ASD and LRFD of Reinforced SRW with the use of software Program MSEW(3.0)

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The title of this article contains acronyms, enough to confuse most engineers. Imagine the confusion when the abbreviations have to be translated into numbers followed by a structure. To alleviate some of the concern, here is the literal "conversion": ASD=Allowable Stress Design (e.g., AASHTO 1998, 2002 or NCMA in the private sector); LRFD=Load Resistance Factor Design (e.g., AASHTO 2004); SRW=Segmental Retaining Walls reinforced with geosynthetics (e.g., reinforced block walls); Program MSEW(3.0)=Version 3.0 of software analyzing Mechanically Stabilized Earth Walls including reinforced SRW. Details of MSEW(3.0) are posted at www.GeoPrograms.com. Abbreviated names are just names, not substance; however, such names imply design procedures with very serious outcome. While all wall designers in the US are familiar with the ASD process (though some may not be even aware of the name), only a few are familiar with or even aware of the LRFD concept. Yet, as of October 2007, the Federal Highway Administration (FHWA) mandates design of MSE walls using LRFD as currently presented in AASHTO 2004 with updates to appear in 2006. Since procedures in AASHTO are usually accepted as the prevailing design in the public sector, it will be quite difficult for designers to avoid LRFD. This article shows common elements between ASD and LRFD. As the LRFD is mandated by FHWA, the following legitimate question is asked: "Considering the wide and successful use of ASD, why LRFD is needed for design of MSE walls?" No clear answer is provided in this article…

Principles of Design

The essence of limit state design is to insure that the supply (e.g., system resistance) matches the demand. That is, the capacity of a system can safely sustain the applied loading. For example, the geosynthetic long term strength needs to equal the applied load. Actually, design ensures that the supply is larger than the demand. The difference between ASD and LRFD is how the "larger" supply versus demand is defined.

The same basic mechanics (i.e., statics) is utilized by ASD and LRFD. Both require assessment of internal stability analyses to assess whether the long terms strength of the reinforcement, the geosynthetic-block connection, and the resistive pullout length, are all satisfied. Also required are external stability analyses to assess whether the coherent reinforced soil mass resistance to direct sliding, its eccentricity, and its bearing capacity, are all satisfied. The final dimensioning of the reinforcement structure is a synergy of all six stability analyses. It should be pointed out that often, global stability of the reinforced mass is needed. However, this stability analysis is beyond AASHTO specifications as it relates to slope stability which, per AASHTO, is a geotechnical aspect of design (i.e., beyond the scope of the bridge design section). Traditionally, global stability analysis is conducted using conventional limit equilibrium analysis (ASD). Clearly, in the current LRFD, two different design concepts are interfacing each other for

MSE walls. As often global stability controls the design (especially when sloping toe or complex geometry exists), one has to be competent with both ASD and LRFD when designing stable MSE walls.

In ASD, the ratio between the available strength and required strength for stability is defined as the margin of safety or factor of safety. Variations of this definition include the ratio between resisting force and driving force or the ratio between resisting moment and driving moment. For various stability analyses, the minimum factor of safety should exceed a minimum prescribed value. Such an approach has been used successfully since the introduction of modern soil mechanics in the early 1920's. In a sense, the ASD insures that the demand is matched with a resistance that is decreased by a factor of safety to insure that a margin of safety for uncertainties exists.

In contrast to ASD, LRFD assumes that there are uncertainties with both load and resistance. Hence, some failure resisting components are decreased, each by a respective factor, while the loads (failure driving components) are increased, each by its own respective factor. Once the resistance (i.e., capacity or supply) is decreased and the load (i.e., demand) is increased, the static in LRFD is utilized for the factored values. The factored resistance must be greater than the factored load when solving the limit state equilibrium equations. The Capacity Demand Ratio, CDR, is defined as the ratio between the reduced resistance and increased load while solving the limit state equilibrium equation. The convenience of solving a problem for a factor of safety in ASD (i.e., optimizing design with respect to a single factor) can be replicated in LRFD by requiring that the calculated CDR will have a minimum value of 1.0. The various factors are given in AASHTO including increase of vertical earth pressure in internal stability, increase in lateral earth pressure in external stability, increase of live and dead loads, etc. Subsequently, from a computational standpoint, both LRFD and ASD are equivalent.

At present, most of the factors in LRFD are set so as to produce the same design output as in ASD with its AASHTO 2002 recommended performance criteria. That is, the factors in LRFD should yield the same factors of safety corresponding to respective analysis. However, identical design outcome is not always possible, especially as the geometry gets more complex. The example problem shown next demonstrates this deviation.

