PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 5 No. 2 (2024) p. 549-555
https://publisher.uthm.edu.my/periodicals/index.php/peat

Lateral Earth Pressure Analysis for Gabion Retaining Wall Structure Design with Geogrid Optimisation: A Numerical Study

Muhammad Ikhwan Arif Zamri[1], Salina Sani[1], Chee Ming Chan[1]

[1] *Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Muar, Johor, MALAYSIA*

*Corresponding Author: salinas@uthm.edu.my
DOI: https://doi.org/10.30880/peat.2024.05.02.058

Article Info

Received: 27 June 2024
Accepted: 30 June 2024
Available online: 25 November 2024

Keywords

Gabion Retaining Wall, PLAXIS 2D, Displacement

Abstract

Developing sustainable and economically earth retaining structures become essential, especially in the context of urbanization and infrastructure development. Ensuring the safety of these structures is a major concern in geotechnical engineering. This research addresses the failure modes of natural clay slopes and backfill, emphasizing the need for effective gabion retaining walls to prevent collapse. Using PLAXIS 2D finite element software, the study models the interaction between soil and gabion structures, analysing lateral earth pressure distribution and vertical displacement. Objectives of this study include evaluating structural response towards lateral pressure and displacement occurred, optimizing gabion retaining wall designs, and comparing FEM results with manual calculations. This study explores two solutions for enhancing gabion retaining wall performance: testing different vertical layers to determine the most optimise design for retaining an 8-meter height of backfill and examining the use of geogrid reinforcement in the soil backfill under various loading conditions. The result is the step-looking gabion retaining wall is the most optimise structure to be used and can retain the soil backfill due to acceptable limit for vertical displacement and low lateral effective earth pressure occurred on gabion retaining wall.

1. Introduction

In recent years, the focus has shifted towards the development of sustainable structures, particularly in the context of earth retaining structures. Ensuring safety of earth retaining structure in construction practices has become a major concern in geotechnical engineering due to urbanisation and development of infrastructure. The design of retaining structures plays an essential role in safeguarding against slope failure, depending on factors such as soil properties, the mode of wall movement, soil-wall roughness, and the shape of the wall [1].

In Malaysia, gabion retaining wall structures are commonly employed for slope protection due to their versatility, durability, ability to resist lateral earth pressure, permeability, ecological sustainability, environmental protection, integrity, cost-effectiveness, and natural aesthetic appeal [2]. The typical approach involves determining the forces on the wall by applying either the Rankine or Coulomb theories of earth pressure after the properties of the retained soil have been estimated [3]. Furthermore, the hybrid system that

This is an open access article under the CC BY-NC-SA 4.0 license.

involves integrating reinforced soil, geotextile, and other internal stabilisation methods into retaining structure which can carry most of the lateral earth pressure [4].

Gabions are widely utilized in earth retaining structures due to their benefits, including stability, cost-effectiveness, flexibility, and porosity [5]. PLAXIS 2D is the finite element software employed to model the interaction between soil and structures using parameters derived from geological surveys and laboratory tests [6]. This study focuses on analysing lateral earth pressure's distribution and its impact on earth retaining structures in terms of technical efficiency, economic viability, and sustainable development.

1.1 Objective

The aim of this study is to:

