allanblock.com

Designing Terraces using the Limit Equilibrium Method

Terraced Walls

Sometimes it is desirable to build two or more smaller walls at different elevations rather than one very tall wall. Such an arrangement is called a terraced wall and an example is pictured in Figure 1. The analysis of terraced walls can become very complicated. Before now a standard design method was used to analyze terraced wall applications:

1. Determine geometry of walls (total height, number of tiers, spacing between tiers, grid length, etc.).
2. Design top wall.
3. Find average bearing stress of the top wall to apply as surcharge on the wall below.
4. Design next wall down with upper wall applied as a surcharge.
5. Repeat steps 3-4 for every tier.
6. Run a global stability analysis to determine overall site stability.

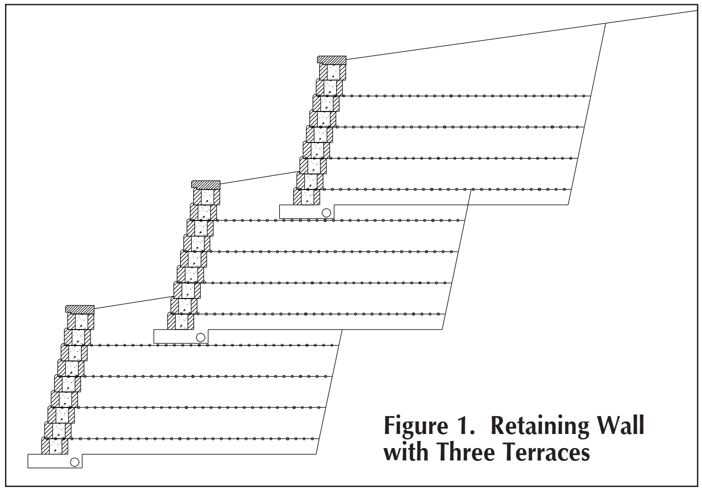

Figure 1. Retaining Wall with Three Terraces

This was a simple method but may not model the walls and slope effectively. As computers have gotten better we now can use Limit Equilibrium (LE), which is essentially a global analysis calculation that is limited to the wall design envelope, that makes designing terraces even simpler as listed here.

1. Determine geometry of walls (total height, number of tiers, spacing between tiers, grid length, etc.).
2. Design total structure using the LE Method built into AB Walls 3D+Terreces.
3 Run a global stability analysis to determine overall site stability in a global modeling program such as ReSSA.

You should also be aware that, as the number and walls increase, the threat of global instability increases. Therefore, for every terraced wall application a global stability analysis should be conducted.

Limit Equilibrium

Limit Equilibrium (LE) is not a new term but it is new to the Segmental Retaining Wall (SRW) design practice. LE is a way to describe the process of determining the global stability of a slope or wall structure. The Limit Equilibrium Method (LEM) has been developed by University Professor Dov Leshchinsky, PH.D. through years of research and was recently adopted by the Federal Highways Administration National Geotechnical Team (FHWA), the National Concrete Masonry Association (NCMA), and American Association of State Highway Transportation Officials (AASHTO) as a viable alternative for traditional SRW internal design calculations. The FHWA published manual (FHWA–HIF-17-004) is available for download at the FHWA Office of Bridges and Structures website.

Looking at the steps listed above, by adopting LEM, the industry is abandoning the old, more theoretical Coulomb pressure calculations for this easy to understand and highly accurate global modeling method. LEM uses a Simplified Method of Slices - Bishop's model - to determine the forward forces that need to be resisted by the geogrid layers and facing material. The forward forces are determined simply by subtracting the Resisting Forces (Fr) along a slip arc from the Sliding Forces (Fs) along that same slip arc (Figure 2). If the resulting forces are positive, there are forward Siding Forces that need to be accounted for by layers of geogrid. These forces will be discussed later as we define the required resisting forces within a grid layer (*Treq*). Likewise, if the resulting forces are negative, the slip arc has no sliding forces and thus the slip arc is stable without geogrid interaction. Therefore, LEM determines the true loads on the grids to maintain equilibrium - stability.

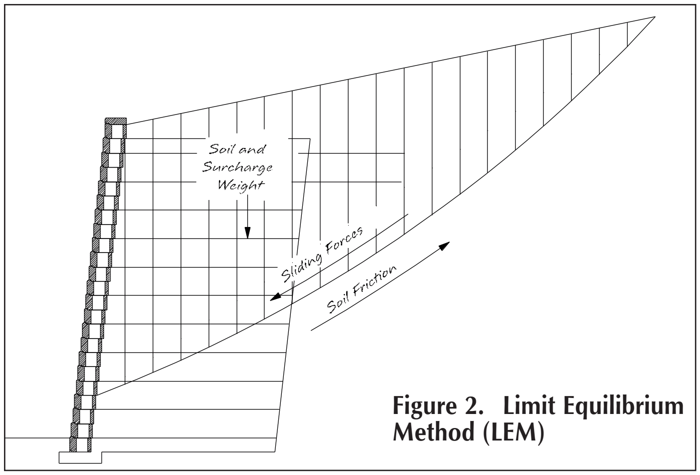

Figure 2. Limit Equilibrium Method (LEM)

We as an industry know so much more about SRWs than we did when they were first introduced in the early 1980's. We now know there should be minimum things to consider regardless of design method when starting a design. Such as:

- Minimum suggested grid lengths should still be at least 60% of the total structure height.
- Recommendations limit grid spacing to 16 in. (40 cm) or generally referred to as 2 course spacing.