Example Problem

Program MSEW(3.0) is used to analyze the same MSE wall using ASD (AASHTO 2002) and LRFD. The main menu in MSEW(3.0), Figure 1, makes it easy to compare the calculated outcome for four design methods considering the same geometry, material properties and reinforcement layout. It is literally one click away. The wall geometry is depicted in the screenshot shown in Figure 2. Note the backslope as well as the strip footing (or highway lane) surcharge. The uniform contact pressure exerted by this footing is 25 kPa (about 520 psf). The long-term strength and layout of the reinforcement is shown in Figure 3. Note that 12 layers of equally spaced geogrid were specified. The shear strength of the soil: cohesion is zero for all soils while the friction angles are 34, 30, and 32 degrees for the reinforced, retained and foundation soils, respectively. Because of publication space restrictions, the load and resistance factors in the LRFD mode, as well as the prescribed design criteria in the ASD mode are not presented here. However, AASHTO default values for these designs were invoked.

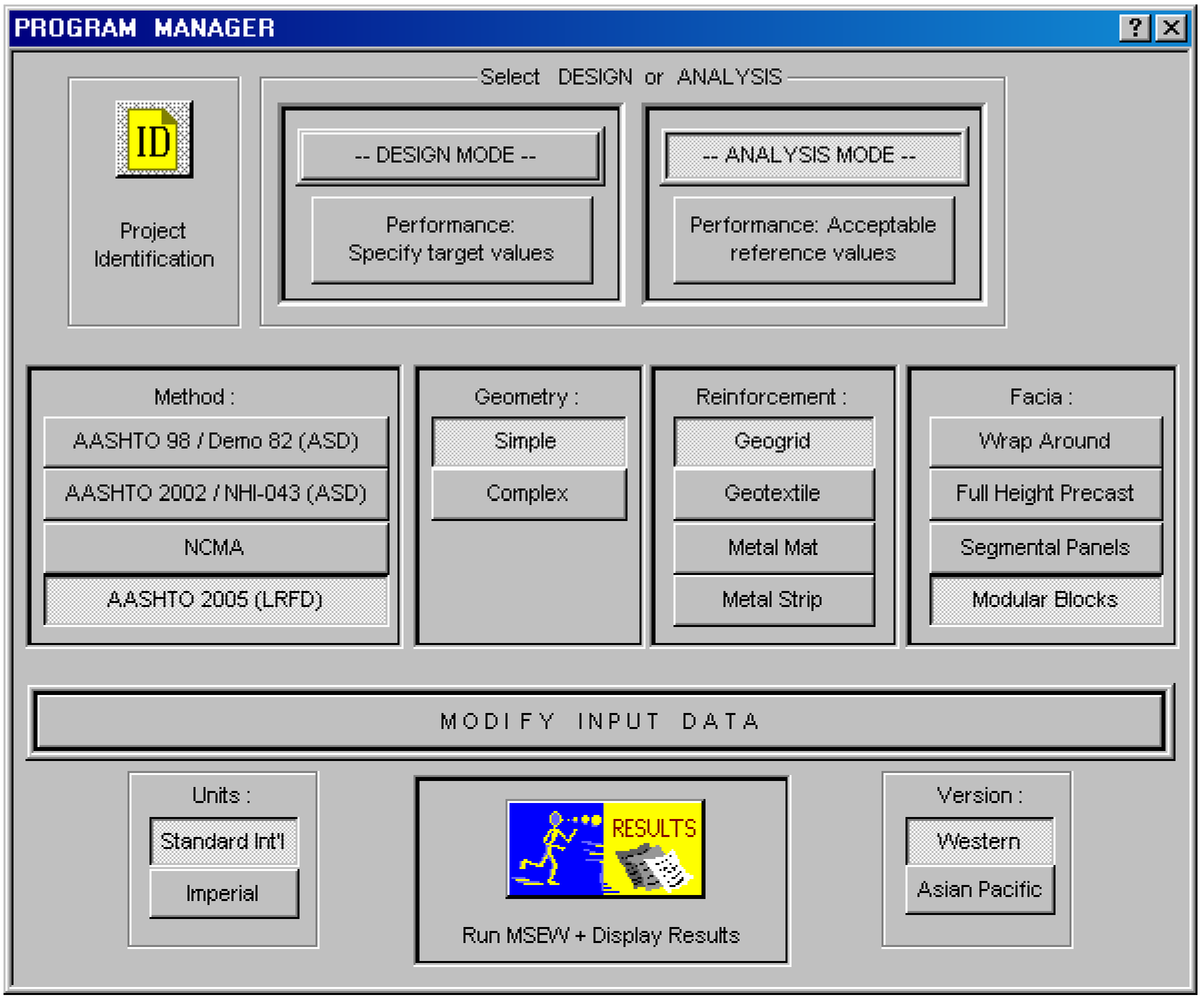


Figure 1. Main Menu in MSEW(3.0)

Running MSEW(3.0) in its ASD/AASHTO 2002 mode, one gets the results summary as shown in Figure 4. Close examination of the results reveals that all the minimum design requirements are exceeded. The geogrid strength is nearly ideal as its factor of safety on long term strength is 1.51. The length of the reinforcement just meets the eccentricity requirement along the base of the wall: e/L=1/6=0.167 (the requirement is that e/L should be equal or less than 0.167).

