Parametric Study of Mechanically Stabilized Earth Wall

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***Abstract*— Conventional embankment construction needs more right of way space and more backfill material or heavy retaining walls to retain the soil. This may lead to foundation problems in areas of weak soil. Reinforced soil can be used for greater heights, vertical slopes, less and uniform deformations. They are easy to work with, takes less time and are cost effective. This paper attempts to make parametric analysis of geosynthetic reinforced wall known as Mechanically Stabilized Earth (MSE) wall. Numerical simulations are done using a Finite Element Program (PLAXIS 2D). Soil is simulated as Mohr-Coulomb material and geosynthetic reinforcement modeled as elastic material. The foundation soil and reinforced soil having angle of internal friction value of 30° and 32° is used in the analysis. Plate element with axial stiffness value of 42 x 10^6 kN/m and bending stiffness 78,500 kNm^2/m is used in the analysis. Parametric analysis of spacing of geosynthetic reinforcement, geosynthetics stiffness value, aspect ratio (L/H), slope of wall, angle of internal friction and height of wall on factor of safety (FOS) and maximum horizontal displacement are studied. The FOS initially increased marginally with increase in the stiffness value whereas axial stiffness value of 2000 kN/m and 2500 kN/m yielded the same FOS value of 2.091. With the decrease in the slope of wall, the FOS increased from a value of 1.886 with vertical wall face to 2.299 for 75.96° angle slope.**

Keywords*—*MSE wall, Geosynthetics.

I. INTRODUCTION

The settlement in urban areas is increasing enormously in search for better education, opportunities and a higher standard of living. As a result, urban areas are becoming crowded and more restricted in space as compared to the countryside. Road construction in these areas is limited by the right of way availability demanding for vertical walls. Conventional near vertical walls like masonry retaining wall, concrete retaining wall are in practice, but these walls exert a great pressure on the foundation soil and demands for foreign materials (cement, sand, aggregate, reinforcement etc.). Geosynthetics reinforced earth wall have been in use for many decades in other countries but very limited use can be seen in our country Nepal. This technology can be used for attaining very high walls in limited space.

ASTM (1997) as cited in [1] has defined geosynthetics as a planar product manufactured from a polymeric material used with soil, rock, earth, or other geotechnical-related material as an integral part of a civil engineering project, structure, or system. The common type of geosynthetics includes geotextiles, geomembranes, geogrids, geocomposites, geofoams, geocells etc. The basic functions of geosynthetics are drainage, filtration, separation and reinforcement.

Inclusions have been used since ancient times to improve soil strength. Earlier examples can be seen in using straw, stick and branches to reinforce mud dwellings. During the 17th and 18th centuries, French settlers along the Bay of Fundy in Canada used sticks to reinforce mud dikes. Some other early examples of manmade soil reinforcement include dikes of earth and tree branches that have been used in China for at least 1000 years and along the Mississippi River in the 1880s. Other examples include wooden pegs used for erosion and landslide control in England and bamboo or wire mesh, used universally for revetment erosion control. Soil reinforcing can also be achieved by using plant roots [2].

Soil is weak in tension and good in compression and shear. When reinforcing elements are placed in soil the shear resistance of the system is a combination of the interface friction between materials, adhesion between material and in some cases like geogrids the passive resistance of reinforcements. The interface friction can be found from direct shear test.

Finite Element Method is more powerful, accurate, reliable and versatile method to find the slope deformation and stress analysis. The soil mass is divided into small noded elements. This method utilizes the stress-strain relationship among the soil elements and helps better visualization of deformation of soil mass and no assumption for location of failure surface is made. This method has been widely accepted for the analysis of slope stability. Material is controlled by the infinitesimal incremental stress and strain relationship. Strength reduction method, also called ϕ-c reduction method is used to obtain the factor of safety of the slope. In this technique, the strength parameters 'tan ϕ' and 'c" of the soil are reduced in steps until the soil mass fails.

