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Research paper

Behaviour of Tall Tiered MSE Walls Reinforced with Geogrid by using Plaxis 2D software

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Abstract

Soil is feeble in tension and relatively strong in shear and compression under confinement. Inclusions (or reinforcement) which are strong in tensile resistance are used as reinforcements in a reinforced soil mass. The reinforcement restrains lateral deformation of the surrounding soil through soil reinforcement interface bonding and increases its confinement, reduces its tendency for dilation and consequently increases the stiffness and strength of the soil mass. Over the past 20 years,popularity of reinforced soil structures including slopes,retaining walls, roadways, embankments, and load-bearing foundations have increased. Over the last 20 years Mechanically Stabilized Earth (MSE) structures have been growingly used in many Central, state and private projects. MSE walls are reliable, constructible, and cost-effective. However, analysis and design of tall MSE walls (higher than 6 to 8 m) has been a challenge for the designers. In this research work, Finite-Element Program (FEM) PLAXIS 2D is used to predict the behaviour of 5m, 10m, 15m and 20m high MSE walls by varying the parameters like berm width; backfill and foundation soil strength; strength, stiffness and spacing of reinforcement; surcharge on reinforced backfill.

***Keywords**: Mechanically stabilized earth (MSE), Plaxis 2D, Geogrid, Foundation soil, Retained backfill soil, Reinforced backfill soil.*

1. Introduction

1.1 Reinforced soil

Soil is an abundant construction material, which is strong in shear and compression under confinement, but very weak in tension. To overcome this weakness, high tensile strengthmaterialscan be used as reinforcements for soil. The principle of earth reinforcement is the generation of frictional resisting force between the reinforcing element and backfill soil. Since the earliest part of human history adobe bricks and mud dwellings were reinforced did by using sticks, straw, and branches. Modern form of MSE was invented in the 1970s by Sir Henri Vidal (French engineer), which he termed as Terre Armee or reinforced earth. He covered every possible reinforcement and facing typein his patents submission. In the USA it is usually termed asMSE, justto distinguish it from "Reinforced Earth", a trade name of the Reinforced Earth Company, but elsewhere the generally accepted termis Reinforced Soil.

1.2 MSE wal

MSE is a method of reinforcing earthen materials. They can support their own weight within the minimum space, maximum side slopes and able to sustain significant tensile loads. MSE walls are well-recognized alternatives to conventional retaining walls. The use of MSE walls has increased broadly since 1970s. They became the most common wall type preferred, basically for transportation projects, because of their simple construction techniques, cost-effectiveness,rapid construction,reliability, aesthetics, durability and ability to tolerate large deformations without structural distress. The first MSE wall was built in 1971 on State Route 39 near Los Angeles, United States. Since 1997, approximately 23,000 MSE walls have been constructed all over the world. The highest MSE wall built in the United States is 30 m (98 ft.) high.

1.3 The components of MSE walls

The various components of MSE walls are as follows:
a. Reinforcement element
b. Facing
c. Reinforced backfill soil
d. Retained backfill soil

Metal strips, metal bar mats, geogrids and geotextiles are the most common reinforcement types used in MSE walls. The facing is provided to prevent the erosion of reinforced backfill soil and for good aesthetic purpose. Facing element may be metal sheet and plates, precast concrete panels, dry cast modular blocks,welded wire mesh,gabions, shotcrete, wrapped sheet of geosynthetics, wood lagging and panels.

1.4 Plaxis 2D

PLAXIS 2D is a two-dimensionalfinite element program.It is developed for the analysis of stability,deformation and groundwater flow in geotechnical engineering. Real situations may be modelled either byan axisymmetric model or a plane strain. A convenient graphical user interface was used by this program,so that userenables to generate a geometry model and finite element mesh based on a representative vertical cross section of the situation. Advance constitutive models are required for geotechnical applicationsfor the simulation of the time dependent,non-linear and anisotropic soil's and/or rock's behaviour. Since soil is multi-phase material, distinctive procedures are required to concern with hydrostatic and non-hydrostatic pore pressures in the soil. In spite of the modelling of soil itself is an majorissue, many geotechnical schemes involve the modelling of structures and the interaction between the soil andthe structures. PLAXIS is suited with attributes to deal with diverse aspects of complicated geotechnical structures.