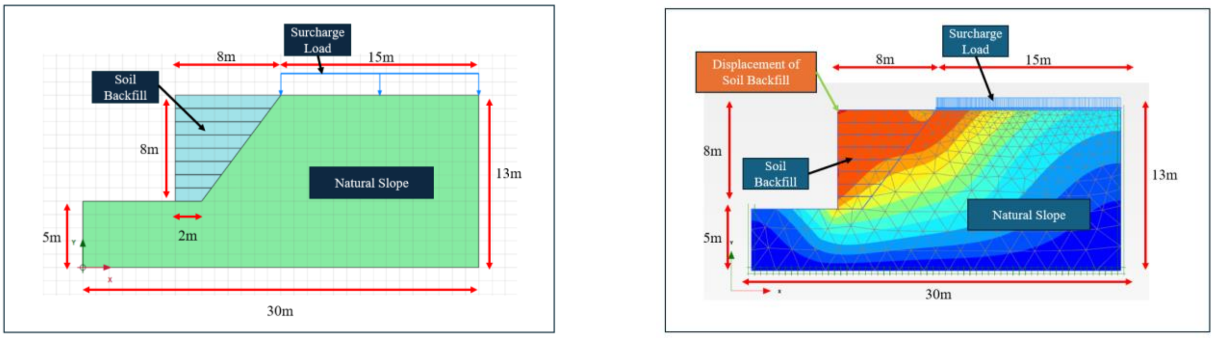
- To evaluate the lateral earth pressure response on retaining structures under different design conditions using the Finite Element Method (FEM).
- To formulate the optimised retaining structures design for the cut slopes conditions examined using FEM.
- To analyse and selected comparison result via FEM with manual calculations.

1.2 Scope of Study

This study focuses on analysing three conditions using PLAXIS 2D, including a cut slope with soil backfill, a gabion retaining wall design arrangement, and the use of geogrid. This design of the gabion retaining wall considers the surcharge load from road embankment and limited space availability of the construction site. Then, the geogrid was added behind the gabion retaining to analyse the response to retain soil backfill which is the vertical displacement and lateral pressure. PLAXIS 2D enables the assessment of soil structure behaviour and stability, considering factors such as soil characteristic and structural element of retaining structure by employing Finite Element Method (FEM) models. Then, the result obtained from the PLAXIS 2D is selected to compare with the manual calculation to validate the accuracy and reliability of the PLAXIS 2D simulation. Three phases with different conditions of design will be analysed for the lateral earth pressure and displacement of gabion retaining wall using Finite Element Method (FEM).

2. Design Solution Implemented

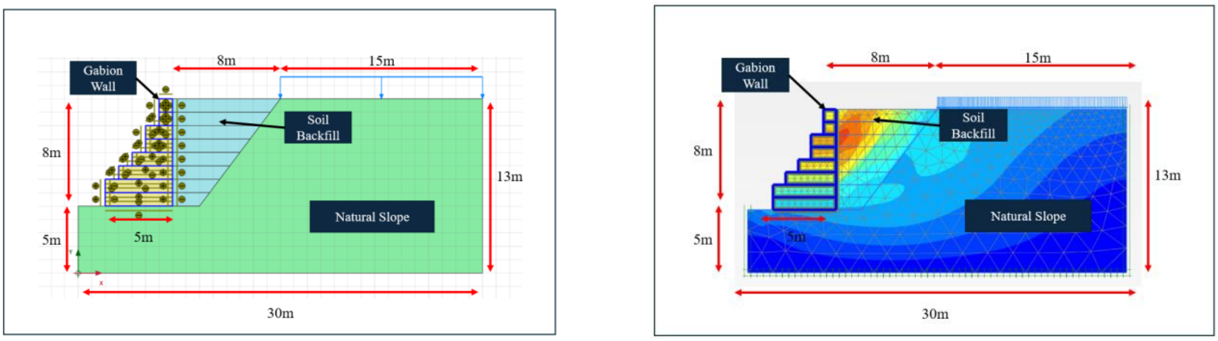
Based on case condition before implementing two design solution, the initial design aims to demonstrate the failure mode of the cut slope with backfill, excluding the gabion retaining wall. The case condition is focusing on the natural slope is added with surcharge load. The value of the surcharge load is 218 kN/m for 15m long of the road embankment.



