Retaining Wall Global Stability & AASHTO LRFD

Unnecessary, Unreasonable Guideline Changes Result in Huge Wastes of Money at Some Wall Locations

The implementation of the AASHTO LRFD Bridge Design Specifications includes a change in the level of conservatism for typical retaining walls with respect to overall global stability. The most recent ASD guideline (AASHTO, 2002, 17th edition Standard Specification for Highway Bridges) discusses global stability (Section 4 "Foundations" Articles 4.4.9 & 4.11.4.4 and Section 5 "Retaining Walls" Articles 5.2.2.3 & 5.14.6.4). The method requires that the designer determine the "criticality" of the structure to determine the appropriate factor of safety (FOS). With the provision that an adequate site investigation was conducted and that the ground characterization was completed by in-situ or laboratory testing, a FOS of 1.3 is specified for slopes and non-critical structures. For critical structures or structures supporting bridge abutments the recommended FOS is 1.5. Although the criteria to establish whether a given structure is critical or non-critical are left to the designer, generally, ***unless a wall is used to support a bridge abutment, a FOS of 1.3 complies with AASHTO ASD***. Note that specific site conditions notwithstanding, nearly all roadway retaining walls may classify as "non-critical" structures where the overall purpose and function, from a global stability viewpoint, is to maintain the roadway – similar, if not identical, to the function of roadway embankment slopes. Therefore, it is rational that "non-critical" retaining walls, performing the same or similar global stability function of an embankment slope, would be designed using the same global stability FOS. It is also rational to expect that the global stability factor of safety in the recent AASHTO LRFD guidelines would be the same as in the more mature ASD approach. However, this is not the case.

In the latest AASHTO LRFD Bridge Design Specifications, Section 11 "Abutments, Piers and Walls," Article 11.6.2.3 "Overall Stability," of the AASHTO LRFD guideline (AASHTO, 2007, 4th edition LRFD Bridge Design Specifications with 2009 interims) the criticality test has been removed and replaced with language that recommends a resistance factor (RF) of 0.65 for structures and 0.75 for slopes applied to service limit load states. Note that the RF as applied to overall stability is the inverse of the FOS used in ASD. Most software used to analyze the overall global stability calculates a FOS. The designer must then invert the FOS to arrive at the RF. Table 1 below summarizes the desired level of design conservatism recommended by AASHTO in the two structural design guidelines using "equivalent" RF and FOS to compare the two approaches.

Design Item	ASD (17th ed)		LRFD (4th ed)		% Increase from ASD
	Factor of Safety	*Equivalent* Resistance Factor	Resistance Factor	*Equivalent* Factor of Safety	
Slopes	1.3	0.77	0.75	1.33	2.6%
Non-Critical Structures	1.3	0.77	0.65	1.54	18.3%
Critical Structures	1.5	0.67	na	na	

Table 1. Comparison between Factors of Safety and Resistance Factors from AASHTO ASD & LRFD Design Guidelines.

As shown in Table 1, the implementation of AASHTO LRFD carries an increase in FOS of nearly 20% from the ASD design methodology for "non-critical" structures. Historically, the *desired* overall global stability FOS targeted by transportation agencies for slopes and retaining walls has been 1.3. (In sloping terrain such as occurs in mountainous regions even a FOS of 1.3 may be impractical.) One may wonder what impacts, in terms of materials and cost, may result by increasing the global stability FOS from 1.3 to 1.54. The accompanying analyses attempt to estimate the potential cost differences of this increase as applied to highway MSE retaining walls.

For this illustration a uniform homogeneous embankment slope of 2H:1V supporting a roadway with highway loading (250 psf uniform vertical surcharge) is assumed. An MSE retaining wall with a 20 foot exposed wall face is proposed using typical design standards (eg 1:1 excavation replaced with a select granular fill). For convenience, an overall reinforcement length to wall design height ratio of 70% is maintained throughout the iterations. The software program SLOPE/w by Geoslope was used to calculate the minimum global stability factor of safety and to perform probability analyses. Two examples, A & B, are analyzed. In both examples the soil properties for the select granular fill (Class 1 Structure Backfill) are identical. The embankment soils for Example A; however, were chosen to provide an ***existing*** slope stability FOS of approximately 1.3. The embankment materials for Example B were chosen to provide an

existing slope stability FOS of approximately 1.5. The material properties used in the analyses are listed below in Table 2.

