IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 2 Ver. II (Mar. - Apr. 2018), PP 01-09
www.iosrjournals.org

Behavior of MSE Wall with Strips and Georgics Reinforcement Subjected To Compaction Loadings

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Abstract : *This paper focuses on the comparison of the behavior of a panel type MSE wall using the existing geosynthetic strip and steel strip reinforcement with the behavior of a suggested design of panel type MSE wall using wider geogrid reinforcement subjected to various compaction loadings and built above bedrock and stiff clay soil foundation. The behavior of the MSE wall is analyzed using finite element method in Plaxis 3D program. The numerical simulations showed that wider geogrid reinforcement exhibited similar lateral displacement with negligible difference compared to steel strip reinforcement having 26 times larger stiffness value. Also, wider geogrid reinforcement obtained higher stability level compared to strip reinforcements. The results may infer that wider reinforcement is better than narrow strip reinforcement despite the high value of stiffness in restraining deformations of MSE wall. This study also showed that the deformations of MSE wall increases and stability level decreases as the application of compaction loading increases and more when the foundation soil softens. Here, the behavior of wider geogrid with respect to strip reinforcements remained consistent upon the application of compaction loadings and change of soil foundation. Moreover, this study infer that compaction should be considered in modelling MSE wall to prevent underestimation of MSE wall deformations, which is important in design and construction.*

Keywords – *MSE wall, compaction effect, geogrids, steel strips, geo-strips, lateral displacement*

Date of Submission: 12-03-2018 Date of acceptance: 26-03-2018

I. Introduction

The MSE wall is composed majorly of backfill soil, reinforcement and facing system that form a composite system that is capable of sustaining lateral forces. 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 [1]).

Generally, panel type MSE wall uses metal or geosynthetic strips as reinforcement material. On the other hand, block type MSE wall uses sheet type of geogrid as reinforcement material. The principle of reinforced soil is to increase the shear strength due to the restraining effect caused by the frictional force developed at the interface between the soil and the reinforcement. Therefore, the reinforcing effect can be expected to be larger as the soil-reinforcement interface is wider (Abdelouhab, et.al. 2011 [2]).

In this study, a panel type MSE wall that could use wider geogrid reinforcement than strip reinforcement is suggested. The suggested panel is designed in such a way that geogrid reinforcement can be installed between panel and panel. Henceforth, this study is going to compare the behavior of panel type MSE wall using the existing geosynthetic strip and steel strip reinforcement with the behavior of panel type MSE wall using wider geogrid reinforcement which is suggested in this study. The behavior of the MSE wall is analyzed using finite element method in Plaxis 3D program.

To study the influence of compaction on the behavior of the MSE wall, the mentioned panel type MSE walls will be subjected to various compaction loadings on every phases of the wall construction. According to Castellanos [3], the compaction equipment used within 1m from the wall facing should be a vibratory roller or plate weighing less than 4.45 kN and from beyond the 1m from the wall facing panels a roller up to 78.45 kN may be used subject to satisfactory performance (see Fig.1).
Figure 1 Compaction equipment (Castellano, 2012 [3])

II. Design of the Suggested Panel Type Muse Wall

Fig.2 shows the modified panel type facing with steel pipe slip-on, steel bar, and geogrid reinforcement connections. The steel bars and geogrid reinforcements are arranged in discrete and staggered manner having the width of 1.20 meters and spaced horizontally at 1.50 meters on centers. The vertical spacing of the reinforcements may vary depending on the magnitude of loads that will be supported. For the connection, the geogrid reinforcement is wrapped around the steel bar with an adequate overlapping length. The alternating design of the reinforcement arrangements creates an interlocking effect which could help connect the panel to another panel and hold the two panels together during excessive deformations to prevent detachment of wall facing element from the reinforcements. Also, this design is favorable during rare situations wherein panel facings cannot be aligned. The connection between panel and panel plus the geogrid reinforcements help hold the panels in place.