(a) **(b)**

Fig. 1 *Case Condition (a) Include Surcharge Load (b) Total Displacement Result*

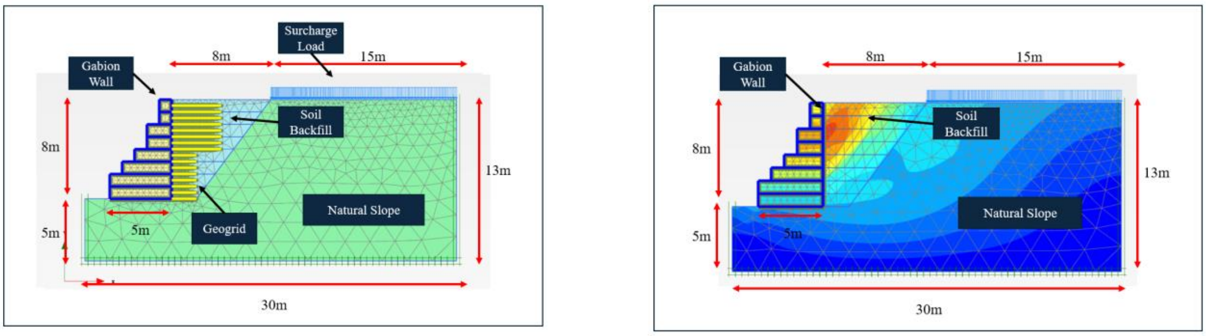
For the first solution of the case condition, a 1m×1m gabion retaining wall, known as a gravity wall, was utilised in this phase. There are five different vertical layer use which is the base of the structure of gabion retaining wall increase along with horizontal layer. One customises gabion layer which is the step-looking gabion is added due to the typical gabion retaining wall used in construction [7]. Gabion in PLAXIS 2D is considered as soil and interfaces in material selection [8] and gabion basket or mesh wire is considered as plate in PLAXIS 2D using elastoplastic for the material type [9].



(a) (b)

Fig. 2 *First Solution (a) Custom Gabion Wall Design (b) Total Displacement Result*

For the second solution, the 16 layers of geogrid with spacing 500mm c/c from bottom of the soil backfill and two different length which is 2m and 4m length is added into the back of the gabion retaining wall. All the parameter for soil from case condition and first solution is not changed and permanently used in the design simulation while integrating with eight layers of geogrid.



(a) (b)

Fig. 3 *Second Solution (a) Custom Gabion Wall with Geogrid Design (b) Total Displacement Result*

3. Numerical Modelling

The behaviour of a gabion retaining wall can be simulated using Finite Element Method (FEM) by considering external forces, material and soil properties subjected to design of gabion retaining wall. However, PLAXIS 2D limitation lies in its ability to evaluate the wall's behaviour primarily in a two-dimensional plane, which may not fully represent the actual three-dimensional deformation. Gabion retaining wall is separated to two component to simulate in PLAXIS 2D which is soil and interfaces for gabion and plate for wire mesh of gabion basket [9]. For this study, the Mohr-Coulomb constitutive model is used to simulate stress-strain behaviour in both the backfill and existing ground. PLAXIS 2D consists of three programs: input, calculation, and output. It can analyse plane strain or axisymmetric scenarios with either (a) 15 or (b) six nodes triangular nodules. The PLAXIS 2D program operated through five modes to execute the simulation which is: Soil Mode, Structure mode, Mesh mode, Flow Condition mode, and Staged Construction mode. These modes are sequentially employed to conduct geotechnical modelling.