Switching to the LRFD mode and running the same problem, the results shown in Figure 5 are obtained. The CDR (Capacity Demand Ratio) is in excess of the minimum value of 1.0. Only for the geogrid strength CDR is nearly one (i.e., 1.01) which is equivalent to Fs=1.51 in ASD. Subsequently, calculated values related to resistance are satisfactory.   At first glance, however, the eccentricity at the base of the wall appears to be excessive: e/L=0.2513. Considering that the maximum permissible value of e/L in LRFD is 0.25, the calculated value of 0.2513 is only marginally excessive. In fact, changing the reinforcement length from 3.45 m to 3.48 m will solve this “problem.” This example essentially yielded the same structure using ASD or LRFD.

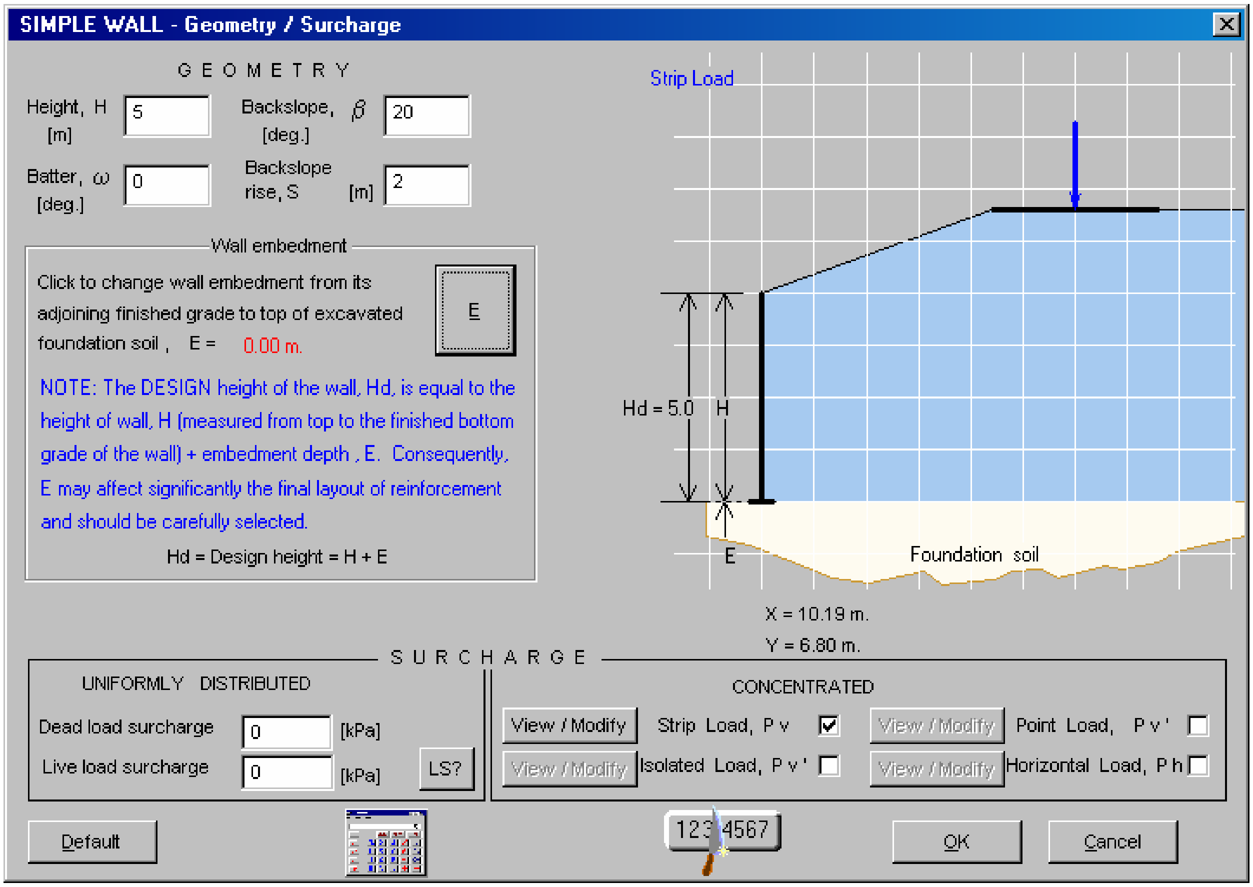


Figure 2. Specified Geometry of Wall including Surcharge

Commentary

The premise of LRFD is that its various factors could be determined with an accepted level of probability (or reliability) thus will allow for refined input data. More refined input should yield more refined designs. The writer can just hope that there will be sufficient field data to enable statistical analysis so as to refine these factors. For example, how one measure lateral earth pressures so that their current load factor of 1.5 could be refined? How one measures the vertical earth pressure within the reinforced mass so as to refine the current load factor of 1.35? How one refines the load factor for live load so as to refine its current value of 1.75? As a matter of fact, live load exerted by vehicles has always been represented by an extra 2 feet of soil (about 20 kPa or 400 psf). Can this equivalency of soil surcharge in lieu of point loads by vehicle be further “refined”? The writer does not have an answer but is hoping that indeed, such refinement would be possible. At present, the value of these factors has been determined so as to render the same designs for ASD and LRFD (i.e., the factors were “calibrated”).

A fundamental difficulty with the concept of LRFD applied to geotechnical problems, especially MSE analysis, is whether to consider the soil shear strength (internal angle of friction) as a resistance or load. As a shear resistance it is a failure resisting element so a load resistance factor is appropriate. Conversely, active lateral earth pressure is directly related to the friction angle hence making it a load factor. Obviously, LRFD cannot increase and decrease the same element as it simultaneously acts in opposing directions. AASHTO seems to have ignored this key element in geotechnical limit state design, implicitly applying a load and resistance factor of 1.0 (meaning: use it as is). From a conceptual standpoint, this approach is inconsistent. In Australia, for example, the angle is reduced by a factor. This approach results in an increased lateral earth pressure (increased load) and decreased resistance. At face value, such a single operation seems to satisfy the objective of LRFD while making it feasible to statistically determine a meaningful reduction factor for soil strength. However, as the size of the reinforced soil zone is a direct function of the internal friction angle, any reduction of its value will render longer required reinforcement length. The required extra length might be substantial.

