Parametric Study of Mechanically Stabilized Earth Wall Using GEO 5

V. S. Krishnapriya, Swetha Maria Charles, Sharon Shogu, T. C. Nithul, and K. Panjami

Abstract A mechanically stabilized earth (MSE) wall is an engineered system consisting of alternating layers of soil reinforcement and compacted backfill material fixed to the wall facing and supported on a foundation. The present study is focused on parametric analysis of MSE walls using an analytical method, GEO5 MSE to determine the factor of safety of the wall. The factor of safety of a 10 m high MSE wall was computed with respect to varying environments of backfill soil, the length of reinforcement to height of the wall (L/H), reinforcement characteristic strength and spacing of reinforcement. This study mainly focuses on finding out how variations in the factors affect the behaviour of the wall and its factor of safety. It was observed that improvement in the angle of friction leads to an increase the factor of safety. It was also noted that, increase in L/H ratio from 0.4 to 1.0 showed an increase in factor of safety by 15.92% and increase in reinforcement spacing from 0.2 m to 1 m showed a decrease in factor of safety by 74.52%. Factor of safety was also found to increase with an increase in characteristic strength of embedded reinforcement. From the parametric analysis, MSE walls were developed to replace the failed retaining walls at various locations in India.

Keywords MSE retaining wall · Factor of safety · Reinforcement · GEO5

1 Introduction

Conventional retaining structures were made from concrete and were designed as gravity or cantilever walls which are essentially rigid structures and cannot accommodate significant differential settlements unless founded on deep foundations. With increasing height of soil to be retained and poor subsoil conditions, the cost of reinforced concrete retaining walls increases rapidly and structures try to

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overturn due to the earth pressure. In order to deal with this problem Mechanically Stabilized Earth Technique is employed [1].

French engineer Henri Vidal invented the modern form of MSE, termed Terre Armee (reinforced earth) using reinforcements made of steel strips in the 1960s. Since the 1980s the development of reinforced soil has been considerable using a range of construction forms and reinforcements including metallic and polymeric anchors, strips and grids.

The first contemporary forms of MSE walls were constructed in Europe in the late 1960s.

A mechanically stabilized earth (MSE) wall is a composite system consisting of soil reinforcement in the form of steel strips or bars, welded wire mats or geotextile sheets, backfill material which acts as a retaining structure, a facing element in the form of precast concrete panels, dry cast modular blocks and panels, and wrapped sheets of geosynthetics which acts as a supporting system and a foundation. In the construction of MSE wall, reinforcements are placed in layers in the backfill soil, and this reinforced mass resists the earth pressure caused by the retained soil using the relative motion between reinforcement and soil. Tensile capacity is built in the soil through friction and confinement by interaction between steel or synthetic reinforcing elements and soil. This combination of soil and reinforcement combine their best characteristics and behave as a gravity mass and resist lateral earth pressure [1].

Mechanically stabilized earth (MSE) retaining walls are the foremost suitable design alternatives to the traditional retaining walls because of their simple, rapid and cost-effective construction, reduced right-of-way acquisition and can bear large settlements compared to conventional concrete retaining walls [1]. They have a wide range of applications which are bridge abutments, overpasses and underpasses for conveyors, roadways, railways, vertical walls, ramps and steepened slopes for haul roads, highways and railways. The ability of MSE walls to withstand extreme settlement and seismic forces has increased its usage. Various methods are available for the analysis and design of an MSE wall. Analytical methods of analysis include Limit Equilibrium analysis like Bishop, Spencer etc. and finite element analysis are done with the help of computer programs like PLAXIS, GEO5 etc.

The present study is concentrated on parametric sensitivity analysis of MSE walls employing an analytical method, which uses the GEO5 MSE to work out the factor of safety of the wall. The MSE walls have been analyzed for horizontal and vertical movements with respect to length of the reinforcement, type of soil, height of wall and type of reinforcement. External stability analysis have also been executed for the overturning, sliding and bearing capacity. This study mainly focuses on the factors affecting the wall and its effect on the factor of safety of the wall.

2 Design Concept of MSE Wall

Ultimate limit state and serviceability limit states are the two limit states considered in the design of Mechanically Stabilised Earth walls. The stability of the MSE structures is checked for two conditions: External stability and Internal stability. Internal and external stability of MSE walls depend upon interaction between the backfill soil and reinforcement, reinforcement characteristic strength and vertical spacing. When determining internal stability, the strength of the reinforcement and its interrelation to the facing, as well as its pullout resistive length are checked. When determining external stability, the reinforced soil mass subjected to loading exerted by the retained soil is taken as a coherent mass, and implicitly treated as a rigid body [1, 2]. The fundamental mechanisms of mechanically stabilized earth and reinforced concrete are alike.