Figure 2 Modified panel type facing with steel pipe slip-on, steel bar, and geogrid connections

III. Three-dimensional modeling

A three-dimensional (3D) model of the MSE wall is created and analyzed using Plaxis 3D program as shown in Fig.3. The height of the MSE wall is 6.0m above the soil foundations. There will be twelve layers of 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 reinforcement length is 4.50m (0.75H) in all layers. The vertical spacing between reinforcements is 0.50m on-centers while the horizontal spacing varies depending on the type of reinforcement being modeled.

Figure 3 Numerical model of MSE wall using Plaxis 3D program

There will be a 5kN compaction loading applied within 1.0m from the wall facing and 10-100kN compaction loadings applied uniformly beyond 1.0m from the wall facing in every construction lift (see TABLE 1). The compaction load is assumed to be great to see the extent of deformations that may occur at the MSE wall. The compaction loading is removed immediately upon the construction of the next lift. The influence of the pore water pressure is not considered in the analyses. Nevertheless, all models have the same soil backfill, soil foundation and wall facing material properties to avoid complexity with the results. The models are analyzed in thirteen construction phases wherein the deformation from previous lifts are carried until the final stage of construction. To properly compare the behavior between the panel type MSE wall using the existing geosynthetic strip and steel strip reinforcement with the behavior of panel type MSE wall using wider geogrid reinforcement which is suggested in this study, wall failure should not occur.

IV. Schedule of numerical analyses in Plaxis 3D

To study the influence of reinforcement width, there will be three cases of MSE walls having different reinforcement arrangements will be analyzed in Plaxis 3D program. Case 1 refers to panel type MSE wall using wider geogrid reinforcement which is suggested in this study. Case 2 refers to panel type MSE wall using the existing geosynthetic strip reinforcement. And Case 3 refers panel type MSE wall using the existing steel strip reinforcement (see TABLE 1).

Table 1. Designated cases used in numerical analyses

To study the influence of compaction on the behavior of the MSE wall, four different calculations have been performed for each cases of MSE walls. The model will be subjected to various compaction loadings in every phases of the wall construction. During the application of compaction, a 5kPa load is applied only within 1.0m from wall facing, the rest of the areas will be subjected to the following cases. First, Case A_0 refers to MSE wall above bedrock foundation without compaction loading. Next, Case B_{10} refers to MSE wall above bedrock foundation subjected to 10kPa compaction loading. Third, Case C_{100} refers to MSE wall above bedrock foundation subjected to 100kPa compaction loading. Lastly, Case D_{10} refers to MSE wall above stiff clay foundation subjected to 10kPa compaction loading.

V. Material parameters

5.1 Reinforcement material

The 1.50mWx1.50mH panel type MSE wall using geogrid, geosynthetic strip, and steel strip reinforcement will be modelled according to the specified arrangements as shown in Fig.4.

Case 1 refers to panel type MSE wall using 1.20m-width geogrid reinforcement and are arranged in discrete and staggered manner with horizontal spacing of 1.50m on centers. Case 2 refers to panel type MSE wall using 0.10m-width geo-strips and are arranged in discrete and linear manner spaced at 0.75m horizontally on centers. Case 3 refers to panel type MSE wall using 0.05m-width steel strips and are arranged also discretely and aligned uniformly with horizontal spacing of 0.75m on centers.

Figure 4 Three cases of panel type MSE wall and its reinforcement arrangement

Geogrids, geo-strips and steel strips reinforcements are modeled as geogrid element with elastic material property in Plaxis 3D. Reinforcements were assumed fixed to the precast concrete panel type wall facing, thus reinforcement anchorage is considered. Case 1, geogrids, are assumed to be made by polypropylene with normal stiffness equal to 1,632kN/m, elastic modulus of 940MPa and thickness of 1.45mm. Case 2, geo-strips, are specified with normal stiffness of 750kN/m, elastic modulus of 2.5GPa and thickness of 3.0mm. Lastly, Case 3, steel strips, have normal stiffness of 42,000kN/m, elastic modulus of 210GPa and thickness of 4.0mm (see TABLE 2).

