A study on mechanically stabilized earth wall lateral displacements reinforced with geosynthetics and steel strips using GeoStudio (2D) and Plaxis 3D

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ABSTRACT: Discrete reinforcements such as metal or geosynthetic strips and geogrids are generally used for mechanically stabilized earth (MSE) walls using precast concrete panel type wall facing. Considering discrete reinforced MSE walls, this study aims to show the lateral displacement behavior of the MSE walls. There will be three cases of MSE wall reinforced with geogrids, geo-strips and steel strips having different arrangements that are modelled and analyzed in staged construction using GeoStudio Sigma/W and Plaxis 3D software. The numerical simulation results showed that the 1.2m-width geogrids reinforcement, regardless of having lesser stiffness, exhibited similar lateral displacement behavior compared with 0.05m-width steel strips having very high stiffness. Moreover, the narrow strip reinforcement with very low stiffness value exhibited slightly higher lateral displacements compared to wider geogrids. This may imply that MSE wall with precast concrete panel type wall facing that uses wider width of reinforcement can better sustain lateral displacements than narrow strip reinforcements.

Keywords: MSE wall, geogrids, steel strips, geo-strips, Plaxis 3D, GeoStudio, lateral displacements

1 INTRODUCTION

The modern reinforced earth wall was introduced, developed and patented by Sir Henry Vidal in 1966 (Koerner and Koerner, 2013). The general term Mechanically Stabilized Earth (MSE) wall is used to distinguish from the trademark Reinforced Earth, but both refers to the similar structure (Berg, et.al, 2009). MSE walls are gravity structures that are relatively flexible which can tolerate horizontal and vertical deformations (Tarawneh and Siddiqi, 2014). These are reinforced soil walls wherein reinforcements are properly placed between compacted lift of soil layers and are firmly attached to the facing element developing a composite system which can restrain lateral forces.

MSE wall has three major components, namely backfill soil, reinforcement and facing system. The facing elements prevent the backfill soil from raveling out of the wall at the same time holds the reinforcements in place. There are several facing elements that have been used such as gabions, cast-in-place concrete, welded wire mesh, geosynthetic materials, other facings; but the most common are the precast concrete panels and modular blocks. MSE walls using modular blocks are also known as segmental retaining walls. These walls generally use sheet reinforcements. Precast concrete panels are widely used especially for transportation system. These walls generally use metal or geosynthetic strips reinforcements. The reinforcements improved the mechanical properties of the reinforced soil mass by compensating the tension and shear strength needed to support the soil mass against deformations. This improvement is caused by the interaction at the interface between the reinforcement and the soil wherein stresses are transferred by friction or passive resistance (Berg, et.al. 2009).

Wider reinforcement compared to narrow reinforcement can greatly sustains wall deformations because it will have greater frictional area. Therefore using precast concrete panels, this study considered to use wide geogrids to compare with the usual steel and geosynthetic strips reinforcements. A numerical analysis using Plaxis 3D and GeoStudio Sigma/W will be performed for the MSE walls in staged construction to find out the behavior of the wall, specifically lateral displacements, considering the three types of reinforcements. Since discrete reinforcements used in this study have 3D geometry condition, a modification was made to translate from 3D into 2D condition. To fairly differentiate the influence to the reinforcements on the wall lateral displacements, all numerical cases in this study will have uniform wall facing parameters, soil parameters and model conditions.

2 NUMERICAL MODELLING

Numerical analysis using Plaxis 3D and GeoStudio Sigma/W are used to calculate the lateral displacements of the MSE wall given the condition shown in the figure.