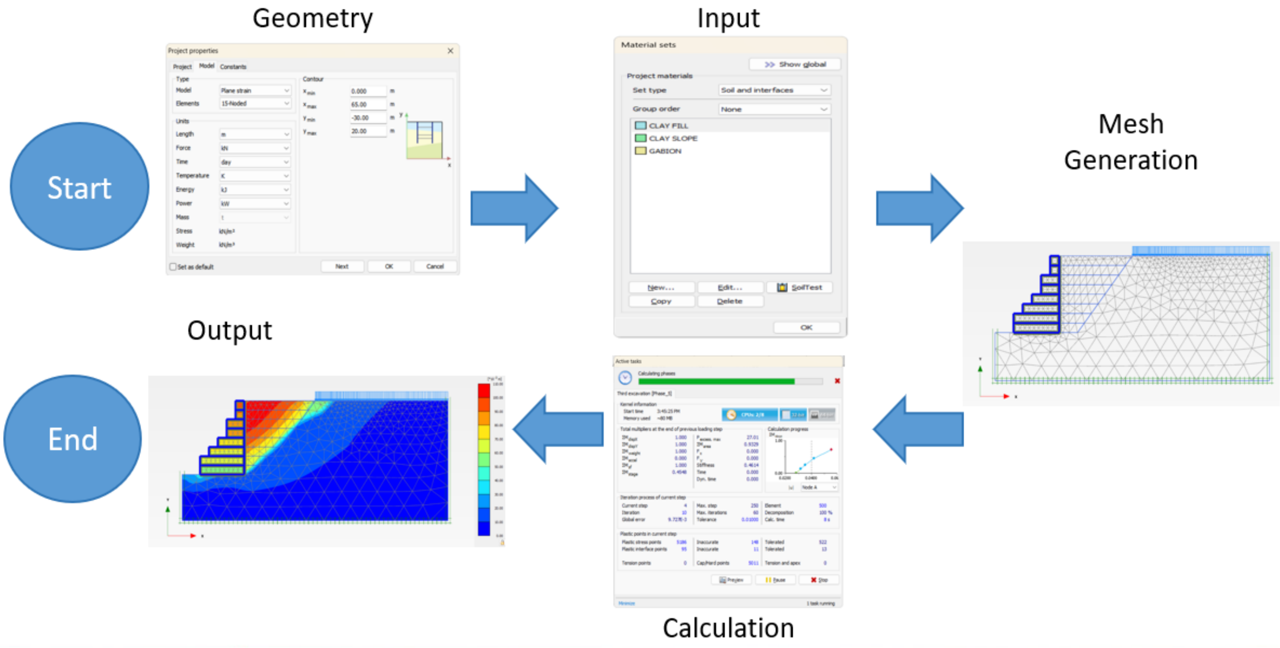


Fig. 4 *Process of Numerical Modelling in PLAXIS 2D*

The model was analysed using a two-dimensional plain strain model with 15-noded elements for 3m retained soil and 10 m embedment. Limit for the soil contour are x_{min} =0.0 m, x_{max} =30.0 m, y_{min} =0.0 m, and y_{max} =13.0 m. In the Soil mode, the input of soil properties and gabion properties shows in Table 1, Table 2, and Table 3.

Table 1 *Soil Properties for Backfill [.....]*

Parameter	Clay	Unit
Type	Undrained (A)	-
γ_{sat}	18	kN/m³
γ_{unsat}	18	kN/m³
E	30000	kN/m²
v'	0.3	kN/m²
c'_{ref}	1	kN/m²
φ'	35	-
R_{inter}	0.5	-

Table 2 *Soil Properties for Natural Slope [....]*

Parameter	Clay	Unit
Type	Undrained (A)	-
γ_{sat}	18	kN/m³
γ_{unsat}	18	kN/m³
E	60000	kN/m²
v'	0.3	kN/m²
c'_{ref}	1	kN/m²
φ'	30	-
R_{inter}	0.5	-

Table 3 *Gabion Properties [....]*

Parameter	Clay	Unit
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	-
R_{inter}	1	-

The structure properties than applied to the soil structure which is the gabion wire mesh and geogrid. The gabion basket or mesh wire is considered as plate in PLAXIS 2D using elastoplastic for the material type [9]. The customise gabion retaining wall is added with geogrid for each horizontal layer of the gabion which is 16 layers of geogrid due to spacing of each layer is 500mm c/c. From the bottom layer until the fourth layer, the length of the geogrid is 2m and continued with 4m length of geogrid. Table 4 and Table 5 shows the properties used in PLAXIS 2D.