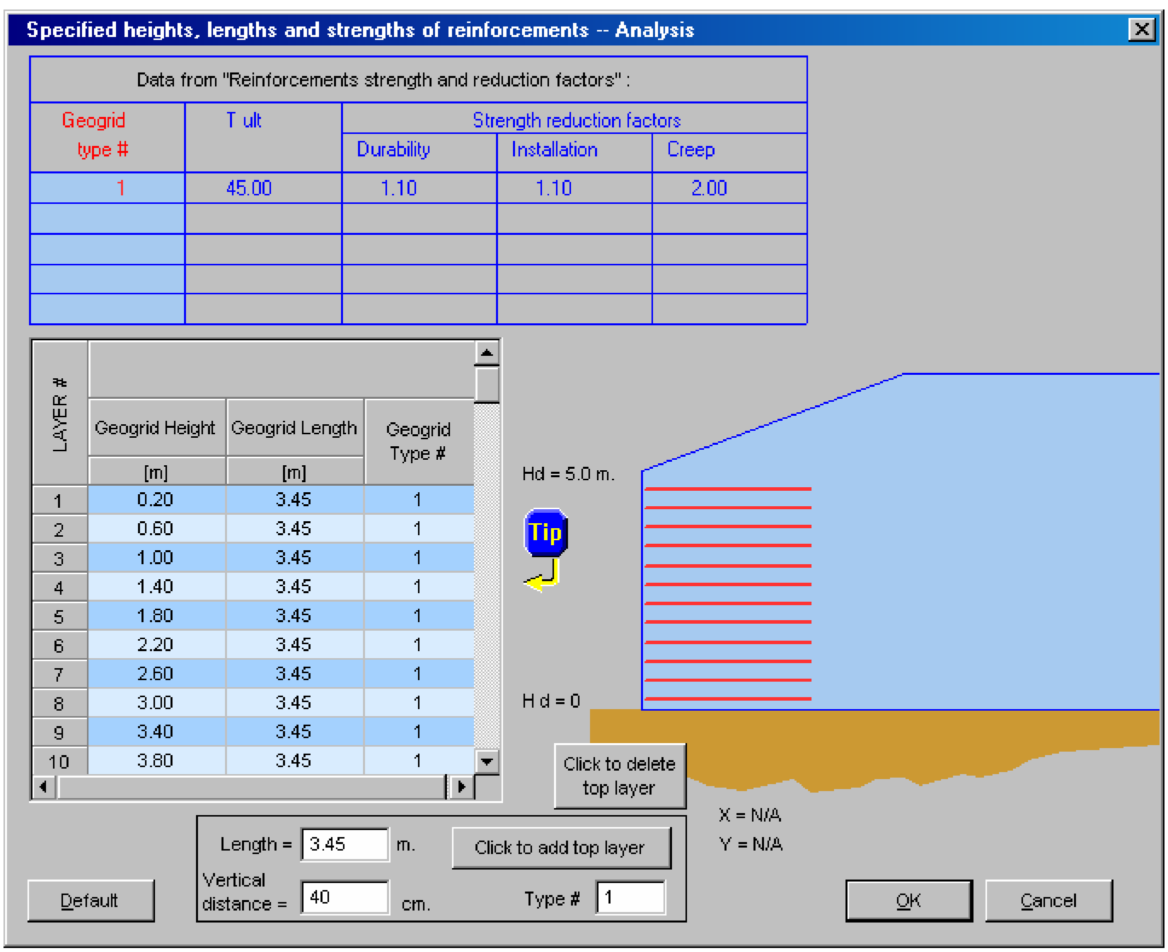
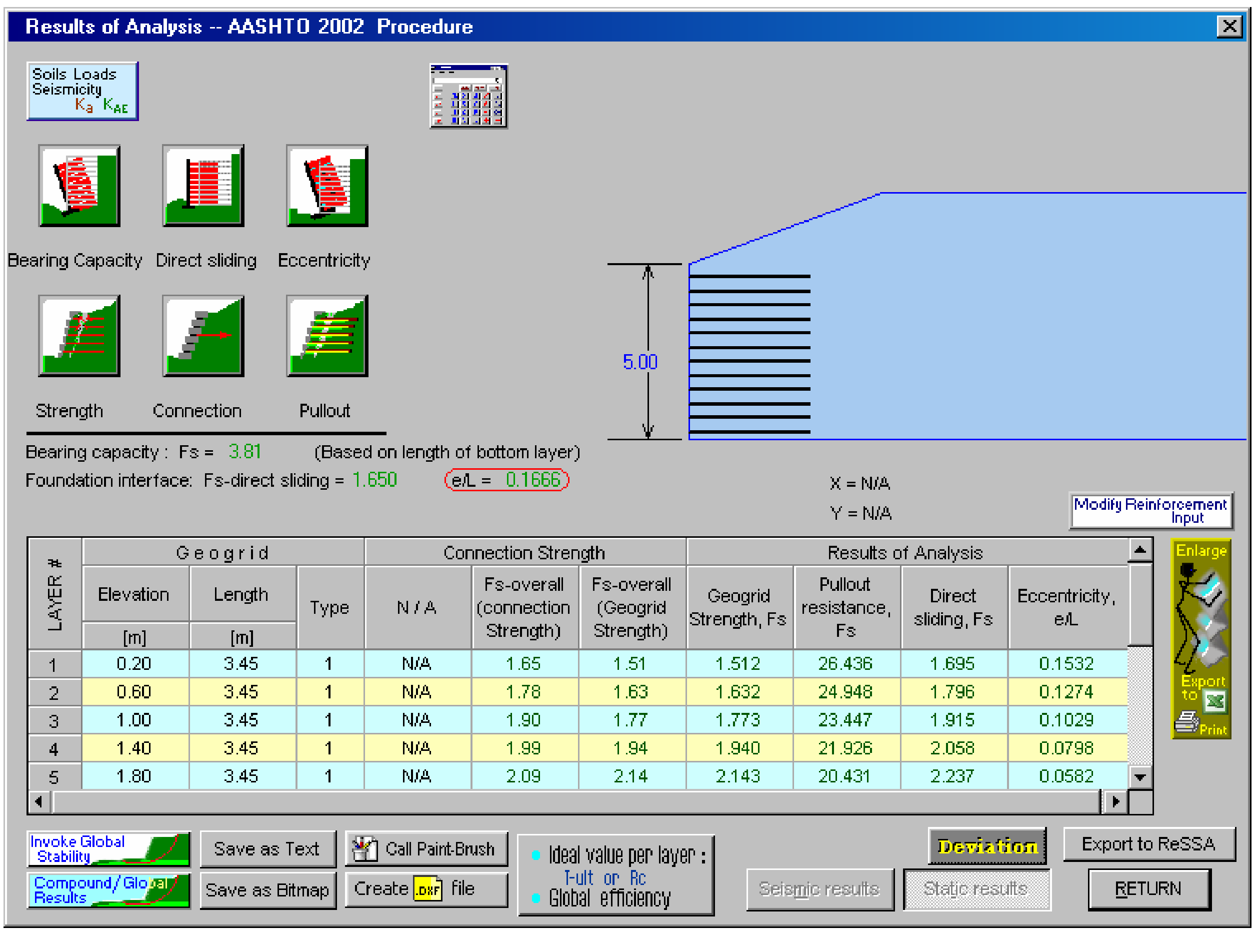


Figure 3. Specified Geogrid: Strength and Layout

Specific to the current resistance factor for bearing capacity, one notes that AASHTO value relates to shallow rigid footings where high level of conservatism is warranted. Hence, the range of resistance values will result in an equivalent factor of safety of 3.0 or more using Meyerhof formulation for eccentrically loaded footing. However, the recommended factor of safety for bearing capacity in AASHTO 2002 is 2.0.