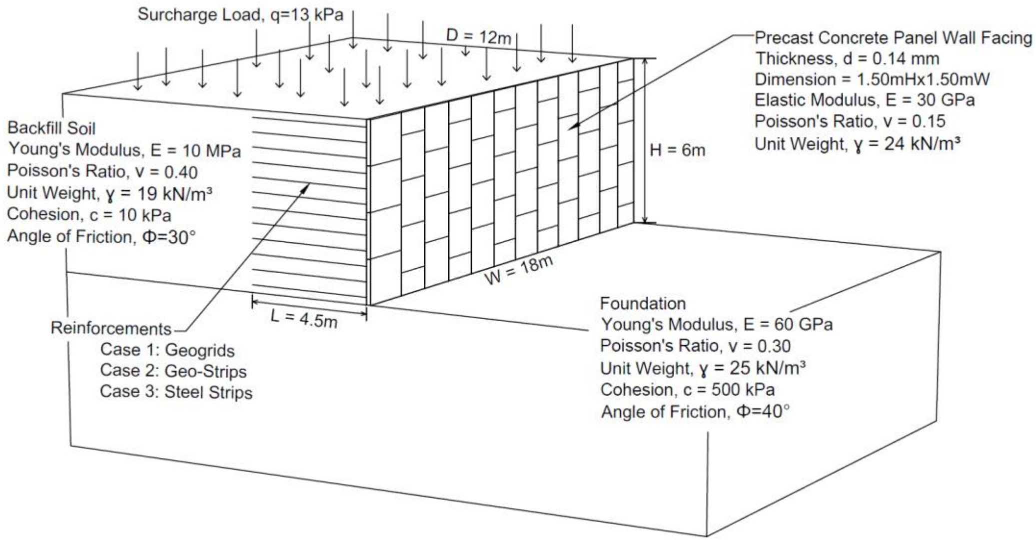
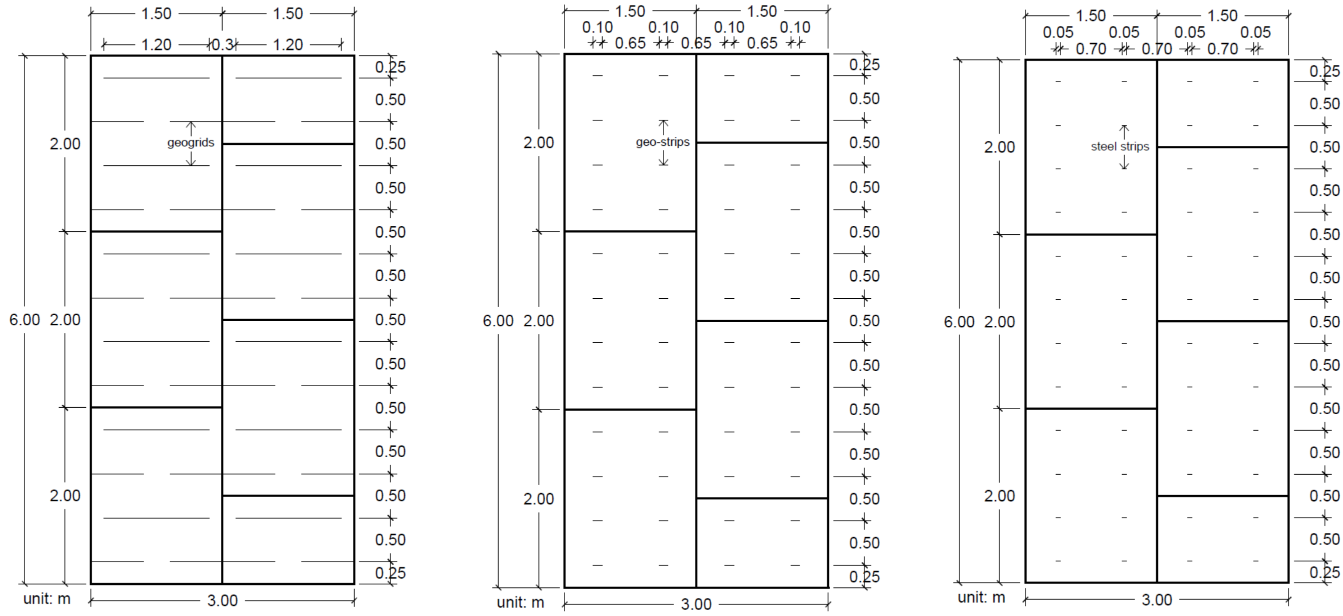


Figure 1. Cases of MSE wall with different reinforcement materials.