Soil Type	Property	unit	min	average	max	SD
Select Granular Backfill (Class 1 Structure Backfill)	Phi	deg	32	**34**	36	***0.67***
	C	psf	0	**0**	0	***0.00***
	Gamma	pcf	119	**127**	135	***2.67***
Example A Embankment Soil	Phi	deg	25	**29**	33	***1.33***
	c	psf	25	**87.5**	150	***20.83***
	gamma	pcf	110	**119.5**	129	***3.17***
Example B Embankment Soil	phi	deg	28	**32**	36	***1.33***
	c	psf	75	**125**	175	***16.67***
	gamma	pcf	115	**126.5**	138	***3.83***

Table 2. Material Properties Used in Global Stability Analyses for Examples A & B

The standard deviations used in the probability analyses were estimated by selecting arbitrary minimum and maximum values, which are thought to represent 99.7% of the range of possible values (6sigma), and dividing this range by six. Because the standard deviations listed are small, the global stability analyses were repeated for each example using the same average values and tripling the standard deviations for each soil property. The SLOPE/w program uses a normal distribution for the material properties and probability distribution functions. The size of the reinforced zone for the MSE wall was adjusted to arrive at the targeted minimum stability value and the resulting material quantities for excavation, backfill, facing & reinforced fill estimated. A summary of these quantities, unit prices and cost information is provided in Table 3 for Examples A & B.

Wall	Description	Unit	Unit Cost	FOS=1.30 (RF=0.77) Qty	FOS=1.30 (RF=0.77) Cost	FOS=1.54 (RF=0.65) Qty	FOS=1.54 (RF=0.65) Cost
Example A	Excavation	cyd	$17	138	$2,346	359	$6,103
	Select Backfill	cyd	$19	183	$3,477	403	$7,657
	Reinforcement Zone	cyd	$23	106	$2,438	235	$5,405
	Wall Facing	sft	$15	111	$1,665	165	$2,475
	Total Cost per square ft of wall exposure **(above ground surface)**			**$165**		**$361**	
Example B	Excavation	cyd	$17	25	$ 425	169	$2,873
	Select Backfill	cyd	$19	69	$1,311	213	$4,047
	Reinforcement Zone	cyd	$23	40	$ 920	124	$2,852
	Wall Facing	sft	$15	68	$1,020	120	$1,800
	Total Cost per square ft of wall exposure **(above ground surface)**			**$61**		**$193**	

Table 3. Material Quantities and Cost Estimate for MSE Retaining Wall Examples A & B. The Soil Properties selected provide a FOS of 1.316 (Example A) and 1.507 (Example B) for the Highway Embankment without a Retaining Wall (the "existing" condition).

The quantities and costs shown in Table 3 indicate that the initial retaining wall quantities and cost for implementing RF=0.65 (LRFD) are over twice the FOS=1.3 (ASD) design. Copies of the SLOPE/w analyses for Example A & Example B are provided in Appendices A & B, respectively.

The results of a probability analyses is presented in Table 4. The reliability index and probability of failure were determined for each example using the standard deviations for material properties listed in Table 2 and calculated again with standard deviations tripled to simulate a higher degree of uncertainty. For these two examples it is apparent that justifying a higher factor of safety for a typical AASHTO retaining wall based upon risk is baseless. Even with consideration of the marginal reliability examples, the *additional* construction costs imposed by the LRFD global resistance factor will challenge underfunded transportation budgets.

Note that the MSE example could be applied to other "typical" earth retention systems that require a slope stability analyses with a resistance factor of 0.65 for design. We wonder why the language in the latest AASHTO LRFD has not yet been revised to reflect a continuation of the ASD state of practice. Other geotechnical resistance factors have been adjusted as more and more users notice higher costs associated with implementing the LRFD methodology. We request that the AASHTO authors either revise the slope stability language in the guideline that would allow earth retention systems to be designed to an ASD standard or provide a cost benefit analyses that justifies the changes in the current LRFD.

Ex	SD	Probability Item	ASD	LRFD
Example A	SD (Table 2)	FOS (Bishop)	1.302	1.541
		Resistance Factor	0.768	0.649
		Reliability Index	**5.641**	**8.338**
		Standard Deviation	0.054	0.065
		Probability of Failure (Normal Distribution)	8.45E-09	0.00E+00
		Risk per sft exposed wall cost (Normal Distribution)	***$0.00***	***$0.00***
	Triple SD	FOS (Bishop)	1.303	1.541
		Resistance Factor	0.767	0.649
		Reliability Index	**1.887**	**2.792**
		Standard Deviation	0.161	0.194
		Probability of Failure (Normal Distribution)	2.96E-02	2.62E-03
		Risk per sft exposed wall cost (Normal Distribution)	***$4.90***	***$0.95***
Example B	SD (Table 2)	FOS (Bishop)	1.303	1.537
		Resistance Factor	0.767	0.651
		Reliability Index	**6.623**	**9.532**
		Standard Deviation	0.046	0.056
		Probability of Failure (Normal Distribution)	1.76E-11	0.00E+00
		Risk per sft exposed wall cost (Normal Distribution)	***$0.00***	***$0.00***
	Triple SD	FOS (Bishop)	1.303	1.537
		Resistance Factor	0.767	0.651
		Reliability Index	**2.216**	**3.176**
		Standard Deviation	0.136	0.169
		Probability of Failure (Normal Distribution)	1.33E-02	7.47E-04
		Risk per sft exposed wall cost (Normal Distribution)	***$0.82***	***$0.14***

Appendix A

Appendix B