Consequently, adopting the current values of LRFD may lead to more conservative design than ASD if bearing capacity controls the reinforcement length. Recognizing that MSE walls are flexible and are far from behaving as rigid footing, the writer is in the opinion that the resistance factor for bearing capacity can be increased from 0.4—0.5 to 0.65. As ASD design is acceptable, one may run each problem twice to verify what “calibrated” resistance factor will yield Fs=2.0 in ASD. As the bearing capacity is an unrealistic mode of failure, the writer prefers the alternative approach of global stability to ascertain sufficient stability against deep seated failure. Such analysis may also reveal potential instabilities not directly addressed by AASHTO.



LAYER #	Geogrid Elevation [m]	Geogrid Length [m]	Geogrid Type	Connection Strength N / A	Connection Strength Fs-overall (connection Strength)	Connection Strength Fs-overall (Geogrid Strength)	Results of Analysis Geogrid Strength, Fs	Results of Analysis Pullout resistance, Fs	Results of Analysis Direct sliding, Fs	Results of Analysis Eccentricity, e/L
1	0.20	3.45	1	N/A	1.65	1.51	1.512	26.436	1.695	0.1532
2	0.60	3.45	1	N/A	1.78	1.63	1.632	24.948	1.796	0.1274
3	1.00	3.45	1	N/A	1.90	1.77	1.773	23.447	1.915	0.1029
4	1.40	3.45	1	N/A	1.99	1.94	1.940	21.926	2.058	0.0798
5	1.80	3.45	1	N/A	2.09	2.14	2.143	20.431	2.237	0.0582

Figure 4. Results of Run for ASD/AASHTO 2002 Mode

One can also hope that the culprit in what appears to be an overly conservative design relates only to the input data and not to the analysis used. That is, the analyses for ASD and LRFD are fundamentally the same, only the objectives of analyses are different (Fs versus CDR). Essentially, it is the same good old lady just with a different dress. Indications are that design based on lateral earth pressures leads to overly conservative results when examining the reinforced soil coherent mass. However, as will be shown later, this perception of conservatism might be single-sided; i.e., it stems from internal/external stability but ignores global stability.