Vashi, Patel and Patel [3] conducted a parametric study of impact of spacing of geogrid and impact of height of wall on displacement using PLAXIS 2D. It was found that the total displacement increased by 10% when spacing increased from 1m to 1.5m and reduced by 24.31 % when spacing reduced to 0.5m. Also with the increase in height of wall, the total displacement increased. Mahmood [4] studied the effect of different parameters like reinforcement length, stiffness, water table, cohesion and friction angle on total displacement of a wall 13ft high for both cohesive and cohesionless soil. It showed that for both cohesive and cohesionless soil, the extreme total displacement decreased with increasing grid strength and the effect was more pronounced for water table at mid height. The results also showed that increasing the grid length decreased extreme total displacement upto certain point after which displacement remained unaffected which can be attributed to the effective length required being reached. For cohesive soil increase in angle of internal friction decreased displacement and value were similar for three different grid length for the case water level at bottom but displacement was more for small grid length in case of water level at mid height. Also sandy soil with some cohesion showed less displacement compared to cohesionless soil. Abdelrahman, Youssuf and Kamel [5] studied behaviour of narrow mechanically stabilized earth wall (wall aspect ratio, L/H<0.7). The results indicated that increasing aspect ratio increases the factor of safety, maximum horizontal displacement, maximum tensile force. Increasing elastic stiffness increases factor of safety, maximum tension force of reinforcement element while decreasing the maximum horizontal displacement.

II. METHODOLOGY

The material model is prepared using PLAXIS V8.2 for both soil and geosynthetics. Mohr-Coulomb model (elastic-perfectly plastic) which can be considered as a first order approximation of real soil behavior requiring less number of model parameters is selected for analysis. Two types of soil parameters are taken for the study. One is the foundation soil which is the soil available at site in its natural condition. Reinforced soil is the fill material in which the reinforcements are placed. The backfill material used in the structure shall be free from organic or other deleterious material and plasticity index shall not exceed 6.

TABLE I. MODEL PARAMETERS OF SOIL

SN	Parameters	Foundation Soil	Reinforced Soil
1	Cohesion, c (kPa)	0.2	0.2
2	Angle of internal friction, ϕ (Degree)	30	32
3	Modulus of Elasticity, E (kPa)	30,000	50,000
4	Poisson's ratio, υ	0.3	0.32
5	Dilation angle, ψ (Degree)	0	0
6	Unit weight (unsaturated), γ_{unsat}(kN/m^3)	19	20
7	Unit weight (saturated), γ_{sat}(kN/m^3)	19	20
8	Material type	Drained	Drained

The design of reinforcement materials are a function of geometric characteristics, strength, durability and material type. The axial stiffness values adopted for geosynthetics are 1000 kN/m and 800 kN/m.

TABLE II. MODEL PARAMETERS FOR PLATE

S. No.	Parameter	Adopted Value
1	Axial Stiffness, EA (kN/m)	42 x 10^6
2	Bending Stiffness, EI (kNm^2/m)	78500
3	Weight, w (kN/m/m)	3.6
4	Poisson's ratio, υ	0.15

Geometric Model

MSE wall of 10m and 5m height are taken in consideration for parametric studies. The boundary condition of the model is done by restraining the horizontal and vertical displacement on the bottom boundary considering the strain at the boundary to be negligible. The left and right boundaries are restrained horizontally. The upper horizontal and slope portion are set free to analyze the behavior of ground surface as practicable to the actual ground condition in the analysis to study its effects. MSE wall free face soil is prevented from raveling out between the rows of reinforcement by using facing like precast concrete panels, dry cast modular blocks, metal sheets and plates, gabions, welded wire mesh, shotcrete, wood lagging and panels and wrapped sheets of geosynthetics. In PLAXIS facing is modelled using a plate. Plates are the structural objects used to model slender structures in the ground with a significant flexural rigidity and a normal stiffness. The geosynthetics are installed from the face of slope to the back of reinforced soil for the full width of the wall.

