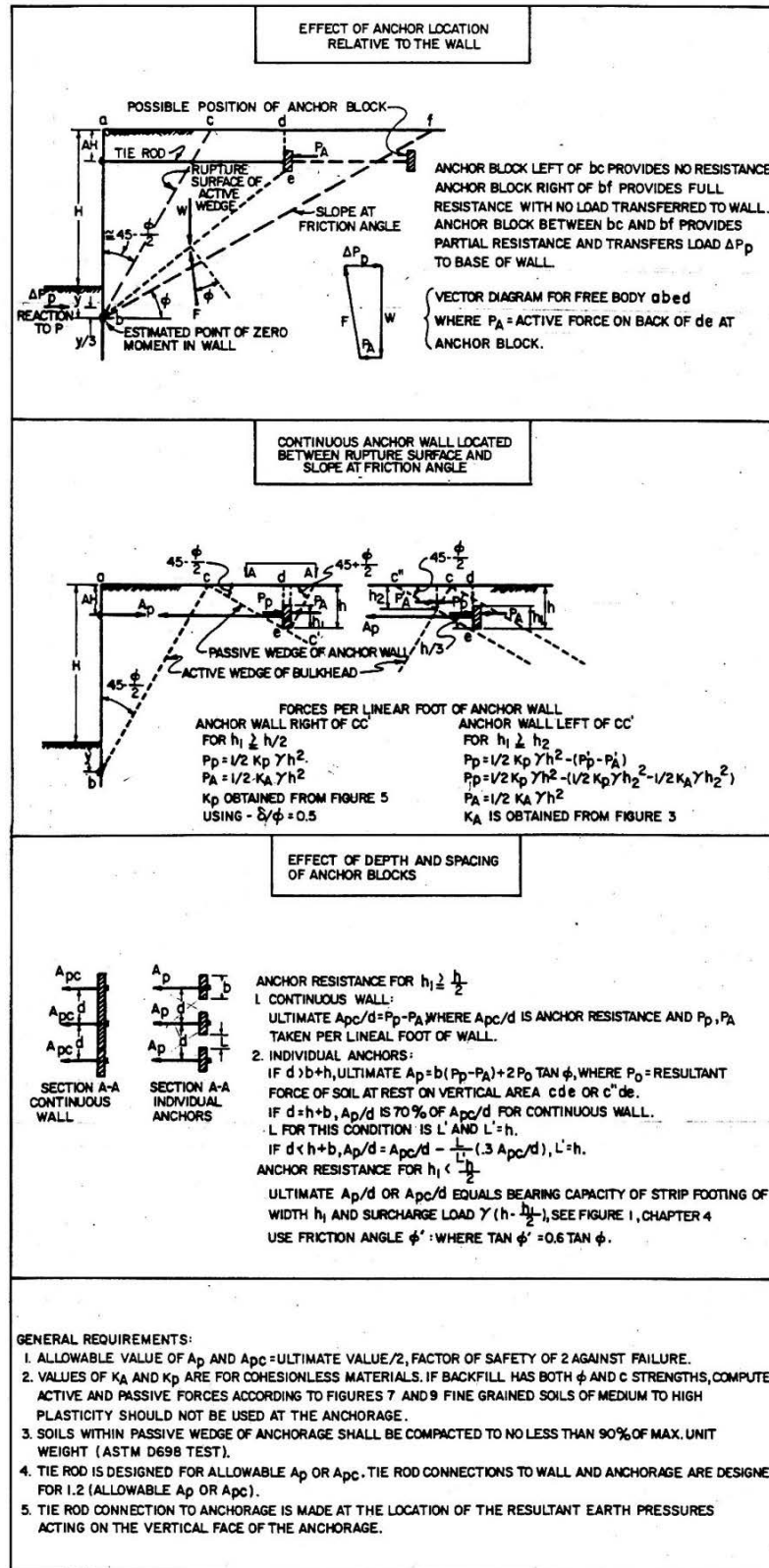
Wall design shall be in accordance with the AASHTO *LRFD Bridge Design Specifications*, except as noted below regarding the use of the K-Stiffness Method for internal stability design.

##### 15.5.3.1 Live Load Considerations for MSE Walls

The AASHTO design specifications allow traffic live load to not be specifically considered for pullout design (note that this does not apply to traffic barrier impact load design as discussed above). The concept behind this is that for the most common situations, it is unlikely that the traffic wheel paths will be wholly contained within the active zone of the wall, meaning that one of the wheel paths will be over the reinforcement resistant zone while the other wheel path is over the active zone. However, there are cases where traffic live load could be wholly contained within the active zone.

Therefore, include live load in calculation of  $T_{\max}$ , where  $T_{\max}$  is as defined in the AASHTO *LRFD Bridge Design Specifications* (i.e., the calculated maximum load in each reinforcement layer), for pullout design if it is possible for both wheels of a vehicle to drive over the wall active zone at the same time, or if a special live loading condition is likely (e.g., a very heavy vehicle could load up the active zone without having a wheel directly over the reinforcement in the resistant zone). Otherwise, live load does not need to be considered. For example, with a minimum 2 ft shoulder and a minimum vehicle width of 8 ft, the active zone for steel reinforced walls would be wide enough for this to happen only if the wall is over 30 ft high, and for geosynthetic walls over 22 ft high. For walls of greater height, live load would need to be considered for pullout for the typical traffic loading situation.





**Deadman Anchor Design (After NAVFAC, 1982)**  
Figure 15-4

### 15.5.3.2 Backfill Considerations for MSE Walls

For steel reinforced MSE walls, the design soil friction angle for the backfill shall not be greater than 40° even if soil specific shear strength testing is conducted, as research conducted to date indicates that measured reinforcement loads do not continue to decrease as the soil shear strength increases (Bathurst, et al., 2009). For geosynthetic MSE walls, however, the load in the soil reinforcement does appear to be correlated to soil shear strength even for shear strength values greater than 40° (see Allen, et al., 2003 and Bathurst, et al., 2008). A maximum design friction angle of 40° should also be used for geosynthetic reinforced walls even with backfill specific shear strength testing, unless project specific approval is obtained from the WSDOT State Geotechnical Engineer to exceed 40°. If backfill shear strength testing is conducted, it shall be conducted in accordance with WSDOT GDM Section 15.3.7.

In general, low silt content backfill materials such as Gravel Borrow per the WSDOT Standard Specifications should be used for MSE walls. If higher silt content soils are used as wall backfill, the wall should be designed using only the frictional component of the backfill soil shear strength as discussed in WSDOT GDM Section 15.3.7. Other issues that shall be addressed if higher fines content soils are used are as follows:

- **Ability to place and compact the soil, especially during or after inclement weather.** In general, as the fines content increases and the soil becomes more well graded, water that gets into the wall backfill due to rain, surface water flow, or ground water flow can cause the backfill to “pump” during placement and compaction, preventing the wall backfill from being properly compacted. Even some gravel borrow gradations may be susceptible to pumping problems when wet, especially when the fines content is greater than 5 percent. Excessive wall face deformation during wall construction can also occur in this case. Because of this potential problem, higher silt content wall backfill should only be used during extended periods of dry weather, such as typically occurs in the summer and early fall months in Western Washington, and possibly most of the year in at least some parts of Eastern Washington.
- **For steel reinforced wall systems, the effect of the higher fines content on corrosion rate of the steel reinforcement.** General practice nationally is that use of backfill with up to 15 percent silt content is acceptable for steel reinforced systems (AASHTO, 2010; Berg, et al., 2009). If higher silt content soils are used, elevated corrosion rates for the steel reinforcement should be considered (see Elias, et al., 2009).
- **Prevention of water or moisture build-up in the wall reinforced backfill.** When the fines content is greater than 5percent, the material should not be considered to be free draining (see WSDOT GDM Section 15.3.7). In such cases where the fines content is greater than that

allowed in the WSDOT gravel borrow specification (i.e., greater than 7 percent), special measures to prevent water from entering the reinforced backfill shall be implemented. This includes placement of under-drains at the back of the reinforced soil zone, sheet drains to intercept possible ground and rainwater infiltration flow, and use of some type impermeable barrier over the top of the reinforced soil zone.

- **Potential for long-term lateral and vertical deformation of the wall due to soil creep, or in general as cohesive soil shear strength is lost over the life of the wall.** Strain and load increase with time in a steel reinforced soil wall was observed for a large wall in California, a likely consequence of using a backfill soil with a significant cohesion component (Allen, et al., 2001). The K-Stiffness Method (see WSDOT GDM Section 15.5.3.1) may be used to estimate the reinforcement strain increase caused by loss of cohesive shear strength over time (i.e., estimate the reinforcement strain using the  $c-\phi$  shear strength at end of construction, and subtract that from the reinforcement strain estimated using only the frictional component of that shear strength for design to get the long-term strain). This would give an indication of the long-term wall deformation that could occur.

### 15.5.3.3 Compound Stability Assessment for MSE Walls

If the MSE wall is located over a soft foundation soil or on a relatively steep slope, compound stability of the wall and slope combination should be evaluated as a service limit state in accordance with the AASHTO LRFD Specifications. It is recommended that this stability evaluation only be used to evaluate surfaces that intersect within the bottom 20 to 30 percent of the reinforcement layers. As discussed by Allen and Bathurst (2002) and Allen and Bathurst (2003), available limit equilibrium approaches such as the ones typically used to evaluate slope stability do not work well for internal stability of reinforced soil structures, resulting in excessively conservative designs, at least for geosynthetic or otherwise extensible reinforced systems.

The results of the compound stability analysis, if it controls the reinforcement needs near the base of the wall, should be expressed as minimum total reinforcement strength and total reinforcement pullout resistance for all layers within a “box” at the base of the wall to meet compound stability requirements. The location of the critical compound stability failure surface in the bottom portion of the wall should also be provided so that the resistant zone boundary location is identified.

Regarding pullout, the length of reinforcement needed behind the critical compound stability failure surface may vary significantly depending on the reinforcement coverage ratio anticipated and the frictional characteristics of the soil reinforcement. Therefore, several scenarios for these two key variables may need to be investigated to assure it is feasible to obtain the desired level of compound stability for all wall/reinforcement types that are

to be considered for the selected width “B” of the box. For convenience, to define the box width “B” required for the pullout length, an average active and resistant zone length should be defined for the box. This concept is illustrated in Figure 15-5. In this figure “H” is the total wall height, “T” is the load required in each reinforcement layer that must be resisted to achieve the desired level of safety in the wall for compound stability, and  $T_{\text{total}}$  is the total force increase needed in the compound stability analysis to achieve the desired level of safety with regard to compound stability. This total force should be less than or equal to the total long-term tensile strength,  $T_{\text{al}}$ , of the reinforcement layers within the defined “box” and the total pullout resistance available for the reinforcement contained within the box, considering factored loads and resistance values. The engineer needs to select the value of “B” that meets this pullout length requirement. However, the value of “B” selected should be minimized to keep the wall base width required to a minimum, to keep excavation needs as small as possible.

From the wall supplier’s view, the contract would specify a specific value of “B” that is long enough such that the desired minimum pullout resistance can be obtained but that provides a consistent basis for bidding purposes with regard to the amount of excavation and shoring needed to build the wall.

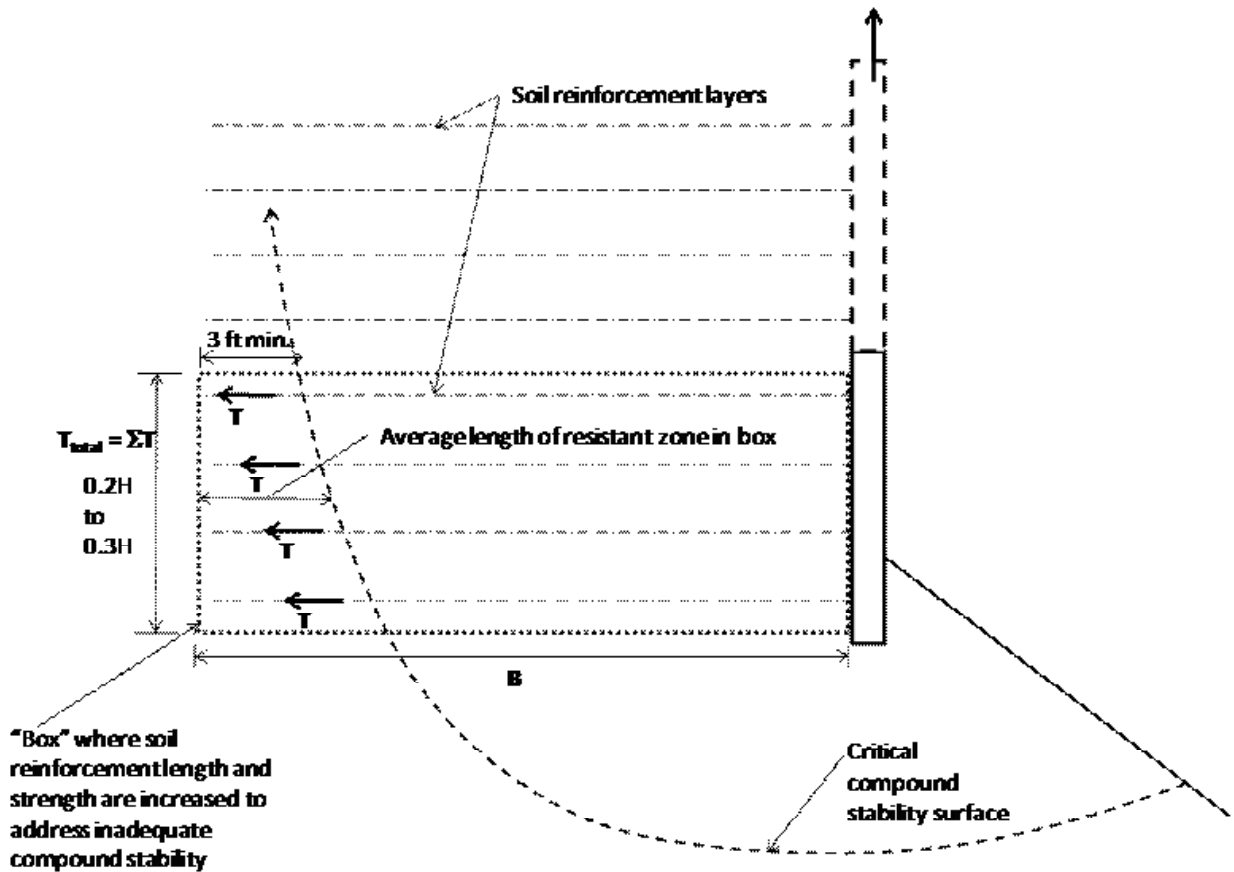
Note that for taller walls, it may be desirable to define more than one box at the wall base to improve the accuracy of the pullout length for the intersected reinforcement layers. If the wall is tiered, a box may need to be provided at the base of each tier, depending on the horizontal separation between tiers.

#### 15.5.3.4 Design of MSE Walls Placed in Front of Existing Permanent Walls or Rock

Widening existing facilities sometimes requires MSE walls to be built in front of those existing facilities with inadequate room to obtain the minimum  $0.7H$  wall base width. To reduce excavation costs and shoring costs in side hill situations, the “existing facility” could in fact be a shoring wall or even a near vertical rock slope face. See Figure 15-6 for a conceptual illustration of this situation.

In such cases, assuming that the existing facility is designed as a permanent structure with adequate design life, or if the barrier to adequate reinforcement length is a rock slope, the following design requirements apply:

- The minimum base width is  $0.4H$  or 6 ft, whichever is greater, where  $H$  is the total height of the new wall. Note that for soil reinforcement lengths that are less than 8 ft, the weight and size of construction equipment used to place and compact the soil backfill will need to be limited in accordance with the AASHTO *LRFD Bridge Design Specifications* Article C11.10.2.1.

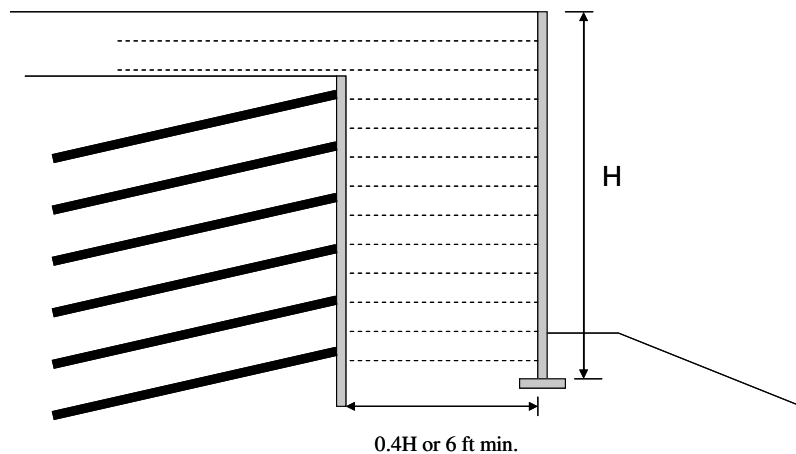


### Compound Stability Assessment Concept for MSE Wall Design

Figure 15-5

- A minimum of two reinforcement layers, or whatever is necessary for stability, but no less than 3 ft of reinforced soil, shall extend over the top of the existing structure or steep rock face an adequate distance to insure adequate pullout resistance. The minimum length of these upper two reinforcement layers should be  $0.7H$ , 5 ft behind the face of the existing structure or rock face, or the minimum length required to resist the pullout forces applied to those layers, whichever results in the greatest reinforcement length. Note that to accomplish this, it may be necessary to remove some of the top of the existing structure or rock face if the existing structure is nearly the same height as the new wall. The minimum clearance between the top of the existing structure or rock face and the first reinforcement layer extended beyond the top of the existing structure should be 6 in to prevent stress concentrations.
- The MSE wall reinforcements that are truncated by the presence of the existing structure or rock face shall not be directly connected to that existing near vertical face, due to the risk of the development of downdrag forces at that interface and the potential to develop bin pressures and higher reinforcement forces (i.e.,  $T_{max}$ ).