Table 2. Reinforcement material properties

5.2 Wall facing material

A square precast concrete panel-type wall facing is designed with 1.50m width, 1.50m height, and 14mm thickness. The wall facing is modeled as plate element in Plaxis 3D. The plate is specified as linear elastic and can resist forces in tension and compression. Properties of the wall facing are specified with unit weight of 24kN/m3, Young's modulus, E, equivalent to 30x106kPa and Poisson's ratio value is 0.15 (see TABLE 3).

5.3 Backfill and foundation soil material

Soil material models characterize the stress-strain constitutive behavior of the soil. In this study, reinforced backfill and retained backfill soils are assumed to have the same material properties to simplify the analysis. The backfill material is categorized as Mohr-Coulomb with drained drainage type condition during the staged construction. The backfill soil is a granular soil whose properties are as follows: effective elastic modulus, E', is 20,000kPa; effective cohesion, c', is 10kPa; effective angle of friction, φ', is 30°; Poisson's ratio equals to 0.40 and unit weight, γ, is 19kN/m³ (see TABLE 3).

For the soil foundation materials, there will be two types: bedrock and stiff clay. Bedrock foundation is modelled as jointed rock material with non-porous drainage type wherein pore pressures cannot occur. The assumed bedrock properties are as follows: total elastic modulus, E, is 60x106kPa; total cohesion, c, is 500kPa, angle of friction, φ, equivalent to 40°, Poisson's ratio of 0.3 and unit weight, γ, of 25kN/m³. Stiff clay foundation is categorized as Mohr-Coulomb with undrained drainage type whose properties are specified with total elastic modulus, E, of 50,000kPa, Poisson's ratio of 0.45, undrained cohesion is 100kPa and unit weight, γ, of 19kN/m³. Interface between reinforcements, soil and wall facing are considered as rigid. Boundary conditions are assigned to have free surface displacements along x-direction and y-direction at wall facing and on top of reinforced soil.

Table 3. Wall facing and soil material properties

VI. Results and Discussion

6.1 Effect of Compaction Loading

The application of 5kN compaction loading within 1.0m from the wall facing and 10-100kN compaction loadings beyond 1.0m from the wall facing in every construction lift has significant effects on the behavior of the MSE wall as shown in Fig.5. In this study, the compaction load is assumed to be great to see the extent of deformations that may occur at the MSE wall. Hence, the results showed that the lateral displacement increased when the compaction loading increased. A 100 kN compaction loading is too large for the MSE wall, thus, exhibited large lateral displacements. This may infer that large loadings can cause great deformations on the MSE wall which eventually leads to failure. This effect should be considered during the design of MSE wall to prevent underestimation of the MSE wall deformations.

Figure 5 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation

To show the amount of increase on each case, consider Case A_0 as the reference model for MSE wall built on bedrock foundation. As tabulated in TABLE 4, Case 1 has an increase of 43-50% and 817-821% after subjected to compaction loading of 10kPa and 100kPa, respectively. Case 2 has a remarkable increase of 88-100% and 2965-4300% after subjected to compaction loading of 10kPa and 100kPa, respectively. And Case 3 has an increase of 42-60% and 617-700% after subjected to compaction loading of 10kPa and 100kPa, respectively.

Table 4 Maximum lateral displacements, dx_{max} (mm) | percent increased (%)

Moreover, the results showed that stability of the MSE wall at the final stage of construction decreased as the compaction loading increased (see Fig.6). The factor of safety (FS) has decreased by 8.7%, 2.4%, and 8.8% after the application of 10kN compaction load for Case 1, Case 2, and Case 3, respectively. Also, the FS has decreased by 29.7%, 34.3%, and 29.8% after the application of 100kN compaction load for Case 1, Case 2, and Case 3, respectively (see TABLE 5). This may imply that application of large compaction loading greatly reduced the stability level of MSE wall.

