

Lateral Earth Pressure Analysis for Cantilever wall and Mechanically Stabilised Earth wall Optimisation: A Numerical Study

Nur Iman Elianie Mustapah¹, Chan Chee Ming^{1*}, Salina Sani¹

¹ Department of Civil Engineering Technology,

Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Muar, Johor, MALAYSIA.

*Corresponding Author: chan@uthm.edu.my

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Abstract

The construction of infrastructure on elevated ground requires the development of earth embankments. Ensuring these embankments are stable and sustainable is crucial to prevent excessive land use and reduce costs. Retaining walls are essential for maintaining the stability and safety of these structures. This research focuses on the necessity of retaining walls to resist sudden soil movements and maintain stability. Using Plaxis 2D, a finite element analysis software, the study aims to analyze the lateral earth pressure on cantilever and Mechanically Stabilized Earth (MSE) walls through displacement and deformation. The research will propose two solutions for managing soil movement: MSE walls with geogrid reinforcement and inclined cantilever retaining walls. Variations in geogrid layers, reinforcement length, and inclination ratios will be explored. Additionally, replacing clayey sand backfill with sand-rubber backfill will be examined as a sustainable step to reduce soil usage. The outcomes will highlight which solutions meet allowable horizontal deflection limits (30mm) [1].

1. Introduction

The rapid development of infrastructure includes building highways in elevated areas, requiring careful planning. Earth embankments for stable foundations and retaining walls are important to prevent soil erosion and maintain stability. Retaining walls resist lateral soil pressure, ensuring embankments remain intact. PLAXIS 2D use Finite Element Method (FEM) to simulate cantilever retaining wall and MSE wall.

1.1 Objective

The aim of this study is to:

- i) To analyse the lateral earth pressure for Mechanically Stabilised Earth (MSE) wall with geogrid reinforcement via displacement.
- ii) To analyse the lateral earth pressure for cantilever wall with inclination ratio via displacement.
- iii) To establish the lateral earth pressure effect on the deformation, shear force and bending moment distribution of its optimisation.

1.2 Scope of Study

This study focuses on constructing a road pavement (3m wide, 0.75m thick) on backfill, analysing lateral earth pressure on cantilever and MSE walls using Plaxis 2D. It compares wall displacement and soil behavior through literature review, aiming to refine research objectives and fill knowledge gaps. PLAXIS 2D simulates interactions between fill material and structures, understanding active and passive earth pressures to assess stability impacts.

2.0 Variable conditions

This project simulated into 1 case, 2 solutions and each solutions have its own optimisations with sand-rubber backfill to identify soil movement and both cantilever and MSE wall horizontal displacement. Figure 1 explains the geometric modelling in Plaxis 2D where the simulation for solution 1 analysed each of these stages where each stages have different number of geogrid layers with surcharge load 40kN/m/m.

