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Project Summary Report 0-4485-S
Project 0-4485: Design Methodology for Tiered MSE or Concrete Block Retaining Walls
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PROJECT SUMMARY REPORT

Design of Multi-Tiered Mechanically Stabilized Earth (MMSE) Walls

What We Did...

Existing Federal Highway Administration (FHWA) and American Association of State Highway Officials' (AASHTO) design guidelines for single- and multi-tiered mechanically stabilized earth (MMSE) walls, as well as general limit equilibrium approaches, were reviewed and evaluated. The variables and assumptions employed in each design approach were identified and compared.

Various computer software, including both specialized MSE wall design programs and general-purpose limit equilibrium software, was examined and compared. Both the MSEW2.0 software, which implements the current FHWA design guidelines, and the UTEXAS4 software, a general purpose slope stability analysis program, were compared and used to analyze a number of selected wall systems.

Analyses were first performed to evaluate single-tier MSE walls and to qualify the importance of differences in the various design and analysis approaches. Two walls were selected for these analyses. These are actual walls designed and built for the Texas Department of Transportation (TxDOT). The first wall is located along US 183 in the Austin District of TxDOT. The wall is approximately 20 ft tall and employs steel-ribbed reinforcement strips as the reinforcing material. The second wall is located along FM 2524 in Brown County, Texas. This wall also uses steel reinforcement strips and is approximately 23 ft tall in its tallest section. Important differences in the various design and analysis procedures were identified and summarized from these analyses.

Once the analyses were completed for the single-tiered walls, five multi-tiered walls that had been designed and built for TxDOT were identified and selected for further analyses. The original designs for each of these walls were reviewed and additional analyses were performed using various design and analysis procedures. Analyses for both internal and external stability were performed using the MSEW 2.0 and UTEXAS4 software. Based on these analyses, important differences in the analysis procedures were identified and discussed.

The review of existing design procedures revealed that none adequately addresses the design of multi-tiered walls, particularly walls that have more than two tiers. Accordingly, an extensive series of additional parametric studies was performed to develop a set of procedures and guidelines that could be used for design of multi-tiered MSE walls. These additional analyses were all performed using limit equilibrium procedures and the UTEXAS4 software. From the results of these analyses, a set of simple design charts was developed that can be used to determine the required resistance that reinforcement must provide and the minimum lengths of reinforcement required to provide adequate stability of multi-tiered wall systems.

The design procedures that we developed for multi-tiered walls were applied to compute the reinforcement requirements for two walls that were actually designed and built for TxDOT. The two walls are a four-tiered wall located on US 290 in Austin, Texas, and a two-tiered wall with a sloping soil backfill located at the Socorro Bridge on US 375. The design reinforcement requirements computed using the procedures developed in this study were compared to those determined by the original designers and used to build the walls.

What We Found...

The review and analyses of the two single-tiered wall systems in this research revealed that there are significant differences among the various FHWA and AASHTO guidelines and the software that has been developed to implement these guidelines. Aspects in which the various guidelines and software differ include the following:

1. The manner in which the vertical stress on the reinforcement is calculated: this affects the load and pullout resistance of the reinforcement
2. The earth pressure coefficient used to calculate the lateral earth pressures on the wall and reinforcement system
3. The distribution of force and/or resistance along the length of individual layers of reinforcing
4. How the reinforcement force is treated in terms of its contribution to stability when a potential slip surface exits the wall face at the same elevation as the reinforcement
5. The characteristics of the assumed slip surfaces used to calculate internal and/or external stability, including the shape of the slip surface, whether for circles the center point of the circle is allowed to lie below the top of the wall, and to what extent a search is conducted to find the most critical slip surface
6. How the reinforcement force(s) is applied to individual slices when a limit equilibrium procedure of slices is used to compute stability
7. If the reinforcement force is assumed to be in the initial (horizontal) direction of the reinforcement or is assumed to rotate and become closer to tangent to the slip surface
8. How the factor(s) of safety is defined: different definitions of the factor of safety are used in various design procedures and software
9. The manner in which the maximum tension in reinforcement layers is calculated
10. How a sloping backfill is assumed to contribute to stresses on the wall and in the wall backfill
11. The manner in which vertical surcharge loads on the wall backfill, including effects of a sloping backfill, are treated for internal stability
12. The manner in which vertical surcharge loads on the wall backfill, including effects of a sloping backfill, are treated for external stability
13. The manner in which soil in front of an embedded wall is treated in computing stability: this affects the stability in several ways and is not currently treated the same in all approaches.

In some instances the variables and conditions are not stipulated in the guidelines; however, they must be defined in any software or before an analysis can be performed. Depending on the assumptions made by the user or the developer of the software, the resulting designs may differ.

