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Analysis of Innovative Gabion Wall Design with Geotextile Reinforcement and Dredged Marine Soil as Backfill Material via PLAXIS 2D

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Abstract

This study investigates the stability of an innovative gabion retaining wall reinforced with geotextile layers and backfilled with dredged marine soil (DMS). DMS, known for its high moisture content and low shear strength, presents major challenges as a backfill material due to its poor geotechnical properties. The research addresses the limitations of conventional gabion walls under surcharge loads, which often experience excessive deformation and insufficient factors of safety (FOS). The main objectives were to assess the stability of gabion walls using DMS and to optimize the design through geotextile reinforcement. Laboratory tests were conducted to determine soil properties, and six gabion configurations were modeled using finite element analysis in PLAXIS 2D. Among these, Model 6 featured an optimized stepped design with geotextile reinforcement. Results showed that deformation was significantly reduced to 0.80 meters, and the FOS improved to 1.54, exceeding standard safety requirements. The findings demonstrate that incorporating geotextile layers enhances the structural performance of gabion walls on weak soils and promotes sustainable slope stabilization. The study recommends future work involving 3D modeling and the use of soil stabilizers to further improve DMS behavior. This approach supports sustainable development goals by encouraging resilient infrastructure and the reuse of waste materials.

1. Introduction

In recent years, sustainable design solutions for earth retaining systems have gained importance due to urbanization and infrastructure expansion. Gabion walls have emerged as a preferred solution due to their flexibility, durability, and eco-friendliness, making them effective for slope stabilization, erosion control, and retaining structures[1][2]. However, their stability depends on factors such as lateral earth pressures, wall height, and soil properties[3][4]. The arrangement of gabion compartments and external influences, including slope properties and groundwater conditions, further impact performance[4]. A comprehensive approach is needed to optimize gabion wall designs for long-term reliability [5].

The use of dredged marine soil (DMS) as backfill presents challenges due to its weak geotechnical properties, requiring innovative reinforcement techniques. Numerical modeling tools like PLAXIS 2D enable precise analysis of soil-structure interaction, deformation, and stress distribution under staged construction[6]. This y investigates the stability of gabion walls with DMS backfill, focusing on optimized arrangements enhanced with geotextile reinforcement.

The arrangement of gabion structures offers potential improvements in load distribution and stability, addressing the limitations of traditional designs. This approach aligns with sustainable engineering practices, promoting the reuse of dredged materials while ensuring structural integrity. The findings contribute to advancing gabion wall technology for resilient infrastructure in challenging soil conditions.

2. Methodology

This study investigates the deformation and stability of an innovative gabion wall design using Dredged Marine Soil DMS from Jabatan Laut Malaysia JLM, as backfill material. The DMS used in this study was sourced from Endau, Rompin, an area known for its abundant marine sediments. Due to its challenging geotechnical properties such as high-water content and low strength. PLAXIS 2D software was utilized to simulate various gabion wall arrangements. The analysis focuses on assessing deformation and stability across multiple arrangements, including the incorporation of geotextile reinforcement to improve performance.

2.1 Geotechnical Numerical Modelling

The behavior of a gabion retaining wall can be simulated using the Finite Element Method (FEM) by accounting for external forces, material properties, and soil-structure interactions specific to the wall's design. However, PLAXIS 2D has evaluates behavior primarily in a two-dimensional plane. In this study, the gabion wall is modeled in PLAXIS 2D by separating it into two components: soil (for the backfill and existing ground) and structural elements (interfaces for the gabion units and plates for the wire mesh). The Mohr-Coulomb constitutive model is adopted to simulate stress-strain behavior of both the backfill and DMS. PLAXIS 2D operates through three core programs input, calculation, and output and supports plane strain or axisymmetric analyses using 6- or 15-node triangular elements. The simulation process is executed sequentially across five modes: Soil Mode, Structure Mode, Mesh Mode, Flow Condition Mode, and Staged Construction Mode[7]. These modes collectively enable comprehensive geotechnical modeling of the gabion wall system.