With this said, Columbia University and University of Delaware researchers conducted full-scale seismic testing on segmental walls using Allan Block facing units under various seismic loading conditions. The results were extremely good and although there were many specific recommendations that came from this testing for all types of SRW products, the most important one was the positive results of closer grid spacing.

Lastly, one of the major positives for LEM is its flexibility of global modeling. This method allows for a similar design approach for all types of wall and sloped structures including standard single wall applications, terraced wall applications, water applications, static and seismic applications, etc. Basically, any wall application that can be modeled in global can be modeled in LEM.

Bishop's Approach to determine forward sliding forces:

The Simplified Bishop Method of Slices is one of the most popular global design methods used today and for that reason is used as the base method for determining the forward sliding forces in LEM. The ultimate goal is to calculate the required tensile force (*Treq*) along each grid layer from the back of the facing to the end of each layer of grid. LEM is using the Bishops modeling to determine the sliding and resisting force within the soils alone. We do this by forcing the calculations to run with a safety factor of 1.0, or in other words, at equilibrium. By simplifying the process down to equilibrium (1.0), we can determine how much force (*Treq*) has to be transferred into the geogrid layer and even where these forces are located. By using the 1.0 safety factor, the Bishop calculation provides the resulting forward forces.

It should be noted that the soils and grid are not the only elements that resist the sliding forces. As these walls are utilizing a segmental block as a face, it is appropriate to take a fraction of the tested block shear value (Sblock) and add it as a resistance component.

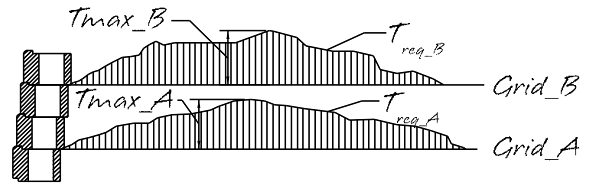

Figure 3. Treq Envelope Along Grid Layer

Once Bishops calculates the Treq for each slip arc, that value is then divided equally between each grid layer the slip arc comes in contact with. This even distribution assumes that all contacted layers share the load equally and thus fail simultaneously. Using a top-down analysis approach, meaning, starting with all slip arcs exiting the wall at or near the top, one can start to develop the worst case Treq values. This process is repeated for every possible slip arc and all Treq values are recorded for each particular arc/grid-layer intersection point thus creating a Treq envelope of each grid layer as shown in Figure 3. From this envelope, all geogrid information will be found including strength, soil pullout and connection requirements.

Now with the overall Treq divided to each grid layer along each slip arc, the Treq is now known for any location along any one of the individual grid layers. It is now easy to determine the maximum Treq or Tmax for each grid layer, (Figure 3). Once we have Tmax for each grid layer an appropriate safety factor, such as our commonly used 1.5, can be applied and the designer can select a geogrid with an LTADS that exceeds this value.

For a LEM Bishops Model to be as accurate as possible, a methodical approach of creating enough slip arcs to produce a virtually continuous interaction along the length of each grid layer is necessary, as seen in Figure 3. Therefore, each block course will represent an exit node and there will be no slip arcs allowed to exit below the top of the leveling pad. LEM is not meant to replace the need for external stability or a complete global stability analysis, but rather provides a more refined and precise evaluation of the internal forces in the reinforced mass.

Using this approach, we accurately capture loads and locations of those loads along each grid layer, including loads at the face of the structure. This allows for the first true opportunity to analyze the connection requirements at the face of the structure. With a clear understanding of the loads on the face, analyzing the maximum connection requirement (To) along with an appropriate factor of safety is straightforward. Along with To, a typical force between grid layers (Tbg) can be determined by considering the bin pressure of the material directly behind the facing. This Tbg force is determined for each grid layer based on its position within the wall and the geogrid spacing. The tighter the grid spacing, the less Tbg force applied to the back of the wall. Likewise, to ensure we have sufficient anchorage at the end of the grid, a similar approach to analyzing the end of the grids is used to determine their ability to intersect slip arcs passing at the back end of the reinforced mass. The soil pullout capacity (P-End) will limit the amount of resistance a geogrid can provide to the forward sliding forces from the Bishop's model. When a Treq value exceeds the P-End capacity, the excess amount is then redistributed to the other geogrid layers the slip arc intersects, thus satisfying equilibrium, see Figure 4.