- For internal stability design of MSE walls in this situation, see Morrison, et al. (2006). Global and compound stability, both for static (strength limit state) and seismic loading, shall be evaluated, especially to determine the strength and pullout resistance needed for the upper layers that extend over the top of the existing feature. At least one surface that is located at the face of the existing structure but that goes through the upper reinforcement layers shall be checked for both static and seismic loading conditions. That surface will likely be critical for sizing the upper reinforcement layers.
- For new walls with a height over 30 ft, a lateral deformation analysis should be conducted (e.g., using a properly calibrated numerical model). Approval from the State Geotechnical and Bridge Design Engineers is required in this case.
- This type of MSE wall design should not be used to support high volume mainline transportation facilities if the vertical junction between the existing wall or rock face and the back of the new wall is within the traffic lane, especially if there is potential for cracking in the pavement surface to occur due to differential vertical movement at that location.



**Example of Steep Shored MSE Wall**

*Figure 15-6*

### 15.5.3.5 MSE Wall Supported Abutments

MSE walls directly supporting spread footing bridge abutments shall be 30 ft or less in total height (i.e., height of exposed wall plus embedment depth of wall). If for any specific wall system the height limit specified for that wall system is less than the 30 ft maximum limit, the height limit for the specific wall system shall not be exceeded. Abutment spread footings should be designed for service loads not to exceed 3.0 TSF and factored strength limit state footing loads not to exceed 4.5 TSF. Because this is an increase relative to what is specified in the AASHTO LRFD Bridge Design Specifications, for footing bearing service loads greater than 2.0 TSF, a vertical settlement

monitoring program with regard to footing settlement shall be conducted. As a minimum, this settlement monitoring program should consist of monitoring settlement measurement points located at the front edge and back edge of the structure footing, and settlement monitoring points directly below the footing at the base of the wall to measure settlement occurring below the wall. The monitoring program should be continued until movement has been determined to have stopped. If the measured footing settlement exceeds the vertical deformation and angular distortion requirements established for the structure the footing supports, corrective action shall be taken.

Proprietary MSE walls supporting abutments shall not be considered preapproved, and shall not be used beyond the limits described herein unless approved by the State Geotechnical Engineer and the Bridge Design Engineer.

For this MSE wall application, only precast or cast-in-place concrete facings should be used. Dry cast concrete blocks, welded wire, or timber facings should not be used.

The front edge of the abutment footing shall be 2 ft or more from the back of the MSE facing units. There shall be at least 5 ft vertical clearance between the MSE facing units and the bottom of the superstructure, and 5 ft horizontal clearance between the back of the MSE facing units and face of the abutment wall to provide access for bridge inspection. Fall protection shall be installed as necessary.

For spans up to 30 ft, the front edge of the bearings, placed on top of a load distribution slab located at the wall top, need only be at least 1 ft behind the back of the MSE wall facing units, with at least 1 ft of vertical clearance between the MSE facing units and the bottom of the superstructure used to span between the two MSE walls.

The bearing resistance for the footing supported by the MSE wall is a function of the soil reinforcement density in addition to the shear strength of the soil. If designing the wall using LRFD, two cases should be evaluated to size the footing for bearing resistance for the strength limit state, as two sets of load factors are applicable (see the AASHTO LRFD *Bridge Design Manual*, Section 3, for definitions of these terms):

- The load factors applicable to the structure loads applied to the footing, such as DC, DW, EH, LL, etc.
- The load factor applicable to the distribution of surcharge loads through the soil, ES.

When ES is used to factor the load applied to the soil to evaluate bearing, the structure loads and live load applied to the footing should be unfactored. When ES is not used to factor the load applied to the soil to evaluate bearing, the structure loads and live load applied to the footing should be factored using DC, DW, EH, LL, etc. The wall should be designed for both cases, and

the case that results in the greatest amount of soil reinforcement should be used for the final strength limit state design. See the *Bridge Design Manual* for additional guidance on the application of load groups for design of MSE wall supported abutments, especially regarding how to handle live load, and for the structural detailing required.

The potential lateral and vertical deformation of the wall, considering the affect of the footing load on the wall, should be evaluated. Measures shall be taken to minimize potential deformation of the reinforced soil, such as use of high quality backfill such as Gravel Borrow compacted to 95 percent of maximum density. The settlement and lateral deformation of the soil below the wall shall also be included in this deformation analysis. If there is significant uncertainty in the amount of vertical deformation in or below the wall anticipated, the ability to jack the abutment to accommodate unanticipated abutment settlement should also be considered in the abutment design.

### 15.5.3.6 Full Height Propped Precast Concrete Panel MSE Walls

This wall system consists of a full height concrete facing panel directly connected to the soil reinforcement elements. The facing panel is braced externally during a significant percentage of the backfill placement. The amount the wall is backfilled before releasing the bracing is somewhat dependent on the specifics of the wall system and the amount of resistance needed to prevent the wall from moving excessively during placement of the remaining fill. Once the external bracing is released, the wall facing allowed to move in response to the release of the bracing.

A key issue regarding the performance of this type of wall is the differential settlement that is likely to occur between the rigid facing panel and the backfill soil as the backfill soil compresses due to the increase in overburden pressure as the fill is placed. Since the facing panel, for practical purposes, can be considered to be essentially rigid, all the downward deformation resulting from the backfill soil compression causes the reinforcing elements to be dragged down with the soil, causing a strain and load increase in the soil reinforcement at its connection with the facing panel. As the wall panel becomes taller, the additional reinforcement force caused by the backfill settlement relative to the facing panel becomes more significant.

WSDOT has successfully built walls of this nature up to 25 ft in height. For greater heights, the uncertainty in the prediction of the reinforcement loads at the facing connection for this type of MSE wall can become large. Specialized design procedures to estimate the magnitude of the excess force induced in the reinforcement at the connection may be needed, requiring approval by the WSDOT State Geotechnical Engineer.



### 15.5.3.7 Flexible Faced MSE Walls With Vegetation

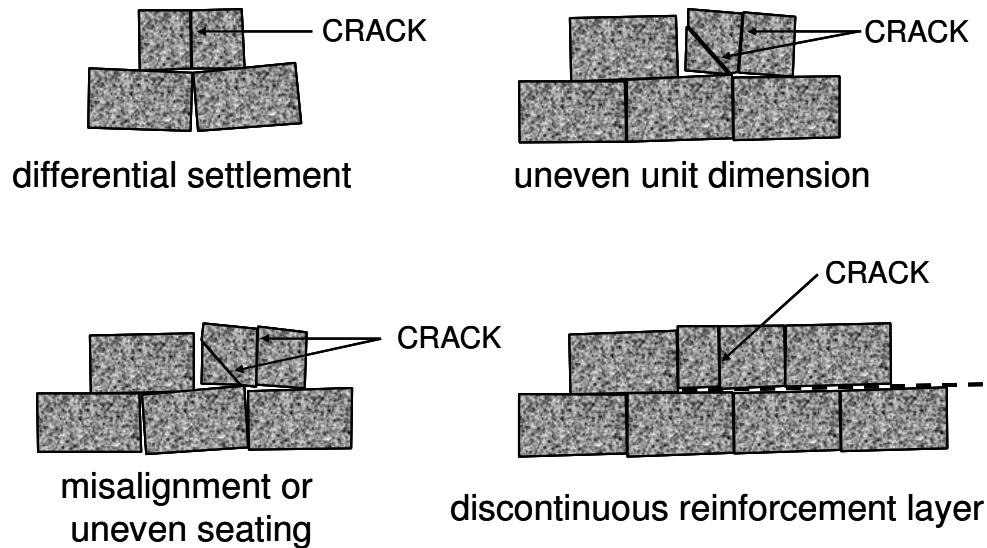
If a vegetated face is to be used with an MSE wall, the exposed (i.e., above ground) wall height shall be limited to 20 ft or less, and the wall face batter shall be no steeper than 1H:6V, unless the facing is battered at 1H:2V or flatter, in which case the maximum height could be extended to 30 ft). A flatter facing batter may be needed depending on the wall system – see appendices to this GDM chapter for specific requirements. For the vegetated facing, if the facing batter is steeper, or if the height is greater than specified here, the compressibility of the facing topsoil could create excessive stresses, settlement, and/or bulging in the facing, any of which could lead to facing stability or deformation problems.

The topsoil placed in the wall face to encourage vegetative growth shall be minimized as much as possible, and should be compacted to minimize internal settlement of the facing. For welded wire facing systems, the effect of the topsoil on the potential corrosion of the steel shall be considered when sizing the steel members at the face and at the connection to the soil reinforcement.

In general, placement of drip irrigation piping within or above the reinforced soil volume to encourage the vegetative growth in the facing should be avoided. However, if a drip irrigation system must be used and placed within or above the reinforced soil volume, the wall shall be designed for the long-term presence of water in the backfill and at the face, regarding both increased design loads and increased degradation/corrosion of the soil reinforcement, facing materials, and connections.

### 15.5.3.8 Dry Cast Concrete Block Faced MSE Walls

For modular dry cast block faced walls, WSDOT has observed block cracking in near vertical walls below a depth of 25 ft from the wall top in some block faced walls. Key contributing factors include tolerances in the vertical dimension of the blocks that are too great (maximum vertical dimension tolerance should be maintained at  $+1/16$  in or less for walls built as part of WSDOT projects, even though the current ASTM requirements for these types of blocks have been relaxed to  $+1/8$  in), poor block placement technique, soil reinforcement placed between the blocks that creates too much unevenness between the block surfaces, some forms of shimming to make facing batter adjustments, and inconsistencies in the block concrete properties. See Figure 15-7 for illustrations of potential causes of block cracking. Another tall block faced wall problem encountered by others includes shearing of the back portion of the blocks parallel to the wall, possibly face due to excessive buildup of downdrag forces immediately behind the blocks. This problem, if it occurs, has been observed in the bottom 5 to 7 ft of walls that have a hinge height of approximately 25 to 30 ft (total height of 35 ft or more) and may have been caused by excessive downdrag forces due to backfill soil compressibility immediately behind the facing.



**Example Causes of Cracking in Modular  
Dry Cast Concrete Block Wall Facings**

*Figure 15-7*

Considering these potential problems, for modular dry cast concrete block faced walls, the wall height should be limited to 30 ft if near vertical, or to a hinge height of 30 ft if battered. Block wall heights greater than this may be considered on a project specific basis, subject to the approval of the State Geotechnical and State Bridge Design Engineers, if the requirements identified below are met:

- Total settlement is limited to 2 in and differential settlement is limited to 1.5 in as identified in Table 15-3. Since this is specified in Table 15-3, this also applies to shorter walls.
- A concrete leveling pad is placed below the first lift of blocks to provide a uniform flat surface for the blocks. Note that this should be done for all preapproved block faced walls regardless of height.
- A moderately compressible bearing material is placed between each course of blocks, such as a geosynthetic reinforcement layer. The layer must provide an even bearing surface (many polyester geogrids or multi-filament woven geotextiles provide an adequately even bearing surface with sufficient thickness and compressibility to distribute the bearing load between blocks evenly). The bearing material needs to extend from near the front edge of the blocks (without protruding beyond the face) to at least the back of the blocks or a little beyond. As a minimum, this should be done for all block lifts that are 25 ft or more below the wall top, but doing this for block lifts at depths of less than 25 ft as well is desirable.

If the wall face is tiered such that the front of the facing for the tier above is at least 3 ft behind the back of the facing elements in the tier below, then these height limitations only apply to each tier. The minimum setback between tiers is needed to reduce build-up of excessive down drag forces behind the lower tier wall facing.

Success in building such walls without these block cracking or shear failure problems will depend on the care with which these walls are constructed and the enforcement of good construction practices through proper construction inspection, especially with regard to the constructability issues identified previously. Success will also depend on the quality of the facing blocks.

Therefore, making sure that the block properties and dimensional tolerances meet the requirements in the contract through testing and observation is also important and should be carried out for each project.

### **15.5.3.9 Internal Stability Using K-Stiffness Method**

The K-Stiffness Method, as described by Allen and Bathurst (2003) and as updated by Bathurst, et al. (2008b), may be used as an alternative to the Simplified Method provided in the AASHTO *LRFD Bridge Design Specifications* (Sections 3 and 11) to design the internal stability for walls up to 35 ft in height that are not directly supporting other structures and that are not in high settlement areas (i.e., total settlement beneath the wall of 6 in or more). Use of the K-Stiffness Method for greater wall heights, in locations where settlement is anticipated to be 6 in or more, or for walls that support other structures shall be considered experimental, will require special monitoring of performance, and will require the approval of the State Geotechnical Engineer. The AASHTO *LRFD Bridge Design Specifications* are applicable, as well as the traffic barrier design provisions in the WSDOT BDM, except as modified in the provisions that follow.

#### **15.5.3.9.1 K-Stiffness Method Loads and Load Factors**

The methods used in historical design practice for calculating the load in the reinforcement to accomplish internal stability design include the Simplified Method, the Coherent Gravity Method, and the FHWA Structure Stiffness Method. All of these methods are empirically derived, relying on limit equilibrium concepts for their formulation, whereas, the K-Stiffness Method, also empirically derived, relies on the difference in stiffness of the various wall components to distribute a total lateral earth pressure derived from limit equilibrium concepts to the wall reinforcement layers and the facing. Though all of these methods can be used to evaluate the potential for reinforcement rupture and pullout for the Strength and Extreme Event limit states, only the K-Stiffness Method can be used to directly evaluate the potential for soil backfill failure and to design the wall internally for the service limit state. These other methods used in historical practice indirectly account for soil failure and service limit state conditions based on the successful construction

of thousands of structures (i.e., if the other limit states are met, soil failure will be prevented, and the wall will meet serviceability requirements for internal stability).

These MSE wall design procedures also assume that inextensible reinforcements are not mixed with extensible reinforcements within the same wall. MSE walls that contain a mixture of inextensible and extensible reinforcements are not recommended.

The design procedures provided herein assume that the wall facing combined with the reinforced backfill acts as a coherent unit to form a gravity retaining structure. The effect of relatively large vertical spacing of reinforcement on this assumption is not well known and a vertical spacing greater than 2.7 ft should not be used without full scale wall data (e.g., reinforcement loads and strains, and overall deflections) which supports the acceptability of larger vertical spacings. Allen and Bathurst (2003) do report that based on data from a number of wall case histories, the correlation between vertical spacing and reinforcement load appears to remain linear for vertical spacings ranging from 1 to 5 ft, though the data at vertical spacings greater than 2.7 ft are very limited. However, larger vertical spacings can result in excessive facing deflection, both localized and global, which could in turn cause localized elevated stresses in the facing and its connection to the soil reinforcement.

The factored vertical stress,  $\sigma_v$ , at each reinforcement level shall be calculated as:

$$\sigma_v = \gamma_p \gamma_r H + \gamma_p \gamma_f S + \gamma_{LL} q \quad (15-1)$$

where:

- $\sigma_v$  = the factored pressure due to resultant of gravity forces from soil self weight within and immediately above the reinforced wall backfill, and any surcharge loads present (KSF)
- $\gamma_p$  = the load factor for vertical earth pressure EV in Table 15-5
- $\gamma_{LL}$  = the load factor for live load surcharge per the AASHTO LRFD Specifications
- $q$  = live load surcharge (KSF)
- $H$  = the total vertical wall height at the wall face (FT)
- $S$  = average soil surcharge depth above wall top (FT)
- $\gamma_r$  = the unit weight of the reinforced soil backfill (KCF)
- $\gamma_f$  = the unit weight of the soil backfill behind and above the reinforced soil zone (KCF)

Note that sloping soil surcharges are taken into account through an equivalent uniform surcharge and assuming a level backslope condition. For these calculations, the wall height “H” is referenced from the top of the wall at the wall face to the top of the bearing pad, excluding any copings and appurtenances.

Methods used in historical practice (e.g., the Simplified Method) calculate the vertical stress resulting from gravity forces within the reinforced backfill at each level, resulting in a linearly increasing gravity force with depth and a triangular lateral stress distribution. The K-Stiffness Method instead calculates the maximum gravity force resulting from the gravity forces within the reinforced soil backfill to determine the maximum reinforcement load within the entire wall reinforced backfill,  $T_{\text{mxmx}}$ , and then adjusts that maximum reinforcement load with depth for each of the layers using a load distribution factor,  $D_{\text{tmax}}$  to determine  $T_{\text{max}}$ . This load distribution factor was derived empirically based on a number of full scale wall cases and verified through many numerical analyses (see Allen and Bathurst, 2003).

