NCMA TEK

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SEGMENTAL RETAINING WALL GLOBAL STABILITY

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INTRODUCTION

The general mass movement of a segmental retaining wall (SRW) structure and the adjacent soil is called a global stability failure. Global stability analysis is an important component in SRW design, particularly when the following conditions occur:

- groundwater table is above or within a depth of the wall height below the SRW,
- a 3H:1V or steeper slope at the toe of the wall,
- a 3H:1V or steeper slope above the top of the wall,
- for tiered SRWs,
- for seismic design, and
- when the wall is founded on soft soils, organic soils, peat, high plastic clay, swelling or shrinking soils (such as leda clay) or fill soil.

The designer should also review local code requirements applicable to design of soil retention structures.

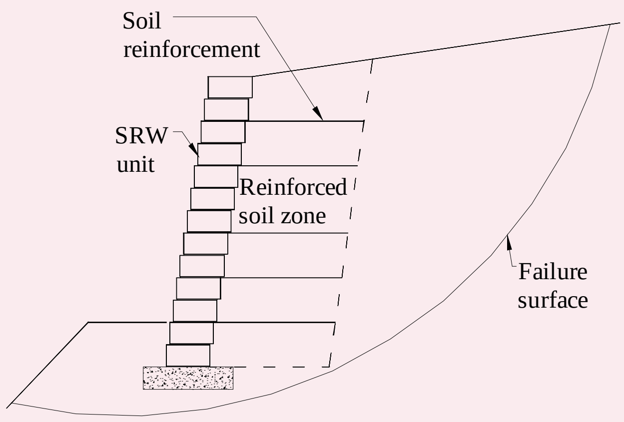

Figure 1—Deep-Seated Failure

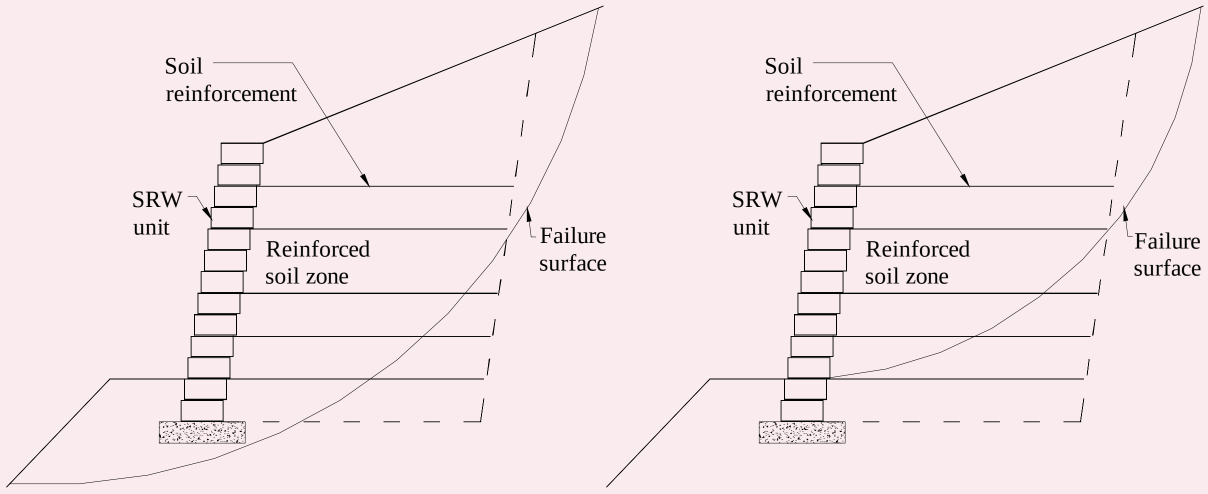

Figure 2—Compound Failure

There are two primary modes of global stability failure, deep-seated and compound. A deep-seated failure is characterized by a failure surface that starts in front of an SRW, passes below the base of the wall and extends beyond the tail of the soil reinforcement (see Figure 1). Compound failures are typically described by a failure surface that passes through either the face of the SRW or in front of the wall, through the reinforced soil zone and continues into the unreinforced/retained soil (Figure 2).