2. Review of Existing Literature

Bilgin (2009) studied dominate failure mode in ascertaining the minimum design length ofreinforcement for various criterions involved in the designof retaining walls with reinforced soil. The minimum required length of reinforcement can be controlled by both internal and externalfailure modes, based on the parameter values involved and would be case specific.
Bilgin and Mansour (2013) studied the governing design mode determining the lengths of reinforcement and under varying conditionsthe shortest possible lengths that can be used for walls for four reinforcement types geotextile, geogrid, metal bar mat and metal strip (ribbed), were investigated. The metal strips usually require the longest lengths, the metal bar mats need the shortest lengths. Yan Yu et al. (2017) describe the results of numerical modelling of two full-scale instrumented wrapped-face walls,which were constructed and monitored in a laboratory environment with controlled indoor. Nominally similar walls were used except that one wall was constructed with reinforced layers of welded wire mesh (WWM) and the other with biaxial polypropylene (PP) geogrid layers.Numerical predictions forreinforcement strains, wall facing deformationsand loads were in generally healthy agreement with measurements for the WWM wrapped-face wall. Poor agreement was observed betweenmeasured facing profile and numerical predictions of facing deformations for the PP geogrid wrapped-face wall. The poor agreements are probably related to the excessive flexibility of the facing which facing stiffness did not have the added and soil confinement due to reinforcement turn-around flaps that are a typical feature of field structures.

3. Finite Element Analysis

In the present study, the analysis of different heights (5m, 10m, 15m and 20m) of MSE wall has been carried out using finite element program PLAXIS 2D.The fallowing different cases of MSE walls are taken in the analysis based on:

A. Berm provided
a. Single full length wall
b. Wall with berm 2m wide at every 5m height
c. Wall with berm 4m wide at every 5m height
B. Back fill soil strength
a. Good (C=30kPa, Φ=36°, γ=20kN/m^3)
b. Medium (C=25kPa, Φ=28°, γ=18kN/m^3)
c. Weak (C=20kPa, Φ=20°, γ=16kN/m^3)
C. Strength of geogrid
a. Weak (EA=100kN/m)
b. Medium (EA=1000kN/m)
c. Good (EA=5000kN/m)
D. Surcharge on reinforced backfill
a. 20kPa
b. 50kPa
c. 100kPa
E. Foundation soil
a. Good (C=30kPa, Φ=36°, γ=20kN/m^3)
b. Medium (C=25kPa, Φ=28°, γ=18kN/m^3)
c. Weak (C=20kPa, Φ=20°, γ=16kN/m^3)

4. Methodology

FEM analysis is to be carried using Plaxis 2D software. Plane strain model of 15 nodded elements is used for the analysis of retaining structure with pre-existing surrounding soil and base soil.
By using the borehole feature of the program, soil stratigraphy can be defined in the soil mode. Boreholes are locations in the draw area, which contains the information on the position of the soil layers and the water table. In the model tab sheet of the Project properties windowthe model extension can be specified.Geogrids are slender structures with an axial stiffness. It can sustain only tension force and no compression. The objects are normally used to model reinforcements for soil. An elastic axial (normal) stiffness EA is the only material property of a geogrid. Geogrids are formed of geogrid line elements with two translational degrees of freedom in each node (u_x, u_y). Geogrid element is defined by five nodes when 15-noded soil elements are employed, it as shown in Figure 1. Newton-Cotes stress points are used to evaluate axial forces. These stresses coexist with the nodes.

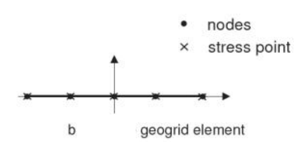

Fig. 1: Position of nodes and stress points in geogrid elements

Interfaces are joint elements, which are to be added to geogrids to allow for a right modelling of soil-structure interaction. Interface may be used to simulate the think intensely shearing material zone at the contact between soil boundaries or two different materials. Properties like material mode, virtual thickness factorsand permeability conditions are accessible for each interface in the model. Interfaces are formed of interface elements. Figure 2 shows how soil elementsare connected tointerface elements. When using 15-node elements, the corresponding interface elements are described by five pairs of nodes. In the Figure 2, the interface elements are shown to have a finite thickness, but the coordinates of each node pair are identicalin the finite element formulation, that means the element has a zero thickness.