For the K-Stiffness Method, the load in the reinforcements is obtained by multiplying the factored vertical earth pressure by a series of empirical factors which take into account the reinforcement global stiffness for the wall, the facing stiffness, the facing batter, the local stiffness of the reinforcement, the soil strength and stiffness, and how the load is distributed to the reinforcement layers. The maximum factored load in each reinforcement layer shall be determined as follows:

$$T_{\text{max}} = 0.5S_v K \sigma_v D_{\text{tmax}} \Phi_g \Phi_{\text{local}} \Phi_{\text{fb}} \Phi_{\text{fs}} \Phi_c \quad (15-2)$$

where:

- $S_v$  = tributary area (assumed equivalent to the average vertical spacing of the reinforcement at each layer location when analyses are carried out per unit length of wall), in FT
- $K$  = is an index lateral earth pressure coefficient for the reinforced backfill, and shall be set equal to  $K_0$  as calculated per Article 3.11.5.2 of the AASHTO LRFD Specifications.  $K$  shall be no less than 0.3 for steel reinforced systems.
- $\sigma_v$  = the factored pressure due to resultant of gravity forces from soil self weight within and immediately above the reinforced wall backfill, and any surcharge loads present, as calculated in Equation 15-1 (KSF)
- $D_{\text{tmax}}$  = distribution factor to estimate  $T_{\text{max}}$  for each layer as a function of its depth below the wall top relative to  $T_{\text{mxmx}}$  (the maximum value of  $T_{\text{max}}$  within the wall)
- $S_{\text{global}}$  = global reinforcement stiffness (KSF)
- $\Phi_g$  = global stiffness factor
- $\Phi_{\text{local}}$  = local stiffness factor
- $\Phi_{\text{fb}}$  = facing batter factor
- $\Phi_{\text{fs}}$  = facing stiffness factor
- $\Phi_c$  = soil backfill cohesion factor

$D_{\text{tmax}}$  shall be determined from Figure 15-6.

The global stiffness,  $S_{global}$ , considers the stiffness of the entire wall section, and it shall be calculated as follows:

$$S_{global} = \frac{J_{ave}}{(H/n)} = \frac{\sum_{i=1}^n J_i}{H} \quad (15-3)$$

where:

$J_{ave}$  is the average stiffness of all the reinforcement layers within the entire wall section on a per FT of wall width basis (KIPS/FT),  $J_i$  is the stiffness of an individual reinforcement layer on a per FT of wall width basis (KIPS/FT),  $H$  is the total wall height (FT), and  $n$  is the number of reinforcement layers within the entire wall section.

$$\Phi_g = 0.25 \left( \frac{S_{global}}{p_a} \right)^{0.25} \quad (15-4)$$

where:

$p_a$  = atmospheric pressure (a constant equal to 2.11 KSF), and the other variables are as defined previously.

The local stiffness considers the stiffness and reinforcement density at a given layer and is calculated as follows:

$$S_{local} = \frac{J}{S_v} \quad (15-5)$$

where:

$J$  is the stiffness of an individual reinforcement layer (KIPS/FT), and  $S_v$  is the vertical spacing of the reinforcement layers near a specific layer (FT). The local stiffness factor,  $\Phi_{local}$ , is then defined as follows:

$$\Phi_{local} = \left( \frac{S_{local}}{S_{global}} \right)^a \quad (15-6)$$

where

$a$  = a coefficient which is also a function of stiffness. Based on observations from the available data, set  $a = 1.0$  for geosynthetic walls and  $= 0.0$  for steel reinforced soil walls.

The wall face batter factor,  $\Phi_{fb}$ , which accounts for the influence of the reduced soil weight on reinforcement loads, is determined as follows:

$$\Phi_{fb} = \left( \frac{K_{abh}}{K_{avh}} \right)^d \quad (15-7)$$

where:

$K_{abh}$  is the horizontal component of the active earth pressure coefficient accounting for wall face batter, and  $K_{avh}$  is the horizontal component of the active earth pressure coefficient assuming that the wall is vertical, and  $d$  = a constant coefficient (recommended to be 0.5 to provide the best fit to the empirical data).

$K_{abh}$  and  $K_{avh}$  are determined from the Coulomb equation, assuming no wall/soil interface friction and a horizontal backslope (AASHTO 2010), as follows:

$$K_{ab} = \frac{\cos^2(\phi + \omega)}{\cos^3 \omega \left[ 1 + \frac{\sin \phi}{\cos \omega} \right]} \quad (15-8)$$

where:

$\phi$  = peak soil friction angle ( $\phi_{peak}$ ), and  $\omega$  = wall/slope face inclination (positive in a clockwise direction from the vertical). The wall face batter  $\omega$  is set equal to 0 to determine  $K_{av}$  using Equation 15-8. The horizontal component of the active earth pressure coefficient, assuming no wall/soil interface friction, is determined as follows:

$$K_{abh} = K_{ab} \cos(\omega) \quad (15-9)$$

Since for a vertical wall,  $\omega = 0^\circ$ ,  $K_{av} = K_{avh}$ .

The facing stiffness factor,  $\Phi_{fs}$ , was empirically derived to account for the significantly reduced reinforcement stresses observed for geosynthetic walls with segmental concrete block and propped panel wall facings. It is not yet known whether this facing stiffness correction is fully applicable to steel reinforced wall systems. On the basis of data available at the time of this report, Allen and Bathurst (2003) recommend that this facing stiffness factor be determined as a function of a non-dimensional facing column stiffness parameter  $F_f$ :

$$F_f = \frac{1.5H^3 P_a}{Eb_w^3 \left( \frac{h_{eff}}{H} \right)} \quad (15-10)$$

and

$$\Phi_{fs} = \eta (F_f)^\kappa \quad (15-11)$$

where:

$b_w$  is the thickness of the facing column,  $H$  = the total wall face height,  $E$  = the modulus of the facing material,  $h_{eff}$  is the equivalent height of an un-jointed facing column that is 100 percent efficient in transmitting moment throughout the facing column, and  $p_a$ , used to preserve dimensional consistency, is atmospheric pressure (equal to 2.11 KSF). The dimensionless coefficients  $\eta$  and  $\kappa$  were determined from an empirical regression of the full-scale field wall data to be 0.69 and 0.11, respectively.

Equation 15-10 was developed by treating the facing column as an equivalent uniformly loaded cantilever beam. It is recognized that Equation 15-10 represents a rather crude model of the stiffness of a retaining wall facing column, considering that the wall toe may not be completely fixed, the facing column often contains joints (i.e., the beam is not continuous), and the beam is attached to the reinforcement at various points. Since this analysis is being used to isolate the contribution of the facing to the load carrying capacity of the wall system, a simplified model that treats the facing as an isolated beam can be used. Once significant deflection occurs in the facing column, the reinforcement is then forced to carry a greater percentage of the load in the wall system. The full-scale wall data was used by Allen and Bathurst (2003) to empirically determine the percentage of load carried by these two wall components. Due to these complexities, these equations have been used in this analysis only to set up the form of a parameter that can be used to represent the approximate stiffness of the facing column.

For modular block faced wall systems, due to their great width,  $h_{eff}$  can be considered approximately equal to the average height of the facing column between reinforcement layers, and that the blocks between the reinforcement layers behave as if continuous. The blocks are in compression, partially due to self weight and partially due to downdrag forces on the back of the facing (Bathurst, et al. 2000), and can effectively transmit moment throughout the height of the column between the reinforcement layers that are placed between the blocks where the reinforcement is connected to the facing. The compressibility of the reinforcement layer placed between the blocks, however, can interfere with the moment transmission between the blocks above and below the reinforcement layer, effectively reducing the stiffness of the facing column. Therefore,  $h_{eff}$  should be set equal to the average vertical reinforcement spacing for this type of facing. Incremental panel faced systems are generally thinner (a thickness of approximately 4 to 5.5 in) and the panel joints tend to behave as a pinned connection. Therefore,  $h_{eff}$  should be set equal to the panel height for this type of facing. The stiffness of flexible wall facings is not as straight-forward to estimate. Until more is known, a facing stiffness factor  $\Phi_{fs}$  of 1.0 should be used for all flexible faced walls



(e.g., welded wire facing, geosynthetic wrapped facings, including such walls where a precast or cast-in-place concrete facing is placed on the wall after the wall is built).

The maximum wall height available where facing stiffness effects could be observed was approximately 35 ft. Data from taller stiff faced walls were not available. It is possible that this facing stiffness effect may not be as strong for much taller walls. Therefore, for walls taller than approximately 35 ft, approval for use of the K-Stiffness Method by the State Geotechnical Engineer is required.

Allen and Bathurst (2003) also discovered that the magnitude of the facing stiffness factor may also be a function of the amount of strain the soil reinforcement allows to occur. It appears that once the maximum reinforcement strain in the wall exceeds approximately 2 percent strain, stiff wall facings tend to reach their capacity to restrict larger lateral earth pressures. To accommodate this strain effect on the facing stiffness factor, for stiff faced walls, the facing stiffness factor increases for maximum reinforcement strains above 2 percent. Because of this, it is recommended that stiff faced walls be designed for maximum reinforcement strains of approximately 2 percent or less, if a facing stiffness factor  $\Phi_{fs}$  of less than 0.9 is used.

For steel reinforced walls, this facing stiffness effect has not been verified, though preliminary data indicates that facing stiffness does not affect reinforcement load significantly for steel reinforced systems. Therefore, a facing stiffness factor  $\Phi_{fs}$  of 1.0 shall be used for all steel reinforced MSE wall systems.

The backfill soil cohesion factor,  $\Phi_c$ , is calculated as:

$$\Phi_c = 1 - \lambda \frac{c}{\gamma H} \quad (15-12)$$

where:

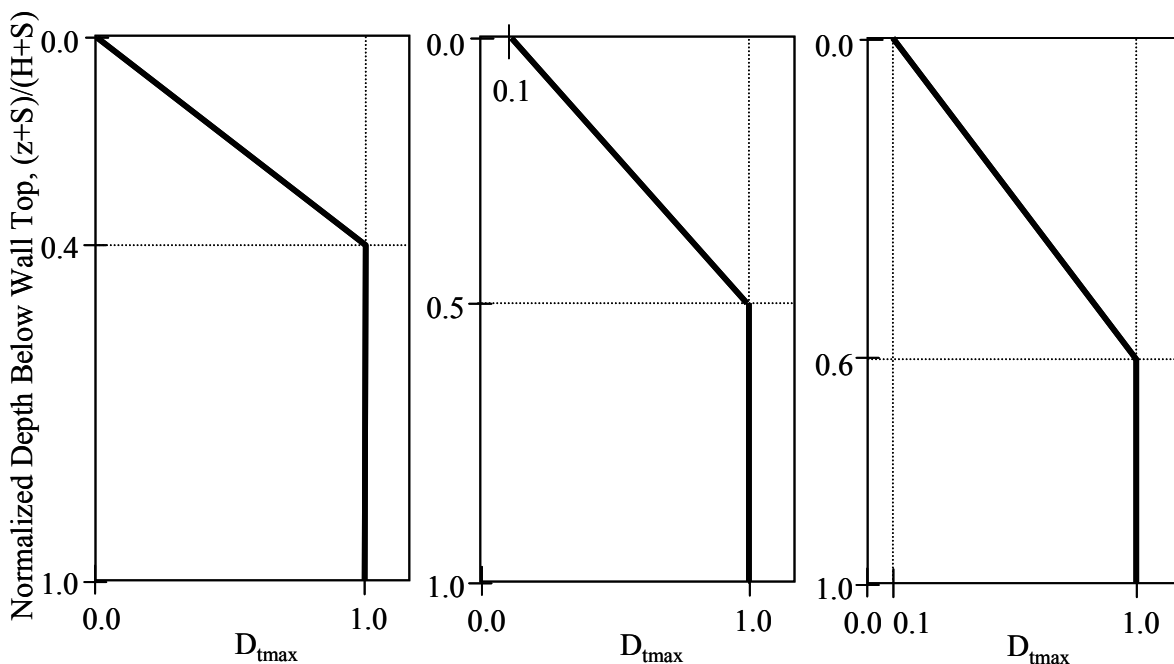
the cohesion coefficient  $\lambda = 6.5$ ,  $c$  is the soil cohesion,  $\gamma$  is the soil unit weight, and  $H$  is the wall height. The practical limit  $0 \geq \Phi_c \geq 1$  requires  $c/\gamma H \leq 0.153$ . It is possible that a combination of a short wall height and high cohesive soil strength could lead to  $\Phi_c = 0$ . In practical terms this means that no reinforcement is required for internal stability. However, this does not mean that the wall will be stable at the facing (e.g., connection over-stressing may still occur).

Note that in general, soil cohesion should not be relied upon for final wall design (i.e., set  $c = 0$ ). If a backfill soil with significant cohesion must be used, with the use of such backfill soils subject to the approval of the State Geotechnical Engineer, the loss of cohesion over time due to backfill moisture gain, or possibly other reasons, should be considered during the design to

estimate the long-term performance of the wall, and the potential for long-term deformations. Limited full scale wall data indicate that reinforcement loads could increase over time for soils with a significant cohesion component.

$D_{tmax}$  shall be determined as shown in Figure 15-8. Allen and Bathurst (2003) found that as the reinforcement stiffness increases, the load distribution as a function of depth below the wall top becomes more triangular in shape.  $D_{tmax}$  is the ratio of  $T_{max}$  in a reinforcement layer to the maximum reinforcement load in the wall,  $T_{mxmx}$ . Note that the empirical distributions provided in Figure 15-8 apply to walls constructed on a firm soil foundation. The distributions that would result for a rock or soft soil foundation may be different from those shown in this figure, and in general will tend to be more triangular in shape as the foundation soils become more compressible.

The factored tensile load applied to the soil reinforcement connection at the wall face,  $T_o$ , shall be equal to the maximum factored reinforcement tension,  $T_{max}$ , for all wall systems regardless of facing and reinforcement type.



(a)  $1 \leq S_{global} < 100$  Kips/ft<sup>2</sup> (b)  $100 \leq S_{global} < 400$  Kips/ft<sup>2</sup> (c)  $400 \leq S_{global} < 6,500$  Kips/ft<sup>2</sup>

**$D_{tmax}$  as a Function of Normalized Depth Below Wall Top Plus Average Surcharge Depth: (A) Generally Applies to Geosynthetic Walls, (B) Generally Applies to Polymer Strap Walls and Extensible or Very Lightly Reinforced Steel Reinforced Systems, and (C) Generally Applies to Steel Reinforced Systems.**

Figure 15-8

Triaxial or direct shear soil friction angles should be used with the Simplified Method provided in the AASHTO LRFD Specifications, to be consistent with the current specifications and empirical derivation for the Simplified Method, whereas plane strain soil friction angles should be used with the K-Stiffness Method, to be consistent with the empirical derivation and calibration for that method. The following equations maybe used to make an approximate estimate of the plane strain soil friction angle based on triaxial or direct shear test results.

For triaxial test data (Lade and Lee, 1976):

$$\phi_{ps} = 1.5\phi_{tx} - 17 \quad (15-13)$$

For direct shear test data (based on interpretation of data presented by Bolton (1986) and Jewell and Wroth (1987)):

$$\phi_{ps} = \tan^{-1} (1.2 \tan \phi_{ds}) \quad (15-14)$$

All soil friction angles are in degrees for both equations. Direct shear or triaxial soil friction angles may be used for design using the K-Stiffness Method, if desired, but it should be recognized that doing so could add some conservatism to the resulting load prediction. Note that if presumptive design parameters are based on experience from triaxial or direct shear testing of the backfill, a slight increase in the presumptive soil friction angle based on Equations 15-13 or 15-14 is appropriate to apply.

#### 15.5.3.9.2 K-Stiffness Method Load Factors

In addition to the load factors provided in Section 3.4.1 of the AASHTO LRFD specifications, the load factors provided in Table 15-5 shall be used as minimum values for the K-Stiffness Method. The load factor  $\gamma_p$  to be applied to maximum load carried by the reinforcement  $T_{max}$  due to the weight of the backfill for reinforcement strength, connection strength, and pullout calculations shall be EV, for vertical earth pressure. The load factors presented in Table 15-5 were developed using the soil reinforcement load data presented by Allen and Bathurst (2003), Allen et al. (2003, 2004), and Bathurst et al. (2008b), and the load factor calibration methodology as described in Allen, et al. (2005) and Bathurst, et al. (2008a).

Loads carried by the soil reinforcement in mechanically stabilized earth walls are the result of vertical and lateral earth pressures which exist within the reinforced soil mass, reinforcement extensibility, facing stiffness, wall toe restraint, and the stiffness and strength of the soil backfill within the reinforced soil mass. The calculation method for  $T_{max}$  is empirically derived, based on reinforcement strain measurements, converted to load based on the reinforcement stiffness, from full scale walls at working stress conditions (see Allen and Bathurst, 2003; and Bathurst, et al., 2008). Research by

Allen and Bathurst (2003) indicates that the working loads measured in MSE wall reinforcement remain relatively constant throughout the wall life, provided the wall is designed for a stable condition, and that the load statistics remain constant up to the point that the wall begins to fail. Therefore, the load factors for MSE wall reinforcement loads provided in Table 15-5 can be considered valid for strength limit states.

Another strength limit state that needs to be considered for these walls is the prevention of soil failure. Soil failure is defined as contiguous or near-contiguous zones of soil with shear strains in excess of the strain at peak strength. Contiguous shear zones have been observed in test walls taken to collapse under uniform surcharge loading (Bathurst 1990, Bathurst et al. 1993b, Allen and Bathurst 2002b). Allen and Bathurst (2002b) found that once a wall goes beyond working stress conditions, the load levels in the reinforcement begin to increase as internal soil shear surfaces continue to develop and the soil approaches a residual strength. Once the soil has exceeded its peak shear strain and begins to approach its residual shear strength, for all practical purposes the wall has failed and an internal strength limit state for the soil achieved.

