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RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

# Analysis of Mechanically Stabilised Earth (MSE) Retaining Wall using Finite Element and AASHTO Methods

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**Abstract:**. **Introduction.** For the quick and accurate analysis and design of MSE walls, many methods are available. Some of the standard methods are as follows: analytical method of analyses which include the BS, FHWA-NHI, AASHTO recommendations, Limit equilibrium analysis (Bishop's, Spencer, Janbu etc.), Finite element (FE) analysis using computer programs like PLAXIS, GEO5, GEOSTASE etc. and finite difference analysis using computer programs such as FLAC 2D. As per the review of literature, the finite element and finite difference methods of analysis are more accurate and convenient than the analytical, limit equilibrium and other methods. Discrepancies in analytical and limit equilibrium methods are due to different underlying assumptions associated with these methods and different standards of recommendations. **Methodology.** The present study is focused on parametric sensitivity analysis of MSE walls using a numerical model, which uses the finite element method (FEM) to determine the factors of safety of the wall and its comparison with the analytical methods. The finite element computer program, GEO5 FEM is used to develop the numerical model and the GEO5 MSE (as per AASHTO) is used for the analytical method. The MSE walls have been analysed for horizontal and vertical movements with respect to length of the reinforcement. External stability analyses have also been carried out for the overturning, sliding and bearing capacity, for three different soil types. Geogrid reinforcements are checked for the factor of safety with respect to pullout resistance and tensile strength and against the height of the wall for three different backfill soils. The global factors of safety obtained from the FEM and AASHTO method for three different soils with different lengths of the reinforcement are compared with each other. **Results and Conclusions**. The study shows, horizontal and vertical movements of MSE wall decreases, as the length of the reinforcement increases. Also, from this study it is found that, as the length of the reinforcement, cohesion and angle of internal friction increases the FOS for internal, external and global stability increases. From the results of analytical analysis, Factor of safety for pullout resistance and tensile strength increases as the height of the wall increases. From FEM and AASHTO methods, FEM gives little higher factor of safety than AASHTO method. This is because of discretization of single structure in to number of nodes, element and regions. So, it gives more convenient results than other methods. Based on the comparison, it is noted that both the analyses have provided the acceptable range of safety values and are in good agreement.

**Keywords:** MSE retaining wall, Reinforcement, Finite element analysis (FEA), Analytical method, Stability, Wall movement, Factor of safety.

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## 1. Introduction

**Reinforced Earth**.

Soil is a most widely used construction material, which is strong in compression and very weak in tension and similarly the steel is widely used as reinforcing material in almost of all civil engineering infrastructure projects which is very strong in tensile strength. Hence the combination of both these soil and reinforcement will a very good engineering property than properties of an individual materials. So, by observing all the above conditions a French engineer Henry Vidal proposed a theory called Mechanically Stabilized Earth (MSE) in the year 1963. Later at the invitation of the Federal Highway Administration (FHWA-NH-10-024), reinforced earth structures with their inextensible (steel) reinforcements were introduced in the United States in 1971 [1]. Basically, reinforced soil section has two components which are earth/soil and reinforcement with different properties but basic concept is that the embedded reinforcement in soil provides tensile strength to the soil it is because of higher stiffness of the reinforcement. The basic mechanism of MSE is, while reinforcement is in the soil system the friction is formed between them and due to this friction soil movement is hold on the surface of reinforcement and then the shear stress is developed which produces tension in reinforcement which leads to confinement to the soil and results in decrease in soil deformation and increase in shear strength of the soil.