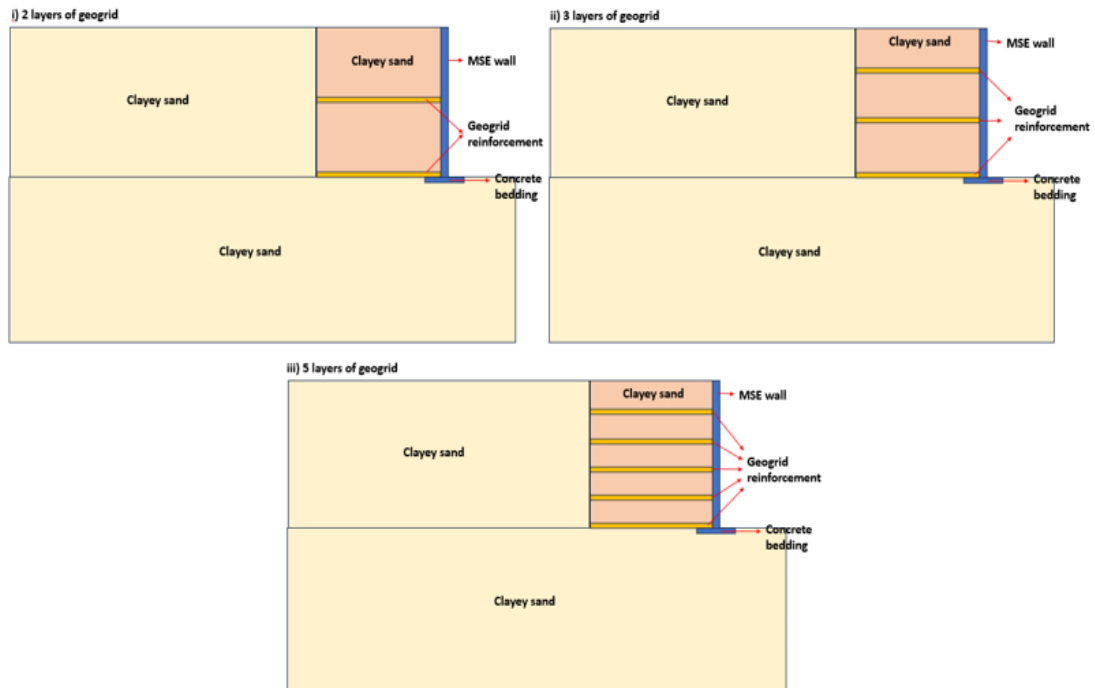


Figure 1 MSE wall with number of geogrid layers

Figure 2 explains the geometric modelling in Plaxis 2D where the simulation for solution 2 analysed each of these stages where each stages have different inclination ratio (1H:4V, 1H:6V and 1H:8V) with surcharge load 40kN/m/m.