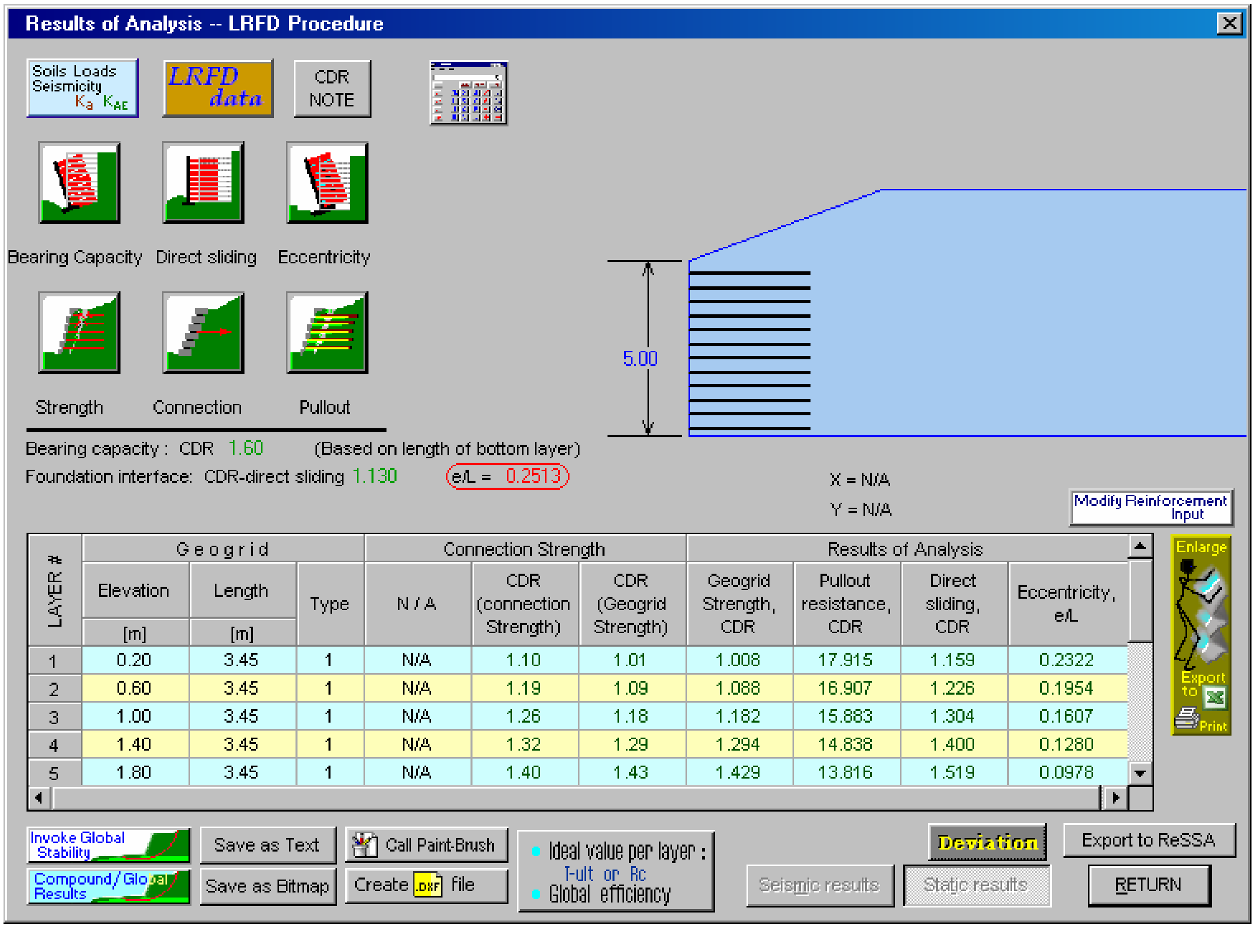


Figure 5. Results of Run for LRFD Mode

MSEW(3.0) can export input data files to program ReSSA(2.0) for in-depth global stability analysis (e.g., see button above Return in Figure 4). The transferred data includes also the connection strength calculated using the AASHTO or NCMA procedures. Analyzing the problem using Bishop Method for rotational failure and Spencer Method for translational failure along reinforcement layers yield the safety maps shown in Figures 6 and 7. To realize the impact of the safety map as a diagnostic tool in design, the reader is referred to “The Power of Software in Reinforcement Applications: Part I, Part II, Part III, Part IV,” *Geotechnical Fabrics Report*, March, 2005, Vol. 23, Numbers 5, 6, 7, and 8, written by Dov Leshchinsky. Alternatively, visit www.GeoPrograms.com. As seen from Figures 6 and 7:

1. The critical rotational and translational slip surfaces define similar traces of slip surfaces.
2. The factors of safety for Bishop and Spencer are very close (1.17 versus 1.19). Such proximity of results using different mechanisms and stability methods increase the confidence in the results.
3. FHWA accepts minimum global factor of safety of 1.3. Both safety maps show that there is a substantial zone where the safety factor is unacceptable. The map based on Bishop's indicates that deep seated surfaces render safety factors less than 1.3. Hence, just using stronger reinforcement would not increase the safety factors for such surfaces. The maps imply that both the strength and the length of the geogrid should be increased. Increase in length of the bottom few layers will likely be effective.
4. Looking at the range within the safety factor is unsatisfactory, it is clear that the strip footing (exerting pressure of 25 kPa) combined with the backslope have significant impact on global stability. Yet, the simplified analysis by AASHTO (regardless if it is ASD or LRFD) cannot capture the impact of such a situation. The inclination of the slip surface (or active wedge) in methods based on lateral earth approach depends only on the internal angle of friction phi (it is inclined at and angle of 45+phi/2 degrees). Clearly, the active wedge does not capture the impact of the backslope and the footing if it is practically outside the active wedge. Since slope stability analysis is an optimization process in which a large number of slip surfaces are examined and the one yielding the minimum factor of safety is considered critical, the effects of long backslope and/or footing can be realized as in the example problem.

Conclusion

This article shows the use of program MSEW(3.0) in which a certain wall is analyzed based on two procedures: ASD (AASHTO 2002) and LRFD (AASHTO 2004). The design outcomes are close; this is not surprising as the load and resistance factors in LRFD were "calibrated" to yield similar results to ASD. It is noted that LRFD resistance factor for bearing capacity needs further "calibration" for MSE walls since the current value is intended to produce an equivalent minimum factor of safety of 3.0. Such a value is justified for shallow foundations; however, it is excessive for MSE walls as is evident from AASHTO 2002.

The most important conclusion, perhaps, is that while little differences in design outcome exist between ASD and LRFD, the important issue of global stability of MSE structures is not stressed strong enough in any of the methods (AASHTO or NCMA). The example problem demonstrates this point. Note that the design parameters used in the example are realistic. Based on the writer's experience, failures frequently can be attributed to insufficient global stability. Such failures may not manifest themselves as catastrophic collapse but as large deformations or bulging. In such cases the global factor of safety could be between 1.0 and 1.1. Seeping water and sloping toe are two main factors that facilitate global failure. A consistent check for global stability, regardless if NCMA, AASHTO ASD or LRFD, should be part of the design process.