Table 5 Factor of safety results

Figure 6 Factor of safety results

6.2 Effect of Reinforcement Width and Arrangement

The numerical simulations from Plaxis 3D program showed that for MSE wall above bedrock foundation, there is no lateral displacement at the base of the wall as shown in the Figs.7 and 8. Also, the results showed that for MSE wall above stiff clay foundation, there is a movement of 5-8mm at the base of the wall as shown in Fig.9. It is visible from the figures that Case 1 and Case 3 exhibited similar lateral displacement pattern with minimal differences of 1-3mm and 15-43mm when subjected to 10kN and 100kN compaction loading, respectively. The difference in lateral displacements is almost negligible taking into consideration the fact that steel strip has 42,000kN/m stiffness while wider geogrid has 1,632kN/m stiffness, approximately 26 times smaller than steel strip. However, Case 2 has a different pattern of lateral displacements compared with the other two cases. It displaced up to 16-64mm and 352-1042mm when subjected to 10kN and 100kN compaction loading, respectively. A possible failure may have occurred during the application of 100kN, which is neglected in the analysis. The behavior of Case 2 may be affected by its low stiffness value of 750kN/m and narrow width of 0.10m. The results may infer that wider reinforcement is better than narrow strip reinforcement despite the high value of stiffness.

Figure 7 Lateral displacement at the wall facing of MSE wall above bedrock foundation

Figure 8 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation

Figure 9 Lateral displacements of MSE wall above stiff clay foundation subjected to 10kPa compaction loading

Moreover, the safety calculation results, as tabulated in TABLE 5, showed that Case 1 obtained the highest factor of safety, and Case 2 obtained the least factor of safety at the final stage of construction. This may imply that wider reinforcements have higher stability level compared with narrower strip reinforcements.

6.3 Effect of Foundation Condition

To study the influence of soil foundation on the behavior of MSE wall subjected with 10kN compaction loading, Case B_{10} will be compared with Case D_{10}. From TABLE 6 we can see that Case D_{10} exhibited larger deformations than Case B_{10}. Yet, Case 1 and Case 3 still showed almost equal lateral displacements with minimal difference of 1-3mm. And Case 2 also showed larger deformations compared with the other two cases.

Table 6 Maximum lateral displacements of MSE above stiff clay foundation, dx_{max} (mm)

Moreover, the panel type MSE wall constructed above bedrock foundation, Case B_{10} for example, obtained higher stability compared with stiff clay foundation, Case D_{10}as shown in TABLE 5. This may imply that MSE wall above stronger soil foundation are more stable than weaker soil foundation especially when compaction loadings are applied.

VII. Conclusion

The study compared the behavior of panel type MSE wall using the existing geosynthetic strip and steel strip reinforcement with the behavior of panel type MSE wall using wider geogrid reinforcement which is suggested in this study. The behavior of the MSE wall is analyzed using finite element method in Plaxis 3D program. To compare the influence of compaction, the mentioned panel type MSE walls are subjected to 10kN and 100kN compaction loadings on every phases of the wall construction.

Consequently, the results of the study showed that MSE wall with geogrid reinforcements exhibited similar deformations with negligible difference compared to steel strip reinforcements. Also, MSE wall with geogrid reinforcements obtained the highest factor of safety on bedrock and stiff clay foundation when subjected to compaction loadings. The results implied that wider geogrid reinforcement is more stable than narrow steel strip reinforcements despite having about 26 times higher stiffness value. Therefore, this study inferred that panel type MSE wall with wider geogrid reinforcement is better than panel type MSE wall with existing narrow strip reinforcements.

Moreover, this study showed the extent of deformations on the MSE wall when subjected to compaction loadings. The lateral displacement of the MSE wall increased and the stability level decreased when the compaction loading increased. For MSE wall with narrow strip reinforcement and low stiffness, application of large compaction may be harmful and eventually may result to failure. Thus, the effects of compaction should be considered in analysis of MSE wall to prevent underestimation of its behavior.