**Design of MSE Wall**

The design of MSE retaining structure mainly involves the following basic and important components, which are backfill, retained fill, foundation soil, reinforcing material, facing panels if required. Some of the recommended properties by AASHTO, FHWA, NCMA and BS are, length of the reinforcement should be less than or equal to 0.6 to 0.7 times of height of the wall, backfill material should be free draining and should not contain any organic substances. Generally the backfill used in MSE structure is critical to their overall performance so to meet the performance requirements, MSE structure backfill is specified by AASHTO, FHWA, NCMA and BS are as granular material with a 100 mm maximum size and less than 15 % fines with assumed unit weight of 20 $kN/m^3$ and maximum friction angle is of $34^0$ similarly retained fill with unit weight of 20 $kN/m^3$ and maximum friction angle of $30^0$ and foundation soil with maximum friction angle of $30^0$ are preferred [1]. The reinforcements used in design are metallic strips, geogrids, wire grids etc and facing panels are provided to prevent erosion of soil at the face of the wall which are of different types and sizes. The design of a mechanically stabilized earth (MSE) retaining wall includes analysis of internal, external and global stabilities as well as horizontal and vertical wall movements [2]. In these three parameters, the internal stability of MSE wall by means of pullout resistance and tensile strength of the reinforcement mainly depends on type of reinforcement, spacing and length of the reinforcement. Similarly, the external stabilities by means of failure modes such as sliding, overturning, wall bearing and global stability failure. Hence these both internal and external failure modes are considered as slope failure through sliding surfaces, and the overall stability of an MSE wall can be determined by using slope stability analysis.

**Review on Numerical and Analytical studies**

Some of the important previous studies related to numerical and analytical analysis of MSE wall are discussed here. Adis Skejic et al. (2013) conducted experimental test of MSE wall under applied over burden load to examine the behavior of MSE wall with inextensible inclusions. Results were in good agreement with measured values obtained on the test wall using FEM programme PLAXIS. Results were compared with test wall and observed that the mismatch between measured and predicted horizontal displacements in first phase of surcharge load application because of inadequate soil constitutive model [3]. Golam Kibria, et al. (2014) conducted a series of numerical analysis tests on a MSE retaining wall to simulate the horizontal movement and stability of the MSE wall using FEM programme PLAXIS- 2D. From test results, understood that the horizontal displacement of wall is decreased and stability is increased with an increase in reinforcement stiffness, length and friction angle of backfill soil at a fixed wall height [6].

**Key Importance of the study**

MSE walls are more economical than conventional retaining wall. During earthquakes, these walls are more sustainable because of their flexibility. In recent years, many MSE wall failure cases have been observed because of insufficient knowledge about wall design and analysis. So, it is very important to understand the behavior of MSE wall with respect to various aspects, such as internal and external stability analysis. With this aim, present study is carried out to analyze the behavior of MSE wall for reinforcement lengths and backfill soil properties. The wall deformations, factor of safety checks are determined which are very much essential for wall analysis. Before, planning this kind of structure, one can do systematic analysis based on the present study.

**Impact/Benefit of the study**

Analysis of MSE wall using different methods help wall designers, to decide the dimensions and properties of wall. With proper analysis of wall, one can predict its behavior in advance for different properties of backfill soil and reinforcements. Failures of MSE walls can be minimized tremendously by this kind of analyses.

## 2 Analysis of MSE Wall Using Finite Element and AASHTO Method

### 2.1 Numerical Modelling Using GEO5 FEM

This section deals with the parametric study of a 4-m height MSE retaining wall. The wall is modelled using finite element programme GEO FEM for three different types of soils and three different lengths of reinforcements. Wall geometry and properties of soils as well as details of reinforcements are given in Table 1 and 2. A 4-meter height MSE wall is completely analysed using finite element method. In the finite element analysis, the MSE wall is discretized into 1678 nodes and 1004 elements (448 regions, 139 beams, 417 interfaces) as shown in Figure 1. The results obtained from FE analysis are vertical and horizontal wall movements and over all factor of safety of wall.

