Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 2 (2023) 091-100

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

A Simulation Study on the Effect of Fluctuation of Water Level on the Stability of Reinforced Soil Wall

Tay Yong Chyi [1], Felix Ling Ngee Leh[1]*

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Associate Professor, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia

DOI: https://doi.org/10.30880/rtcebe.2023.04.02.011
Received 06 January 2022; Accepted 15 January 2023; Available online 20 July 2023

Abstract:
Sea level rise has induced the soil erosion and the effects of coastal lines erosion has contributed to sedimentation in streams and rivers and can eventually lead to flooding. Therefore, bank protection structure is required to protect the riverbank against erosion. When applied as a waterfront structure, the bank protection structure must has the ability to resist the effect of water level fluctuation originating from daily water tidal cycle and thus ensure the stability of river bank. This study is aimed to evaluate the effectiveness of using reinforced soil wall as riverbank protection structure. A numerical simulation with combination of seepage analysis and slope stability analysis was carried out by using PLAXIS LE (V21.02) to study the effect of water table fluctuation on the stability of reinforced soil wall. Case study of failed levee at Phase 3 of Kerian River Flood Mitigation Project was taken as base model and reinforced soil wall with geotextile and Betotitan wall panel was proposed to improve the stability of slope. Betotitan wall panel was used in the reinforced soil wall design because it is a precast interlocking wall system that combined with geotextile as reinforcement in order to enhance its capacity in retaining the soil behind it. The results of numerical simulation have proven that the geotextile reinforced soil wall is able to treat the failed slope by improving its factor of safety (FOS) and eventually meet the Jabatan Kerja Raya (JKR)'s requirement for slope design.

Keywords: Reinforced soil wall, Soil erosion, Water level fluctuation, PLAXIS LE

1. Introduction

Irreversible climate change due to global warming has brought adverse effect to the Earth. In this context, melting of ice glaciers due to global warming has caused the Earth is undergoing sea level rise issue. The subsequence effect of this phenomena is soil erosion. Bruun model explained the linear relationship between sea level rise and riverbank erosion based on equilibrium theory. As the sea level rises, the space of the initial riverbank increases and set up new sea level. The initial riverbank will move upward to the same position with respect to sea level as before. Hence, the topsoil starts to erode

*Corresponding author: felix@uthm.edu.my

and the eroded materials are deposited at riverbed, resulting in a rise of the riverbed which maintains a constant water depth. [1]

Reinforced soil wall was proposed in this study to address this issue because it offers a lower cost, faster construction operations and requires less manpower. [2] A reinforced soil wall is a composite structure consisting of alternating layers of compacted backfill and soil reinforcement elements, fixed to a wall facing. The interaction between the backfill and soil reinforcements produces friction and tension, thus holding the soil in its places and preventing it from collapse. [3] [4]

The application of reinforced soil wall as a riverbank protection structure should be further evaluated with its stability when subjected to water level fluctuation. [5] Fluctuations in water level is an environmental disturbance that can reduce the stability of bank slope and eventually cause it to collapse. The change in water level can be due to the tidal water level variations. Tides is a natural phenomenon caused by the gravity pull exerted by the moon and sun on the Earth as well as the rotational force of Earth, the results of tidal force are high tides and low tides. Normally, a coastal region will experience high tides and low tides alternately twice in a day. [6] In fact, the height of tide will be increased with the risen of sea level. Consequently, high tides are reaching higher and extending further inland than in the past. [7]

When a reinforced soil wall was subjected to the water fluctuation, water flow through the soil pores and develop pore water pressure in soil. Thus, reduce the effective stress and shear strength of soil, which in turn give devastating effects on the stability of soil slopes. [8] This study is utilizing the PLAXIS LE for conducting a numerical simulation of reinforced soil wall when subjected to water level variation. PLAXIS LE is a commercial geotechnical software utilized for analyzing two-dimensional seepage problem and stability in geotechnical engineering. PLAXIS LE - Groundwater Module is used to model the water movement and pore water pressure distribution in soil in seepage analysis. PLAXIS LE - Slope Stability Module is used to compute factor of safety in slope stability analysis. The objectives of this study can be broadly divided into three which are aimed to determine the stability of reinforced soil wall at steady and transient state condition, to identify the critical factors that affect the stability of reinforced soil wall and to evaluate the suitability use of reinforced soil wall as bank protection.