The key to prevent reaching the soil failure limit state is to estimate how much strain can be allowed in the reinforced wall system (i.e., the soil reinforcement) without causing the soil to reach what is defined above as a soil failure condition. Preventing the reinforcement strain from exceeding a 3 to 3.5 percent design value will be adequate for the high shear strength granular backfill soils typically specified for walls in Washington State and likely conservative for weaker backfill soils. Since the maximum reinforcement strain to prevent soil failure was derived from high shear strength soils, the 3 to 3.5 percent strain value represents what is effectively a lower bound value. For geosynthetic wall design, the maximum strain in the reinforcement is kept below 3 percent everywhere in the wall; therefore, only the maximum reinforcement strain in the wall must be estimated, and the distribution of the load among the reinforcement layers is not relevant to this calculation. For the K-Stiffness Method, much of the uncertainty in the prediction accuracy of the method is in the distribution of the loads among the reinforcement layers relative to the maximum load in all the reinforcement layers, i.e., the maximum reinforcement load can be predicted more accurately and the loads in all the reinforcement layers. Therefore, a smaller load factor can be used for this limit state for geosynthetic walls. Note that this approach is conservative in that many of the reinforcement layers will be at a strain level that is much less than the maximum value.

For steel reinforced walls, the key to preventing soil failure is to prevent the steel from exceeding its yield strength. Assuming that is accomplished in the design, the strain in the reinforcement and soil will be far below the strain that would allow soil failure to occur. Past design practice has been to ensure that the stress in all the layers of steel reinforcement does not exceed the yield

strength of the steel. Since all the reinforcement layers must be checked and designed so that they do not exceed yield, the full distribution of load to each reinforcement layer is important for this calculation. Therefore, the load factor for reinforcement rupture for steel reinforced walls is also used for designing the wall reinforcement layers to not exceed yield.

Type of Load	Load Factor	
	Maximum	Minimum
EV: Vertical Earth Pressure:		
MSE Wall soil reinforcement loads (K-Stiffness Method, steel strips and grids)	1.55	N/A
MSE Wall soil reinforcement/facing connection loads (K-Stiffness Method, steel grids attached to rigid facings)	1.80	N/A
MSE Wall soil reinforcement loads (K-Stiffness Method, geosynthetics, reinforcement rupture)	1.55	N/A
MSE Wall soil reinforcement loads (K-Stiffness Method, geosynthetics, soil failure)	1.40	N/A
MSE Wall soil reinforcement/facing connection loads (K-Stiffness Method, geosynthetics)	1.80	N/A

**Load Factors for Permanent Loads for Internal Stability of MSE Walls Designed Using the K-Stiffness Method,  $\gamma_p$ , for the Strength Limit State**

*Table 15-5*

The load factors provided in Table 15-5 were determined assuming that the appropriate mean soil friction angle is used for design. In practice, since the specific source of material for wall backfill is typically not available at the time of design, presumptive design parameters based on previous experience with the material that is typically supplied to meet the backfill material specification (e.g., Gravel Borrow per the WSDOT Standard Specifications for construction) are used (see WSDOT GDM Chapter 5). It is likely that these presumptive design parameters are lower bound conservative values for the backfill material specification selected.

Other loads appropriate to the load groups and limit states to be considered as specified in the AASHTO LRFD specifications for wall design are applicable when using the K-Stiffness Method for design. Note that for seismic design (Extreme Event I), a load factor of 1.0 should be used for the total load combination (static plus seismic loads) acting on the soil reinforcement.

### 15.5.3.9.3 K-Stiffness Method Resistance Factors

For the service limit state, a resistance factor of 1.0 should be used, except for the evaluation of overall slope stability as prescribed by the AASHTO LRFD specifications (see also Section 15.4.12). For the strength and extreme event limit states for internal stability using the K-Stiffness Method, the resistance

factors provided in Table 15-6 shall be used as maximum values. These resistance factors were derived using the data provided in Allen and Bathurst (2003). Reliability theory, using the Monte Carlo Method as described in Allen, et al. (2005) was applied to statistically characterize the data and to estimate resistance factors. The load factors provided in Table 15-5 were used for this analysis.

The resistance factors, specified in Table 15-6 are consistent with the use of select granular backfill in the reinforced zone, homogeneously placed and carefully controlled in the field for conformance with the WSDOT Standard Specifications. The resistance factors provided in Table 15-6 have been developed with consideration to the redundancy inherent in MSE walls due to the multiple reinforcement layers and the ability of those layers to share load one with another. This is accomplished by using a target reliability index,  $\beta$ , of 2.3 (approximate probability of failure,  $P_f$ , of 1 in 100 for static conditions) and a  $\beta$  of 1.65 (Approximate  $P_f$  of 1 in 20) for seismic conditions. A  $\beta$  of 3.5 (approximate  $P_f$  of 1 in 5,000) is typically used for structural design when redundancy is not considered or not present; see Allen et al. (2005) for additional discussion on this issue. Because redundancy is already taken into account through the target value of  $\beta$  selected, the factor  $\eta$  for redundancy prescribed in the AASHTO LRFD specifications should be set equal to 1.0. The target value of  $\beta$  used herein for seismic loading is consistent with the overstress allowed in previous practice as described in the AASHTO *Standard Specifications for Highway Bridges* (AASHTO 2002).

#### **15.5.3.9.4 Safety Against Structural Failure (Internal Stability)**

Safety against structural failure shall consider all components of the reinforced soil wall, including the soil reinforcement, soil backfill, the facing, and the connection between the facing and the soil reinforcement, evaluating all modes of failure, including pullout and rupture of reinforcement.

A preliminary estimate of the structural size of the stabilized soil mass may be determined on the basis of reinforcement pullout beyond the failure zone, for which resistance is specified in Article 11.10.6.3 of the AASHTO *LRFD Bridge Design Specifications*.

The load in the reinforcement shall be determined at two critical locations: the zone of maximum stress and the connection with the wall face. Potential for reinforcement rupture and pullout are evaluated at the zone of maximum stress, which is assumed to be located at the boundary between the active zone and the resistant zone in Figure 11.10.2-1 of the AASHTO *LRFD Bridge Design Specifications*. Potential for reinforcement rupture and pullout are also evaluated at the connection of the reinforcement to the wall facing. The reinforcement shall also be designed to prevent the backfill soil from reaching a failure condition.

Limit State and Reinforcement Type			Resistance Factor
Internal Stability of MSE Walls, K-Stiffness Method			
$\phi_{rr}$	Reinforcement Rupture	Metallic	0.85
		Geosynthetic	0.85 <sup>(3)</sup>
$\phi_{sf}$	Soil Failure	Metallic	0.85
		Geosynthetic	1.00 <sup>(1)</sup>
$\phi_{cr}$	Connection rupture	Metallic	0.85
		Geosynthetic	0.80 <sup>(3)</sup>
$\phi_{po}$	Pullout <sup>(2)</sup>	Steel ribbed strips (at $z < 2$ m)	1.10
		Steel ribbed strips (at $z > 2$ m)	1.00
		Steel smooth strips	1.00
		Steel grids	0.60
		Geosynthetic	0.80
$\phi_{EQr}$	Combined static/ earthquake loading (reinforcement and connector rupture)	Metallic	1.00
		Geosynthetic	0.85 <sup>(3)</sup>
$\phi_{EQp}$	Combined static/ earthquake loading (pullout) <sup>(2)</sup>	Steel ribbed strips (at $z < 2$ m)	1.25
		Steel ribbed strips (at $z > 2$ m)	1.15
		Steel smooth strips	1.15
		Steel grids	0.75
		Geosynthetic	0.80

<sup>(1)</sup>If default value for the critical reinforcement strain of 3.0 percent or less is used for flexible wall facings, and 2.0 percent or less for stiff wall facings (for a facing stiffness factor of less than 0.9).

<sup>(2)</sup>Resistance factor values in table for pullout assume that the default values for  $F^*$  and  $\alpha$  provided in Article 11.10.6.3.2 of the AASHTO LRFD Specifications are used and are applicable.

<sup>(3)</sup>This resistance factor applies if installation damage is not severe (i.e.,  $RF_{ID} < 1.7$ ). Severe installation damage is likely if very light weight reinforcement is used. Note that when installation damage is severe, the resistance factor needed for this limit state can drop to approximately 0.15 or less due to greatly increased variability in the reinforcement strength, which is not practical for design.

### Resistance Factors for the Strength and Extreme Event Limit States for MSE Walls Designed Using the K-Stiffness Method

Table 15-6

Loads carried by the soil reinforcement in mechanically stabilized earth walls are the result of vertical and lateral earth pressures, which exist within the reinforced soil mass, reinforcement extensibility, facing stiffness, wall toe restraint, and the stiffness and strength of the soil backfill within the reinforced soil mass. The soil reinforcement extensibility and material type are major factors in determining reinforcement load. In general, inextensible reinforcements consist of metallic strips, bar mats, or welded wire mats, whereas extensible reinforcements consist of geotextiles or geogrids.

Internal stability failure modes include soil reinforcement rupture or failure of the backfill soil (strength or extreme event limit state), and excessive reinforcement elongation under the design load (service limit state). Internal stability is determined by equating the factored tensile load applied to the reinforcement to the factored tensile resistance of the reinforcement, the tensile resistance being governed by reinforcement rupture and pullout. Soil backfill failure is prevented by keeping the soil shear strain below its peak shear strain.

#### **15.5.3.9.5 Strength Limit State Design for Internal Stability Using the K-Stiffness Method – Geosynthetic Walls**

For geosynthetic walls, four strength limit states (soil failure, reinforcement failure, connection failure, and reinforcement pullout) must be considered for internal reinforcement strength and stiffness design. The design steps, and related considerations, are as follows:

1. Select a trial reinforcement spacing,  $S_v$ , and stiffness,  $J_{EOC}$ , based on the time required to reach the end of construction (EOC). If the estimated time required to construct the wall is unknown, an assumed construction time of 1,000 hours should be adequate. Note that at this point in the design, it does not matter how one obtains the stiffness. It is simply a value that one must recognize is an EOC stiffness determined through isochronous stiffness curves at a given strain and temperature, and that it represents the stiffness of a continuous reinforcement layer on a per ft of wall width basis. Use the selected stiffness to calculate the trial global stiffness of the wall,  $S_{global}$ , using Equation 15-3, with  $J_{EOC}$  equal to  $J_i$  for each layer. Also select a soil friction angle for design (see WSDOT GDM Section 15.5.3.9.1). Once the design soil friction angle has been obtained, the lateral earth pressure coefficients needed for determination of  $T_{max}$  (Step 4) can be determined (see WSDOT GDM Section 15.5.3.9.1). Note that if the reinforcement layer is intended to have a coverage ratio,  $R_c$ , of less than 1.0 (i.e., the reinforcement is to be discontinuous), the actual product selected based on the K-Stiffness design must have a stiffness of  $J_{EOC}(1/R_c)$ .
2. Begin by checking the strength limit state for the backfill soil. The goal is to select a stiffness that is large enough to prevent the soil from reaching a failure condition.
3. Select a target reinforcement strain,  $\epsilon_{targ}$ , to prevent the soil from reaching its peak shear strain. The worst condition in this regard is a very strong, high peak friction angle soil, as the peak shear strain for this type of soil will be lower than the peak shear strain obtained from most backfill soils. The results of full-scale wall laboratory testing showed that the reinforcement strain at which the soil begins to exhibit signs of failure is on the order of 3 to 4 percent for high shear strength sands (Allen and Bathurst, 2003). This empirical evidence reflects very high shear strength



soils and is probably a worst case for design purposes, in that most soils will have larger peak shear strain values than the soils tested in the full-scale walls. A default value for  $\epsilon_{\text{targ}}$  adequate for granular soils is 3 percent for flexible faced walls, and 2 percent for stiff faced walls if a  $\Phi_{\text{fs}}$  of less than 0.9 is used for design. Lower target strains could also be used, if desired.

4. Calculate the factored load  $T_{\text{max}}$  for each reinforcement layer (Equation 15-2). To determine  $T_{\text{max}}$ , the facing type, dimensions, and properties must be selected to determine  $\Phi_{\text{fs}}$ . The local stiffness factor  $\Phi_{\text{local}}$  for each layer can be set to 1.0, unless the reinforcement spacing or stiffness within the design wall section is specifically planned to be varied. The global wall stiffness,  $S_{\text{global}}$ , and global stiffness factor,  $\Phi_{\text{g}}$ , must be estimated from  $J_{\text{EOC}}$  determined in Step 1.
5. Estimate the factored strain in the reinforcement at the end of the wall design life,  $\epsilon_{\text{rein}}$ , using the K-Stiffness Method as follows:

$$\epsilon_{\text{rein}} = \left( \frac{T_{\text{max}}}{J_{\text{DL}} \phi_{\text{sf}}} \right) \quad (15-15)$$

where,  $T_{\text{max}}$  is the factored reinforcement load from Step 4,  $J_{\text{DL}}$  is the reinforcement layer stiffness at the end of the wall design life (typically 75 years for permanent structures) determined with consideration to the anticipated long-term strain in the reinforcement (i.e.,  $\epsilon_{\text{targ}}$ ),  $\phi_{\text{sf}}$  is the resistance factor to account for uncertainties in the target strain, and other variables are as defined previously. If a default value of  $\epsilon_{\text{targ}}$  is used, a resistance factor of 1.0 will be adequate.

6. If  $\epsilon_{\text{rein}}$  is greater than  $\epsilon_{\text{targ}}$ , increase the reinforcement layer stiffness  $J_{\text{EOC}}$  and recalculate  $T_{\text{max}}$  and  $\epsilon_{\text{rein}}$ .  $J_{\text{EOC}}$  will become the stiffness used for specifying the material if the reinforcement layer is continuous (i.e.,  $R_c = 1$ ). Note that if the reinforcement layer is intended to have a coverage ratio,  $R_c$ , of less than 1.0 (i.e., the reinforcement is to be discontinuous), the actual product selected based on the K-Stiffness design must have a stiffness of  $J_{\text{EOC}}(1/R_c)$ . For final product selection,  $J_{\text{EOC}}(1/R_c)$  shall be based product specific isochronous creep data obtained in accordance with AASHTO PP66-10 at the estimated wall construction duration (1,000 hours is an acceptable default time if a specific construction duration of the wall cannot be estimated at time of design) and site temperature. Select the stiffness at the anticipated maximum working strains for the wall, as the stiffness is likely to be strain level dependent. For design purposes, a 2 percent secant stiffness at the wall construction duration from the beginning of wall construction to the end of wall construction (EOC) is the default strain. If strains of 3 percent are anticipated, determine the stiffness at the higher strain level. If strains of significantly

less than 2 percent are anticipated, and a geosynthetic material is being used that is known to have a highly non-linear load-strain curve over the strain range of interest (e.g., some PET geosynthetics), then a stiffness value determined at a lower strain should be obtained. Otherwise, just determine the stiffness at 2 percent strain. This recognizes the difficulties of accurately measuring the stiffness at very low strains. Note that for calculating  $T_{\max}$ , if multifilament woven geotextiles are to be used as the wall reinforcement, the stiffness values obtained from laboratory isochronous creep data should be increased by 15 percent to account for soil confinement effects. If nonwoven geotextiles are planned to be used as wall reinforcement,  $J_{\text{EOC}}$  and  $J_{\text{DL}}$  shall be based on confined in soil isochronous creep data, and use of nonwoven geotextiles shall be subject to the approval of the State Geotechnical Engineer.

7. Next, check the strength limit state for reinforcement rupture in the backfill. The focus of this limit state is to ensure that the long-term factored rupture strength of the reinforcement is greater than the factored load calculated from the K-Stiffness Method.  $T_{\max}$  calculated from Step 4 is a good starting point for evaluating this limit state. Note that the global wall stiffness for this calculation is based on the EOC stiffness of the reinforcement, as the reinforcement loads should still be based on EOC conditions, even though the focus of this calculation is at the end of the service life for the wall.
8. Calculate the strength reduction factors  $RF_{\text{ID}}$ ,  $RF_{\text{CR}}$ , and  $RF_{\text{D}}$  for the reinforcement type selected using the approach prescribed in AASHTO PP66-10. Because the focus of this calculation is to prevent rupture, these factors must be based on reinforcement rupture. Applying a resistance factor to address uncertainty in the reinforcement strength, determine  $T_{\text{ult}}$ , the ultimate tensile strength of the reinforcement as follows:

$$T_{\max} \leq \frac{T_{\text{ult}} \phi_{\text{rr}} R_c}{RF_{\text{ID}} RF_{\text{CR}} RF_{\text{D}}} \quad (15-16)$$

where:

$T_{\max}$  is the factored reinforcement load,  $\phi_{\text{rr}}$  is the resistance factor for reinforcement rupture,  $R_c$  is the reinforcement coverage ratio,  $RF_{\text{ID}}$ ,  $RF_{\text{CR}}$ , and  $RF_{\text{D}}$  are strength reduction factors for installation damage, creep, and durability, respectively, and the other the variables are as defined previously. The strength reduction factors should be determined using product and site specific data when possible (AASHTO, 2010; WSDOT, 2009).  $T_{\text{ult}}$  is determined from an index wide-width tensile test such as ASTM D4595 or ASTM D6637 and is usually equated to the MARV for the product.

9. Step 8 assumes that a specific reinforcement product will be selected for the wall, as the strength reduction factors for installation damage, creep, and durability are known at the time of design. If the reinforcement

properties will be specified generically to allow the contractor or wall supplier to select the specific reinforcement after contract award, use the following equation the long-term design strength of the reinforcement,  $T_{al\text{design}}$ :

$$T_{al\text{design}} = \frac{T_{\text{max}}}{\phi_{rr} R_c} \quad (15-17)$$

where:

$T_{\text{max}}$  is the factored reinforcement load from Step 6. The contractor can then select a product with the required  $T_{al\text{design}}$ .