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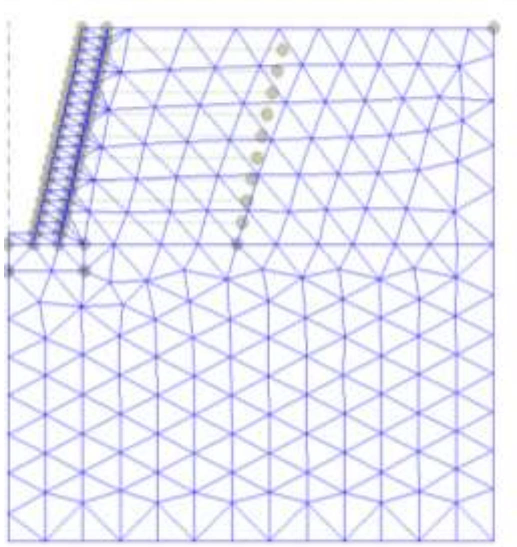

**Figure. 1.** Discretized MSE wall (Meshing)

**Table 1.** Geometry of wall

| Sl No | Properties | Values |
|---|---|---|
| 1 | Height of the wall | 4 |
| 2 | Type of facing panels | Modular concrete blocks |
| 3 | Number of facing panels | 20 |
| 4 | Width of facing panels | 0.5 |
| 5 | Height of facing panels | 0.2 |
| 6 | Offset for facing panels | 0.05 |
| 7 | Height of foundation | 0.5 |
| 8 | Width of foundation | 1.5 |
| 9 | Offset for foundation | 0.5 |

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**Table 2.** Properties of different soil and reinforcement

| SI No | Properties | Soil - 1 | Soil - 2 | Soil - 3 |
|---|---|---|---|---|
| 1 | Soil type (for both backfill and foundation soils) | Silty - Gravel | Clayey-Gravel | Clayey-Gravel |
| 2 | Unit weight (kN/m$^3$) | 20 | 21 | 22 |
| 3 | Cohesion (kPa) | 10 | 12 | 14 |
| 4 | Angle of internal friction | 30$^0$ | 32$^0$ | 34 |
| 5 | Angle of friction soil-structure | 10$^0$ | 8$^0$ | 10$^0$ |
| 6 | Saturated unit weight (kN/m$^3$) | 20 | 21 | 22 |
| 7 | Type surcharge | UDL on Surface | UDL on Surface | UDL on Surface |
| 8 | Magnitude of surcharge (kN/m$^2$) | 40 | 40 | 40 |
| 9 | Type of reinforcement | Geogrid | Geogrid | Geogrid |
| 10 | Length of reinforcement (meters) | 2.8, 3, 3.5 | 2.8, 3, 3.5 | 2.8, 3, 3.5 |

**Results and Summary**

In this section, results of completely analysed MSE wall are summarised. A 4-meter height wall is modelled for three types of soils and with three different lengths of reinforcements. Figure 2 and 3, shows the Finite Element model of MSE wall subjected to horizontal and vertical movement, for a soil type-1, with length of reinforcement as 2.8m.