Table 4 *Gabion Wire Mesh Properties [...]*

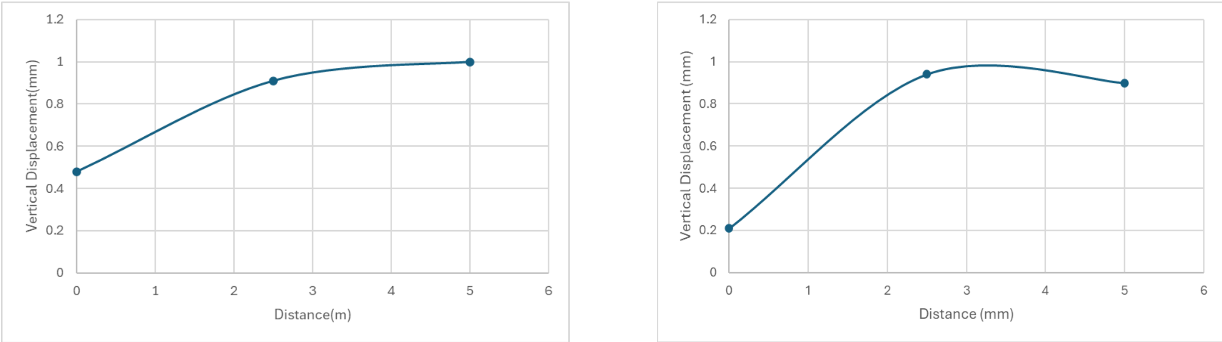
Parameter	Name	Value	Unit
Type of behaviour	Material type	Elastoplastic	
Axial stiffness	EA	62832	kN/m
Flexural rigidity	EI	0.251	kNm^2/m
Weight	w	0.023	kN/m/m
Poisson's ratio	ν	0.3	-
Maximum bending moment	M_p	0.23	kN/m/m
Maximum Axial Force	N_p	135	kN/m

Table 4 *Geogrid Properties [...]*

Parameter	Name	Value	Unit
Type of behaviour	Material type	Elastoplastic	-
Axial stiffness	EA	3000	kN/m
Maximum Axial Force	N_p	300	kN/m

4. Result

The vertical displacement on base of each gabion increases due to the gabion layers increase. The vertical displacement or the settlement occurred due their self-weight of each gabion layer, but the displacement of them is not exceed limitation which is 150mm[8]. This mean all the design can be implemented on the site but must consider other factor such as ground water level, the properties of each material, the magnitude and value of the surcharge, and lateral earth acting on them. This consideration is crucial to increase the efficiency of the gabion retaining wall to the maximum potential. For the result obtained, the custom gabion wall is preferable due to acceptable displacement, and the less gabion consumed to retain the soil backfill. The three nodes were taken from different sections of the gabion wire mesh: one from the front, one from the middle, and one from the section in front of the backfill. The geogrid is reducing the vertical displacement from 0.48 mm, 0.91 mm, 1.00 mm to 0.21 mm,0.94 mm, 0.90 mm.



(a) **(b)**

Fig 5 *Vertical Displacement (a) Custom Gabion (b) Custom Gabion with Geogrid*

The lateral effective earth pressure is obtained from PLAXIS 2D is compared with the manual calculation using manual calculation. The result obtained is -61.3 kN/m^2 for the soil backfill. The negative value means the lateral pressure moves from right to left side.