10. If the geosynthetic reinforcement is connected directly to the wall facing (this does not include facings that are formed by simply extending the reinforcement mat), the reinforcement strength needed to provide the required long-term connection strength must be determined. Determine the long-term connection strength ratio  $CR_{cr}$  at each reinforcement level, taking into account the available normal force between the facing blocks, if the connection strength is a function of normal force.  $CR_{cr}$  is calculated or measured directly per the AASHTO LRFD Specifications.
11. Using the unfactored reinforcement load from Step 6 and an appropriate load factor for the connection load to determine  $T_{\text{max}}$  (factored) at the connection, determine the adequacy of the long-term reinforcement strength at the connection. Compare the factored connection load at each reinforcement level to the available factored long-term connection strength as follows:

$$T_{\text{max}} \leq \phi_{cr} T_{ac} R_c = \frac{\phi_{cr} T_{ult} CR_{cr} R_c}{RF_D} \quad (15-18)$$

where:

$T_{\text{max}}$  is the factored reinforcement load. Note that for modular block faced walls, the connection test data produced and used for design typically already has been converted to a load per unit width of wall facing – hence,  $R_c = 1$ . For other types of facing (e.g., precast concrete panels, if discontinuous reinforcement is used (e.g., polymer straps), it is likely that  $R_c < 1$  will need to be used in Equation 15-18. If the reinforcement strength available is inadequate to provide the needed connection strength as calculated from Equation 15-18, decrease the spacing of the reinforcement or increase the reinforcement strength. Then recalculate the global wall stiffness and re-evaluate all previous steps to ensure that the other strength limit states are met. If the strength limit state for reinforcement or connection rupture is controlling the design, increase the reinforcement stiffness and check the adequacy of the design, increasing  $T_{al}$  or  $T_{ult}$  if necessary.

12. It must be recognized that the strength ( $T_{ult}$  and  $T_{al}$ ) and stiffness ( $J_{EOC}$ ) determined from the K-Stiffness Method could result in the use of very light weight geosynthetics. In no case shall geosynthetic reinforcement be used that has an  $RF_{ID}$  applicable to the anticipated soil backfill gradation and installation conditions anticipated of greater than 1.7, as determined per AASHTO PP66-10. Furthermore, reinforcement coverage ratios,  $R_c$ , of less than 1.0 may be used provided that it can be demonstrated the facing system is fully capable of transmitting forces from un-reinforced segments laterally to adjacent reinforced sections through the moment capacity of the facing elements. For walls with modular concrete block facings, the gap between soil reinforcement sections or strips at a horizontal level shall be limited to a maximum of one block width in accordance with the AASHTO LRFD Specifications, to limit bulging of the facing between reinforcement levels or build up of unacceptable stresses that could result in performance problems. Also, vertical spacing limitations in the AASHTO LRFD Specifications for MSE walls apply to walls designed using the K-Stiffness method.
13. Determine the length of the reinforcement required in the resisting zone by comparing the factored  $T_{max}$  value to the factored pullout resistance available as calculated per the AASHTO LRFD Specifications. If the length of the reinforcement required is greater than desired (typically, the top of the wall is most critical), decrease the spacing of the reinforcement, recalculate the global wall stiffness, and re-evaluate all previous steps to ensure that the other strength limit states are met.

#### **15.5.3.9.6 Strength Limit State Design for Internal Stability Using the K-Stiffness Method – Steel Reinforced Walls**

For steel reinforced soil walls, four strength limit states (soil failure, reinforcement rupture, connection rupture, and pullout) shall be evaluated for internal reinforcement strength and stiffness design. The design steps and related considerations are as follows:

1. Select a trial reinforcement spacing and steel area that is based on end-of-construction (EOC) conditions (i.e., no corrosion). Once the trial spacing and steel area have been selected, the reinforcement layer stiffness on a per ft of wall width basis,  $J_{EOC}$ , and wall global stiffness,  $S_{global}$ , can be calculated (Equation 15-3). Note that at this point in the design, it does not matter how one obtains the reinforcement spacing and area. They are simply starting points for the calculation. Also select a design soil friction angle to calculate  $K$  (see Section 15.5.3.9.1). Note that for steel reinforced wall systems, the reinforcement loads are not as strongly correlated to the peak plane strain soil friction angle as are the reinforcement loads in geosynthetic walls (Allen and Bathurst, 2003). This is likely due to the fact that the steel reinforcement is so much stiffer than the soil.

The K-Stiffness Method was calibrated to a mean value of  $K_0$  of 0.3 (this results from a plane strain soil friction angle of  $44^\circ$ , or from triaxial or direct shear testing a soil friction angle of approximately  $40^\circ$ ). Therefore, soil friction angles higher than  $44^\circ$  shall not be used. Lower design soil friction angles should be used for weaker granular backfill materials.

2. Begin by checking the strength limit state for backfill soil failure. The goal is to select a reinforcement density (spacing, steel area) that is great enough to keep the steel reinforcement load below yield ( $A_s F_y R_c / b$ , which is equal to  $A_s F_y / S_h$ ).  $F_y$  is the yield stress for the steel,  $A_s$  is the area of steel before corrosion (EOC conditions), and  $S_h$  is the horizontal spacing of the reinforcement (use  $S_h = 1.0$  for continuous reinforcement). Depending on the ductility of the steel, once the yield stress has been exceeded, the steel can deform significantly without much increase in load and can even exceed the strain necessary to cause the soil to reach a failure condition. For this reason, it is prudent to limit the steel stress to  $F_y$  for this limit state. Tensile tests on corroded steel indicate that the steel does not have the ability to yield to large strains upon exceeding  $F_y$ , as it does in an uncorroded state, but instead fails in a brittle manner (Terre Armee, 1979). Therefore, this limit state only needs to be evaluated for the steel without corrosion effects.
3. Using the trial steel area and global wall stiffness from Step 1, calculate the factored  $T_{\max}$  for each reinforcement layer using Equations 15-1 and 15-2.
4. Apply an appropriate resistance factor to  $A_s F_y / S_h$  to obtain the factored yield strength for the steel reinforcement. Then compare the factored load to the factored resistance, as shown in Equation 15-19 below. If the factored load is greater than the factored yield strength, then increase  $A_s$  and recalculate the global wall stiffness and  $T_{\max}$ . Make sure that the factored yield strength is greater than the factored load before going to the next limit state calculation. In general, this limit state will not control the design. If the yield strength available is well in excess of the factored load, it may be best to wait until the strength required for the other limit states has been determined before reducing the amount of reinforcement in the wall. Check to see that the factored reinforcement load  $T_{\max}$  is greater than or equal to the factored yield resistance as follows:

$$T_{\max} \leq \frac{A_s F_y}{b} R_c \phi_{sf} = \frac{A_s F_y}{S_h} \phi_{sf} \quad (15-19)$$

where:

$\phi_{sf}$  is the resistance factor for steel reinforcement resistance at yield, and  $S_h$  is the horizontal spacing of the reinforcement. For wire mesh, and possibly some welded wire mats with large longitudinal wire spacing, the stiffness of the reinforcement macro-structure could cause the overall stiffness of the reinforcement to be significantly less than the stiffness of the steel itself. In-soil pullout test data may be used in that case to evaluate the soil failure limit state, and applied to the approach provided for soil failure for geosynthetic walls (see Equation 15-15 in Step 5 for geosynthetic wall design).

5. Next, check the strength limit state for reinforcement rupture in the backfill. The focus of this limit state is to ensure that the long-term rupture strength of the reinforcement is greater than the load calculated from the K-Stiffness Method. Even though the focus of this calculation is at the end of the service life for the wall, the global stiffness for the wall should be based on the stiffness at the end of wall construction, as reinforcement loads do not decrease because of lost cross-sectional area resulting from reinforcement corrosion.  $T_{\max}$  obtained from Step 5 should be an adequate starting point for this limit state calculation.
6. Calculate the strength of the steel reinforcement at the end of its service life, using the ultimate strength of the steel,  $F_u$ , and reducing the steel cross-sectional area,  $A_s$ , determined in Step 5, to  $A_c$  to account for potential corrosion losses. Then use the resistance factor  $\phi_{rr}$ , as defined previously, to obtain the factored long-term reinforcement tensile strength such that  $T_{al}$  is greater than or equal to  $T_{\max}$ , as shown below:

$$T_{al} = \frac{F_u A_c}{S_h} \phi_{rr} \quad (15-20)$$

and

$$T_{\max} \leq \frac{F_u A_c}{b} R_c \phi_{rr} = \frac{F_u A_c}{S_h} \phi_{rr} \quad (15-21)$$

where:

$F_u$  is the ultimate tensile strength of the steel, and  $A_c$  is the steel cross-sectional area per FT of wall length reduced to account for corrosion loss. The resistance factor is dependent on the variability in  $F_u$ ,  $A_s$ , and the amount of effective steel cross-sectional area lost as a result of corrosion. As mentioned previously, minimum specification values are typically used for design with regard to  $F_u$  and  $A_s$ . Furthermore, the corrosion rates provided in the AASHTO LRFD Specifications are also maximum rates based on the available data (Terre Armee, 1991). Recent post-mortem evaluations of galvanized steel in reinforced soil walls also show that AASHTO design specification loss rates are quite conservative (Anderson and Sankey, 2001). Furthermore, these corrosion loss rates have been correlated to tensile strength loss, so that strength loss due to uneven corrosion and pitting is fully taken into account. Therefore, the resistance factor provided in Table 15-6, which is based on the variability of the un-aged steel, is reasonable to use in this case, assuming that non-aggressive backfill conditions exist.

If  $T_{al}$  is not equal to or greater than  $T_{\max}$ , increase the steel area, recalculate the global wall stiffness on the basis of the new value of  $A_s$ , reduce  $A_s$  for corrosion to obtain  $A_c$ , and recalculate  $T_{\max}$  until  $T_{al}$  based on Equation 15-21 is adequate to resist  $T_{\max}$ .

7. If the steel reinforcement is connected directly to the wall facing (this does not include facings that are formed by simply extending the reinforcement mat), the reinforcement strength needed to provide the required long-term connection strength must be determined. This connection capacity, reduced by the appropriate resistance factor, must be greater than or equal to the factored reinforcement load at the connection. If not, increase the amount of reinforcing steel in the wall, recalculate the global stiffness, and re-evaluate all previous steps to ensure that the other strength limit states are met.
8. Determine the length of reinforcement required in the resisting zone by comparing the factored  $T_{\max}$  value to the factored pullout resistance available as calculated per Section 11 of the AASHTO LRFD specifications. If the length of reinforcement required is greater than desired (typically, the top of the wall is most critical), decrease the spacing of the reinforcement, recalculate the global wall stiffness, and re-evaluate all previous steps to ensure that the other strength limit states are met.

### 15.5.3.9.7 Combining Other Loads With the K-Stiffness Method Estimate of $T_{max}$ for Internal Stability Design

**Seismic Loads** – Seismic design of MSE walls when the K-Stiffness Method is used for internal stability design shall be conducted in accordance with Articles 11.10.7.2 and 11.10.7.3 of the AASHTO LRFD Specifications, except that the static portion of the reinforcement load is calculated using the K-Stiffness Method. The seismic load resulting from the inertial force of the wall active zone within the reinforced soil mass ( $T_{md}$  in AASHTO LRFD Article 11.10.7.3) is added to  $T_{max}$  calculated using the K-Stiffness Method by superposition. A load factor of 1.0 for the load combination (static plus seismic), and the resistance factors for combined seismic and static loading provided in Table 15-6 shall be used for this Extreme Event Limit State.

**Concentrated Surcharges and Traffic Barrier Impact Loads** – The load increase at each reinforcement layer resulting from the concentrated surcharge and traffic barrier impact loads calculated as specified in the AASHTO LRFD Design Specifications, Articles 3.11.6.3 and 11.10.10 and WSDOT GDM Sections 15.5.3.4 and 15.4.15, shall be added to the K-Stiffness calculation of  $T_{max}$  by superposition at each affected reinforcement level, considering the tributary area of the reinforcement. The load factor used for each load due to the surcharge or traffic impact load shall be as specified in the AASHTO *LRFD Bridge Design Specifications*.

### 15.5.3.9.8 Design Sequence Considerations for the K-Stiffness Method

A specific sequence of design steps has been proposed herein to complete the internal stability design of reinforced soil walls. Because global wall stiffness is affected by changes to the reinforcement design to meet various limit states, iterative calculations may be necessary. Depending on the specifics of the wall and reinforcement type, certain limit states may tend to control the amount of reinforcement required. It may therefore be desirable to modify the suggested design sequence to first calculate the amount of reinforcement needed for the limit state that is more likely to control the amount of reinforcement. Then perform the calculations for the other limit states to ensure that the amount of reinforcement is adequate for all limit states. Doing this will hopefully reduce the number of calculation iterations.

For example, for geosynthetic reinforced wrap-faced walls, with or without a concrete fascia placed after wall construction, the reinforcement needed to prevent soil failure will typically control the global reinforcement stiffness needed, while pullout capacity is generally not a factor, and connection strength is not applicable. For modular concrete block-faced or precast panel-faced geosynthetic walls, the connection strength needed is likely to control the global reinforcement stiffness. However, it is also possible that reinforcement rupture or soil failure could control instead, depending on the magnitude of the stiffness of a given reinforcement product relative to the



long-term tensile strength needed. The key here is that the combination of the required stiffness and tensile strength be realistic for the products available. Generally, pullout will not control the design unless reinforcement coverage ratios are low. If reinforcement coverage ratios are low, it may be desirable to evaluate pullout early in the design process. For steel strip, bar mat, wire ladder, and polymer strap reinforced systems, pullout often controls the reinforcement needed because of the low reinforcement coverage ratios used, especially near the top of the wall. However, connection strength can also be the controlling factor. For welded wire wall systems, the tensile strength of the reinforcement usually controls the global wall reinforcement stiffness needed, though if the reinforcement must be connected to the facing (i.e., the facing and the reinforcement are not continuous), connection strength may control instead. Usually, coverage ratios are large enough for welded wire systems (with the exception of ladder strip reinforcement) that pullout is not a controlling factor in the determination of the amount of reinforcement needed. For all steel reinforced systems, with the possible exception of steel mesh reinforcement, the soil failure limit state does not control the reinforcement design because of the very low strain that typically occurs in steel reinforced systems.

#### **15.5.4 Prefabricated Modular Walls**

Modular block walls without soil reinforcement, gabion, bin, and crib walls shall be considered prefabricated modular walls.

In general, modular block walls without soil reinforcement (referred to as Gravity Block Walls in the *Standard Specifications*, Section 8-24 shall have heights no greater than 2.5 times the depth of the block into the soil perpendicular to the wall face, and shall be stable for all modes of internal and external stability failure mechanisms. In no case, shall their height be greater than 15 ft. Gabion walls shall be 15 ft or less in total height. Gabion baskets shall be arranged such that vertical seams are not aligned, i.e., baskets shall be overlapped.

#### **15.5.5 Rock Walls**

Rock walls shall be designed in accordance with the Standard Specifications, and the wall-slope combination shall be stable regarding overall stability as determined per WSDOT GDM Chapter 7.

Rock walls shall not be used unless the retained material would be at least minimally stable without the rock wall (a minimum slope stability factor of safety of 1.25). Rock walls are considered to act principally as erosion protection and they are not considered to provide strength to the slope unless designed as a buttress using limit equilibrium slope stability methods. Rock walls shall have a batter of 6V:1H or flatter. The rocks shall increase in size from the top of the wall to the bottom at a uniform rate. The minimum rock sizes shall be:

Depth from Top of Wall (ft)	Minimum Rock Size	Typical Rock Weight (lbs)	Average Dimension (in)
0	Two Man	200-700	18-28
6	Three Man	700-2000	28-36
9	Four Man	2000-4000	36-48
12	Five Man	4000-6000	48-54

**Minimum Rock Sizes for Rock Walls**  
*Table 15-7*

Rock walls shall be 12 ft or less in total height. Rock walls used to retain fill shall be 6 ft or less in total height if the rocks are placed concurrent with backfilling. Rock walls up to 12 ft in height may be constructed in fill if the fill is overbuilt and then cut back to construct the wall. Fills constructed for this purpose shall be compacted to 95 percent maximum density, per WSDOT *Standard Specifications* Section 2-03.3(14)D.

### 15.5.6 Reinforced Slopes

Reinforced slopes do not have a height limit but they do have a face slope steepness limit. Reinforced slopes steeper than 0.5H:1V shall be considered to be a wall and designed as such. Reinforced slopes with a face slope steeper than 1.2H:1V shall have a wrapped face or a welded wire slope face, but should be designed as a reinforced slope. Slopes flatter than or equal to 1.2H:1V shall be designed as a reinforced slope, and may use turf reinforcement to prevent face slope erosion except as noted below. Reinforcing shall have a minimum length of 6 ft. Turf reinforcement of the slope face shall only be used at sites where the average annual precipitation is 20 in or more. Sites with less precipitation shall have wrapped faces regardless of the face angle. The primary reinforcing layers for reinforced slopes shall be vertically spaced at 3 ft or less. Primary reinforcement shall be steel grid, geogrid, or geotextile. The primary reinforcement shall be designed in accordance with Berg, et al. (2009), using allowable stress design procedures, since LRFD procedures are not available. Secondary reinforcement centered between the primary reinforcement at a maximum vertical spacing of 1 ft shall be used, but it shall not be considered to contribute to the internal stability. Secondary reinforcement aids in compaction near the face and contributes to surficial stability of the slope face. Design of the secondary reinforcement should be done in accordance with Berg, et al. (2009). The secondary reinforcement ultimate tensile strength measured per ASTM D6637 or ASTM D4595 should not be less than 1,300 lb/ft in the direction of tensile loading to meet survivability requirements. Higher strengths may be needed depending on the design requirements. Gravel borrow shall be used for reinforced slope construction as modified by the *General Special Provisions* in Division 2. The design and construction shall be in accordance with the *General Special Provisions*.