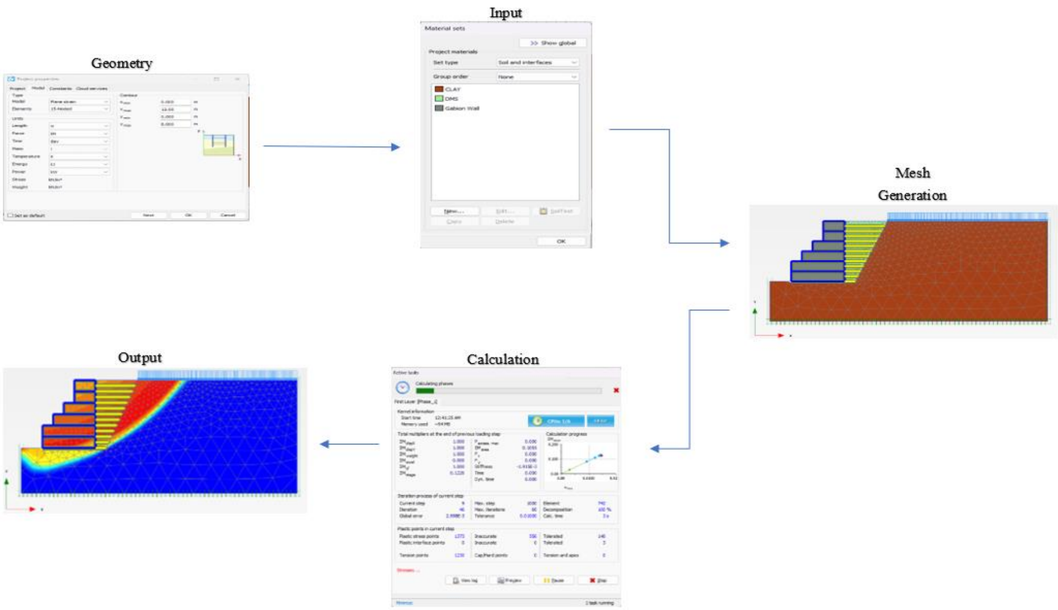


Fig. 1 *Process of modelling in PLAXIS 2D*

In the structure mode, the design of the gabion retaining wall, gabion baskets, and surcharge load was determined. Soil properties for DMS and existing clay from Tables 1 and 2 were used to assign characteristics to the soil polygons and interfaces. The properties of DMS were obtained through laboratory testing, while the properties of the existing clay were sourced from previous studies[8]. Gabion properties, derived from table 3, were also assigned as soil interfaces, while the wire mesh was treated as a plate using properties from table 4, with positive and negative interfaces assigned accordingly. Geotextile properties from table 5 were assigned. Finally, the surcharge load 218kN/m of road embankment was placed on top of the slope.

Table 1 *Properties for DMS*

Parameter	Silt	Units
Type	Drained	-
γ_{sat}	20	kN/m^3
γ_{unsat}	19	kN/m^3
E	3000	kN/m^2
v'	0.3	-
c'_{ref}	0.09	kN/m^2
φ'	1.78	-

Table 2 *Properties for existing clay*

Parameter	Silt	Units
Type	Undrained (A)	-
γ_{sat}	18	kN/m^3
γ_{unsat}	15	kN/m^3
K_0	0.5774	-
v'	0.15	-
c'_{ref}	1.00	kN/m^2
φ'	25.00	-

Table 3 *Properties for gabion wall*

Parameter	Silt	Units
Type	Undrained (A)	-
γ_{sat}	18	kN/m^3
γ_{unsat}	18	kN/m^3
E	40000	kN/m^2
v'	0.3	kN/m^2
c'_{ref}	27	kN/m^2
φ'	40	-

Table 4 *Properties for gabion wire mesh*

Parameter	Name	Value	Units
Type of Behaviors	Material Type	Elastoplastic	-
Axial Stiffness	EA	62832	kN/m^3
Flexural Rigidity	EI	0.251	kN/m^3
Weight	w	0.023	kN/m^2
Poisson's Ratio	v	0.3	kN/m^2

Table 5 *Properties for geotextile*

Parameter	Silt	Units
Material Type	Elastic	-
EA	2000	kN/m^3

2.2 Model Solution

In the initial phase examines the natural slope's stability under loading conditions without any retaining structure. The analysis focuses on a cut slope with backfill material 218kN/m surcharge load that has been applied on 15m road embankment. Figure 2 (a) and (b) show the deformation of Initial phase without surcharge load and include surcharge load.