The MSE wall is designed to have a height of 6m and a depth of 12m with foundation of 6m thick (see Figure 1). The width of 18m is considered only for models in Plaxis 3D. A uniform surcharge load of 13kPa is assumed to be applied on top of the backfill soil. The water table is assumed to be located below the foundation thus hydraulic effect is not considered in this study. The boundary conditions are applied in such a way that only deformations at the wall facing of the models are allowed and sides are designed as fixed. There are 13 backfill lifts which are analyzed phase-by-phase and 12 layers of longitudinal reinforcements with elevations 0.25m, 0.75m, 1.25m, 1.75m, 2.25m, 2.75m, 3.25m, 3.75m, 4.25m, 4.75m, 5.25m, and 5.625m from the base of the wall. The numerical models in this study shall have uniform parameters except for the reinforcements. Unlike sheet reinforcements, discrete reinforcements have 3D geometry conditions which is ideally favorable for analysis using Plaxis 3D. However, it is expected to have to significant differences with the modelling specifications compared to GeoStudio. There is a need to translate the numerical models into 2D conditions, thus, coverage ratio shall be applied on discrete reinforcements in analyzing using GeoStudio.

2.1 *Reinforcement arrangements and properties*

There are three cases of numerical models being analyzed in this study as drawn in Figure 2. The wall facing element used in this study is 1.5mWx1.5mH precast concrete panel. Each case have the same vertical spacing of reinforcements but with different width and horizontal spacing. Case 1 (see Figure 2(a)) refers to MSE wall reinforced with 1.2m-width geogrids having a vertical spacing of 0.50m and horizontal spacing of 1.50m on centers of reinforcements. Case 1 is arranged in staggered and discrete manner wherein half of the reinforcement connects one panel to another panel. Case 2 (see Figure 2(b)) refers to MSE wall reinforced with 100mm-width geo-strips having a vertical spacing of 0.50m and horizontal spacing of 0.75m on centers of reinforcements. Case 2 is arranged in linear manner equally distributed on the entire precast concrete panel area. Case 3 (see Figure 2(c)) refers to MSE wall reinforced with 50mm-with steel strips having a vertical spacing of 0.50m and horizontal spacing of 0.75m on centers of reinforcements. Case 3 is arranged in linear manner equally distributed on the entire precast concrete panel area.



(a) Case 1 using geogrids (b) Case 2 using geo-strips (c) Case 3 using steel strips

Figure 2. Cases of MSE wall with different reinforcement materials and arrangements.

All cases have the same reinforcement length of 4.5m whose thickness and parameters are given in Table 1. All reinforcements are modelled as geogrid in Plaxis 3D and structural bar in GeoStudio Sigma/W. Case 3 have the highest modulus of elasticity, E, but have the smallest area, A, whose normal stiffness, EA, is given as 42,000kN/m. Case 1, on the other hand, have the smallest E but have the largest A whose normal stiffness is given as 1,632kN/m. Case 2, however, have the smallest value of EA equivalent to 750kN/m. The tensile capacity is calculated in accordance to stipulations from FHWA-NHI-10-024 (Berg, et.al, 2009).

Table 1. Properties of soil materials used in numerical analysis.

Parameters		Reinforcement Materials		
		Case 1 - Geogrids	Case 2 – Geo-Strips	Case 3 – Steel Strips
Material Model	Plaxis 3D	Geogrid	Geogrid	Geogrid
	GeoStudio	Bar	Bar	Bar
Width, w (mm)		1,200	100	50
Thickness, t (mm)		1.45	3.00	4.00
Length, L (m)		4.50	4.50	4.50
Vertical Spacing, S_v (m)		0.50	0.50	0.50
Horizontal Spacing, S_h (m)		1.50	0.75	0.75
Cross-sectional Area, A (mm^2)		1,740	300	200
Modified Cross-sectional Area*, A' (mm^2)		1,392	40	13
Normal Stiffness, EA (kN/m)		1,632	750	42,000
Modified Tensile Capacity*, T_{al} (kN)		44	15	82

* Parameters of discrete reinforcements are modified considering the coverage ratio, R_c=b/S_h, where b is the gross width of the reinforcement and S_h is the center-to-center horizontal spacing between reinforcements (Berg et. al, 2009).