### 15.5.7 Soil Nail Walls

Soil Nail walls are not specifically addressed by the ASHTO *LRFD Bridge Design Specifications*. Soil nail walls shall be designed for internal stability by the geotechnical designer using Gold Nail version 3.11 or SNail version 2.11 or later versions of these programs and the following manuals:

- Lazarte, C. A., Elias, V., Espinoza, R. D., Sabatini, P. J., 2003. *Geotechnical Engineering Circular No. 7, Soil Nail Walls*, U.S. Department of Transportation, Federal Highway Administration, FHWA-IF-03-017, 305 pp.
- Byrne, R. J., Cotton, D., Porterfield, J., Wolschlag, C., and Ueblacker, G., 1996, *Demonstration Project 103, Manual for Design and Construction Monitoring of Soil Nail Walls*, Federal Highway Administration, FHWA-SA-96-069, 468 pp.
- Porterfield, J. A., Cotton, D. A., Byrne, R. J., 1994, *Soil Nail Walls- Demonstration Project 103, Soil Nailing Field Inspectors Manual*, U.S. Department of Transportation, Federal Highway Administration, FHWA-SA-93-068, 86 pp.

The LRFD procedures described in the *Manual for Design and Construction Monitoring of Soil Nail Walls*, FHWA-SA-96-069, shall not be used.

For external stability and compound stability analysis, as described in WSDOT GDM Section 15.5.3.3 and the AASHTO *LRFD Bridge Design Specifications*, limit equilibrium slope stability programs as described in WSDOT GDM Chapter 7 should be used. The program S-Nail also has the ability to conduct compound stability analyses and may be used for this type of analysis as well.

When using SNail, the geotechnical designer should use the allowable option and shall pre-factor the yield strength of the nails, punching shear of the shotcrete, and the nail adhesion. Unfactored cohesion and friction angle shall be used and the analysis run to provide the minimum safety factors discussed above for overall stability.

When using GoldNail, the geotechnical designer should utilize the design mode and the safety factor mode of the program with the partial safety factors identified in the *FHWA Manual for Design and Construction Monitoring of Soil Nail Walls*, FHWA-SA-96-069.

The geotechnical designer shall design the wall at critical wall sections. Each critical wall section shall be evaluated during construction of each nail lift. To accomplish this, the wall shall be analyzed for the case where excavation has occurred for that lift, but the nails have not been installed. The minimum construction safety factor shall be 1.2 for noncritical walls and 1.35 for critical walls such as those underpinning abutments.

Permanent soil nails shall be installed in predrilled holes. Soil nails that are installed concurrently with drilling shall not be used for permanent applications, but may be used in temporary walls.

Soil nails shall be number 6 bar or larger and a minimum of 12 ft in length or 60 percent of the total wall height, whichever is greater. For nail testing, a minimum bond length and a minimum unbonded length of 5 ft is required. Nail testing shall be in accordance with the WSDOT *Standard Specifications* and *General Special Provisions*.

The nail spacing should be no less than 3 ft vertical and 3 ft horizontal. In very dense glacially over consolidated soils, horizontal nail spacing should be no greater than 8 ft and vertical nail spacing should be no greater than 6 ft. In all other soils, horizontal and vertical nail spacing should be 6 ft or less.

Nails may be arranged in a square row and column pattern or an offset diamond pattern. Horizontal nail rows are preferred, but sloping rows may be used to optimize the nail pattern. As much as possible, rows should be linear so that each individual nail elevation can be easily interpolated from the station and elevation of the beginning and ending nails in that row. Nails that cannot be placed in a row must have station and elevation individually identified on the plans. Nails in the top row of the wall shall have at least 1 foot of soil cover over the top of the drill hole during nail installation. Horizontal nails shall not be used. Nails should be inclined at least 10 degrees downward from horizontal. Inclination should not exceed 30 degrees.

Walls underpinning structures such as bridges and retaining walls shall have double corrosion protected (encapsulated) nails within the zone of influence of the structure being retained or supported. All other nails shall be epoxy coated unless the wall is temporary.

## 15.6 Standard Plan Walls

Currently, two Standard Plan walls are available for use on WSDOT projects. These include standard cast-in-place reinforced concrete walls (*Standard Plans* D-10.10 through D-10.45), and standard geosynthetic walls (*Standard Plans* D-3, 3a, 3b, and 3c). For Standard Plan walls, the internal stability design and the external stability design for overturning and sliding stability have already been completed, and the maximum soil bearing stress below the wall calculated, for a range of loading conditions. The geotechnical designer shall identify the appropriate loading condition to use (assistance from the Bridge and Structures Office and/or the project office may be needed), and shall assess overall slope stability, soil bearing resistance, and settlement for each standard plan wall. If it is not clear which loading condition to use, both external and internal stability may need to be evaluated to see if one of the provided loading conditions is applicable to the wall under consideration.

The geotechnical designer shall assess whether or not a Standard Plan wall is geotechnically applicable and stable given the specific site conditions and constraints.

The Standard Plan walls have been designed using LRFD methodology in accordance with the AASHTO *LRFD Bridge Design Specifications*. Standard Plan reinforced concrete walls are designed for internal and external stability using the following parameters:

- $A_s = 0.51g$  for Wall Types 1 through 4, and  $0.20g$  for Wall Types 5 through 8. For sliding stability, the wall is allowed to slide 4 in to calculate  $k_h$  from  $A_s$  using a Newmark deformation analysis, or a simplified version of it.
- For the wall Backfill,  $\phi = 36^\circ$  and  $\gamma = 130$  pcf.
- For the foundation soil, for sliding stability analysis,  $\phi = 32^\circ$ .
- Wall settlement criteria are as specified in Table 15-2.

Standard Plan geosynthetic walls are designed for internal and external stability using the following parameters:

- $A_s = 0.51g$  for Wall Types 1 through 4, and  $0.20g$  for Wall Types 5 through 8. For sliding stability, the wall is allowed to slide 8 in to calculate  $k_h$  from  $A_s$  using a Newmark deformation analysis, or a simplified version of it.
- For the wall Backfill,  $\phi = 38^\circ$  and  $\gamma = 130$  pcf.
- For the foundation soil, for sliding stability analysis,  $\phi = 36^\circ$ , and interface friction angle of  $0.7 \times 36^\circ = 25^\circ$ .
- For the retained soil behind the soil reinforcement, for external stability analysis,  $\phi = 36^\circ$  and  $\gamma = 130$  pcf.
- Wall settlement criteria are as specified in Table 15-2.

Regarding the seismic sliding analysis, the geotechnical and structural designers should determine if the amount of deformation allowed (4 in for reinforced concrete walls and 8 in for geosynthetic walls) is acceptable for the wall and anything above the wall that the wall supports. Note that for both static and seismic loading conditions, no passive resistance in front of the geosynthetic wall is assumed to be present for design.

## 15.7 Temporary Cut Slopes and Shoring

### 15.7.1 Overview

Temporary shoring, cofferdams, and cut slopes are frequently used during construction of transportation facilities. Examples of instances where temporary shoring may be necessary include:

- Support of an excavation until permanent structure is in-place such as to construct structure foundations or retaining walls.

- Control groundwater.
- Limit the extent of fill needed for preloads or temporary access roads/ramps.

Examples of instances where temporary slopes may be necessary include:

- Situations where there is adequate room to construct a stable temporary slope in lieu of shoring.
- Excavations behind temporary or permanent retaining walls.
- Situations where a combination of shoring and temporary excavation slopes can be used.
- Removal of unsuitable soil adjacent to an existing roadway or structure;
- Shear key construction for slide stabilization.
- Culvert, drainage trench, and utility construction, including those where trench boxes are used.

The primary difference between temporary shoring/cut slopes/cofferdams, hereinafter referred to as temporary shoring, and their permanent counterparts is their design life. Typically, the design life of temporary shoring is the length of time that the shoring or cut slope are required to construct the adjacent, permanent facility. Because of the short design life, temporary shoring is typically not designed for seismic loading, and corrosion protection is generally not necessary. Additionally, more options for temporary shoring are available due to limited requirements for aesthetics. Temporary shoring is typically designed by the contractor unless the contract plans include a detailed shoring design. For contractor designed shoring, the contractor is responsible for internal and external stability, as well as global slope stability, soil bearing capacity, and settlement of temporary shoring walls.

Exceptions to this, in which WSDOT provides the detailed shoring design, include shoring in unusual soil deposits or in unusual loading situations in which the State has superior knowledge and for which there are few acceptable options or situations where the shoring is supporting a critical structure or facility. One other important exception is for temporary shoring adjacent to railroads. Shoring within railroad right of way typically requires railroad review. Due to the long review time associated with their review, often 9 months or more, WSDOT has been designing the shoring adjacent to railroads and obtaining the railroad's review and concurrence prior to advertisement of the contract. Designers involved in alternative contract projects may want to consider such an approach to avoid construction delays.

Temporary shoring is used most often when excavation must occur adjacent to a structure or roadway and the structure or traffic flow cannot be disturbed. For estimating purposes during project design, to determine if temporary shoring might be required for a project, a hypothetical 1H:1V temporary excavation slope can be utilized to estimate likely limits of excavation for construction, unless the geotechnical designer recommends a different slope for estimating purposes. If the hypothetical 1H:1V slope intersects roadway or adjacent structures, temporary shoring may be required for construction. The actual temporary slope used by the contractor for construction will likely be different than the hypothetical 1H:1V slope used during design to evaluate shoring needs, since temporary slope stability is the responsibility of the contractor unless specifically designated otherwise by the contract documents.

### **15.7.2 Geotechnical Data Needed for Design**

The geotechnical data needed for design of temporary shoring is essentially the same as needed for the design of permanent cuts and retaining structures. WSDOT GDM Chapter 10 provides requirements for field exploration and testing for cut slope design, and WSDOT GDM Section 15.3 discusses field exploration and laboratory testing needs for permanent retaining structures. Ideally, the explorations and laboratory testing completed for the design of the permanent infrastructure will be sufficient for design of temporary shoring systems by the Contractor. This is not always the case, however, and additional explorations and laboratory testing may be needed to complete the shoring design.

For example, if the selected temporary shoring system is very sensitive to groundwater flow velocities (e.g., frozen ground shoring) or if dewatering is anticipated during construction, as the Contractor is also typically responsible for design and implementation of temporary dewatering systems, more exploration and testing may be needed. In these instances, there may need to be more emphasis on groundwater conditions at a site; and multiple piezometers for water level measurements and a large number of grain size distribution tests on soil samples should be obtained. Downhole pump tests should be conducted if significant dewatering is anticipated, so the contractor has sufficient data to develop a bid and to design the system. It is also possible that shoring or excavation slopes may be needed in areas far enough away from the available subsurface explorations that additional subsurface exploration may be needed. Whatever the case, the exploration and testing requirements for permanent walls and cuts in the WSDOT GDM shall also be applied to temporary shoring and excavation design.

### **15.7.3 General Design Requirements**

Temporary shoring shall be designed such that the risk to health and safety of workers and the public is kept to an acceptable level and that adjacent improvements are not damaged.

### 15.7.3.1 Design Procedures

For geotechnical design of retaining walls used in shoring systems, the shoring designer shall use the AASHTO *LRFD Bridge Design Specifications* and the additional design requirements provided in the WSDOT GDM. For those wall systems that do not yet have a developed LRFD methodology available, for example, soil nail walls, the FHWA design manuals identified herein that utilize allowable stress methodology shall be used, in combination with the additional design requirements in the WSDOT GDM. The design methodology, input parameters, and assumptions used must be clearly stated on the required submittals (see WSDOT GDM Section 15.7.2).

Regardless of the methods used, the temporary shoring wall design must address both internal and external stability. Internal stability includes assessing the components that comprise the shoring system, such as the reinforcing layers for MSE walls, the bars or tendons for ground anchors, and the structural steel members for sheet pile walls and soldier piles. External stability includes an assessment of overturning, sliding, bearing resistance, settlement and global stability.

For geotechnical design of cut slopes, the design requirements provided in WSDOT GDM Chapters 7 and 10 shall be used and met, in addition to meeting the applicable WACs (see WSDOT GDM Section 15.7.5).

For shoring systems that include a combination of soil or rock slopes above and/or below the shoring wall, the stability of the slope(s) above and below the wall shall be addressed in addition to the global stability of the wall/slope combination.

For shoring and excavation conducted below the water table elevation, the potential for piping below the wall or within the excavation slope shall be assessed, and the effect of differential water elevations behind and in front of the shoring wall, or see page in the soil cut face, shall be assessed regarding its affect on wall and slope stability, and the shoring system stabilized for that condition.

If temporary excavation slopes are required to install the shoring system, the stability of the temporary excavation slope shall be assessed and stabilized.

### 15.7.3.2 Safety Factors/Resistance Factors

For temporary structures, the load and resistance factors provided in the AASHTO *LRFD Bridge Design Specifications* are applicable. The resistance factor for global stability should be 0.65 if the temporary shoring system is supporting another structure such as a bridge, building, or major retaining wall (factor of safety of 1.5 for wall types in which LRFD procedures are not available) and 0.75 if the shoring system is not supporting another structure (factor of safety of 1.3 for wall types in which LRFD procedures are not available). For soil nail walls, the safety factors provided in the FHWA manuals identified herein shall be used.



For design of cut slopes that are part of a temporary excavation, assuming that the cut slopes not supporting a structure, a factor of safety of 1.25 or more as specified in WSDOT GDM Chapters 7 and 10, shall be used. If the soil properties are well defined and shown to have low variability, a lower factor of safety may be justified through the use of the Monte Carlo simulation feature available in slope stability analysis computer programs. In this case, a probability of failure of 0.01 or smaller shall be targeted (Santamarina, et al., 1992). However, even with this additional analysis, in no case shall a slope stability safety factor less than 1.2 be used for design of the temporary cut slope.

### 15.7.3.3 Design Loads

The active, passive, and at-rest earth pressures used to design temporary shoring shall be determined in accordance with the procedures outlined in Article 3.11.5 of the AASHTO *LRFD Bridge Design Specifications* or Section 5 of the AASHTO *Standard Specifications for Highway Bridges* (2002) for wall types in which LRFD procedures are not available. Surcharge loads on temporary shoring shall be estimated in accordance with the procedures presented in Article 3.11.6 of the AASHTO LRFD Specifications or Section 5 of the AASHTO *Standard Specifications for Highway Bridges* (2002) for wall types in which LRFD procedures are not available. It is important to note that temporary shoring systems often are subject to surcharge loads from stockpiles and construction equipment, and these surcharges loads can be significantly larger than typical vehicle surcharge loads often used for design of permanent structures. The design of temporary shoring must consider the actual construction-related loads that could be imposed on the shoring system. As a minimum, the shoring systems shall be designed for a live load surcharge of 250 psf to address routine construction equipment traffic above the shoring system. For unusual temporary loadings resulting from large cranes or other large equipment placed above the shoring system, the loading imposed by the equipment shall be specifically assessed and taken into account in the design of the shoring system. For the case where large or unusual construction equipment loads will be applied to the shoring system, the construction equipment loads shall still be considered to be a live load, unless the dynamic and transient forces caused by use of the construction equipment can be separated from the construction equipment weight as a dead load, in which case, only the dynamic or transient loads carried or created by the use of the construction equipment need to be considered live load.

As described previously, temporary structures are typically not designed for seismic loads, provided the design life of the shoring system is 3 years or less. Similarly, geologic hazards, such as liquefaction, are not mitigated for temporary shoring systems.

The design of temporary shoring must also take into account the loading and destabilizing effect caused by excavation dewatering.

#### 15.7.3.4 Design Property Selection

The procedures provided in WSDOT GDM Chapter 5 shall be used to establish the soil and rock properties used for design of the shoring system.

Due to the temporary nature of the structures and cut slopes in shoring design, long-term degradation of material properties, other than the minimal degradation that could occur during the life of the shoring, need not be considered. Therefore, corrosion for steel members, and creep for geosynthetic reinforcement, need to only be taken into account for the shoring design life.

Regarding soil properties, it is customary to ignore any cohesion present for permanent structure and slope design (i.e., fully drained conditions). However, for temporary shoring/cutslope design, especially if the shoring/cutslope design life is approximately six months or less, a minimal amount of cohesion may be considered for design based on previous experience with the geologic deposit and/or lab test results. This does not apply to glacially overconsolidated clays and clayey silts (e.g., Seattle clay), unless it can be demonstrated that deformation in the clayey soil resulting from release of locked in stresses during and after the excavation process can be fully prevented. If the deformation cannot be fully prevented, the shoring/cutslope shall be designed using the residual shear strength of the soil (see WSDOT GDM Chapter 5).

If it is planned to conduct soil modification activities that could temporarily or permanently disturb or otherwise loosen the soil in front of or behind the shoring (e.g., stone column installation, excavation), the shoring shall be designed using the disturbed or loosened soil properties.

#### 15.7.4 Special Requirements for Temporary Cut Slopes

Temporary cuts slopes are used extensively in construction due to the ease of construction and low costs. Since the contractor has control of the construction operations, the contractor is responsible for the stability of cut slopes, as well as the safety of the excavations, unless otherwise specifically stated in the contract documents. Because excavations are recognized as one of the most hazardous construction operations, temporary cut slopes must be designed to meet Federal and State regulations in addition to the requirements stated in the WSDOT GDM. Federal regulations regarding temporary cut slopes are presented in Code of Federal Regulations (CFR) Part 29, Sections 1926. The State of Washington regulations regarding temporary cut slopes are presented in Part N of WAC 296-155. Key aspects of the WAC with regard to temporary slopes are summarized below for convenience. To assure obtaining the most up to date requirements regarding temporary slopes, the WAC should be reviewed.