GLOBAL STABILITY ANALYSIS

Various methods of analysis have been developed to address global stability, including Janbu, Spencer and Bishop methods. Bishop's method is commonly used for global stability analysis. Bishop's method utilizes the method of slices and considers the forces acting on each slice, as shown in Figure 3. Limit equilibrium requirements are applied to the slices comprising the soil structure, with the factor of safety against failure being defined as the ratio of the maximum shear strength possessed by the soil on the trial failure surface plus contributions from soil reinforcement ($\tau_{available}$) to the shear resistance necessary for equilibrium ($\tau_{mobilized}$). $FS = \tau_{available}/\tau_{mobilized}$ or resistance/driving.

Limit equilibrium methods of analysis are typically used to determine the global stability of the SRW. Limit equilibrium analysis assumes that the SRW, the retained soil and the foundation soil will fail by sliding along a critical slip (failure) surface driven by the force of gravity. The critical slip surface is commonly assumed to be a circular arc, logarithmic spiral arc, curve, single plane or multiple planes to simulate the possible sliding movement.

In most limit equilibrium analyses, the minimum shear strength required along a potential failure surface to maintain stability is calculated and then compared to the magnitude of available shear strength. The factor of safety is assumed to be constant along the entire failure surface. The design factor of safety for global stability is typically between 1.3 and 1.5 and is dependent on the criticality of the structure and how well the site conditions are defined. Limit equilibrium global stability analysis involves an iterative process where many (i.e., 250) trial failure surfaces are assumed and analyzed in order to determine the critical failure surface (i.e. minimum factor of safety). For this reason, slope stability analyses are usually carried out using computer programs that implement one or more analysis methods. Many software programs have been developed to perform the global stability of unreinforced soil structures. There are, however, only a limited number of programs that include the stabilizing effects of the geosynthetic reinforcement used to construct the SRW. ReSSA (ref. 1) is one such program that was developed for the Federal Highway Administration.

The global factor of safety of an SRW is a function of: the shear strength of the soil, groundwater table location, site geometry (i.e., sloping toe or crest, tiered walls) and the length, strength and vertical location of the soil reinforcement. The effects of each of these parameters are briefly discussed below.

The shear strength of the reinforced, retained and foundation soil all have an impact on the global stability.

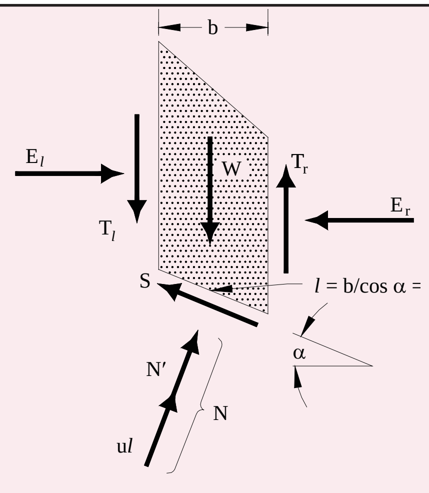

Figure 3—Representative Slope Slice for Bishop's Method of Analysis (ref. 3)