2.1 Methodology

The basic structure of the MSE wall is modelled using GEO5 MSE with the required specifications, which includes the height of blocks and the number of blocks required. Specifications of various soils are entered and assigned to the respective interfaces. Reinforcements are selected and are provided as per the specified length and spacing between them. Surcharge of required magnitude is provided at the top of the fill. Analysis is performed and stability is checked to obtain the factor of safety (see Fig. 1).

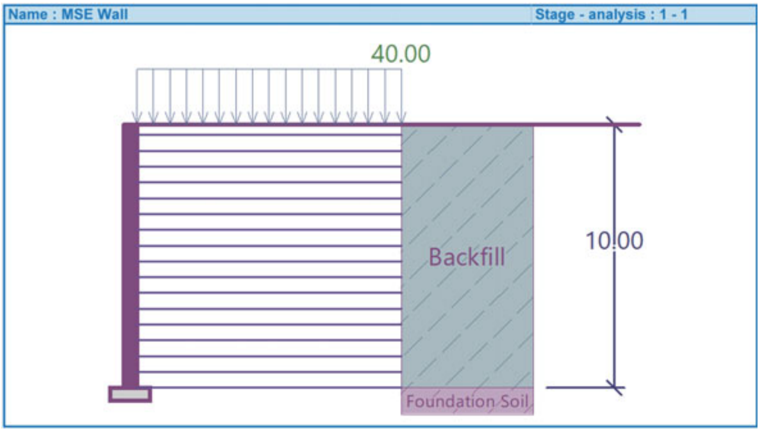

Fig. 1 MSE wall used in modelling

3 Modelling of MSE Wall

An MSE Wall was modelled to check the influence of various parameters on the factor of safety of the MSE Wall. Tables 1 and 2 lists the geometrical and soil properties that were used for modelling the MSE wall using Mohr Coulomb method. The 10 m high MSE wall was provided with a 0.5 m thick facing of standard concrete. Granular soil was proposed in the design of backfill material as high soil content can lead to drainage problems and thus failure. Geogrid of 10 m length was provided as reinforcement (see Fig. 1).

4 Results and Discussion

Four important parameters were chosen to study its effect on the factor of safety of an MSE wall and they are reinforcement characteristic strength, reinforcement spacing, type of backfill soil and L/H ratio. Influences of these parameters are as mentioned below.

4.1 Effect of Reinforcement Characteristic Strength on Factor of Safety

Geogrids are used in the construction of retaining walls and soil slopes. It reinforces the soil by containing the lateral earth pressures. They are manufactured from high quality HDPE which is non-biodegradable and resistant to soil chemicals [2]. Characteristic strength of the reinforcement used varied from 13.24 to 43.59 kN/m

Table 1 Properties of MSE wall

Properties	Values
Height of wall (m)	10
Thickness of facing panel (m)	0.1
Reinforcement characteristic strength (kN/m)	43.59
Length of reinforcement (m)	10

Table 2 Properties of soil at site

Properties	Weathered rock	Reinforced fill
Unit weight (kN/m^3)	20	19
Cohesion (MPa)	20	–
Friction angle (°)	40	35
Elastic modulus (MPa)	100	80
Poisson’s ratio	0.2	0.3

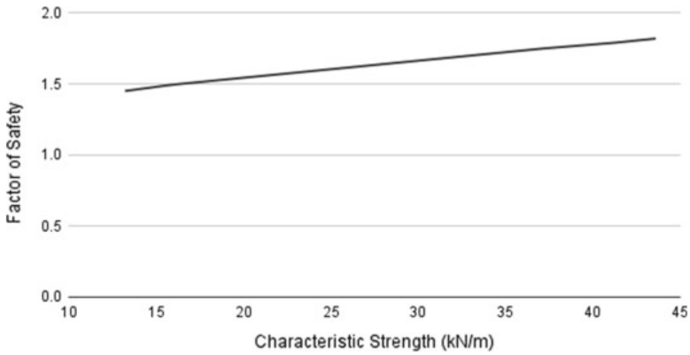

Fig. 2 Factor of safety versus characteristic strength

Table 3 Factor of safety with respect to reinforcement characteristic strength

Characteristic strength (kN/m)	Factor of safety
13.24	1.45
15.67	1.5
16.4	1.75
37.16	1.79
41.19	1.49
43.59	1.82

and the highest factor of safety of 1.82 was seen for geogrid having 43.59 kN/m as the characteristic strength which makes it a good choice of reinforcement (see Fig. 2). Reinforcements of characteristic strengths 13.24, 16.40, 37.16, 41.19, 15.67 and 43.59 kN/m were used to analyse the wall to obtain the corresponding factor of safety (Table 3).