2.2 *Soil properties*

All numerical models are designed to have uniform soil parameters with interface between soil and reinforcement is considered as rigid. The backfill soil is granular soil designed to have drained drainage condition and is modelled in Mohr-Coulomb in Plaxis 3D and effective elastic-plastic in GeoStudio Sigma/W (see Table 2). In this study, the retained backfill and reinforced backfill soils are assumed to have the same parameters for simplicity. Hence, backfill soil have effective Young's modulus of 20,000kPa, dry unit weight of 19kN/m^3, Poisson's ratio of 0.40, effective cohesion of 10kPa, and effective friction angle of 30°. The soil foundation used in this study is considered bedrock to eliminate the influence of foundation deformations to the behavior of the MSE wall. It is modelled as jointed rock in Plaxis 3D and total elastic-plastic in GeoStudio Sigma/W with properties of a bedrock. Foundation is modelled with Young's modulus of 60x10^{6}kPa, unit weight of 25kN/m^3, Poisson's ratio of 0.30, cohesion of 500kPa, and friction angle of 40°.

2.3 *Wall facing properties*

The precast concrete panel type wall facing is designed to have a square shape with 1.50m on each side with thickness of 14mm. The wall facing is modeled as structural beam element in GeoStudio Sigma/W and plate element in Plaxis 3D. It has a cross-sectional area computed as 0.14m^2 and moment of inertia computed as 22.867x10^{-5}m^4 per unit width of the wall facing. Moreover, it has a unit weight of 24kN/m^3, Young's modulus equivalent to 30x10^{6}kPa and Poisson's ratio value of 0.15 (see Table 2).

Table 2. Properties of soil materials used in numerical analysis.

Parameters		Wall Facing	Soil Materials	
			Backfill	Foundation
Material Model	Plaxis 3D	Plates	Mohr-Coulomb	Jointed Rock
	GeoStudio	Beam	Linear Elastic-Plastic (Effective)	Linear Elastic-Plastic (Total)
Young's Modulus, E (kPa)		30x10^6	20,000	60x10^6
Unit Weight, γ (kN/m^3)		24	19	25
Poisson's Ratio, ν		0.15	0.40	0.30
Cohesion, c (kPa)		-	10	500
Friction Angle, φ		-	30°	40°
Thickness, mm		14	-	-

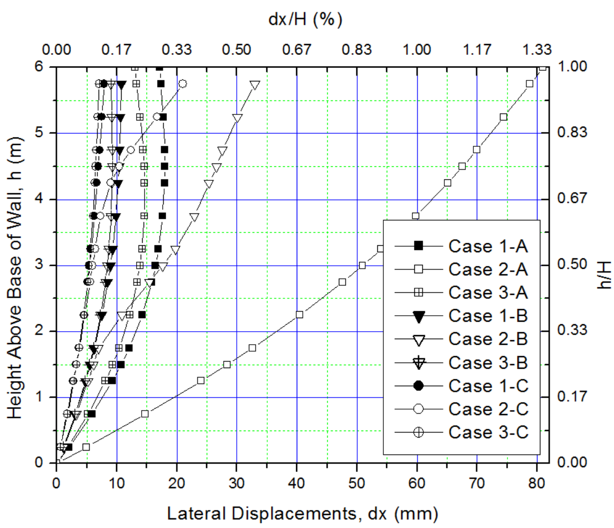
3 NUMERICAL RESULTS

The results from the numerical simulations using Plaxis 3D and GeoStudio are shown in Figure 3.