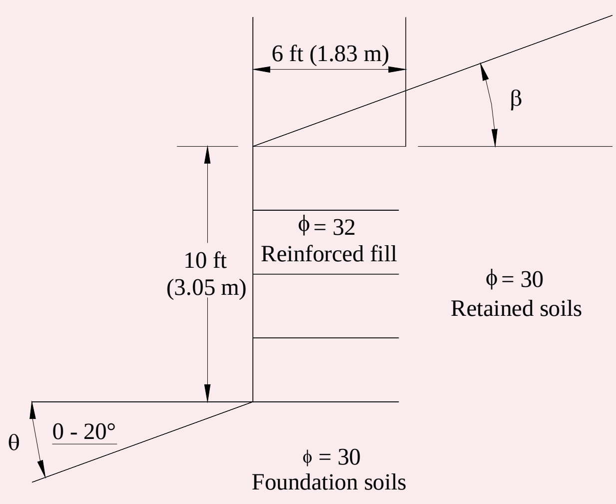

Figure 4—Typical Section for Figures 5 and 6

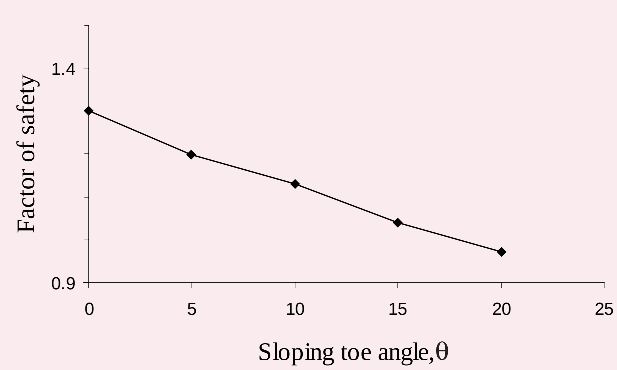

Figure 5—Effect of Sloping Toe Angle on Global Factor of Safety

Weak foundation soils increase the potential for deep-seated stability problems. Low strength reinforced soil will contribute to compound stability problems and low strength retained soils may contribute to either deep-seated or compound failure modes.

The location of the groundwater table will certainly affect the SRW's stability. If the groundwater table is high enough (i.e., at the toe of the wall) the long-term shear strength (i.e., effective shear strength) of the foundation soil will be reduced. This reduction in strength is directly related to the buoyant effect of the groundwater. The effective weight of the soil is reduced by approximately 50%, which will result in a reduction in shear strength along the failure surface in the foundation soil of 50%.

A sloping toe at the bottom of an SRW reduces the resisting forces in deep-seated global stability analysis. As the resisting force decreases, the global factor of safety decreases. Figure 4 illustrates the design case for a parametric analysis of top and toe slope effects. Figure 5 shows the change in factor of safety for deep-seated failure as a function of the toe slope angle for a 10-ft (3.05-m) high wall with a horizontal crest slope founded on a foundation soil with a friction angle of 30°.

A slope above the top of the wall also decreases the SRW global stability. Figure 6 shows the change in factor of safety for the same wall used in Figure 5, with the exception that the toe is level and the crest slope varies. For this example, the change in the toe slope has a more drastic effect than a change in the slope above the top of the wall.

The soil reinforcement spacing, length and strength will all effect the SRW's global stability. Generally speaking, increasing the spacing between reinforcement layers increases the potential for compound failures. Shortening the length of the reinforcement will increase the potential for both compound and deep-seated failure. Changes in the design strength of the reinforcement often has the smallest impact on global stability.

Tiered SRWs

The *NCMA Design Manual for Segmental Retaining Walls* (ref. 2) gives specific guidelines for tiered SRWs with respect to the spacing between tiers and the effect of the upper wall on the internal and external stability of the lower wall (see Figure 7). When the setback of the upper wall (i.e., J) is greater than the height of the lower wall (i.e., H_1), the internal design of the lower wall is not affected by the upper wall. However, this is not true for global stability. NCMA, therefore, recommends that global stability be checked for all tiered walls.

Figure 8 shows the variation in the global factor of safety for two 10-ft (3.05-m) high tiered walls with horizontal crest slopes as a function of the setback J. In this example, the reinforcement length for both walls is 12 ft (3.66 m), which is 0.6 times the combined height of both walls. For this particular example, constructing a tiered wall versus a single wall 20 ft (6.10 m) high (i.e., J = 0) reduces the global factor of safety from 1.3 to 1.2.

CONCLUSIONS

Global stability of an SRW is an important design consideration whenever a slope occurs at the toe or crest of a wall or when tiered SRWs are used. When the global factor of