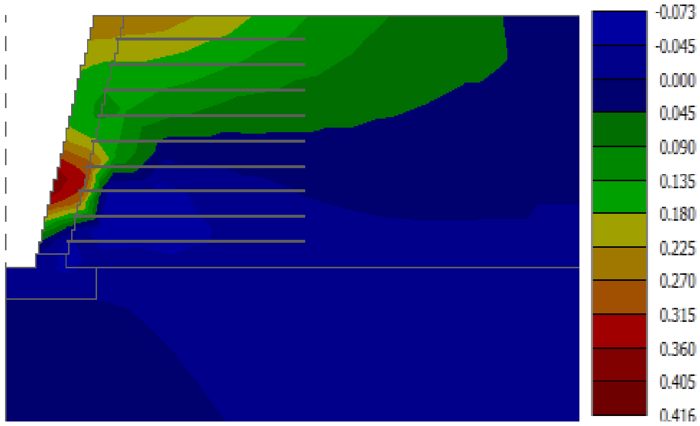


**Figure. 2.** Horizontal wall movement for soil-1, L= 2.8 m

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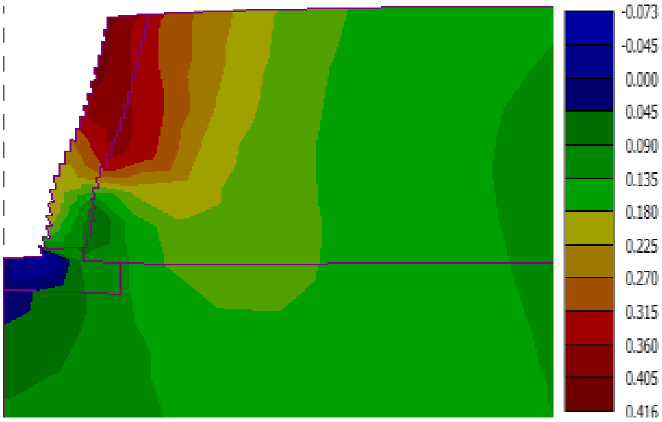


**Figure. 3.** Vertical wall movement for soil -1, L= 2.8 m

For type-1 soil maximum horizontal wall movements for reinforcement lengths 2.8, 3, 3.5 meters are 0.416, 0.308, 0.308 meters respectively and vertical wall movements are 0.405, 0.338, 0.338 meters respectively (shown in Figure. 4) and factor of safety for same soil and reinforcements are 1.57, 1.63, 1.71 respectively.

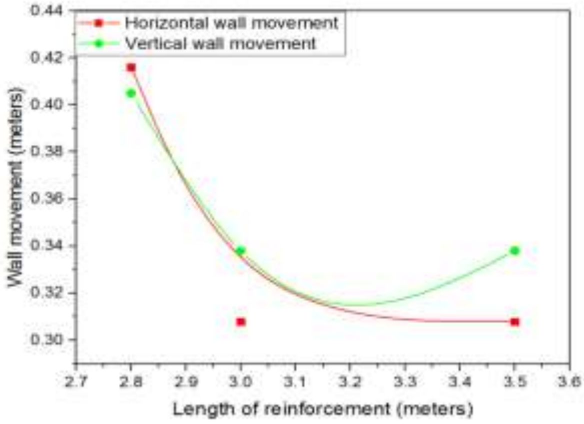


**Figure. 4.** Horizontal and Vertical wall movement for soil type-1

and for type-2 soil maximum horizontal wall movements for reinforcement lengths 2.8, 3, 3.5 meters are 0.318, 0.282, 0.075 meters respectively and vertical wall movements are 0.324, 0.308, 0.160 meters respectively (shown in Figure. 5) and factor of safety for same soil and reinforcements are 1.74, 1.74, 1.86 respectively.

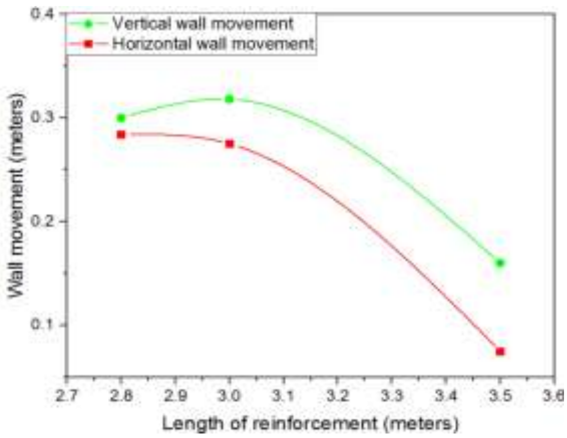


**Figure. 5.** Horizontal and Vertical wall movement for soil type-2

Similarly, for type-3 soil, maximum horizontal walls movements for reinforcement lengths 2.8, 3, 3.5 meters are 0.190, 0.136, 0.134 meters respectively and vertical wall movements are 0.262, 0.194, 0.194 meters respectively (shown in Figure.6) and factor of safety for same soil and reinforcements are 1.85, 1.85, 2.1 respectively. All the results show that, the movement will be decreases as the length of reinforcement increases with increase in cohesion, angle of internal friction and length of reinforcement. These results were compared with analytical method.