4.2 *Effect of Reinforcement Spacing on Factor of Safety*

The reinforcement spacing was identified as a major factor controlling the behavior of MSE Walls. Two types of spacing were considered in studying the effects of spacing: small (less than or equal to 0.4 m) and large (larger than 0.4 m). Increasing reinforcement spacing decreased the factor of safety (see Fig. 3). A reinforcement spacing of 0.1–1 m was provided along the length of the wall and it was seen that as spacing increased, the factor of safety decreased making 0.5 m of reinforcement spacing an affordable option in this case considering the economic point of view [2] (Table 4).

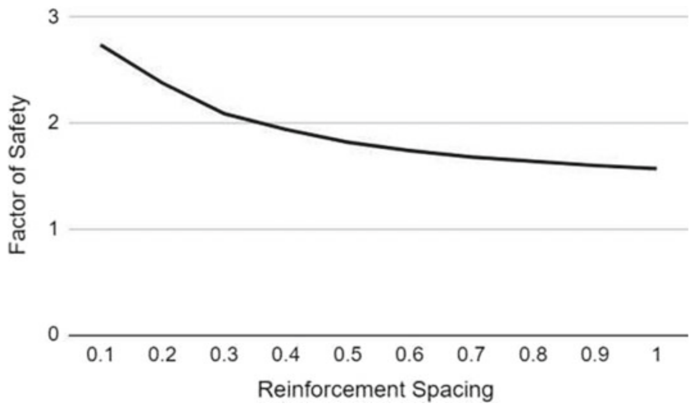

Fig. 3 Factor of safety versus reinforcement spacing

Table 4 Factor of safety with respect to reinforcement spacing

Reinforcement spacing (m)	Factor of safety
0.2	2.38
0.4	1.94
0.6	1.74
0.8	1.64
1	1.57

4.3 Effect of Backfill Soil on Factor of Safety

Stability of an MSE wall is dependent on the shear strength properties of the backfill soil [3] and shear strength is described as a function of Cohesion(c) and Angle of internal friction (φ).Therefore, these two physical parameters play an important role in the stability of an MSE wall. Cohesion is a force that holds like particles together and angle of internal friction is the capability of soil to withstand shear stress. Change in environmental factors can affect cohesive property of soil and they are poorly drained, thus it isn't desirable.

Characteristics of the backfill are as represented in Table 5. It was found that as the friction angle increases, the factor of safety increases whereas cohesion beyond a certain limit could lead to failure of the wall. Example: Soil 3 and Soil 4 though having an angle of internal friction of 34° but shows a variation in the factor of safety. This variation in factor of safety is due to the presence of a cohesive force of 1 MPa in soil 4 whereas cohesive force in soil 3 is zero (see Fig. 4) which implies that presence of cohesive force can affect the factor of safety of the Mechanically Stabilized Earth wall.

From the analysis, it can be inferred that soils with better internal friction contribute to the stability of MSE walls, on the other hand cohesive soils can reduce the factor of Safety [4].

Table 5 Factor of safety with respect to backfill parameter

Material	Unit weight (kN/m^3)	Cohesion (MPa)	Friction angle (°)	Elastic modulus (MPa)	Poisson's ratio	F.O.S
Soil 1	18	–	25	60	0.33	1.82
Soil 2	17	–	30	60	0.33	2.01
Soil 3	15	–	34	60	0.33	2.21
Soil 4	18.88	1	34	12.5	0.32	2.06
Soil 5	18	–	30	60	0.32	1.97
Soil 6	19	–	28	60	0.32	1.88
Soil 7	20.3	–	25	60	0.32	1.75
Soil 8	18.88	1	30	10	0.3	1.97
Soil 9	20	10	30	60	0.3	2.01