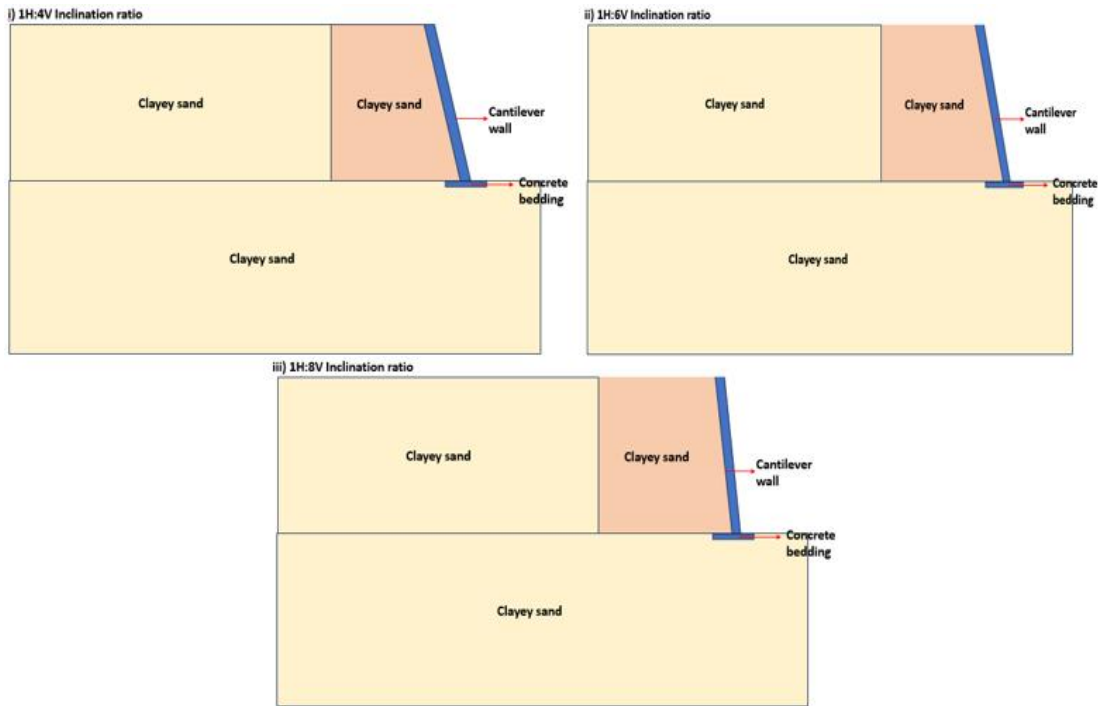


Figure 2 Cantilever wall with inclination ratio

3.0 Geotechnical Numerical Modelling

Plaxis 2D two-dimensional can analyse soil structure interaction problems providing engineers and researchers with a robust platform for modeling, analysis, and design of geotechnical structures [2]. Table 1 shows parameters used for geometric modelling for both cantilever wall and MSE wall and soil and geogrid properties [3][4][5].

Table 1 Parameter used in Plaxis 2D

Name	Parameters Name	Value	Unit
Concrete panel	EA	4019	kN/m
	EI	7.7	kNm ² /m
	d	0.15	m
	ν' (ν)	0.15	
	w	8.8	kN/m/m
Concrete bedding [3]	EA	2.4E6	kN/m
	EI	4500	kNm ² /m
	d	0.15	m
	ν' (ν)	0.20	
Geogrid	EA	1632	kN/m
Soil foundation and backfill (clayey sand) [4]	<i>MC</i>		
	<i>Drained</i>		
	γ_{sat}	21	kN/m ³
	γ_{unsat}	17	kN/m ³
	E'	10000	
	ν' (ν)	0.3	
	c'_{ref}	13	kN/m ²
	ϕ' ($^{\circ}$)	27	
Selected backfill (sand-rubber) [5]	HSS		
	Drained		
	γ_{sat}	18.7	kN/m ³

γ_{unsat}	13.70	kN/m ³
e_{init}	0.36	
e_{max}	0.45	
$Rayleigh_{\alpha}$	5.03	
$Rayleigh_{\beta}$	0.058	
E_{50}^{ref}	10.12e3	kN/m ²
E_{oed}^{ref}	6898	kN/m ²
E_{ur}^{ref}	39.04e3	kN/m ²
m	0.39	
c'_{ref}	20.00	kN/m ²
$\varphi' (^{\circ})$	38.70	
$\psi (^{\circ})$	10.80	
$Y_{0.7}$	0.02	
G_0^{ref}	39.10e3	kN/m ²
ν'_{ur}	0.20	
P_{ref}	100	kN/m ²
K_0^{nc}	0.3748	
R_f	0.90	
D_v	0.25	m ² /day

4.0 Results and discussion

Results obtained shows that case 1(a) and 1(b) shows that the presence of cantilever wall to support the fill structure behind it without any reinforcement does not able to maintain stability and causes the wall to deform. PLAXIS 2D displayed "Soil body seems to collapse." after run the simulation.

4.1 Mechanically Stabilised Earth (MSE) wall with number of geogrid layers.

The cantilever wall was changed to MSE wall with number of geogrid layers to restrain the soil movement. Optimised layers selected based on allowable horizontal deflection limit which is 30mm. Figure 3 shows the horizontal displacement of the MSE wall with number of geogrid layers (2,3 and 5 layers) and 0.8H reinforcement length. It shows that when 5 layers is used, horizontal displacement of the MSE wall is in allowable limit.