WAC 296-155 presents maximum allowable temporary cut slope inclinations based on soil or rock type, as shown in Table 15-8. WAC 296-155 also presents typical sections for compound slopes and slopes combined with trench boxes. The allowable slopes presented in the WAC are applicable to cuts 20 ft or less in height. The WAC requires that slope inclinations steeper than those specified by the WAC or greater than 20 ft in height must be designed by a registered professional engineer.

Soil or Rock Type	Maximum Allowable Temporary Cut Slopes (20 ft Maximum Height)
Stable Rock	Vertical
Type A Soil	¾H:1V
Type B Soil	1H:1V
Type C Soil	1½H:1V

**WAC 296-155 Allowable Temporary Cut Slopes**  
*Table 15-8*

**Type A Soil** – Type A soils include cohesive soils with an unconfined compressive strength of 3,000 psf or greater. Examples include clay and plastic silts with minor amounts of sand and gravel. Cemented soils such as caliche and glacial till (hard pan) are also considered Type A Soil. No soil is Type A if:

- It is fissured.
- It is subject to vibrations from heavy traffic, pile driving or similar effects.
- It has been previously disturbed.
- The soil is part of a sloped, layered system where the layers dip into the excavation at 4H:1V or greater.
- The material is subject to other factors that would require it to be classified as a less stable material.

**Type B Soil** – Type B soils generally include cohesive soils with an unconfined compressive strength greater than 1000 psf but less than 3000 psf and granular cohesionless soils with a high internal angle of friction, such as angular gravel or glacially overridden sand and gravel soils. Some silty or clayey sand and gravel soils that exhibit an apparent cohesion may sometimes classify as Type B soils. Type B soils may also include Type A soils that have previously been disturbed, are fissured, or subject to vibrations. Soils with layers dipping into the excavation at inclinations steeper than 4H:1V can not be classified as Type B soil.

**Type C Soil** – Type C soils include most non-cemented granular soils (e.g., gravel, sand, and silty sand) and soils that do not otherwise meet Types A or B.

The allowable slopes described above apply to dewatered conditions. Flatter slopes may be necessary if seepage is present on the cut face or if localized sloughing occurs. All temporary cut slopes greater than 10 ft in height shall be designed by a registered civil engineer (geotechnical engineer) in accordance with the WSDOT GDM. All temporary cut slopes supporting a structure or wall, regardless of height, shall also be designed by a registered civil engineer (geotechnical engineer) in accordance with the WSDOT GDM.

For open temporary cuts, the following requirements shall be met:

- No traffic, stockpiles or building supplies shall be allowed at the top of the cut slopes within a distance of at least 5 ft from the top of the cut.
- Exposed soil along the slope shall be protected from surface erosion,
- Construction activities shall be scheduled so that the length of time the temporary cut is left open is reduced to the extent practical.
- Surface water shall be diverted away from the excavation.
- The general condition of the slopes should be observed periodically by the Geotechnical Engineer or his representative to confirm adequate stability.

#### **15.7.5 Performance Requirements for Temporary Shoring and Cut Slopes**

Temporary shoring, shoring/slope combinations, and slopes shall be designed to prevent excessive deformation that could result in damage to adjacent facilities, both during shoring/cut slope construction and during the life of the shoring system. An estimate of expected displacements or vibrations, threshold limits that would trigger remedial actions, and a list of potential remedial actions if thresholds are exceeded should be developed. Thresholds shall be established to prevent damage to adjacent facilities, as well as degradation of the soil properties due to deformation.

Typically, the allowance of up to 1 to 2 in of lateral movement will prevent unacceptable settlement and damage of most structures and transportation facilities. A little more lateral movement could be allowed if the facility or structure to be protected is far enough away from the shoring/slope system.

Guidance regarding the estimation of wall deformation and tolerable deformations for structures is provided in the AASHTO *LRFD Bridge Design Specifications*. Additional guidance on acceptable deformations for walls and bridge foundations is provided in WSDOT GDM Chapter 8 and Section 15.4.7.

In the case of cantilever walls, the resistance factor of 0.75 applied to the passive resistance accounts for variability in properties and other sources of variability, as well as the prevention of excess deformation to fully mobilize the passive resistance. The amount of deformation required to mobilize the full passive resistance typically varies from 2 to 6 percent of the exposed wall height, depending on soil type in the passive zone (AASHTO 2010).

### **15.7.6 Special Design Requirements for Temporary Retaining Systems**

The design requirements that follow for temporary retaining wall systems are in addition, or are a modification, to the design requirements for permanent walls provided in WSDOT GDM Chapter 15 and its referenced design specifications and manuals. Detailed descriptions of various types of shoring systems and general considerations regarding their application are provided in WSDOT GDM Appendix 15-E.

#### **15.7.6.1 Fill Applications**

Primary design considerations for temporary fill walls include external stability to resist lateral earth pressure, ground water, and any temporary or permanent surcharge pressures above or behind the wall. The wall design shall also account for any destabilizing effects caused by removal or modification of the soil in front of the wall due to construction activities. The wall materials used shall be designed to provide the required resistance for the design life of the wall. Backfill and drainage behind the wall shall be designed to keep the wall backfill well drained with regard to ground see page and rainfall runoff.

If the temporary wall is to be buried and therefore incorporated in the finished work, it shall be designed and constructed in a manner that it does not inhibit drainage in the finished work, so that:

- It does not provide a plane or surface of weakness with regard to slope stability.
- It does not interfere with planned installation of foundations or utilities.
- It does not create the potential for excessive differential settlement of any structures placed above the wall.

Provided the wall design life prior to burial is three years or less, the wall does not need to be designed for seismic loading.

##### **15.7.6.1.1 MSE Walls**

MSE walls shall be designed for internal and external stability in accordance with WSDOT GDM Section 15.5.3 and related AASHTO Design Specifications. Because the walls will only be in service a short time (typically a few weeks to a couple years), the reduction factors (e.g., creep, durability, installation damage) used to assess the allowable tensile strength of the reinforcing elements are typically much less than for permanent wall

applications. The  $T_{al}$  values (i.e., long-term tensile strength) of geosynthetics, accounting for creep, durability, and installation damage in Appendix D of the WSDOT *Qualified Products List* (QPL) may be used for temporary wall design purposes. However, those values will be quite conservative, since the QPL values are intended for permanent reinforced structures.

Alternatively, for geosynthetic reinforcement, a default combined reduction factor for creep, durability, and installation damage in accordance with the AASHTO specifications (LRFD or Standard Specifications) may be used, ranging from a combined reduction factor RF of 4.0 for walls with a life of up to three years, to 3.0 for walls with a one-year life, to 2.5 for walls with a six month life. If steel reinforcement is used for temporary MSE walls, the reinforcement is not required to be galvanized, and the loss of steel due to corrosion is estimated in consideration of the anticipated wall design life.

#### **15.7.6.1.2 Prefabricated Modular Block Walls**

Prefabricated modular block walls without soil reinforcement are discussed in WSDOT GDM Section 15.5.4 and should be designed as gravity retaining structures. The blocks shall meet the requirements in the WSDOT *Standard Specifications*. Implementation of this specification will reduce the difficulties associated with placing blocks in a tightly fitted manner. Large concrete blocks should not be placed along a curve. Curves should be accomplished by staggering the wall in one-half to one full block widths.

#### **15.7.6.2 Cut Applications**

Primary design considerations for temporary cut walls include external stability to resist lateral earth pressure, ground water, and any temporary or permanent surcharge pressures above or behind the wall. The wall design shall also account for any destabilizing effects caused by removal or modification of the soil in front of the wall due to construction activities. The wall materials used shall be designed to provide the required resistance for the design life of the wall. Backfill and drainage behind the wall should be designed to keep the retained soil well drained with regard to ground water see page and rainfall runoff. If this is not possible, then the shoring wall should be designed for the full hydrostatic head.

If the temporary wall is to be buried and therefore incorporated in the finished work, it shall be designed and constructed in a manner that it does not inhibit drainage in the finished work, so that:

- It does not provide a plane or surface of weakness with regard to slope stability.
- It does not interfere with planned installation of foundations or utilities.
- It does not create the potential for excessive differential settlement of any structures placed above the wall.

Provided the wall design life prior to burial is three years or less, the wall does not need to be designed for seismic loading.

#### **15.7.6.2.1 Trench Boxes**

In accordance with the WSDOT *Standard Specifications*, trench boxes are not considered to be structural shoring, as they generally do not provide full lateral support to the excavation sides. Trench boxes are not appropriate for excavations that are deeper than the trench box. Generally, detailed analysis is not required for design of the system; however, the contractor should be aware of the trench box's maximum loading conditions for situations where surcharge loading may be present, and should demonstrate that the maximum anticipated lateral earth pressures will not exceed the structural capacity of the trench box. Geotechnical information required to determine whether trench boxes are appropriate for an excavation include the soil type, density, and groundwater conditions. Also, where existing improvements are located near the excavation, the soil should exhibit adequate standup time to minimize the risk of damage as a result of caving soil conditions against the outside of the trench box. In accordance with WSDOT GDM Sections 15.7.3 and 15.7.4, the excavation slopes outside of the trench box shall be designed to be stable.

#### **15.7.6.2.2 Sheet Piling, with or without Ground Anchors**

The design of sheet piling requires a detailed geotechnical investigation to characterize the retained soils and the soil located below the base of excavation/dredge line. The geotechnical information required for design includes soil stratigraphy, unit weight, shear strength, and groundwater conditions. In situations where lower permeability soils are present at depth, sheet piles are particularly effective at cutting off groundwater flow. Where sheet piling is to be used to cutoff groundwater flow, characterization of the soil hydraulic conductivity is necessary for design.

The sheet piling shall be designed to resist lateral stresses due to soil and groundwater, both for temporary (i.e., due to dewatering) and permanent ground water levels, as well as any temporary and permanent surcharges located above the wall. If there is the potential for a difference in ground water head between the back and front of the wall, the depth of the wall, or amount of dewatering behind the wall, shall be established to prevent piping and boiling of the soil in front of the wall.

The steel section used shall be designed for the anticipated corrosion loss during the design life of the wall. The ground anchors for temporary walls do not need special corrosion protection if the wall design life is three years or less, though the anchor bar or steel strand section shall be designed for the anticipated corrosion loss that could occur during the wall design life. Easements may be required if the ground anchors, if used, extend outside the right of way/property boundary.

Sheet piling should not be used in cobbly, bouldery soil or dense soil. They also should not be used in soils or near adjacent structures that are sensitive to vibration.

#### **15.7.6.2.3 Soldier Piles With or Without Ground Anchors**

Design of soldier pile walls requires a detailed geotechnical investigation to characterize the retained soils and the soil located below the base of excavation. The geotechnical information required for design includes soil stratigraphy, unit weight, shear strength, surcharge loading, foreslope and backslope inclinations, and groundwater conditions. The required information presented in WSDOT GDM Sections 15.3 and 15.5.3 is pertinent to the design of temporary soldier pile walls.

The wall shall be designed to resist lateral stresses due to soil and groundwater, both for temporary (i.e., due to dewatering) and permanent ground water levels, as well as any temporary and permanent surcharges located above the wall. If there is the potential for a difference in ground water head between the back and front of the wall, the depth of the wall, or amount of dewatering behind the wall, shall be established to prevent boiling of the soil in front of the wall. The temporary lagging shall be designed and installed in a way that prevents running/caving of soil below or through the lagging.

The ground anchors for temporary walls do not need special corrosion protection if the wall design life is three years or less. However, the anchor bar or steel strand section shall be designed for the anticipated corrosion loss that could occur during the wall design life. Easements may be required if the ground anchors, if used, extend outside the right of way/property boundary.

#### **15.7.6.2.4 Prefabricated Modular Block Walls**

Modular block walls for cut applications shall only be used in soil deposits that have adequate standup time such that the excavation can be made and the blocks placed without excessive caving or slope failure. The temporary excavation slope required to construct the modular block wall shall be designed in accordance with WSDOT GDM Sections 15.7.3 and 15.7.4. See WSDOT GDM Section 15.7.6.1.2 for additional special requirements for the design of this type of wall.

#### **15.7.6.2.5 Braced Cuts**

The special design considerations for soldier pile and sheet pile walls described above shall be considered applicable to braced cuts.

#### **15.7.6.2.6 Soil Nail Walls**

Design of soil nail walls requires a detailed geotechnical investigation to characterize the reinforced soils and the soil located below the base of excavation. The geotechnical information required for design includes soil stratigraphy, unit weight, shear strength, surcharge loading, foreslope and



backslope inclinations, and groundwater conditions. The required information presented in WSDOT GDM Sections 15.3 and 15.5.7 is pertinent to the design of temporary soil nail walls. Easements may be required if the soil nails extend outside the right of way/property boundary.

### 15.7.6.3 Uncommon Shoring Systems for Cut Applications

The following shoring systems require special, very detailed, expert implementation, and will only be allowed either as a special design by the State, or with special approval by the State Geotechnical Engineer and State Bridge Engineer.

- Diaphragm/slurry walls
- Secant pile walls
- Cellular cofferdams
- Ground freezing
- Deep soil mixing
- Permeation grouting
- Jet grouting

More detailed descriptions of each of these methods and special considerations for their implementation are provided in WSDOT GDM Appendix 15-E.

### 15.7.7 Shoring and Excavation Design Submittal Review Guidelines

When performing a geotechnical review of a contractor shoring and excavation submittal, the following items should be specifically evaluated:

1. Shoring System Geometry
  - a. Has the shoring geometry been correctly developed, and all pertinent dimensions shown?
  - b. Are the slope angle and height above and below the shoring wall shown?
  - c. Is the correct location of adjacent structures, utilities, etc., if any are present, shown?
2. Performance Objectives for the Shoring System
  - a. Is the anticipated design life of the shoring system identified?
  - b. Are objectives regarding what the shoring system is to protect, and how to protect it, clearly identified?
  - c. Does the shoring system stay within the constraints at the site, such as the right of way limits, boundaries for temporary easements, etc?

3. Subsurface conditions
  - a. Is the soil/rock stratigraphy consistent with the subsurface geotechnical data provided in the contract boring logs?
  - b. Did the contractor/shoring designer obtain the additional subsurface data needed to meet the geotechnical exploration requirements for slopes and walls as identified in WSDOT GDM Chapters 10 and 15, respectively, and Appendix 15-E for unusual shoring systems?
  - c. Was justification for the soil, rock, and other material properties used for the design of the shoring system provided, and is that justification, and the final values selected, consistent with WSDOT GDM Chapter 5 and the subsurface field and lab data obtained at the shoring site?
  - d. Were ground water conditions adequately assessed through field measurements combined with the site stratigraphy to identify zones of ground water, aquitards and aquicludes, artesian conditions, and perched zones of ground water?
4. Shoring system loading
  - a. Have the anticipated loads on the shoring system been correctly identified, considering all applicable limit states?
  - b. If construction or public traffic is near or directly above the shoring system, has a minimum traffic live load surcharge of 250 psf been applied?
  - c. If larger construction equipment such as cranes will be placed above the shoring system, have the loads from that equipment been correctly determined and included in the shoring system design?
  - d. If the shoring system is to be in place longer than three years, have seismic and other extreme event loads been included in the shoring system design?
5. Shoring system design
  - a. Have the correct design procedures been used (i.e., the WSDOT GDM and referenced design specifications and manuals)?
  - b. Have all appropriate limit states been considered (e.g., global stability of slopes above and below wall, global stability of wall/slope combination, internal wall stability, external wall stability, bearing capacity, settlement, lateral deformation, piping or heaving due to differential water head)?

6. Are all safety factors, or load and resistance factors for LRFD shoring design, identified, properly justified in a manner that is consistent with the WSDOT GDM, and meet or exceed the minimum requirements of the WSDOT GDM?
7. Have the effects of any construction activities adjacent to the shoring system on the stability/performance of the shoring system been addressed in the shoring design (e.g., excavation or soil disturbance in front of the wall or slope, excavation dewatering, vibrations and soil loosening due to soil modification/improvement activities)?
8. Shoring System Monitoring/Testing
  - a. Is a monitoring/testing plan provided to verify that the performance of the shoring system is acceptable throughout the design life of the system?
  - b. Have appropriate displacement or other performance triggers been provided that are consistent with the performance objectives of the shoring system?
9. Shoring System Removal
  - a. Have any elements of the shoring system to be left in place after construction of the permanent structure is complete been identified?
  - b. Has a plan been provided regarding how to prevent the remaining elements of the shoring system from interfering with future construction and performance of the finished work (e.g., will the shoring system impede flow of ground water, create a hard spot, create a surface of weakness regarding slope stability)?

## 15.8 References

AASHTO, 2002, *Standard Specifications for Highway Bridges*, American Association of State Highway and Transportation Officials, 17th Edition, Washington, D.C., USA.

AASHTO, 2010, *LRFD Bridge Design Specifications*, American Association of State Highway and Transportation Officials, Fifth Edition, Washington, D.C., USA.

AASHTO, 2010, *Provisional Standard PP66-10: Determination of Long-Term Strength of Geosynthetic Reinforcement*, American Association of State Highway and Transportation Officials, Inc., Washington, D.C.

Allen, T. M., and Bathurst, R. J., 2003, *Prediction of Reinforcement Loads in Reinforced Soil Walls*, WSDOT Research Report WA-RD 513.1 WA-RD 522.2, 364 pp.