Lastly, this study compared the behavior of MSE wall with different soil foundation subjected with 10kN compaction loading. And the results showed that stiff clay foundation exhibited larger lateral displacements and lesser stability level compared with bedrock foundation. This may imply that MSE wall with stronger foundation is more stable and have less deformations.

Acknowledgements

This research was supported by Education & Human Resource Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2017R1D1A3B03034189) and Brain Korea 21 PLUS.

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Figure 1 Compaction equipment (Castellano, 2012[3])

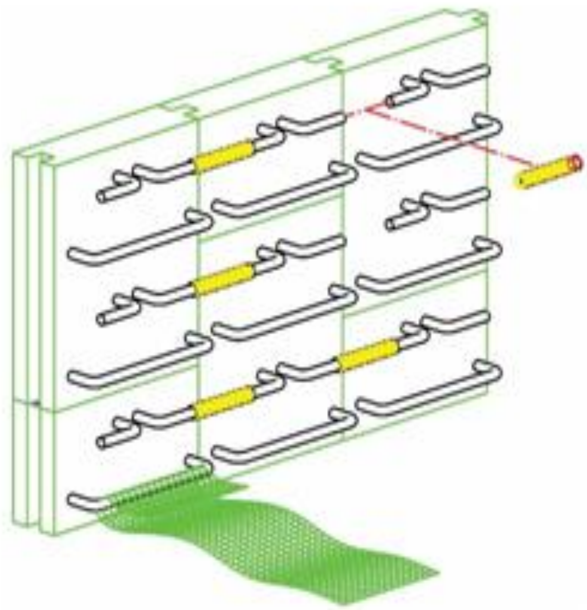


Figure 2 Modified panel type facing with steel pipe slip-on, steel bar, and geogrid connections