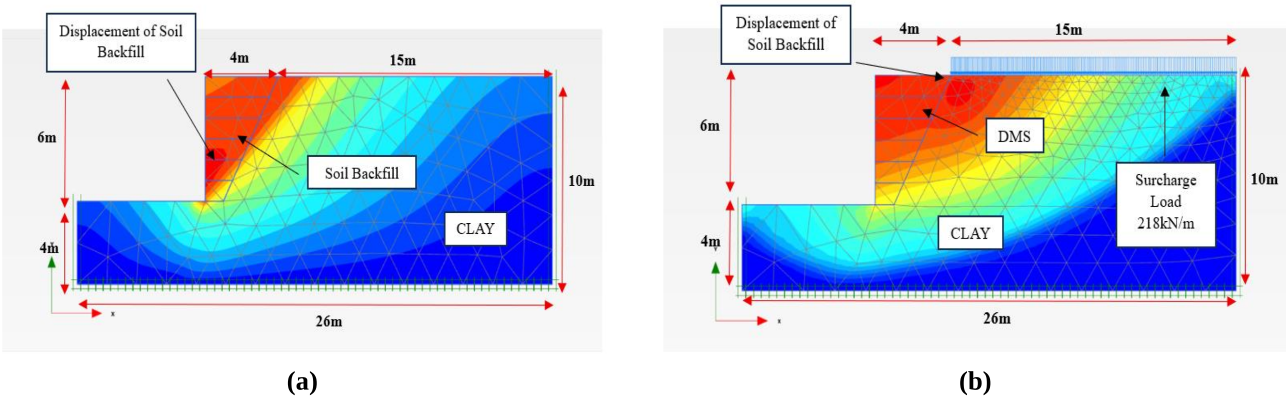


Fig. 2 *Initial phase (a) Without surcharge load; (b) Include surcharge load*

This solution evaluates five gabion wall arrangements with different widths from 1m to 5m vertical layered to evaluate their deformation and stability. Additionally, a custom stepped configuration was included to represent common construction practices. The different arrangement widths allowed comparison of how impact the gabion wall ability to resist soil pressure and prevent slope failure. Figure 3 (a) and (b) shows the deformed mesh and total displacement for the custom stepped arrangement.