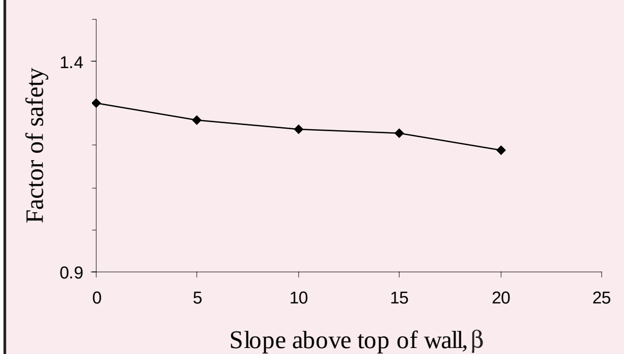

Figure 6—Effect of Slope Above Top of Wall on Global Factor of Safety

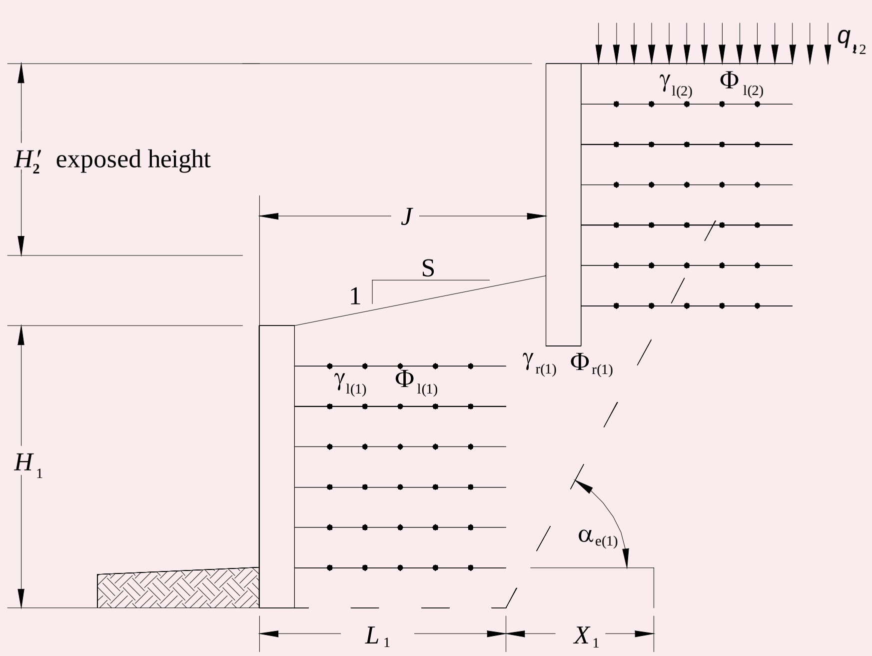

Figure 7—Tiered SRW

Figure 8—Effect of Tiered SRW Setback on Global Factor of Safety

safety of an SRW is below the design requirement, the stability may be increased by increasing the reinforcement length or strength, by decreasing the space between reinforcement layers or by increasing the foundation soil strength (using ground improvement techniques). When a slope occurs at the toe of a wall, changing the geometry of the wall slope may also increase stability. For example, placing the SRW at the bottom of the slope and having a slope above the wall instead may increase the stability to an acceptable level.

Global stability analysis is a complicated analytical procedure. However, computer software is available that greatly reduces the difficulty and time required to perform global stability analysis. Global stability considerations during SRW design are important in assessing the overall wall performance.

REFERENCES

1. ReSSA 1.0, ADAMA Engineering Inc., 2001.
2. *NCMA Design Manual for Segmental Retaining Walls*, 2nd edition. TR 127. National Concrete Masonry Association, 2002.
3. McCarthy, David F. *Essentials of Soil Mechanics and Foundations: Basic Geotechnics*, Fourth Edition, Regents/ Prentice Hall, 1993.

NOTATIONS:

b	=	width of slice, ft (m)
FS	=	factor of safety
H_1	=	height of lower wall for tiered SRWs, ft (m)
H'_2	=	exposed height of upper wall for tiered SRWs, ft (m)
J	=	setback between SRW tiers, ft (m)
L_1	=	length of geosynthetic soil reinforcement, ft (m)
N	=	total normal force, $N = N' + ul$, lb (N)
N'	=	effective normal force, lb (N)
q	=	soil surcharge, lb/ft (N/m)
S	=	ratio of horizontal offset to vertical rise between tiers of slope
u	=	pore water pressure acting on base of slice equal to $\gamma_w z_w$
ul	=	force due to pore water pressure, lb (N)
W	=	total weight of soil in slice, plus surcharge if present, lb (N)
X_1	=	length of influence zone for upper tier, ft (m)
z_w	=	depth below the water surface, ft (m)
α_e	=	orientation of the critical Coulomb failure surface
β	=	soil slope above top of wall, degrees
γ	=	soil unit weight, pcf (kN/m^3)
θ	=	toe angle, degrees
ϕ	=	friction angle of soil, degrees
$\tau_{available}$	=	the maximum shear strength possessed by the soil on the trial failure surface plus contributions from soil reinforcement, lb/ft (N/m)
$\tau_{mobilized}$	=	the shear resistance necessary for equilibrium, lb/ft (N/m)