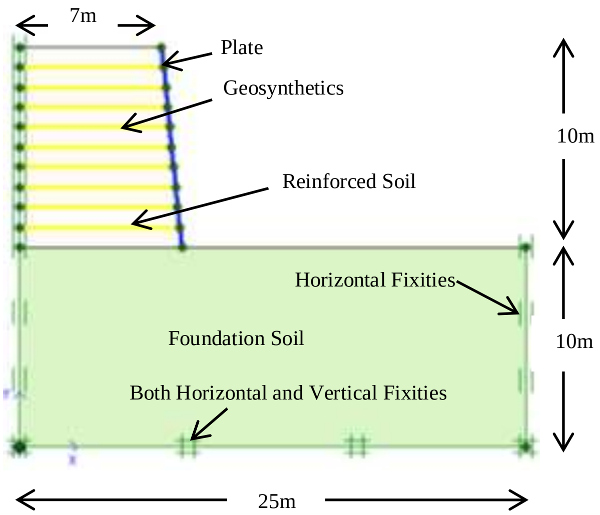

Fig. 1. Geometric Model of MSE Wall

III. RESULTS AND DISCUSSIONS

A. Effect of change in Spacing of Geosynthetics

The distance between two consecutive layers of geosynthetics is varied between 15cm to 60cm known as spacing. The height of wall is taken as 5m. The FOS is found to decrease with increase in the spacing of geosynthetic reinforcement as shown in fig. 2. The horizontal displacement is the accumulated horizontal displacement components at all nodes and the maximum value of it is known as the maximum horizontal displacement. The maximum horizontal displacement is found to increase with the increase in geosynthetics spacing as shown in fig. 3. This may be attributed to the fact that decreasing spacing increases the length of geosynthetics available for friction resistance to counteract the lateral earth pressure.

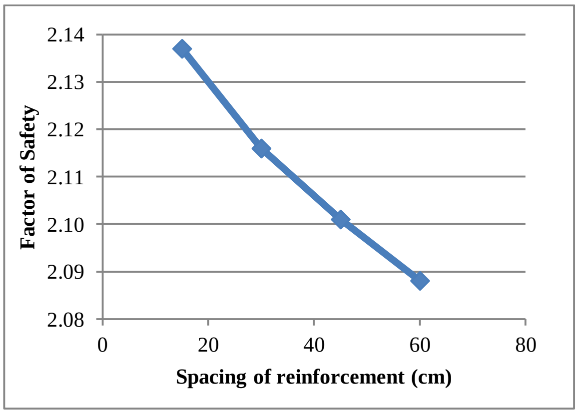

Fig. 2. Effect of spacing of reinforcement on Factor of Safety

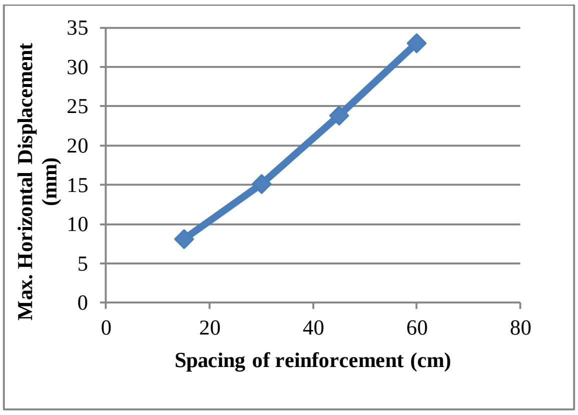

Fig. 3. Effect of spacing of reinforcement on maximum horizontal displacement

B. Effect of change in Axial Stiffness

MSE wall of height 10m and spacing 30cm is taken for analysis. The FOS initially increased marginally with increase in the stiffness whereas axial stiffness value of 2000 kN/m and 2500 kN/m yielded the same FOS value of 2.091 as shown in fig. 4. So, it can be inferred that the FOS remains constant after a certain stiffness value is reached for a certain system. However maximum horizontal displacement is found to reduce considerably with increase in stiffness values as shown in fig. 5. FOS being same after 2000 kN/m axial stiffness value may be due to the maximum resisting force being achieved against the activating forces and further increase in stiffness value has no effect on FOS.