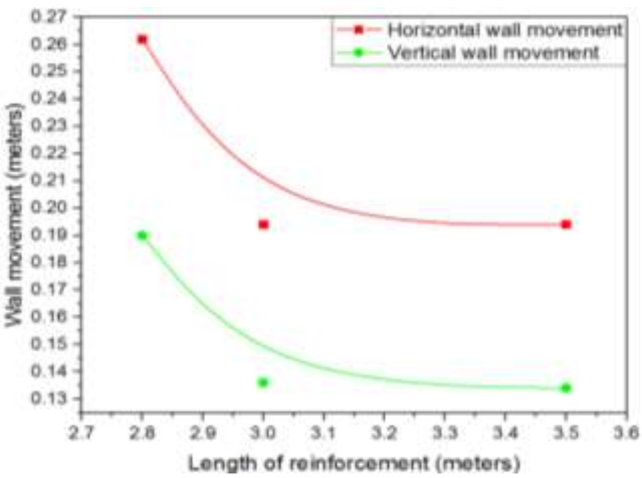


**Figure. 6.** Horizontal and Vertical wall movement for soil type-3

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### 2.2 Analytical Analysis Using GEO5 MSE (AASHTO method)

The 4-meter height MSE retaining wall is modelled using AASHTO recommendation programme GEO MSE for three different types of soils and three different lengths of reinforcements. Internal and external stabilities are calculated by AASHTO extensible recommendation (Straight slip surface) and wall verification is done by allowable stress design (shown in Figure. 7).

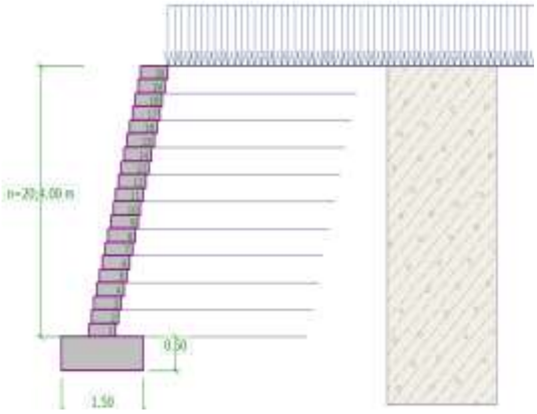
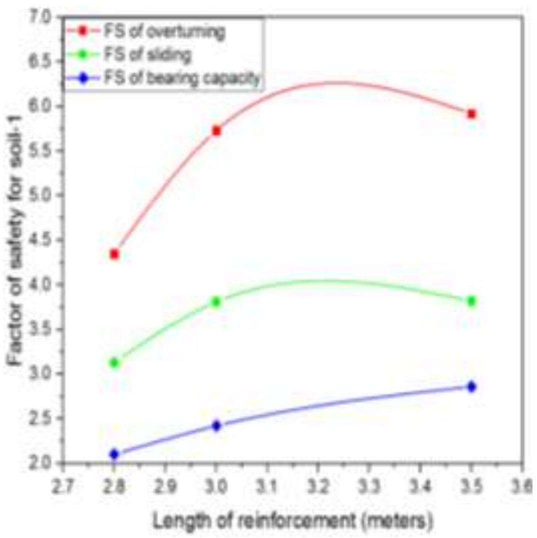