Table 5 *Lateral Effective Earth Pressure Value*

Parameter	Value	Description
10	**0.4264**	**Normal consolidation**
γ_{sat}	**16**	**Unsaturated unit weight**
γ_{unsat}	**18**	**Saturated unit weight**
h_1	**8**	**Soil unsaturated backfills**
h_2	**0**	**Soil saturated backfills**

Lateral effective Earth Pressure Manual Calculation

$$\sigma'_{xx} = k_0((\gamma_{unsat}\, h_1 + (\gamma_{sat} - 10)h_2)$$

$$= 0.4264((18(8) + (18 - 10)0)$$

$$= 61.4 \text{ kN/m}^2$$

From the data obtained in PLAXIS 2D, the five layer and custom layer that have 5 m base produce less lateral effective earth pressure. This means the lateral effective earth pressure is reduce significantly due to gabion retaining wall exist and with support from geogrid, the custom gabion retaining wall design has significantly reduced from -50.5 kN/m^2 to -48.1 kN/m^2. Table 6 shows the overall results from PLAXIS 2D for all design used.

Table 6 *Lateral Effective Earth Pressure for All Design*

Total Vertical Layer of Gabion Wall	Lateral Effective Earth Pressure (kN/m^2)
1	-58.9
2	-53.8
3	-56.6
4	-62.6
5	-49.2
Custom	-50.5
Custom with Geogrid	-48.1

5. Conclusion

In summary, the gabion retaining wall has significant design that must be follow according to standard of the construction. The real-life event has more complicated than simulation, but it can give initial view for construction of the gabion retaining wall. The result obtain shows that the base for gabion of the must be increased to enable the stabilisation of gabion retaining wall design. The utilisation of PLAXIS 2D is essential in analysing the lateral effective earth pressure and displacement of the gabion retaining wall.

Acknowledgement

I am deeply grateful to Allah S.W.T for granting me the strength to complete this study. I extend my heartfelt appreciation to my supervisor, Pn. Salina binti Sani, and my co-supervisor, Prof. Ir. Dr. Chan Chee Ming, for their unwavering support and cooperation throughout the duration of this project.

References

[1] Nguyen, T., & Shiau, J. (2023). Revisiting Active and Passive Earth Pressure Problems using Three Stability Factors. *Computers and Geotechnics*, *163*(August), 105759. https://doi.org/10.1016/j.compgeo.2023.105759

[2] Gao, L., Wang, N., Rao, F., & Yan, Z. (2021). Structural form and main technical requirements of Gabion retaining wall. *Journal of Physics: Conference Series*, *2044*(1). https://doi.org/10.1088/1742-6596/2044/1/012172

[3] Fenton, G. A., Griffiths, D. V., & Williams, M. B. (2005). Reliability of traditional retaining wall design. *Geotechnique*, *55*(1), 55–62. https://doi.org/10.1680/geot.2005.55.1.55

[4] Khan, & Sikder. (2004). Design basis and economic aspects of different types of retaining walls. *Journal of Civil Engineering (IEB)*, *32*(1), 17–34

[5] Gong, C. (2014). Earth retaining structures. *Bridge Engineering Handbook, Second Edition: Substructure Design*, *1*, 283–313. https://doi.org/10.1201/b15621

[6] Mater, A., Università, S., & Bologna, D. I. (2018). *Effects of settlements on Pombalino buildings (Lisbon) taking into account soil-structure interaction*.

[7] Chikute, G. C., & Sonar, I. P. (2019). Techno-Economical Analysis of Gabion Retaining Wall Against Conventional Retaining Walls. *International Research Journal of Engineering and Technology*, 1161–1167. https://www.researchgate.net/publication/335651776

[8] Ayyub, A., Alshameri, B., Jamil, S., Naqeeb Nawaz, M., & Jamil, S. M. (2021). Analysis of Gabion Retaining Wall Using Analytical and Numerical modelling with Plaxis 2D. *UW Journal of Science and Technology*, *5*, 2616–4396. https://www.researchgate.net/publication/362149147

[9] Khan, A. R., & Emidio, G. Di. (2023). Numerical analysis using FEM on the behavior of reinforced fill structure having geogrid and steel wire mesh as a reinforcing element. *Geosynthetics: Leading the Way to a Resilient Planet*, 991–996. https://doi.org/10.1201/9781003386889-121