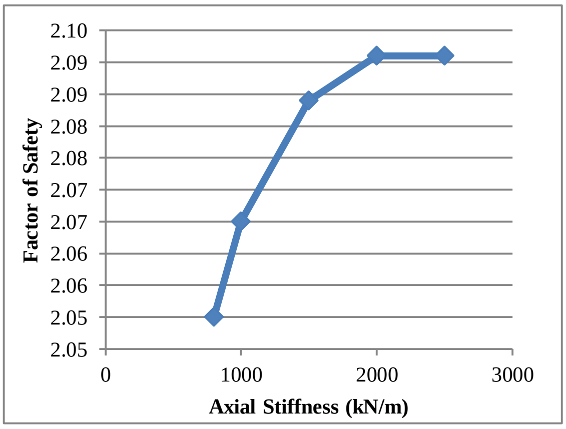

Fig. 4. Effect of Axial Stiffness on Factor of Safety

C. Effect of change in Aspect Ratio

Aspect ratio of MSE wall is the ratio of the length (L) of geosynthetic reinforcement and the height of wall (H). The height of wall is taken 10m, axial stiffness value of 1000 kN/m and spacing 30cm for the study. Factor of safety (FOS) is found to increase with the increase in aspect ratio of the wall as shown in fig. 6. This may be due to the more length of geosynthetics available for resistance. The maximum horizontal displacement increased slightly with increasing aspect ratio as shown in fig. 7.