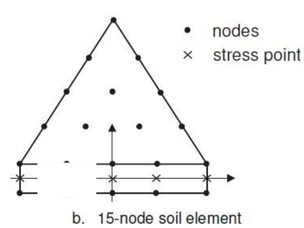

Fig.2: Nodes and stress points distribution of interface elements and their connection to soil elements

5. Geomatric Modelling

A step by step procedure for geometric modelling of MSE wall in plaxis 2D software is as follows:

1. Choose plane strain model
2. Create soil stratigraphy using borehole feature or soil polynomial

3. Create and assign material data sets for soil (Mohr-Coulomb model)
4. Create and assign material data sets for Geogrid layers and interfaces
5. Create line loads on top of MSE wall
6. Generate the mesh
7. Define boundary conditions
8. Generate initial stresses by using the K0 procedure
9. Define a plastic calculation
10. In calculation phase, create required amount of steps as staged construction modes
11. Activate appropriate soil, facing, geogrid and interface elements in each steps, to simulate practical construction process
12. Activate and modify the values of surcharge loads and run the calculation
13. View the calculated results
14. Try different combinations of foundation soil, backfill soil, geogrid and surcharge load, and repeat the calculation

5.1 Example for Geomatric Modelling

An example of step by step procedure for staged construction modes of 20m full height MSE wall is explained as follows:

1. The first calculation phase is always a calculation of initial stress field for the initial geometry configuration by means of K0 procedure. Except initial phase, all other calculation steps are made as plastic calculations.The existing ground with back slope of 18°(from elevation 40m to 60m) above ground level (at an elevation 40m) is as shown in the Figure 3 below:

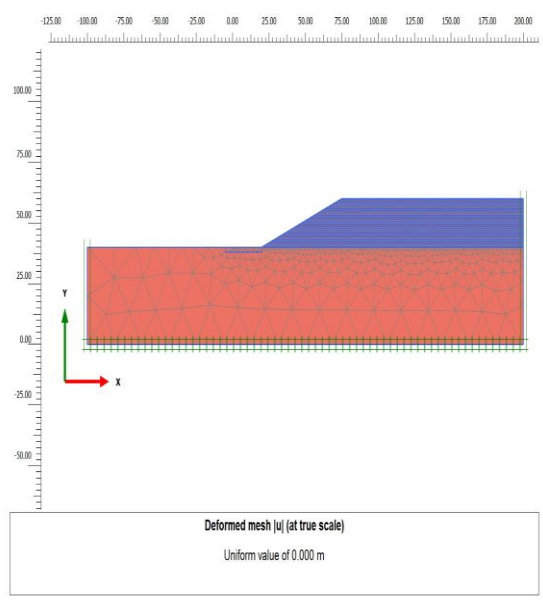

Fig. 3: The existing ground of initial phase in staged construction mode

2. Remove 2m foundation soil from the bottom edge of slope (X=+20m) to 5m more wide as the height of reinforced wall (X=-5m), i.e. reinforced soil zone (MSE wall) will be in square shape and the foundation soil is excavated 5m more wider than that of reinforced soil zone (MSE wall).

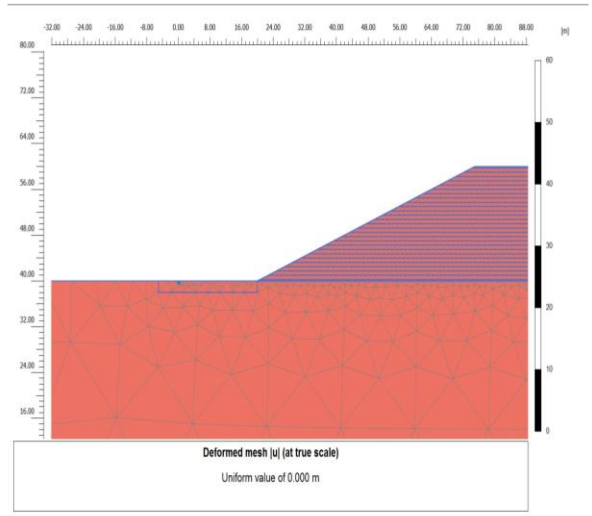

Fig. 4: foundation soil to be excavated

3. Fill the pit with reinforced soil along with the leveling pad (0.5mx0.5m) up to ground level (from elevation +39.5m to +40m).