Allen, T. M., Bathurst, R. J., Holtz, R. D., Walters, D. L. and Lee, W. F., 2003. "A New Working Stress Method for Prediction of Reinforcement Loads in Geosynthetic Walls," *Canadian Geotechnical Journal*, Vol. 40, No. 5, pp. 976-994.

Allen, T. M., Bathurst, R. J., Lee, W. F., Holtz, R. D., and Walters, D. L., 2004, "A New Method for Prediction of Loads in Steel Reinforced Walls," *ASCE Journal of Geotechnical and Geo-environmental Engineering*, Vol. 130, No. 11, pp. 1109-1120.

Allen, T. M., Nowak, A. S., and Bathurst, R. J., 2005, *Calibration to Determine Load and Resistance Factors for Geotechnical and Structural Design*, Transportation Research Board Circular E-C079, Washington, D.C., 93 p.

Allen, T. M., Christopher, B. R., Elias, V., and DiMaggio, J. D., 2001, *Development of the Simplified Method for Internal Stability Design of Mechanically Stabilized Earth (MSE) Walls*, WSDOT Research Report WA-RD 513.1, 96 pp.

Anderson, P. L., and Sankey, J., 2001, "The Performance of Buried Galvanized Steel Reinforcements after 20 Years in Service," *Kyushu 2001, Japan*, pp. \_\_\_.

Bathurst, R. J., Allen, T. M., and Nowak, A. S., 2008a, "Calibration Concepts for Load and Resistance Factor Design (LRFD) of Reinforced Soil Walls," *Canadian Geotechnical Journal*, Vol. 45, pp. 1377-1392.

Bathurst, R. J., Miyata, Y., Nernheim, A., and Allen, T. M., 2008b, "Refinement of K-stiffness Method for Geosynthetic Reinforced Soil Walls," *Geosynthetics International*, Vol. 15, No. 4, pp. 269-295.

Bathurst, R. J., Nernheim, A., and Allen, T. M., 2009. "Predicted Loads in Steel Reinforced Soil Walls Using the AASHTO Simplified Method," *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 135, No. 2, pp. 177-184.

Berg, R. R., Christopher, B. R., and Samtani, N. C., 2009, *Design of Mechanically Stabilized Earth Walls and Reinforced Slopes*, No. FHWA-NHI-10-024, Federal Highway Administration, 306 pp.

Bligh, R. P., Briaud, J.-L., Kim, K. M., and Abu-Odeh, A., 2010, *Design of Roadside Barrier Systems Placed on MSE Retaining Walls*, NCHRP Report 663, Transportation Research Board, Washington, D.C., 195 pp.

Bolton, M. D. 1986, "The Strength and Dilatancy of Sands," *Geotechnique*, Vol. 36, No. 1, pp. 65-78.

Byrne, R. J., Cotton, D., Porterfield, J., Wolschlag, C., and Ueblacker, G., 1996, *Demonstration Project 103, Manual for Design & Construction Monitoring of Soil Nail Walls*, Federal Highway Administration, FHWA-SA-96-069, 468 pp.

Chugh, A. K., 1995, "A Unified Procedure for Earth Pressure Calculations," Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol. III, St. Luis, Missouri.

Elias, V., Fishman, K.L., Christopher, B. R., and Berg, R. R., 2009, *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*, No. FHWA-NHI-09-087, Federal Highway Administration, 144 pp.

Jewell, R. A., and Wroth, C. P., 1987, "Direct Shear Tests on Reinforced Sand," *Geotechnique*, Vol. 37, No. 1, pp. 53-68.

Lade and Lee, 1976, "Engineering Properties of Soils," *Report UCLA-ENG-7652*, 145 pp. [As cited by Holtz and Kovacs (1981)].

Lazarte, C. A., Elias, V., Espinoza, R. D., Sabatini, P. J., 2003. *Geotechnical Engineering Circular No. 7, Soil Nail Walls*, U.S. Department of Transportation, Federal Highway Administration, FHWA-IF-03-017, 305 pp.

Morrison, K. F., Harrison, F. E., Collin, J. G., Dodds, A., and Arndt, B., 2006. *Shored Mechanically Stabilized Earth (SMSE) Wall Systems*, Technical Report, Federal Highway Administration, Washington, D.C., Report No. FHWA-CFL/TD-06-001, 212 pp.

NAVFAC, 1982, *Design Manual: Foundations, and Earth Structures*, DM-7.2.

NAVFAC, 1986, *Design Manual: Foundations, and Earth Structures*, DM-7.1.

Porterfield, J. A., Cotton, D. A., Byrne, R. J., 1994, *Soil Nail Walls-Demonstration Project 103, Soil Nailing Field Inspectors Manual*, U.S. Department of Transportation, Federal Highway Administration, FHWA-SA-93-068, 86 pp.

Sabatini, P. J., Pass, D. G., and Bachus, R. C., 1999, *Geotechnical Engineering Circular No. 4, Ground Anchors and Anchored Systems*, FHWA-IF-99-015, 281 pp.

Samtani, N. C., and Nowatzki, E. A., 2006, *Soils and Foundations, Reference Manual-Volumes I and II*, Washington, D.C., National Highway Institute Publication, FHWA-NHI-06-088/089, Federal Highway Administration.

Santamarina, J. C., Altschaeffl, A. G., and Chameau, J. L., 1992, "Reliability of Slopes: Incorporating Qualitative Information," Transportation Research Board, TRR 1343, Washington, D.C., pp. 1-5.

Terre Armee, 1979, *Experimental Wall Pushed to Break by Corrosion of the Reinforcements*, TAI Research Report R12.

## Appendices

- Appendix 15-A Preapproved Proprietary Wall and Reinforced General Slope Design Requirements and Responsibilities
- Appendix 15-B Preapproved Proprietary Wall/Reinforced Slope Design and Construction Review Checklist
- Appendix 15-C HITEC Earth Retaining Systems Evaluation for MSE Wall and Reinforced Slope Systems, as Modified for WSDOT Use: Submittal Requirements
- Appendix 15-D Preapproved Proprietary Wall Systems
- Appendix 15-E Description of Typical Temporary Shoring Systems and Selection Considerations (NEW)

## Preapproved Wall Appendices

Preapproved Wall Appendix:	Specific Requirements and Details for LB Foster Retained Earth Concrete Panel Walls
Preapproved Wall Appendix:	Specific Requirements and Details for Eureka Reinforced Soil Concrete Panel Walls
Preapproved Wall Appendix:	Specific Requirements and Details for Hilfiker Welded Wire Faced Walls
Preapproved Wall Appendix:	Specific Requirements and Details for KeySystem I Walls
Preapproved Wall Appendix:	Specific Requirements and Details for Tensar MESA Walls
Preapproved Wall Appendix:	Specific Requirements and Details for T-WALL® (The Neel Company)
Preapproved Wall Appendix:	Specific Requirements and Details for Reinforced Earth (RECO) Concrete Panel Walls
Preapproved Wall Appendix:	Specific Requirements and Details for SSL Concrete Panel Walls
Preapproved Wall Appendix:	Specific Requirements and Details for Tensar ARES Walls
Preapproved Wall Appendix:	Specific Requirements and Details for Nelson Walls
Preapproved Wall Appendix:	Specific Requirements and Details for Tensar Welded Wire Form Walls





# ***Preapproved Proprietary Wall and Reinforced Slope General Design Requirements and Responsibilities***

## ***Appendix 15-A***

---

### **Design Requirements**

Wall design shall be in accordance with the WSDOT *Geotechnical Design Manual* (GDM), the LRFD *Bridge Design Manual* (BDM), and the AASHTO LRFD Specifications. Where there are differences between the requirements in the WSDOT GDM and the AASHTO LRFD Specifications, this manual shall be considered to have the highest priority. Note that since a LRFD design method for reinforced slopes is currently not available, the allowable stress design method provided in Berg, et al. (2009) shall be used for reinforced slopes, except that geosynthetic reinforcement long-term nominal strength shall be determined in accordance with AASHTO PP66-10.

The wall/reinforced slope shall be designed for a minimum life of 75 years, unless otherwise specified by the State. All wall/reinforced slope components shall be designed to provide the required design life.

### **Design Responsibilities**

The geotechnical designer shall determine if a preapproved proprietary wall system is suitable for the wall site. The geotechnical designer shall be responsible for design of the wall for external stability (sliding, overturning, and bearing), compound stability, and overall (global) stability of the wall. The wall/reinforced slope supplier shall be responsible to design the wall for internal stability (structural failure of wall/reinforced slope components including the soil reinforcement, facing, and facing connectors to the reinforcement, and pullout), for all applicable limit states (as a minimum, serviceability, strength and extreme event). The wall supplier shall also be responsible to design the traffic barrier (all walls) and the distribution of the impact load into the soil reinforcement (MSE walls) in accordance with the AASHTO LRFD *Bridge Design Manual* and as specified in the WSDOT GDM and BDM. The wall or reinforced slope supplier, or the supplier's consultant, performing the geotechnical design of the structure shall be performed by, or under the direct supervision of, a civil engineer licensed to perform such work in the state of Washington, who is qualified by education or experience in the technical specialty of geotechnical engineering per WAC 196-27A-020. Final designs and plan sheets produced by the wall supplier shall be certified (stamped) in accordance with the applicable RCWs and WACs and as further specified in this manual (see WSDOT GDM Chapters 1 and 23).

The design calculation and working drawing submittal shall be as described in WSDOT *Standard Specifications* (M 41-10) Section 6.13.3(2). All computer output submitted shall be accompanied by supporting hand calculations detailing the calculation process, unless the computer program MSEW 3.0 supplied by ADAMA Engineering, Inc., is used to perform the calculations, in which case supporting hand calculations are not required.

Overall stability and compound stability as defined in the AASHTO LRFD Specifications is the responsibility of the geotechnical designer of record for the project. The geotechnical designer of record shall also provide the settlement estimate for the wall and the estimated bearing resistance available for all applicable limit states. If settlement is too great for the wall/reinforced slope supplier to provide an acceptable design, the geotechnical designer of record is responsible to develop a mitigation design in accordance with this manual (GDM) during contract preparation to provide adequate bearing resistance, overall stability, and acceptable settlement magnitude to enable final design of the structure. The geotechnical designer of record shall also be responsible to provide the design properties for the wall/reinforced slope backfill, retained fill, and any other properties necessary to complete the design for the structure, and the peak ground acceleration for seismic design. Design properties shall be determined in accordance with WSDOT GDM Chapter 5. The geotechnical designer of record is responsible to address geologic hazards resulting from earthquakes, landslides, and other geologic hazards as appropriate. Mitigation for seismic hazards such as liquefaction and the resulting instability shall be done in accordance with WSDOT GDM Chapter 6. The geotechnical designer of record shall also provide a design to make sure that the wall/reinforced slope is adequately drained, considering ground water, infiltration from rainfall and surface runoff, and potential flooding if near a body of surface water, and considering the ability of the structure backfill material to drain.

## Limits of Preapproved Wall/Reinforced Slope Designs

Preapproved wall design is intended for routine design situations where the design specifications (e.g., AASHTO, WSDOT GDM, and WSDOT BDM) can be readily applied. Whether or not a particular design situation is within the limits of what is preapproved also depends specifically on what plan details the proprietary wall supplier has submitted to WSDOT for approval. See the GDM preapproved wall appendices for details. In general, all the wall systems are preapproved up to the wall heights indicated in WSDOT GDM Appendix 15-D, and are also preapproved for use with traffic barriers, guardrail, hand rails, fencing, and catch basins placed on top of the wall. Preapproval regarding culvert penetration through the wall face and obstruction avoidance details varies with the specific wall system, as described in the GDM preapproved wall appendices.

In general, design situations that are not considered routine nor preapproved are as follows:

- Very tall walls, as defined for each wall system in WSDOT GDM Appendix 15-D.
- Vertically stacked or stepped walls, unless the step is less than or equal to 5 percent of the combined wall height, or unless the upper wall is completely behind the back of the lower wall, i.e., (for MSE walls, the back of the soil reinforcement) by a distance equal to the height of the lower wall.
- Back-to-back MSE walls, unless the distance between the backs of the walls (i.e., the back of the soil reinforcement layers) is 50 percent of the wall height or more.
- In the case of MSE walls and reinforced slopes, any culvert or other conduit that has a diameter which is greater than the vertical spacing between soil reinforcement layers, and which does not come through the wall at an angle perpendicular to the wall face and parallel to the soil reinforcement layers, unless otherwise specified in the WSDOT GDM preapproved wall appendix for a specific wall system.
- If the wall or reinforced slope is supporting structure foundations, other walls, noise walls, signs or sign bridges, or other types of surcharge loads. The wall or reinforced slope is considered to support the load if the surcharge load is located within a 1H:1V slope projected from the bottom of the back of the wall, or reinforced soil zone in the case of reinforced soil structures.
- Walls in which bridge or other structure deep foundations (e.g., piles, shafts, micropiles) must go through or immediately behind the wall.
- Any wall design that uses a wall detail that has not been reviewed and preapproved by WSDOT.

**Backfill Selection and Effect on Soil Reinforcement Design** – Backfill selection shall be based on the ability of the material to drain and the drainage design developed for the wall/reinforced slope, and the ability to work with and properly compact the soil in the anticipated weather conditions during backfill construction. Additionally, for MSE walls and reinforced slopes, the susceptibility of the backfill reinforcement to damage due to placement and compaction of backfill on the soil reinforcement shall be taken into account with regard to backfill selection.

Minimum requirements for backfill used in the reinforced zone of MSE walls and reinforced slopes are provided in Table 15-A-1. More stringent requirements will likely be necessary depending on the assessment of backfill needs as described above. This is especially likely in western Washington regarding the fines content and overall gradation; hence Gravel Borrow per the WSDOT *Standard Specifications* is recommended.

Sieve Size	Percent Passing
100 mm (4 in.) <sup>+</sup>	100
0.42 mm (No. 40)	0-60
0.074 mm (No. 200)	0-15

**Minimum Gradation Requirements for  
 MSE Walls and Reinforced Slopes**  
 Table 15-A-1

All material within the reinforced zone of MSE walls, and also within the bins of prefabricated bin walls, shall be substantially free of shale or other soft, poor durability particles, and shall not contain recycled materials, such as glass, shredded tires, portland cement concrete rubble, or asphaltic concrete rubble, nor shall it contain chemically active or contaminated soil such as slag, mining tailings, or similar material.

The corrosion criteria provided in the AASHTO LRFD Specifications for steel reinforcement in soil are applicable to soils that meet the following criteria:

- pH = 5 to 10 (AASHTO T289)
- Resistivity  $\geq$  3000 ohm-cm (AASHTO T288)
- Chlorides  $\leq$  100 ppm (AASHTO T291)
- Sulfates  $\leq$  200 ppm (AASHTO T290)
- Organic Content  $\leq$  1 percent (AASHTO T267)

If the resistivity is 1 greater than or equal to 5000 ohm-cm, the chlorides and sulfates requirements may be waived.

For geosynthetic reinforced structures, the approved products and values of  $T_{al}$  in the Qualified Products List (QPL) are applicable to soils meeting the following requirements, unless otherwise noted in the QPL or special provisions:

- Soil pH (determined by AASHTO T289) = 4.5 to 9 for permanent applications and 3 to 10 for temporary applications.
- Maximum soil particle size  $\leq$  1.25 inches, unless full scale installation damage tests are conducted in accordance with AASHTO PP66-10 so that the design can take into account the potential greater degree of damage.

Soils not meeting the requirements provided above shall not be used.

## MSE Wall Facing Tolerances

The design of the MSE wall (precast panel faced, and welded wire faced, with or without a precast concrete, cast-in-place concrete, or shotcrete facia placed after wall construction) shall result in a constructed wall that meets the following tolerances:

1. Deviation from the design batter and horizontal alignment, when measured along a 10 ft straight edge, shall not exceed the following:
  - a. Welded wire faced structural earth wall: 2 inches
  - b. Precast concrete panel and concrete block faced structural earth wall:  $\frac{3}{4}$  inch
2. Deviation from the overall design batter of the wall shall not exceed the following per 10 ft of wall height:
  - a. Welded wire faced structural earth wall: 1.5 inches
  - b. Precast concrete panel and concrete block faced structural earth wall:  $\frac{1}{2}$  inch
3. The maximum outward bulge of the face between welded wire faced structural earth wall reinforcement layers shall not exceed 2 inches. The maximum allowable offset in any precast concrete facing panel joint shall be  $\frac{3}{4}$  inch. The maximum allowable offset in any concrete block joint shall be  $\frac{3}{8}$  inch.

The design of the MSE wall (geosynthetic wrapped face, with or without a precast concrete, cast-in-place concrete, or shotcrete facia placed after wall construction) shall result in a constructed wall that meets the following tolerances:

Description of Criteria	Permanent Wall	Temporary Wall
Deviation from the design batter and horizontal alignment for the face when measured along a 10 ft straight edge at the midpoint of each wall layer shall not exceed:	3 inches	5 inches
Deviation from the overall design batter per 10 ft of wall height shall not exceed:	2 inches	3 inches
Maximum outward bulge of the face between backfill reinforcement layers shall not exceed:	4 inches	6 inches

## **References**

AASHTO, 2010, *Provisional Standard PP66-10: Determination of Long-Term Strength of Geosynthetic Reinforcement*, American Association of State Highway and Transportation Officials, Inc., Washington, DC.

Berg, R. R., Christopher, B. R., and Samtani, N. C., 2009, *Design of Mechanically Stabilized Earth Walls and Reinforced Slopes*, No. FHWA-NHI-10-024, Federal Highway Administration, 306 pp.