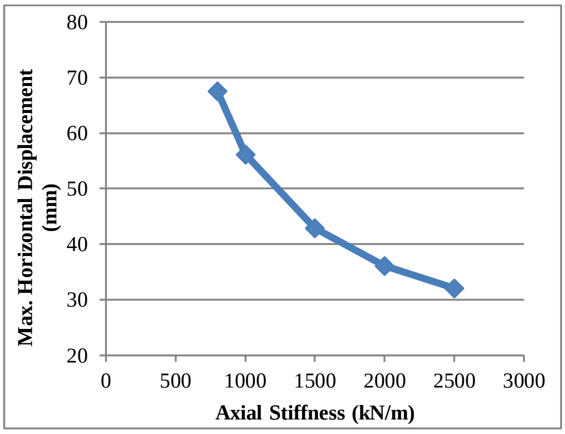

Fig. 5. Effect of Axial Stiffness on maximum horizontal displacement

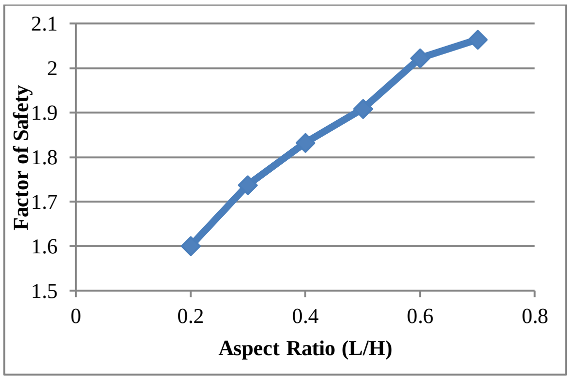

Fig. 6. Effect of Aspect ratio on Factor of Safety

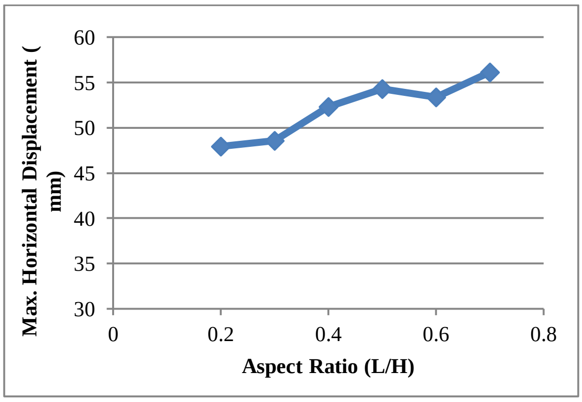

Fig. 7. Effect of Aspect ratio on maximum horizontal displacement

D. Effect of change in Slope of MSE wall

The angle made by the sloping face of wall with the horizontal is varied for a spacing of 30cm known as slope of wall. Fig. 8 shows that as the slope of the wall decreases the FOS increases from a value of 1.886 with vertical wall face to 2.299 for 75.96° angle slope. The horizontal displacement is found to decrease marginally as shown in fig. 9. It can also be attributed to the increase in frictional resistance on both the faces of geosynthetics which increases with the decrease in slope of wall.

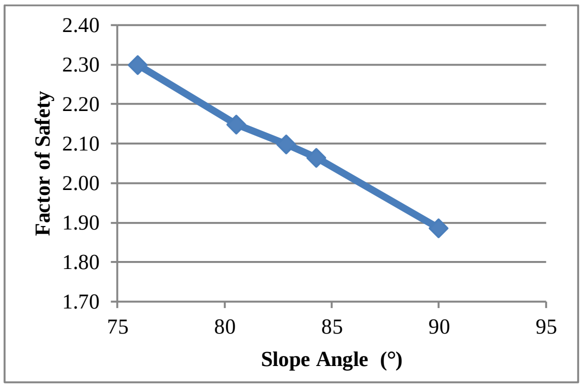

Fig. 8. Effect of Slope angle on Factor of Safety

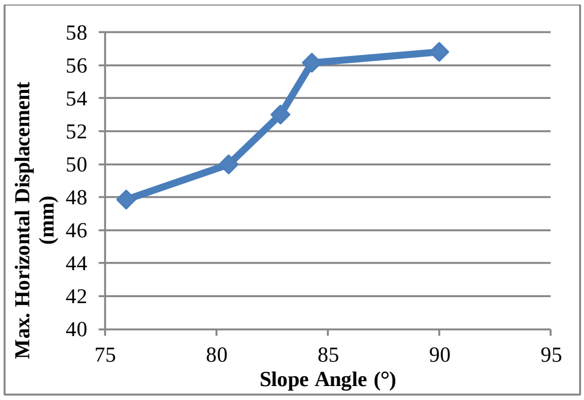

Fig. 9. Effect of Slope angle on maximum horizontal displacement

E. Effect of change in Angle of internal friction of reinforced soil

Fig. 10 shows that the FOS of wall increased with increase in angle of internal friction of reinforced soil by 11.3% and fig. 11 shows that the horizontal displacement decreases by 41.68mm when angle of internal friction increases from 24° to 36° . Angle of internal friction of soil is directly related to its shear strength, so the factor of safety increases with increase in angle of internal friction when other parameters remains constant. Axial stiffness value of 800 kN/m is used for analysis.