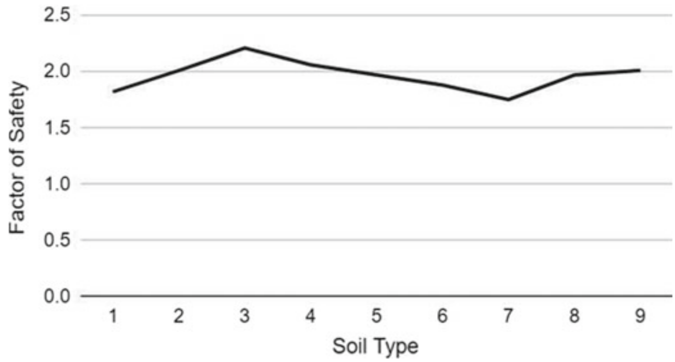

Fig. 4 Factor of safety versus soil type

4.4 Effect of Ratio of Length of Reinforcement to the Height of the Wall on Factor of Safety

Many agencies restrict the length of reinforcement as 0.7 times the height of the wall [5, 6]. However, these restrictions are not followed everywhere. Therefore an analysis was carried out to study the variation in factor of safety with respect to the length of reinforcement to height of the wall (L/H). The L/H ratio was considered and values from 0.4 to 1 were taken by referring to the literature review and the corresponding factor of safety values was obtained. An L/H of 1 gave the highest value of factor of safety of 1.82 (see Fig. 5). It can be inferred that with an increase in the L/H ratio, the factor of safety increases thereby improving the performance of the MSE wall (Table 6).

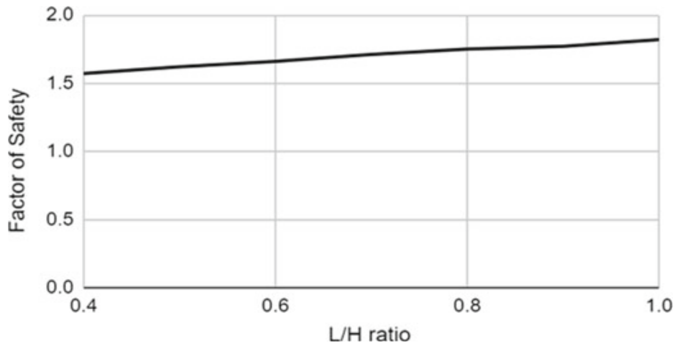

Fig. 5 Factor of safety versus L/H

Table 6 Factor of safety with respect to L/H

L/H	Factor of safety
0.4	1.57
0.5	1.62
0.6	1.66
0.7	1.71
0.8	1.75
0.9	1.77
1	1.82

5 Rehabilitation of Failed Retaining Walls

Retaining walls fail due to improper design, lack of proper reinforcement, insufficient drainage, expansion of soil, overloading etc. Analysis of the retaining walls as mentioned below using GEO5 gave a factor of safety below the prescribed limit whereas an MSE wall gave a satisfactory result which implies that construction of an MSE Wall could have been a better alternative instead of a retaining wall.

CASE 1: Retaining wall at Dwarakanagar, Visakhapatnam

The retaining wall of a multi storeyed building located at Dwarakanagar, Visakhapatnam failed on 3rd November, 2012. Severe cracks were formed around the corner. The wall was about 6.1 m high. The subsoil profile at the site consisted of 4.5 m deep yellowish brown clayey soil with a cohesion value (C) of 5 kN/m^2 and an internal friction (ϕ) of 35°. Backfill soil belonged to the IS classification SC. The retaining wall produced a factor of safety of 1.33 [7]. Since the obtained factor of safety was less than the permissible limit of 1.5, it was planned to replace the retaining wall with an MSE wall using a reinforcement having characteristic strength of 43.59 kN/m with a spacing of 0.5 m and L/H ratio of 0.5. A factor of Safety of 1.92 was obtained after analysis.

CASE 2: Retaining wall at Bypass road in India

Geotechnical investigations on retaining walls located at a bypass road in India showed clear signs of distress immediately after completion of the work and hence it couldn't be opened for the public. Cracks were visible on the pavement and this was due to excessive vertical settlement and lateral displacement. The wall considered was approximately 11.8 m high. Analysis of the retaining wall showed that the factor of safety of the wall was 1.05, making it unsafe for use [8]. As a rehabilitation measure, replacement of the retaining wall with an MSE wall of 11.8 m high with a reinforcement length of 11.8 m and spacing of 0.5 m gave a factor of safety of 1.54.

6 Conclusions

This paper summarises the analysis of a mechanically stabilized earth wall considering four of its parameters. The four parameters used for this study were the reinforcement spacing, reinforcement characteristic strength, L/H ratio and the backfill soil parameters. The various parameters were used in the GEO5 MSE software to find out the factor of safety accordingly and results were obtained.

The spacing of reinforcements differed from 0.2 m to 1 m which showed a decrease in factor of Safety by 74.52%. The characteristic strength of reinforcement were varied from 13.24 to 43.59 kN/m and a factor of safety above 1.5 was observed. Variation in L/H ratio of reinforcements from 0.4 to 1 showed an increase in factor of safety by 15.92%. Type of soil on the basis of its cohesiveness and angle of internal friction had a great influence on the factor of safety. MSE walls with appropriate dimensions were suggested at the end of the paper to replace two failed retaining walls of India.

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