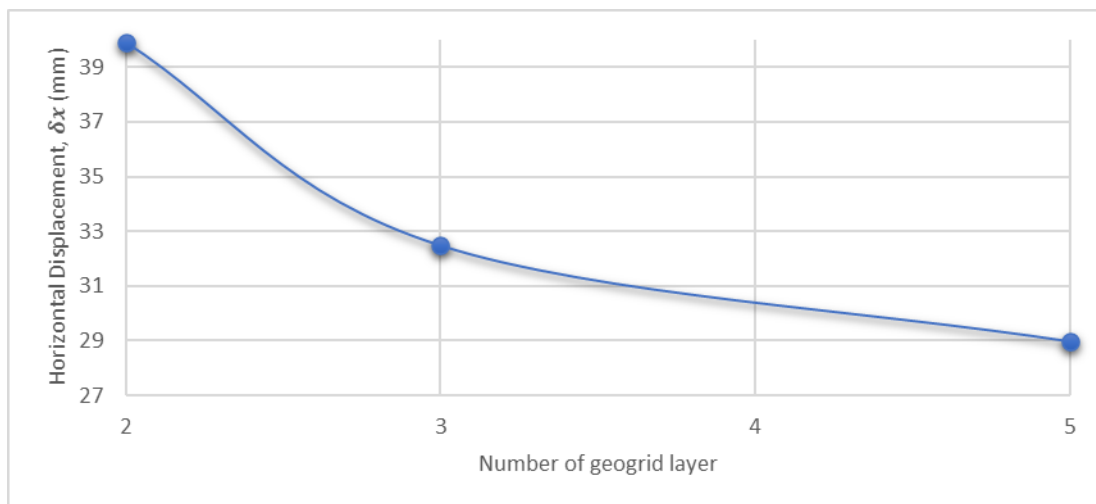


Figure 3 Graph horizontal displacement against number of geogrid layers

4.2 Cantilever retaining wall with inclination ratio.

The inclination of cantilever retaining wall aims to reduce the use of backfill, thereby minimizing construction costs while controlling soil movement. The behaviour of the cantilever retaining wall under different inclination shows how the angle of the wall affects its stability and movement. With a wall height of 3000 mm, The maximum allowable horizontal displacement is 30 mm [1].

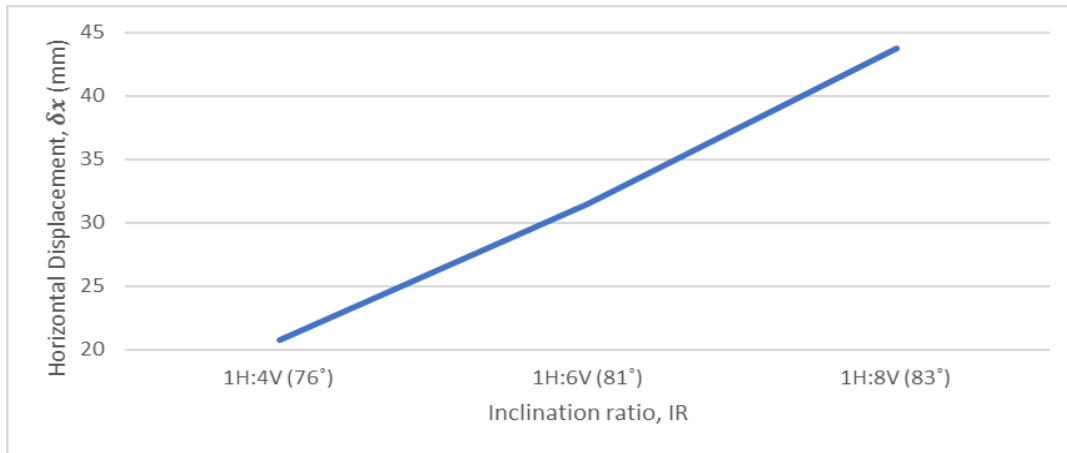


Figure 4 Graph horizontal displacement against inclination ratio

4.3 Comparison PLAXIS 2D Calculation and Manual Calculation

In PLAXIS 2D, the result obtained is - 27.38 kN/m². Based on the result in manual calculation, the result obtained is 27.896 kN/m².

Lateral Effective Earth Pressure

$$\begin{aligned} \sigma'_{xx} &= k_0 ((\gamma_{unsat} h_1 + (\gamma_{sat} - 10)h_2)) \\ &= 0.5460 (17(3) + (21-10)(0)) \\ &= 27.896 \text{ kN/m}^2 \end{aligned}$$

The simulation was done correctly. The negative value shows that the behaviour of the soil behind the MSE wall was in compression state which is in active pressure where the soil behind the MSE wall is about to fall down.