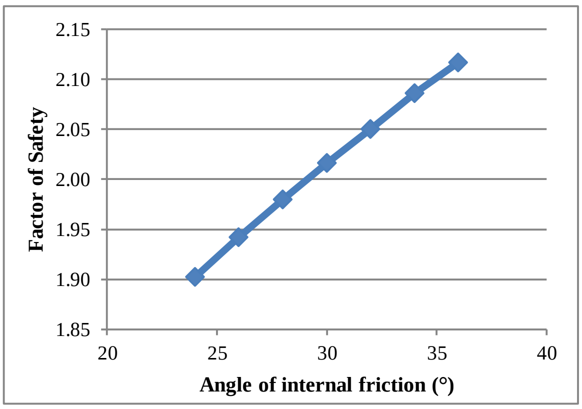

Fig. 10. Effect of Angle of internal friction on Factor of Safety

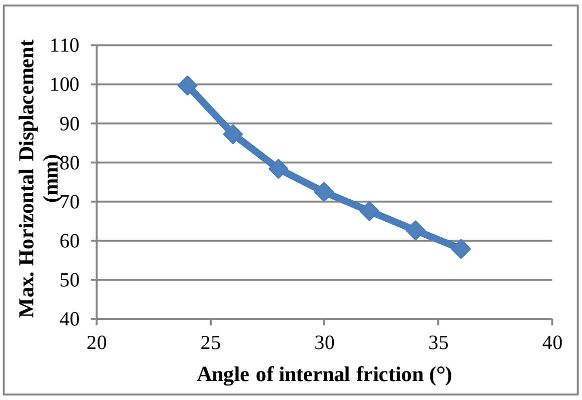

Fig. 11. Effect of Angle on internal friction on maximum horizontal displacement

F. *Effect of increase in Height of wall*

A study is done to see the effect of increase in height of wall on factor of safety (FOS) and horizontal displacement of wall. For this top width of wall is taken as 7m for all cases and height 10m, 12m, 15m and 20m taken into account with a slope of 1:10 for 30cm spacing of reinforcement. As the wall height increases FOS decreases and maximum horizontal displacement increases significantly from 56.14mm to 167.98mm as shown in fig. 12 and fig. 13. This may be due to the increase in lateral earth pressure with increase in height of wall. The graph obtained is more or less linear for both FOS and displacement.

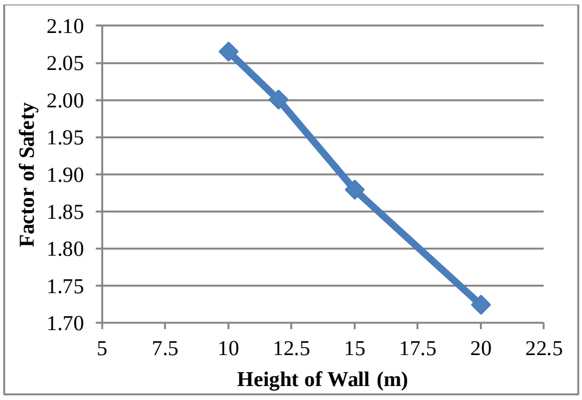

Fig. 12. Effect of Height of wall on Factor of Safety

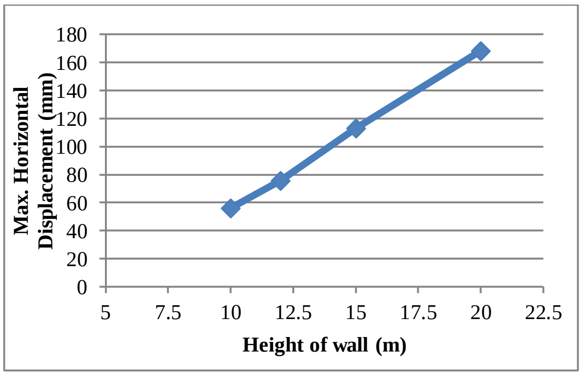

Fig. 13. Effect of Height of wall on maximum horizontal displacement

IV. CONCLUSION

- Decrease in spacing of geosynthetics results in more number and length of geosynthetics available for frictional resistance to counteract the lateral earth pressure and thus increasing FOS.
- Increase in geosynthetics stiffness value has a direct effect on FOS to a certain point after which it remains constant. So geosynthetics of very high stiffness value may not be economical which has to be defined on case basis.
- Increase in angle of internal friction increases FOS and decreases maximum horizontal displacement as the shear strength of soil increases.
- Increase in height of wall decreases FOS due to increase in lateral earth pressure.

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