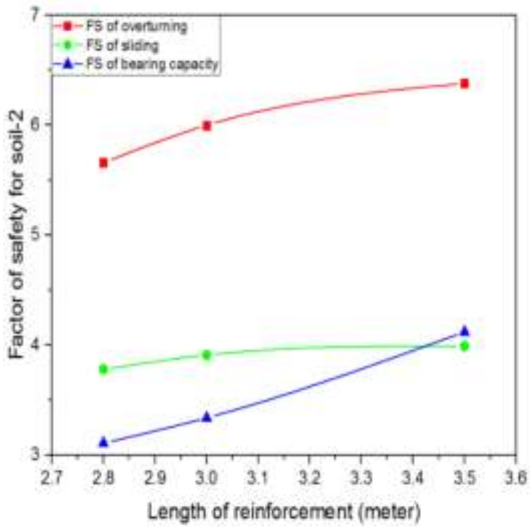

**Figure. 7.** MSE Wall Geometry

**Results and Summary:**

MSE wall is completely analysed using analytical method. The analysis is carried for three different soils with three different lengths of reinforcements. The results generated from GEO5 MSE (AASHTO method) analysis are represented. Factor of safety obtained with respect to overturning, sliding and bearing capacity against length of three different reinforcements for different soils have been analysed. (shown in Figure. 8 a, b, c).




(a)




(b)

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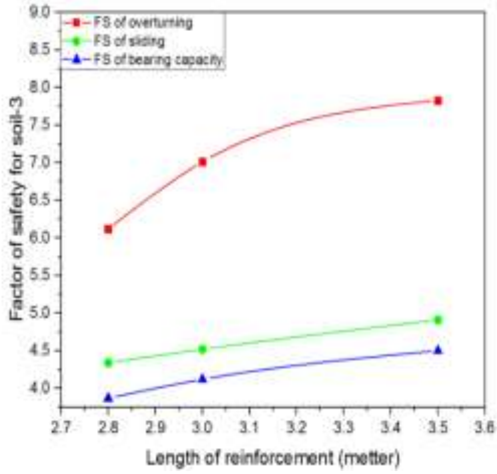
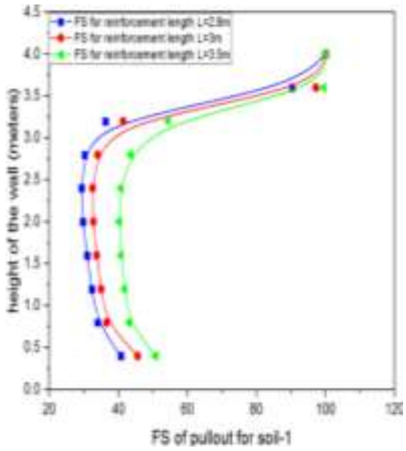


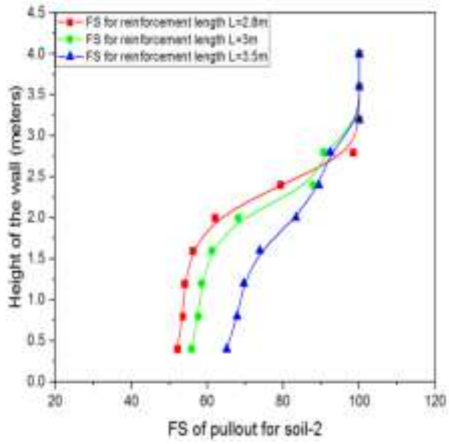

(c)

**Figure. 8. a, b, c.** External Stability Checks for Soil 1, 2 and 3

Further, reinforcements were checked for factor of safety with respect to pullout resistance and tensile strength against height of the wall, for all three different backfill soils (shown in Figure. 9 a, b, c and 10).