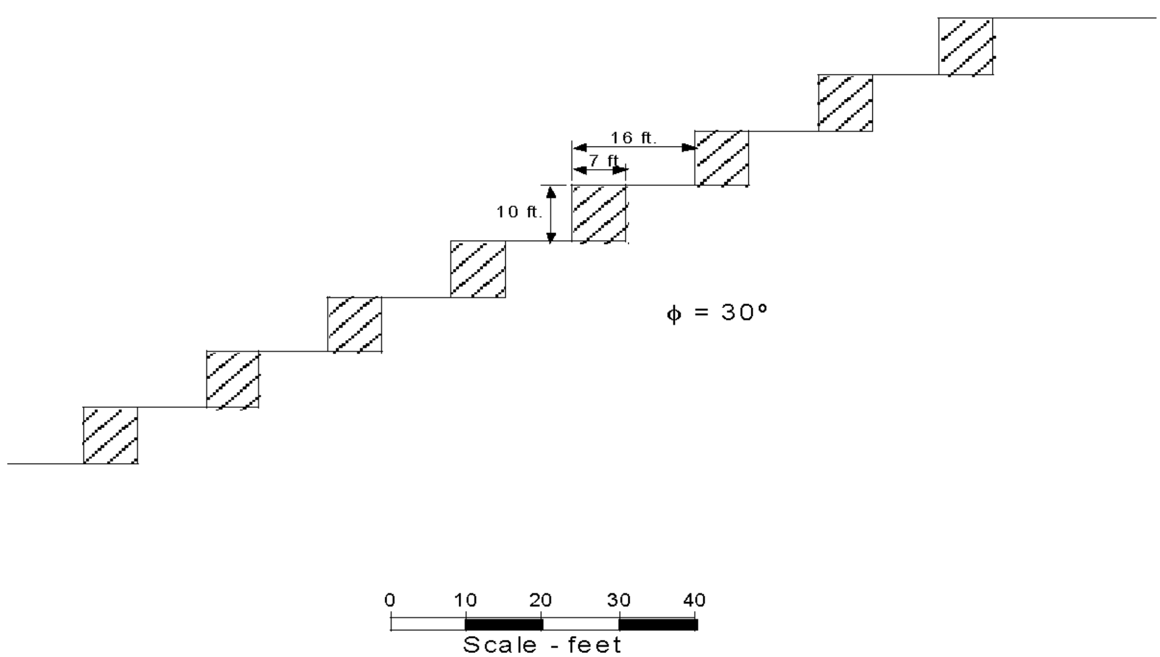

Figure 1 – Example Multi-Tiered Wall System

The review of existing design guidelines and software revealed than none adequately addresses the design of multi-tiered MSE walls, particularly walls that have in excess of two tiers. Our studies do show that the current guidelines for determining when a multi-tiered wall system can be treated as a series of independent single walls rather than as a system of multiple walls are not adequate for wall systems with more than two tiers. For example, the walls in the eight-tier wall system illustrated in Figure 1 would be considered as eight, isolated individual walls according to current FHWA criteria for multi-tiered walls. However, analyses show that the eight-tier wall system should be analyzed as a multi-tiered wall system and cannot be treated as eight isolated walls.

Because there are no guidelines or standards for design of walls with more than two tiers, each designer chooses his own particular approach, and it is difficult to compare and evaluate what has been done. All of the MSE walls designed and built for TxDOT that were examined in this research appear to have performed well. Thus, it is not possible to identify how well the design procedures themselves work, necessarily, except to indicate that the design procedure has apparently resulted in designs that have not yet failed. It cannot be determined if the designs are only marginally adequate or are excessively conservative and, thus, more costly than necessary.

Based on a number of analyses of various multi-tiered wall systems, relatively simple design charts were developed. The charts rely on establishing dimensionless parameters that can be used to calculate the required reinforcement forces and the required lengths of the reinforcement for the wall system. The required reinforcement forces depend on the shear strength and unit weight of the reinforced soil backfill, the relative offset of each wall tier from the immediate underlying tier, and the wall height. Given this information, a simple calculation can be made to determine the total required reinforcement force. Similarly, the length of reinforcement required for each tier of the wall system can be determined.

The design charts developed in this project are restricted to multi-tiered wall systems where each tier is approximately the same height and the offsets between tiers are the same for all tiers. For cases where the wall heights or offsets vary, additional procedures are presented in our report for determining the required reinforcement using conventional limit equilibrium slope stability analysis procedures. While these procedures for variable wall heights and/or wall offsets require somewhat more effort, the procedures are straightforward.

The design procedures developed in this research were applied to determine the required reinforcement for two actual MSE walls designed and built for TxDOT. The required reinforcement determined using the procedures developed in this study was then compared to what was actually used for the design. While the reinforcement requirements were similar in both approaches, the procedures developed in this research generally indicated somewhat greater reinforcement lengths were required for the lowest level of reinforcement. Such longer lengths are believed to be warranted and are recommended.

The Researchers Recommend...

The design guidelines and procedures developed in this research are recommended for use in design of multi-tiered MSE walls. The current AASHTO and FHWA guidelines only address single-tiered walls and, thus, should not be used for walls with more than two-tiers. In addition, the guidelines for determining when a multi-tiered wall can be treated as a series of independent single-tiered walls should not be used for walls of more than two tiers.

Most of the analyses of both hypothetical and actual walls performed for this study showed that global stability where the potential slip surface passes either partially or entirely outside the reinforced soil mass is a critical mode of failure and should always be investigated as part of any wall design. Global stability is also particularly important for multi-tiered wall systems.

The design of any multi-tiered MSE retaining wall system should be preceded by a thorough geotechnical site investigation to define the soil conditions beneath and behind the proposed wall system. The investigation should include characterization of both the drained and undrained shear strength properties of the soils involved, and subsequent analyses should address stability for both drained and undrained loading conditions. In addition, the groundwater and seepage conditions for both short-term and long-term conditions should be firmly established. This should include potential seepage conditions associated with planned roadway and bridge construction and should address how drainage will be handled. No retaining wall design should be undertaken without knowledge of the subsurface foundation and groundwater conditions. The writer is aware of numerous failures of MSE walls and most have been caused by either groundwater or adverse soil conditions behind and beneath the walls. Thus, the importance of these aspects in the design cannot be overstated.

For More Details...

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The research is documented in the following reports:

0-4485-1, *An Examination of Design Procedures for Single- and Multi-tier Mechanically Stabilized Earth Walls*

0-4485-2, *Design Guidelines for Multi-tiered MSE Walls*

To obtain copies of a report: CTR Library, Center for Transportation Research,
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