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Effect of reinforcement type on the design reinforcement length of mechanically stabilized earth walls

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ABSTRACT

This paper presents the results of a parametric study conducted to investigate the effect of different reinforcement types on required minimum reinforcement length and governing design criteria of mechanically stabilized earth walls. There are several reinforcement types with varying properties used in these walls. The reinforcement should be long enough to satisfy both external and internal stability criteria. The minimum reinforcement length criteria vary throughout the world; however most specifications and guidelines require that minimum length should be equal to 70% of wall height. A natural rock formation behind the wall or manmade shoring system may cause limitations on the reinforcement length. The focus of this paper is to investigate the required minimum reinforcement length and the criteria governing the design length for four different reinforcement types; geogrids, geotextiles, metal strips, and metal bar mats. Effect of different parameters on the required minimum reinforcement length and the governing design criteria were investigated for these four reinforcement types. The parameters considered included wall height, surcharge, reinforcement vertical spacing, reinforced soil properties, backfill/retained soil properties, and foundation soil properties. The results indicate that, depending on the parameters involved, the reinforcement type can affect both the required reinforcement length and the governing design criteria. The study also shows that reinforcement lengths shorter than 70% of wall height, as low as 50%, are possible in some cases. Among the four reinforcement types considered, the metal strips usually require the longest lengths; however, it is possible to reduce the required minimum reinforcement lengths of the metal strips by increasing the coverage ratio.

1. Introduction

The use of mechanically stabilized earth (MSE) walls has increased tremendously since 1970s and they became the most common wall type preferred, especially for transportation projects, because of their rapid construction, cost-effectiveness, aesthetics, reliability, durability, simple construction techniques, good seismic performance, and ability to tolerate large deformations without structural distress [1–6]. Stuedlein et al. [7] reported the overall performance of a 46-m-high MSE wall observed through detailed geotechnical instrumentation as excellent. Several MSE wall examples are shown in Fig. 1.

The materials used in MSE walls have been evolving over the years. Geogrids, geotextiles, metal strips, and metal bar mats are the most common reinforcement types used in MSE walls. The minimum reinforcement length, L_{min}, specified or recommended by specifications and guidelines among various countries ranges between 0.5H and 0.8H, where H is the wall height [1]. In the United States, American Association of State Highway and Transportation Officials (AASHTO) [8] specifications require minimum reinforcement length of approximately 70% of the wall height and not less than 2.4 m. National Concrete Masonry Association (NCMA) [9] design manual requires minimum reinforcement length of 0.6H, which is an empirical constraint to prevent wall construction in limited spaces. British Standard BS8006 [10] requires that minimum reinforcement length for walls with normal retaining function should be maximum of 0.7H and 3.0 m. Liu and Evett [11] specifies 0.8H for overall stability. Leshchinsky et al. [12] and Lawson and Yee [13] suggested anchoring the rear end of reinforcements to develop its tensile resistance for MSE walls with limited spaces for reinforcement. Earlier studies reported that reinforcement length affects wall lateral displacements and deformations increase as the reinforcement length decreases [14–17]. Several other studies showed that there is a certain reinforcement length needed to maintain the wall stability, and shorter lengths require higher tensile resistance of reinforcement [18,19]. Han and Leshchinsky [20] analyzed the behavior of back-to-back MSE walls to understand their interaction. Abdelouhab et al. [21] investigated the behavior

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Fig. 1. Several constructed MSE wall examples.

of MSE walls reinforced with different types of strips using numerical analysis.

The current minimum reinforcement length range of 0.5–0.8*H* used by various countries is a very wide range. There is a 60% difference between the lower and upper values. The reasons behind these recommended reinforcement lengths are not clearly stated in these guidelines. The increased use of MSE walls and their construction in places where the space behind the wall is limited require better understanding and quantifying the effects of reinforcement type and various factors on the reinforcement length. This will help engineers with the selection of materials, preparation of specifications, and design of MSE walls.

The objective of this paper is to present the effect of reinforcement type on the required minimum reinforcement length and the governing design criteria for MSE walls under varying conditions. The most commonly used reinforcement types, geogrids, geotextiles, metal strips (ribbed), and metal bar mats, are studied for varying wall height, surcharge, reinforcement vertical spacing, reinforced soil properties, retained/backfill soil properties, and foundation soil properties. The required minimum reinforcement length for MSE walls with different reinforcement types, varying soil conditions, and wall configurations are presented. The governing design criteria in determining the required minimum reinforcement length for these conditions are also presented. The findings of this paper will aid engineers in understanding the effect of reinforcement type on the required minimum reinforcement length and the governing design criteria in determining this length. The results of the parametric study obtained by using wide range of soil properties and wall configurations can be utilized during the design of MSE walls. The findings of the study are greatly beneficial especially when there is a limited space behind the wall and the use of common reinforcement length of 0.7*H* is not feasible.

2. Current MSE wall design practice

Although continuum mechanics numerical methods have been used by researchers to study MSE wall behavior under static and dynamic loading conditions [14–16,18,22–28], current common design practice of MSE walls is based on coherent gravity and lateral earth pressure approach. Current specifications and guidelines used for the design of MSE walls have two primary design requirements: external stability and internal stability. External stability considers the reinforced soil mass as a rigid body subject to lateral earth pressures from backfill/retained soil and surcharge loads. Internal stability considers the position and strength of reinforcement within the reinforced soil mass [29].

The external stability failure modes considered in the design include sliding, overturning, eccentricity, bearing capacity, settlement, and global failures. The overturning and eccentricity are mutually dependent. The eccentricity is usually used because the overturning of MSE walls are not realistic. The bearing capacity and settlement failure modes also depend on each other. The settlements are not considered in this study, because the walls that are designed properly by considering the bearing capacity and eccentricity failure modes have limited settlements. In addition, remedial measures utilized to limit/reduce settlements are independent of the reinforcement length [2]. The global failure mode is not considered in this study either, however type of retained soil, foundation soil, wall geometry, backslope, and heavy loading conditions may affect the global stability and should be considered during the design of MSE walls.

The internal stability modes include pullout and rupture failures of reinforcement. The reinforcement length, position, and strength are determined such that the wall design will satisfy all the stability modes with the required minimum safety factors given in the specifications and guidelines. The minimum safety factors used in this study are given in Table 1. These safety factors were compiled from the AASHTO [8] specifications and National Concrete Masonry Association [9] design guidelines.

3. Minimum design reinforcement length

The reinforced soil zone is assumed to behave as one rigid unit for the external stability analysis. Therefore, the failure mechanisms used for conventional gravity retaining walls also apply to the external stability analysis of MSE walls. A schematic of a typical MSE wall and forces acting on the wall used for external stability analysis are shown in Fig. 2. The analysis and results presented