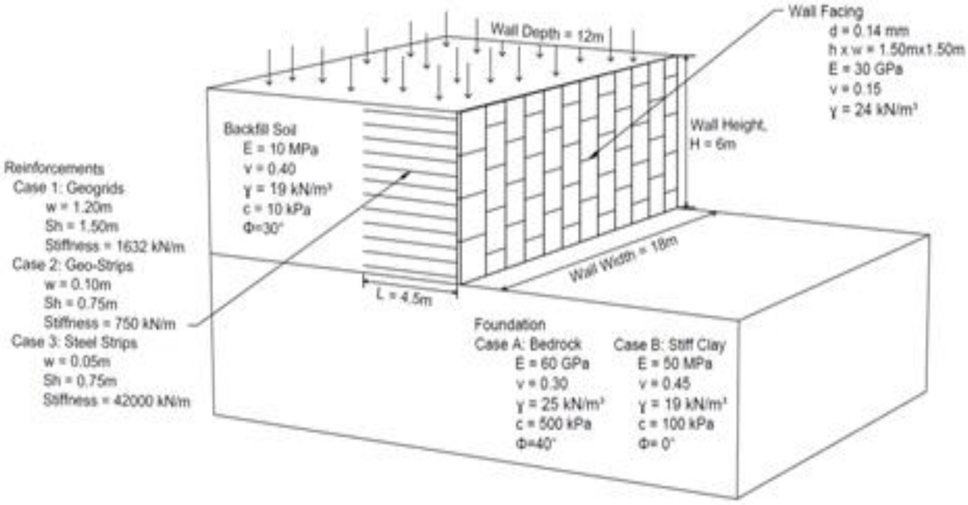
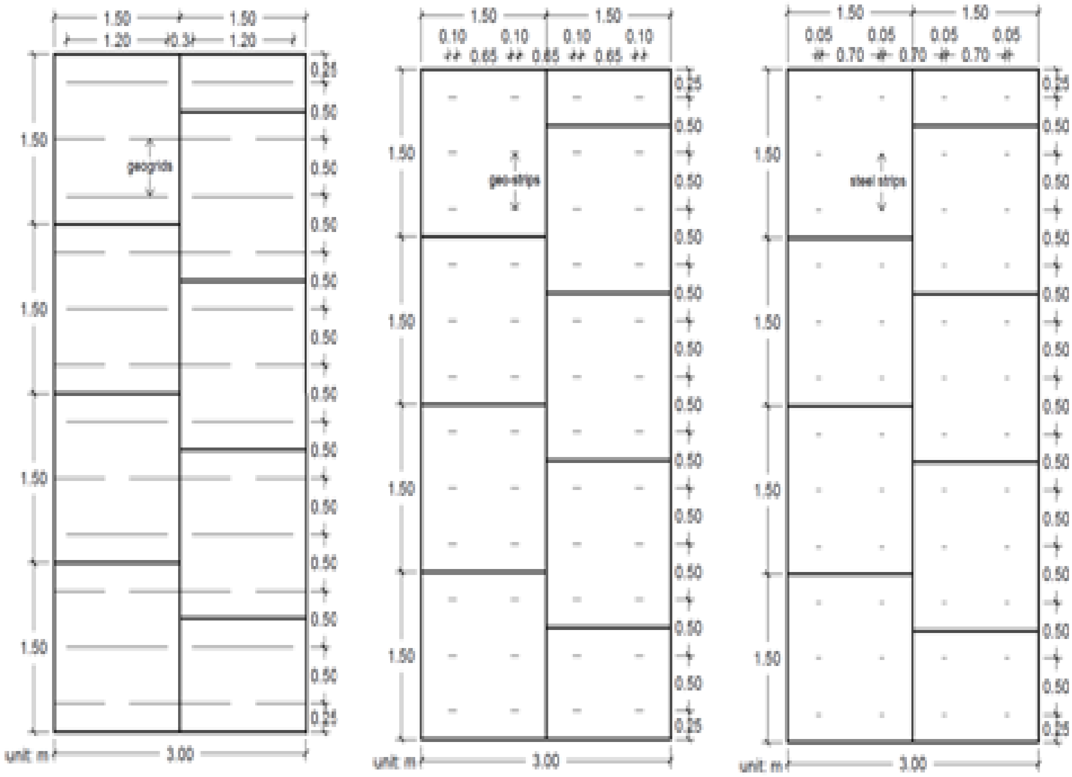
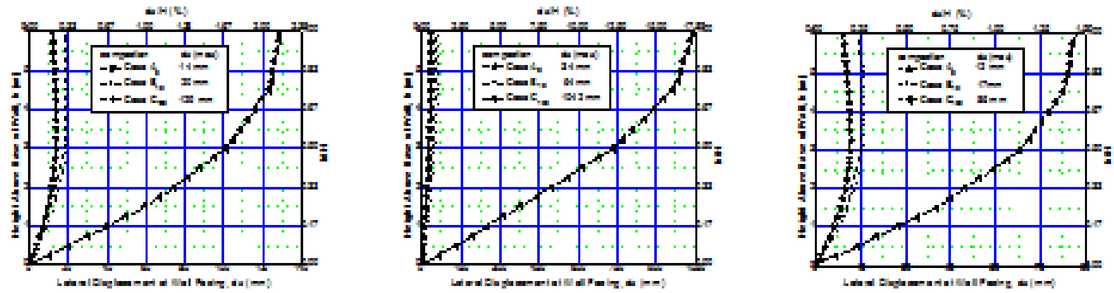