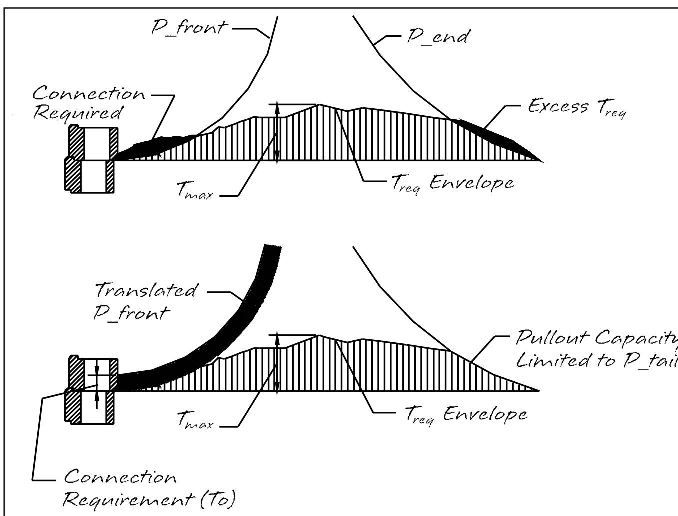

Figure 4. LEM

External Stability Calculations

External calculations are all about the overall size of the mass and whether or not it is large (or heavy) enough and deep enough to resist sliding and overturning forces developed from the active earth pressure from the retained soils. The depth of mass is commonly equated with the length of the common geogrid layers but other than the grid length it has nothing to do with the strength or position of the grid layers. This concept of external design is still very relevant today and will not be affected by the introduction of LEM. The same goes for the traditional SRW bearing calculations. A commonly used bearing calculation is based on Meyerhof formulas that again are still very relevant today and will not be affected by the introduction of LEM.

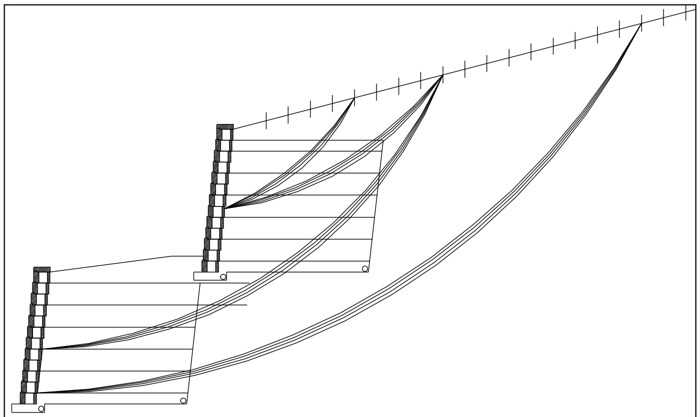

Figure 5. Terraced Section using LEM

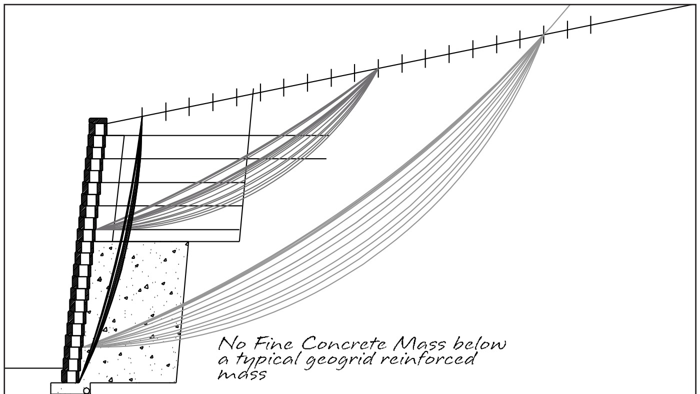

Figure 6. Complex Composite Structure (CCS)

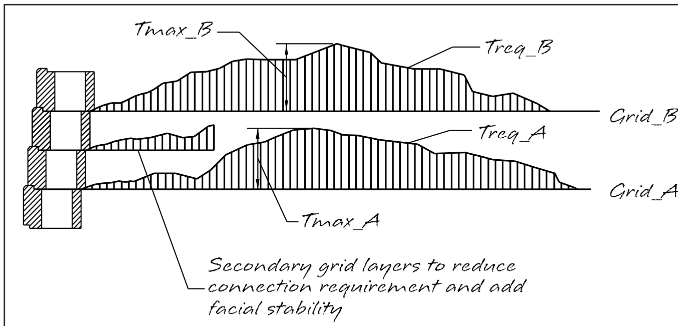

Figure 7. Secondary Geogrid Layers

Discussion on Various Structure Types and Grid Configurations

As mentioned earlier, the fact that LEM is based on global modeling allows the designer to utilize the same technical methods to analyze structures of virtually any configuration including terraced walls (Figure 5) or walls that are considered complex having a combination of geogrid and no-fines concrete making up its internal structure (Figure 6).

Lastly, the addition of secondary short grid layers (Figure 7) is becoming more common in some applications as well. Using them in LEM is very straight forward as they are only relative to the facing. Therefore, we only use them in the front pullout of soil calculations which specifically allows us to determine the required connection strength (*To*).

It is required that with any LEM design, the engineer of record must consider a global stability analysis to ensure overall stability of the site.

For a more complete, in depth discussion on Limit Equilibrium Method (LEM) of design, see Chapter 8 in the Allan Block Engineering Manual.

allanblock.com

The information shown here is for use with Allan Block products only.