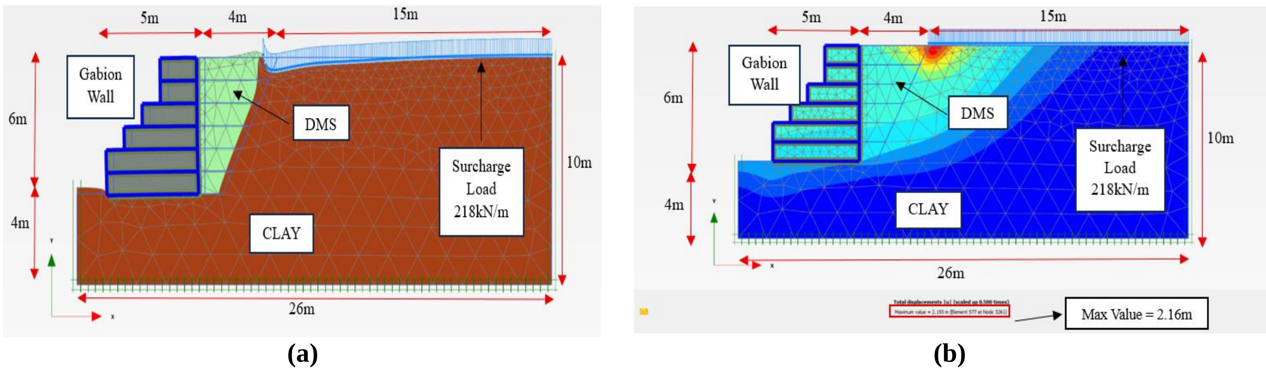


Fig. 3 *Optimized arrangement (a) Deformed mesh; (b) Total displacement*

In the second solution, the custom stepped arrangement incorporated with 12 layers geotextile reinforcement spacing 500mm from bottom of the soil backfill added into back of the gabion wall. This solution maintained all the soil parameters and wall arrangements from the first solution and used in the model simulation while introducing geotextile reinforcement. Figure 4 (a) and (b) shows the deformed mesh and total displacement for the second solution.

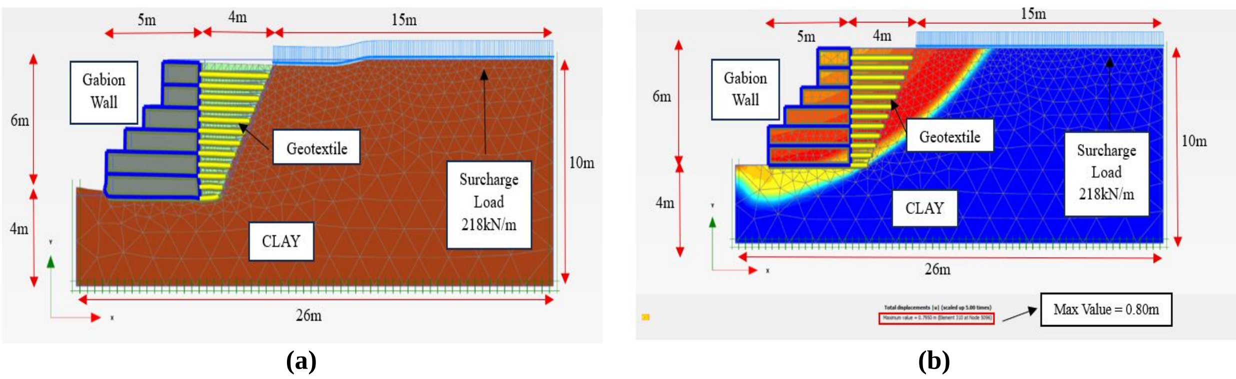
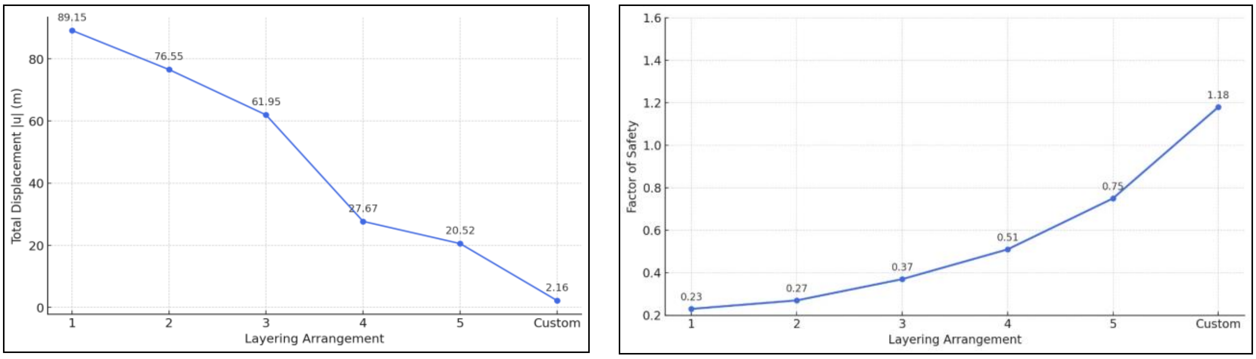


Fig. 4 *Optimized arrangement with geotextile (a) Deformed mesh; (b) Total displacement*

3. Results and Discussion

The optimized custom model demonstrated better performance compared to all vertical layer arrangements, achieving only 2.16 m displacement with an improved FOS of 1.18. This outstanding result was attributed to strategic gabion wall arrangement and advanced layering techniques that maximize interlocking and minimized displacement. The findings clearly establish that while increasing layers improve stability, combining this approach with gabion wall arrangement optimization produces the best results, making the custom model ideal for critical engineering applications where maximum stability is required. Table 6 shows all the total displacement and FOS for every model output. Figure 5 (a) and (b) showed the graph for total displacement and FOS for model 1 to custom arrangement.