Figure 3 Numerical model of MSE wall using Plaxis 3D program



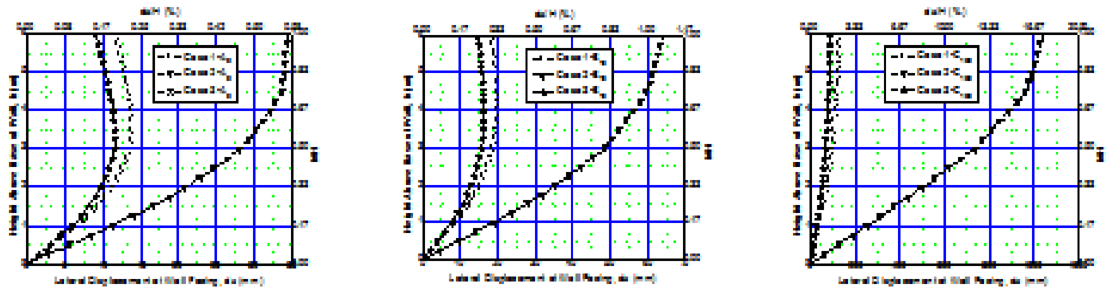
(a) Case 1 using geogrids (b) Case 2 using geo-strips (c) Case 3 using steel strips

Figure 4 Three cases of panel type MSE wall and its reinforcement arrangement



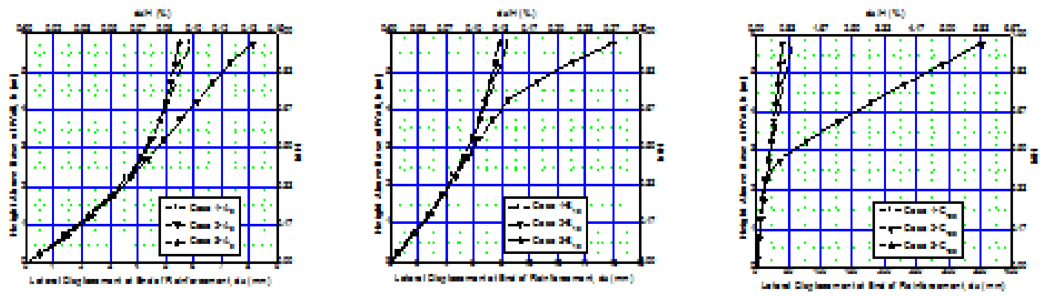
(a) Case 1 (b) Case 2 (c) Case 3

Figure 5 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation



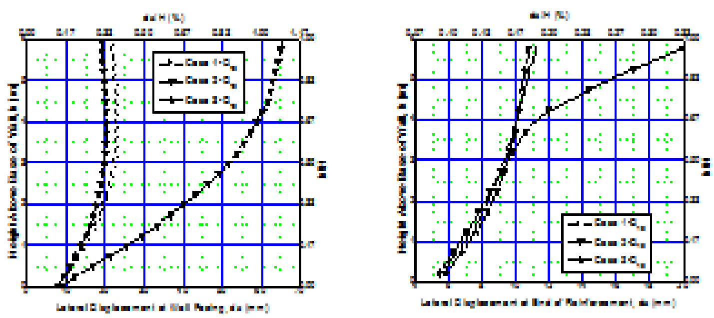
(a) without compaction (b) with 10kN compaction (c) with 100kN compaction

Figure 7 Lateral displacement at the wall facing of MSE wall above bedrock foundation



(a) without compaction (b) with 10kN compaction (c) with 100kN compaction

Figure 8 Lateral displacement at the end of the reinforcements of MSE wall above bedrock foundation



(a) at the wall facing (b) at the end of reinforcement

Figure 9 Lateral displacements of MSE wall above stiff clay foundation subjected to 10kPa compaction loading