(a)

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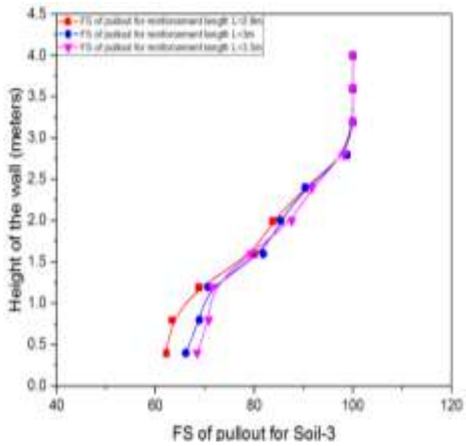


(c)

**Figure. 9 a, b, c.** FOS Against Pullout Resistance for Soil 1, 2 and 3

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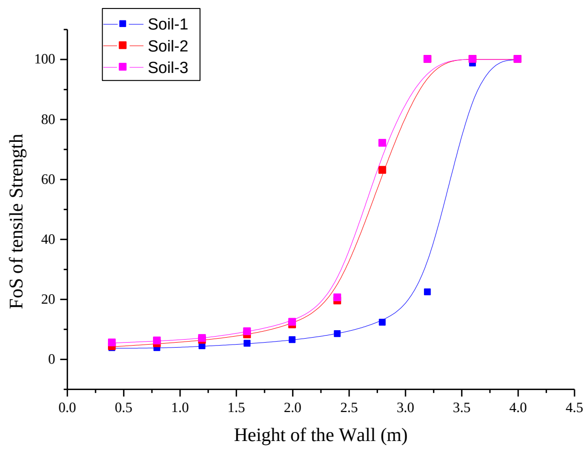


**Figure. 10.** Comparison of Factor of Safeties against tensile strength for three different soils

## 3. Comparison of Numerical and Analytical Solutions

Factor of safety with respect to global stability obtained from GEO5 FEM are compared with analytical method results from GEO5 MSE. Compared results are shown Figure. 11.

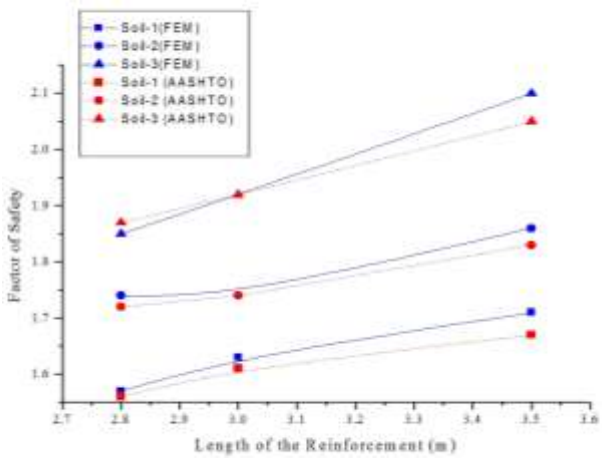


**Figure. 11.** Comparison of Global Factor of safeties obtained from FEM and AASHTO

In this part the global stability of numerical method and analytical methods are compared with each other. In both the cases wall is analyzed for three different types of soils (soil-1, soil-2, soil-3) with three different lengths of reinforcements (2.8m, 3m, 3.5m) for each soil. While observing all the comparisons it shows that in almost all conditions the stability of numerical analysis shows little higher results than analytical. This is because, in finite element analysis, a single structure is discretized into number of nodes, regions and elements and the displacements and stresses are calculated at each node, region and elements, so the results are more accurate in numerical analysis.

## 4 Conclusion

- The present study shows the results of numerical (GEO5 FEM) method and analytical (GEO5 MSE) method and comparisons between numerical and analytical methods. In which, analyzed values from both methods are in well acceptable ranges and are in good agreement.
- From the numerical modeling, it is clear that horizontal and vertical movements of MSE wall decreases, as the length of the reinforcement increases.
- Also, the study shows the effect of soil and reinforcements on stability of mechanically stabilized earth retaining wall. From this study it is found that, as the length of the reinforcement, cohesion and angle of internal friction increases the FOS for internal, external and global stability increases.
- From the results of analytical analysis, Factor of safety for pullout resistance and tensile strength increases as the height of the wall increases.
- From FEM and AASHTO methods, FEM gives little higher factor of safety than AASHTO method. This is because of discretization of single structure in to number of nodes, element and regions. So, it gives more convenient results than other methods.

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