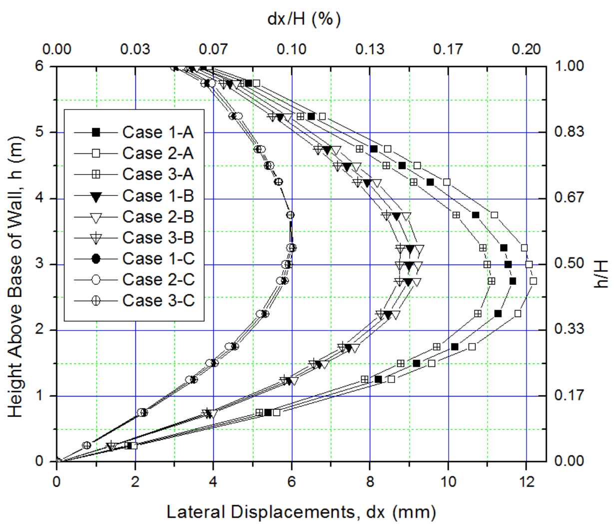
Legend:

Case A – at the wall facing
Case B – at the middle of reinforcement
Case C – at end of the reinforcements

Case 1 – using geogrids
Case 2 – using geo-strips
Case 3 – using steel strips



(a) Plaxis 3D results



(b) GeoStudio Sigma/W results

Figure 3. Lateral displacements of the MSE walls.

The results in Figure 3(a) using Plaxis 3D showed that Case 1 and Case 3 have the same lateral displacements pattern with negligible difference. The lateral displacements for both cases are great between 11th and 12th backfill lifts whose values are 15-18mm at the wall facing, and at the last lift whose values are 9-11mm at the middle of reinforcements and 7-8mm at the end of reinforcements. Note that Case 3 have EA=42,000kN/m while Case 1 have EA=1,632kN/m, yet obtained almost similar lateral displacements. It can be inferred that despite 23x smaller value of Young's modulus, wider width (larger area) of reinforcements can sustain lateral displacements. Another noticeable result from the figure is that Case 2 showed larger lateral displacements and have different lateral displacements pattern compared with Case 1 and Case 2. Since Case 2 have EA=750kN/m, it can be inferred that small Young's modulus and narrow strip reinforcements have larger lateral displacements.

The results in Figure 3(b) using GeoStudio Sigma/W showed that all three cases have similar lateral displacements pattern whose largest deformation occurred at the 7th backfill lift for the wall facing and 9th backfill lifts for the middle and end of reinforcements. All three cases have almost equal lateral displacements with negligible differences. Unlike in Plaxis 3D, Case 2 showed similar deformation with Case 1 and Case 3 but still exhibited the largest lateral displacements.

It can be observed from Figures 3(a) and (b) that Plaxis 3D exhibited larger values compared with GeoStudio Sigma/W, but showed similar pattern of lateral displacements except for Case 2. Moreover, both programs showed that lateral displacements are great at the wall facing and eventually decreases as the points move towards the end of reinforcements. It is also noticeable that there are no displacements at the base of the wall since the soil foundation was assumed as bedrock.

4 CONCLUSION

This study focuses on the lateral displacements of the MSE walls reinforced with three different discrete reinforcements: geogrids, geo-strips and steel strips. Each reinforcements have different width, properties and arrangements. It can be inferred from the numerical simulation results using Plaxis 3D and GeoStudio Sigma/W that reinforcement with wider width and high stiffness are better in resisting lateral displacement at the wall facing. The 1.2m-width geogrids exhibited similar lateral displacement behavior with 0.05m-width steel strips having 26 times larger Young's modulus of 210GPa. Moreover, narrow strip reinforcements with very low stiffness exhibited slightly higher lateral displacements compared to wider geogrids. This may imply that MSE wall with precast concrete panel type wall facing that uses wider width of reinforcement can better sustain lateral displacements than narrow strip reinforcements.

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