4.4 Optimisation with sand-rubber backfill

Optimisation includes implementing an MSE wall with 5 layers of geogrid reinforcement spaced 600 mm apart (center to center), is analyzed, there is a difference in displacement values when changing the backfill material from clayey sand to sand-rubber. Using sand-rubber as the backfill material reduces horizontal displacement compared to using clayey sand. Table 2 below shows comparison displacement value for both backfill for MSE wall with 5 layers of geogrid, 0.8H reinforcement length @ 600 mm spacing.

Table 2 Comparison displacement value between clayey sand backfill and sand-rubber backfill

Backfill material	Total displacement, δ (mm)	Horizontal displacement, δx (mm)	Vertical displacement, δy (mm)
Clayey Sand	40.96	28.97	28.95
Sand 70% + Rubber 30%	43.72	25.12	35.78

The optimised condition for the inclination ratio of the cantilever wall is 1H:4V. As analysed, the 1H:4V ratio falls within the allowable horizontal deflection limit. This condition was also analyzed by replacing the clayey sand backfill with sand-rubber backfill and the value of displacement obtained as shown in Table 3.

Table 3 Comparison displacement value between clayey sand backfill and sand-rubber backfill

Backfill material	Total displacement, δ (mm)	Horizontal displacement, δx (mm)	Vertical displacement, δy (mm)
Clayey Sand	34.29	20.78	27.28
Sand 70% + Rubber 30%	27.79	15.84	22.84

Implementing the MSE wall with 5 layers of geogrid reinforcement spaced 600 mm apart, the switch to sand-rubber significantly reduced horizontal displacement compared to clayey sand. This improvement was evident across all parameters, indicating enhanced stability and reduced deformations. Figures 5 and 6 show a noticeable decrease in shear force and bending moment values with sand-rubber backfill, indicating stronger soil-wall interaction and less structural stress.

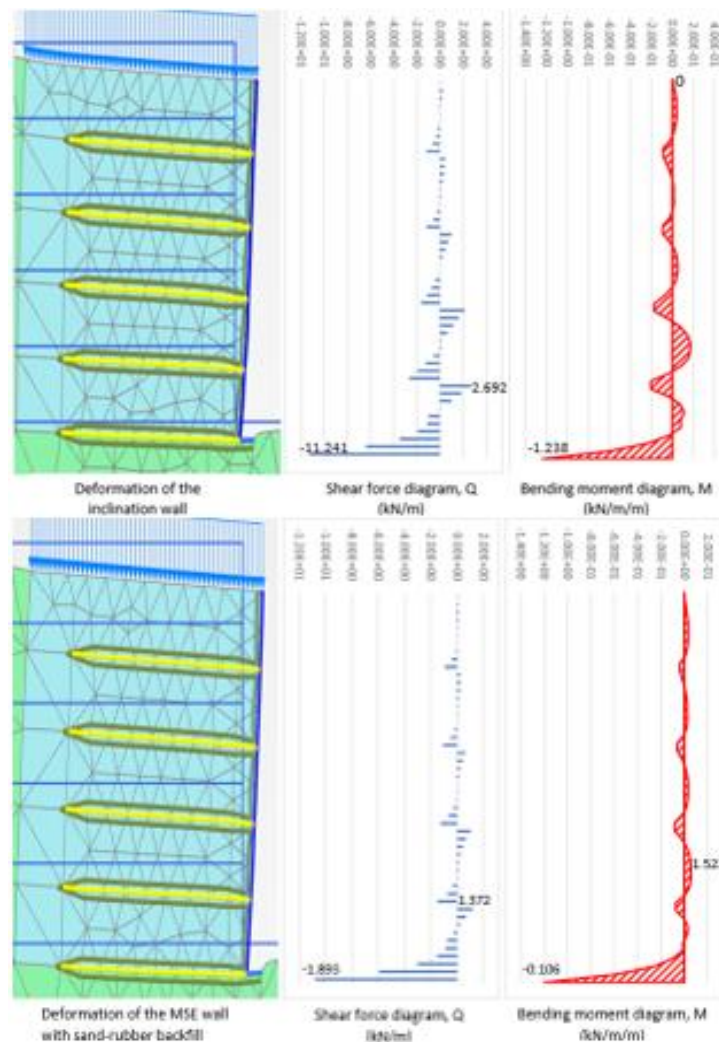


Figure 5 Comparison of deformation, shear force diagram and bending moment of clayey sand backfill and sand-rubber backfill MSE wall with 5 layers of geogrid.