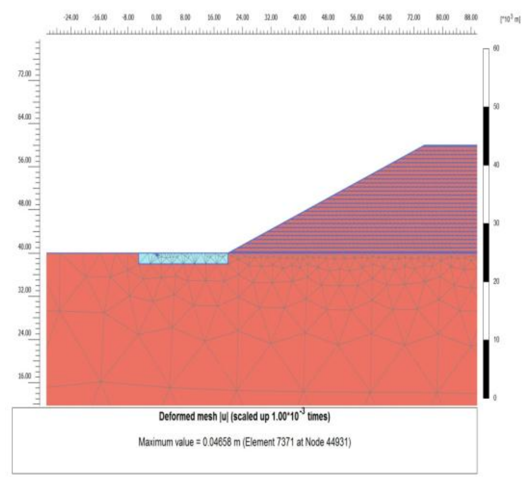

Fig. 5: Filling of 2m foundation pit with reinforced soil

4. Place facing block for 0.25m height (from elevation 40m to 40.25m), fill and compact reinforced soil and place geogrid layer on top of it (at an elevation of 40.25m).Along with this, fill and compact the space between reinforced zone and back slope by back fill soil (from X=+20m to back slope).

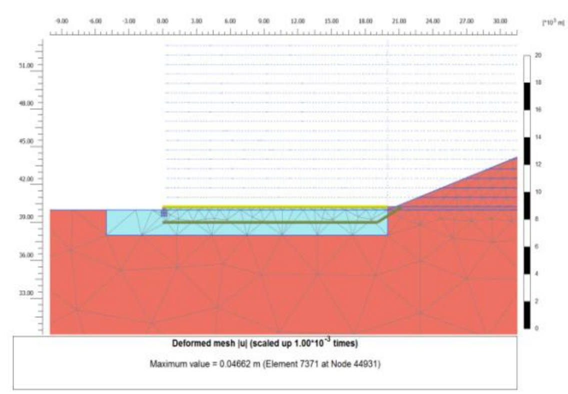

Fig. 6: Filling of reinforced soil along with the placing of facing and geogrid

4. Continue above step by giving spacing 0.75m between every geogrid layer.

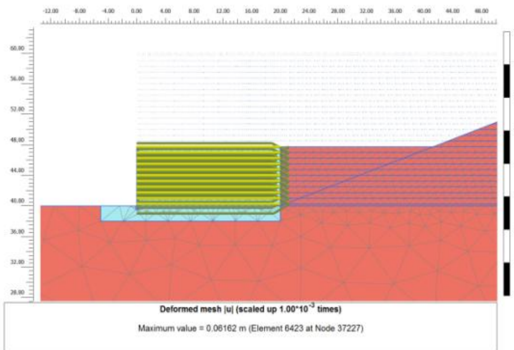

Fig. 7: A half of construction of MSE wall

5. After completion of the construction, surcharge loads can be applied on top of MSE wall (at an elevation of 60m and from X 0m to +20m).

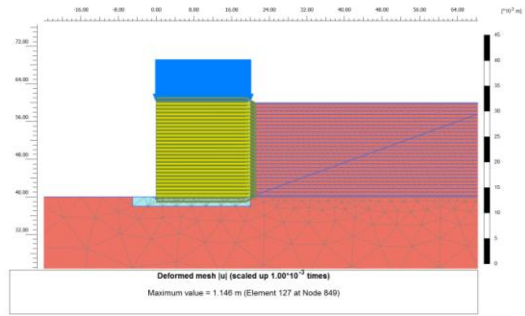

Fig. 8: 20m full height MSE wall with surcharge load on top of it

Table I: Maximum surcharge load ranges for different combinations of foundation soil and backfill soil for different heights of mse wall (5-20m)

Sl No	Height of wall	Foundation soil	Backfill soil	Maximum surcharge capacity range (kN/m^2)	
				min	max
1	5m full height wall	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	595	595
		Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)	800	900
		Good (shear strength = 60 kPa)	Medium (shear strength = 45 kPa)	1020	1050
2	10m full height wall	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	580	590
		Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)	1090	1120
		Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	1140	1180
3	10m height wall with 2m berm at every 5m height	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	520	650
		Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)	850	950
		Good (shear strength = 60 kPa)	Medium (shear strength = 45 kPa)	1100	1100
4	10m height wall with 4m berm at every 5m height	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	270	310
		Medium (shear strength = 45 kPa)	Weak (shear strength = 30 kPa)	520	540
		Good (shear strength = 60 kPa)	Medium (shear strength = 45 kPa)	810	910
5	15m full height wall	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	550	550
		Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)	1100	1100
		Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	1450	1500
6	15m height wall with 2m berm at every 5m height	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	550	700
		Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)	850	1200
		Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	1300	1450
7	15m height wall with 4m berm at every 5m height	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	250	500
		Medium (shear strength = 45 kPa)	Weak (shear strength = 30 kPa)	600	650
		Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	900	1400
8	20m full height wall	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	800	850
		Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)	1200	1250
		Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	1700	1850
9	20m height wall with 2m berm at every 5m height	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	750	750
		Medium (shear strength = 45 kPa)	Weak (shear strength = 30 kPa)	800	800
		Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	950	1000
10	20m height wall with 4m berm at every 5m height	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	150	250
		Medium (shear strength = 45 kPa)	Weak (shear strength = 30 kPa)	500	650
		Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	1000	1100