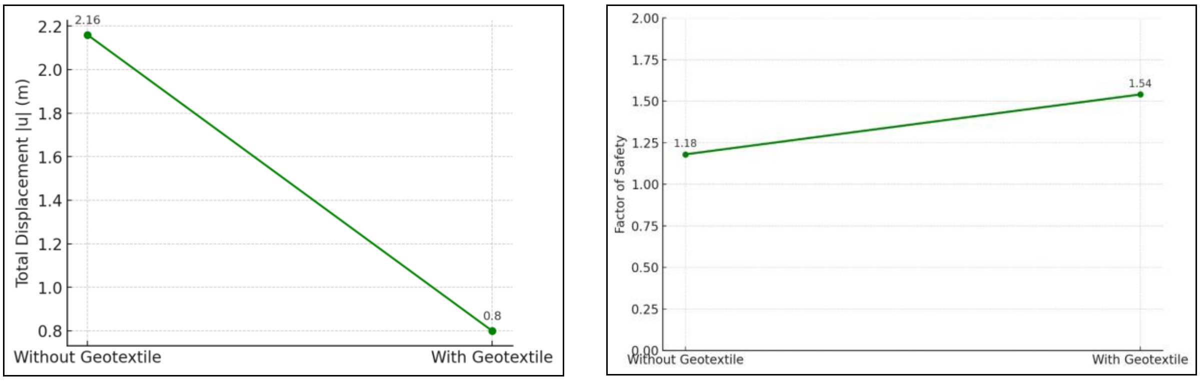


(a) **(b)**

Fig. 5 *(a) Total displacement vs layering arrangement; (b) FOS vs layering arrangement*

3.1 Compared Result Optimized Arrangement

The result compares the performance of the optimized gabion wall arrangement with enhanced model incorporating geotextile reinforcement. The analysis focuses on deformation and stability to evaluate the effectiveness of geotextile reinforcement. From figure 6 (a), the output from these two models show that reduce deformation from 2.16m to 0.80m demonstrates that geotextile reduced deformation in the ability to distribute loads equally and restricts soil movement. From figure 6 (b) showed, the FOS from optimized design without geotextile was 1.18 increase to 1.54 with geotextile exceeding the recommended safety limit by JKR which is 1.5[9].



(a) **(b)**

Fig. 6 *(a) Displacement for optimized arrangement; (b) Factor of safety for optimized arrangement*

The lateral earth pressure is obtained from PLAXIS 2D and compared with the manual calculation. The result obtained is −94.97 kN/m^2 for the soil backfill. The negative value indicates that the lateral pressure acts from right to left, i.e., from the backfill towards the retaining wall, which is characteristic of active earth pressure conditions. The manual calculation is based on Rankine's theory[10], which provides a simplified method to estimate lateral earth pressure for cohesionless soils under active conditions.

$$\sigma_{xx}' = k_0((\gamma_{unsat}\, h1) + (\gamma_{sat} - 10)h_2) = -87.77 kN/m^2 \quad (1)$$

4. Conclusion

In conclusion, this study demonstrates that gabion retaining walls require careful arrangement design following construction standards to ensure deformation control and structural stability. While real-world conditions are more complex than simulations, the PLAXIS 2D analysis provides valuable preliminary insights for construction planning. The results clearly indicate that increasing the gabion wall width significantly contributes to improved stability. Furthermore, the use of geotextile as a reinforcement layer further enhances wall performance by reducing displacement, improving load distribution, and increasing the factor of safety. The simulation proved crucial in evaluating both deformation and stability, confirming the effectiveness of optimized gabion wall designs with geotextile reinforcement for use in challenging backfill conditions such as DMS.

Acknowledgement

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