Table 1. Designated cases used in numerical analyses

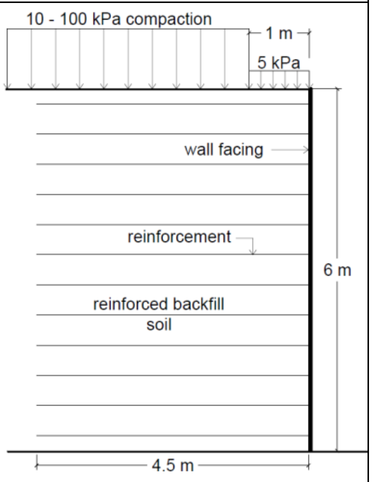
Foundation condition	Compaction loading	Designated cases			Cross-section of Numerical Model
		Case 1	Case 2	Case 3	
Bedrock	No compaction	Case 1-A_0	Case 2-A_0	Case 3-A_0	
	10 kN	Case 1-B_{10}	Case 2-B_{10}	Case 3-B_{10}	
	100 kN	Case 1-C_{100}	Case 2-C_{100}	Case 3-C_{100}	
Stiff Clay Soil	10 kN	Case 1-D_{10}	Case 2-D_{10}	Case 3-D_{10}	

Table 2. Reinforcement material properties

Parameters	Case 1 Geogrids	Case 2 Geo-strips	Case 3 Steel strips
Constitutive model	Geogrid element	Geogrid element	Geogrid element
Width, w (mm)	1,200	100	50
Thickness, t (mm)	1.45	3.0	4.0
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
Normal stiffness, EA (kN/m)	1,632	750	42,000
Modulus of elasticity, E (GPa)	0.94	2.5	210

Table 3. Wall facing and soil material properties

Parameters	Wall Facing	Soil Backfill	Soil Foundation	
			Bedrock	Stiff Clay
Constitutive model	Plate element	Mohr-Coulomb	Jointed rock	Mohr-Coulomb
Drainage type	-	drained	nonporous	undrained
Young's modulus, E (kPa)	$30x10^6$	$20x10^3$	$60x10^6$	$50x10^3$
Unit weight, ɣ (kN/m^3)	24	19	25	19
Poisson's ratio, ν	0.15	0.40	0.30	0.45
Cohesion, c (kPa)	-	10	500	100
Friction angle, φ	-	30°	40°	-
Thickness, t (mm)	14	-	-	-

Table 4 Maximum lateral displacements, dx_{max} (mm) \| percent increased (%)

At wall facing								
Cases	Case A_0		Case B_{10}		Case C_{100}		Case D_{10}	
Case 1	14	0	20	43%	129	821%	23	64%
Case 2	34	0	64	88%	1042	2965%	66	94%
Case 3	12	0	17	42%	86	617%	20	67%
At the end of reinforcement								
Cases	Case A_0		Case B_{10}		Case C_{100}		Case D_{10}	
Case 1	6	0	9	50%	55	817%	11	83%
Case 2	8	0	16	100%	352	4300%	20	150 %
Case 3	5	0	8	60%	40	700%	11	120 %

Table 5 Factor of safety results

Cases	Case A_0	Case B_{10}	Case C_{100}	Case D_{10}
Case 1	3.158	2.882	2.025	2.545
Case 2	2.309	2.253	1.480	1.546
Case 3	3.093	2.820	1.980	2.493

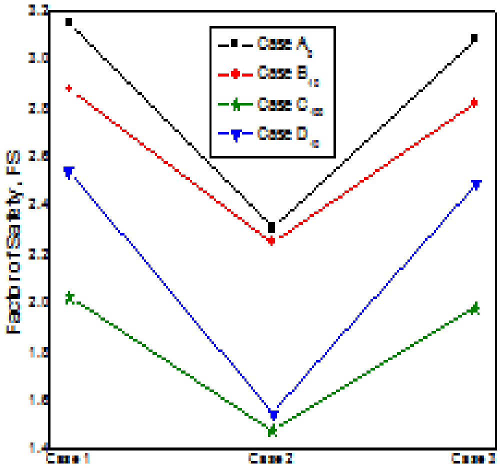


Figure 6 Factor of safety results

able 6 Maximum lateral displacements of MSE above stiff clay foundation, dx_{max} (mm)

Cases	At wall facing		At the end of reinforcement	
	Case B_{10}	Case D_{10}	Case B_{10}	Case D_{10}
Case 1	20	23	9	11
Case 2	64	66	16	20
Case 3	17	20	8	11

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