Table 2: Suitability of geogrid for good performance of mse wall of all heights (5-20m)

Sl No	Foundation soil	Backfill soil	Geogrid
1	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)	Medium (EA = 1000kN/m)
2	Weak (shear strength = 30 kPa)	Medium (shear strength = 45 kPa)	Medium (EA = 1000kN/m)
3	Weak (shear strength = 30 kPa)	Good (shear strength = 60 kPa)	Medium (EA = 1000kN/m)
4	Medium (shear strength = 45 kPa)	Weak (shear strength = 30 kPa)	Weak (EA = 100kN/m)
5	Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)	Good (EA = 5000kN/m)
6	Medium (shear strength = 45 kPa)	Good (shear strength = 60 kPa)	Medium (EA = 1000kN/m)
7	Good (shear strength = 60 kPa)	Weak (shear strength = 30 kPa)	Weak (EA = 100kN/m)
8	Good (shear strength = 60 kPa)	Medium (shear strength = 45 kPa)	Weak (EA = 100kN/m)
9	Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)	Weak (EA = 100kN/m)

Effect of geogrid on load carrying capacity of MSE wall

As explained earlier from the Figure 9, effect of geogrid strength (EA = 100kN/m, 1000kN/m, 5000kN/m) does not have significant effect on maximum load carrying capacity of all heights MSE walls (5-20m), but still by considering small variations, suitable geogrid for different combinations of foundation soil and backfill soil are given below:

Effect of backfill soil on load carrying capacity of MSE wall

Suitable backfill soil should be provided on existing foundation soil forbetter performance and good load carrying capacity of the MSE wall of any height (5-20m). The combination of foundation soil and backfill soil which results in good performance of MSE wall of any height (5-20m) is as tabulated below:

Table 3: Combination of foundation soil and backfill soil that were found to result in good preformance of mse wall of all heights (5-20m)

Sl No	Foundation soil	Backfill soil
1	Weak (shear strength = 30 kPa)	Weak (shear strength = 30 kPa)
2	Medium (shear strength = 45 kPa)	Medium (shear strength = 45 kPa)
3	Good (shear strength = 60 kPa)	Good (shear strength = 60 kPa)

Unfavorable backfill soil for different foundation soils which is responsible for poor performance of MSE walls are tabulated below

Table 4: Combination of foundation soil and backfill soil that were found to result in poor preformance of mse wall (for 15 and 20m heights)

Sl No	Foundation soil	Backfill soil
1	Weak (shear strength = 30 kPa)	Medium (shear strength = 45 kPa)
2	Weak (shear strength = 30 kPa)	Good (shear strength = 60 kPa)
3	Medium (shear strength = 45 kPa)	Good (shear strength = 60 kPa)

6. Conclusion

In this article, an analytical work on different heights of MSE wall reinforced with different strength and stiffness of geogrid reinforcement under static surcharge loading in Plaxis 2D is presented and discussed. This analysis demonstrates that:

Maximum load carrying capacity of MSE walls does not have significant effect of geogrid strength (EA = 100kN/m, 1000kN/m, 5000kN/m). It mainly depends on the foundation soil strength along with the back fill soil strength. But still by considering small variations, Weak geogrid (EA = 100kN/m) performs better than medium (EA = 1000kN/m) and strong geogrid (EA = 5000kN/m), because it is stretched (strained) to maximum and therefore stressed to optimum.

For good performance of any height of MSE wall, suitablebackfill soil should be provided on the foundation soil. On weak foundation soil (shear strength = 30 kPa) weak backfill soil (shear strength = 30 kPa) is more suitable,on medium foundation soil (shear strength = 45 kPa) medium backfill soil (shear strength = 45 kPa) is more suitable and on good foundation soil (shear strength = 60 kPa) good backfill soil (shear strength = 60 kPa) is more suitable.

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