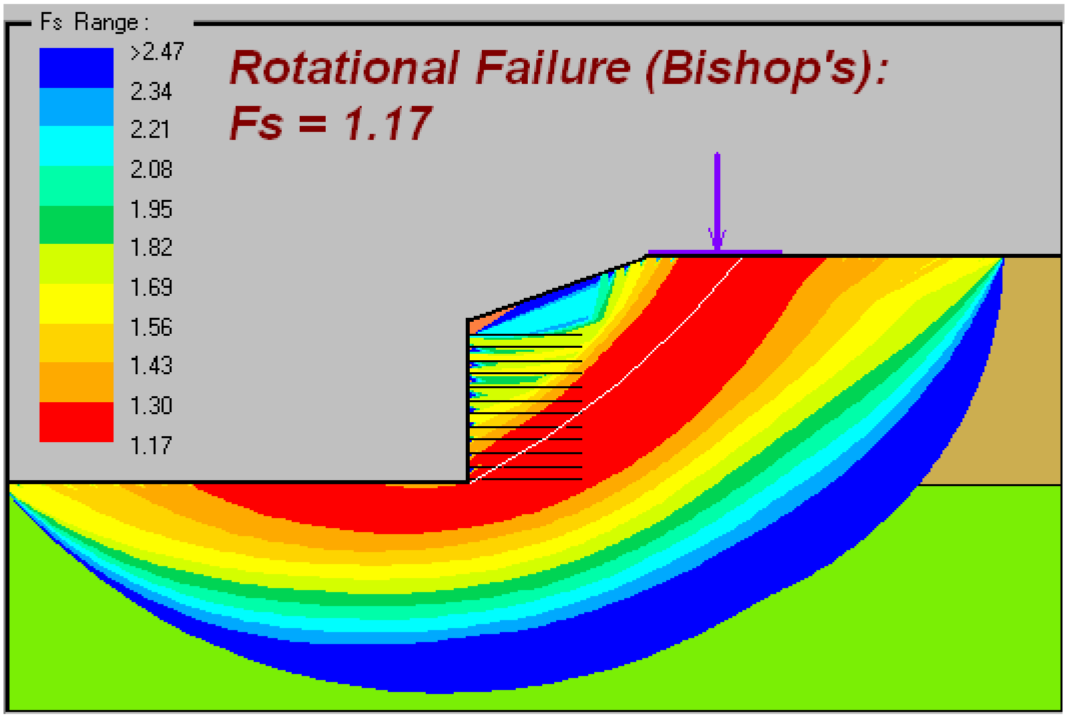


Figure 6. Global Stability for Rotational Failure: Safety Map

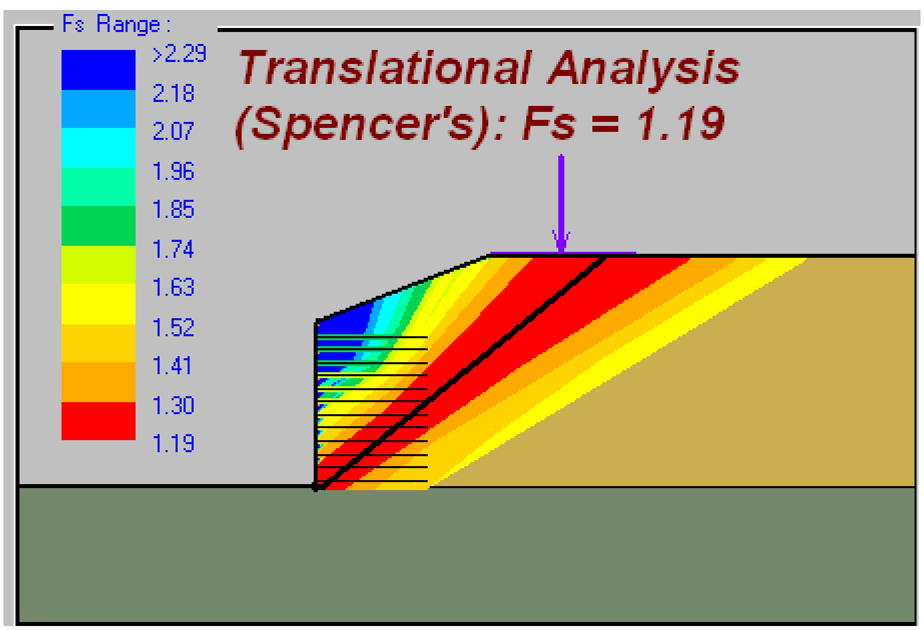


Figure 7: Global Stability for Translational Failure: Safety Map