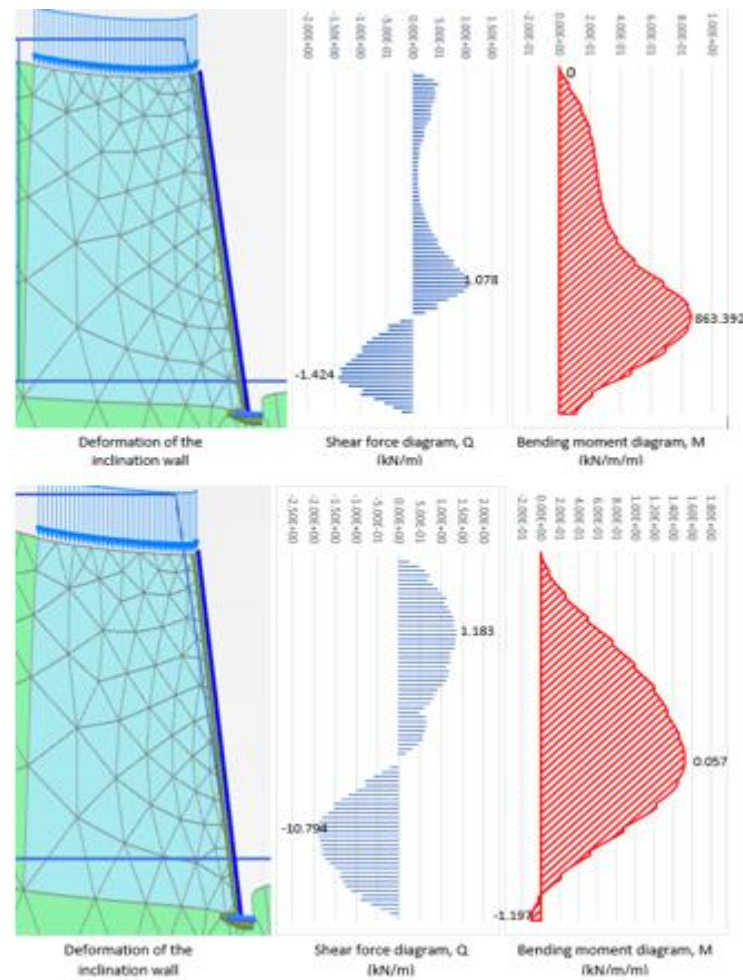


Figure 6 Comparison of deformation, shear force diagram and bending moment of clayey sand backfill and sand-rubber backfill with inclination ratio 1H:4V of cantilever wall.

5.0 Conclusion

This study analysed the behavior of a Mechanically Stabilized Earth (MSE) retaining wall to understand how different factors affect its stability and displacement. Without reinforcement, the MSE wall collapsed under a 40 kN/m/m surcharge load. Adding geogrid layers significantly reduced displacement, with 5 layers keeping it within the allowable limit of 30 mm [1]. Shortening reinforcement length to 0.7H increased displacement but stayed acceptable, and non-uniform lengths performed better than a uniform 0.7H length. Inclining the wall reduced displacements, with a 1H/4V inclination providing the best results.

In simple terms, an unreinforced wall collapsed under load, while five geogrid layers effectively controlled movement. Tilting the wall further reduced displacement, with a 1H/4V slope being the most effective. Recommendations include using at least 5 geogrid layers, aiming for a 0.8H reinforcement length (0.7H is acceptable if needed), and a 1H/4V wall inclination to maximize stability and minimize displacement.

This approach promotes sustainable development by enhancing structural stability and reducing material use, with Plaxis 2D increasing engineering precision and supporting efficient, safe, and environmentally responsible construction.

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