2. Case study

The selected case study area is Kerian river basin, it is 90 km long and has basin size of 1420 km^2. [9] The Federal Government of Malaysia has been implemented a flood mitigation project which divided into 30 phases to solve the flooding problem happened at Kerian river basin. A 350 meters levee stretch was built starting from CH17200 until CH17550 was completely built in 2019 at Dataran Bandar Baharu, Kedah (Phase 3 of Kerian River Flood Mitigation Project). The constructed levee has failed in 2015, 2017 and 2018 because the initial design of levee was based on the steady state seepage analysis and assumed the water level at this area was moderate. But, Kerian River basin was subjected to the varying river water levels caused by tide-induced fluctuations. Thus, inclusion of transient analysis in design was important to prevent the structure was under designed. [10] A numerical modelling was carried out using PLAXIS LE to study the effect of water table fluctuation on the failed levee and geotextile reinforced soil wall was proposed in this research to repair and strengthen the levee slope.

Two-dimensional transient seepage analyses was carried out using the finite element software PLAXIS LE - Groundwater Module to investigate pore water distribution within the levee structure during water fluctuation. To perform the seepage analysis, first an initial boundary condition was set with a steady state analysis to create a hydrostatic condition. An initial water head with constant water level will be set up on the upstream face of the slope. Subsequently, the model of transient seepage flow under the water level fluctuation took the corresponding steady state model above and the change in height of water table as the input parameters. The water level for transient seepage analysis is assigned as a function between change in water level height and time. Assumed that the volumetric water content and hydraulic conductivity will change with time. Under the impact of water level fluctuation, there will be a seepage force developed within the slope and pore water pressure distribution in the slope. The transient analysis was run to obtain the pore water distributions caused by the fluctuation of tide levels. Further, using the pore pressure analysis generated from the PLAXIS LE - Groundwater Module, slope stability analyses have been further carried out using PLAXIS LE – Slope Stability Module to compute factor of safety for different time intervals corresponding to the different water table positions. A global slope stability was considered in this study. Tables below presents the material properties and river water level data adopted in numerical model.

Table 1: Hydraulic properties adopted in the PLAXIS LE - Groundwater Module

Parameter \ Material	Layer 1 Levee fill material [10]	Layer 2 Clay 1 [10]	Layer 3 Clay 2 [10]	Layer 4 Clay 3 [10]	Layer 5 Sand [10]	TenCate Polyfelt® TS nonwoven geotextile [11] [12]	Backfill [12]	Betotitan facing element [13]
Saturated hydraulic conductivity (K_{sat}), m/s	1.42×10^{-8}	7.77×10^{-10}	7.91×10^{-10}	7.37×10^{-10}	1.68×10^{-4}	0.0019	0.0001	1.63×10^{-6}
Residual water content, m^3/m^3	0.125	0.15	0.225	0.14	0.03	0.01	0.005	0.067
Saturated water content, m^3/m^3	0.2528	0.4290	0.4047	0.4272	0.4	0.92	0.38	0.45
Coefficient of compressibility (Mv), 1/kPa	3×10^{-4}	1.833×10^{-4}	1.767×10^{-4}	1.767×10^{-4}	1×10^{-4}	0	1×10^{-4}	0
a, kPa	-	-	--	-	-	3	0.22	4.905
n	-	-	-	-	-	3	1.47	1.41
m	-	-	-	-	-	0.67	0.32	0.29
Fitting method	-	-	-	-	-	Van Genuchten Function	Van Genuchten Function	Van Genuchten Function

Table 2: Material properties adopted in the PLAXIS LE – Slope Stability Module

Parameter \ Material	Layer 1 Levee fill material [10]	Layer 2 Clay 1 [10]	Layer 3 Clay 2 [10]	Layer 4 Clay 3 [10]	Layer 5 Sand [10]	Backfill [14]	Betotitan wall facing [14]
Unit weight, kN/m^3	21.895	19.047	19.435	17.898	19.516	18	17.64
Cohesion (c), kPa	5	28	28	28	5	0	12000
Friction angle (ϕ), deg	37	0	0	0	28	30	27
Shear strength	Drained	Undrained	Undrained	Undrained	Drained	Drained	Drained

Table 3: Geosynthetic reinforcement properties

Type of geosynthetic	Mirafi® PET High-Strength Woven Polyester Geotextiles [15]	TenCate Polyfelt® TS nonwoven geotextile (TS 40) [11]
Tensile strength	100 kN/m	13.5 kN/m
Thickness	2 mm	1.7 mm
Vertical spacing	0.4m	N/A

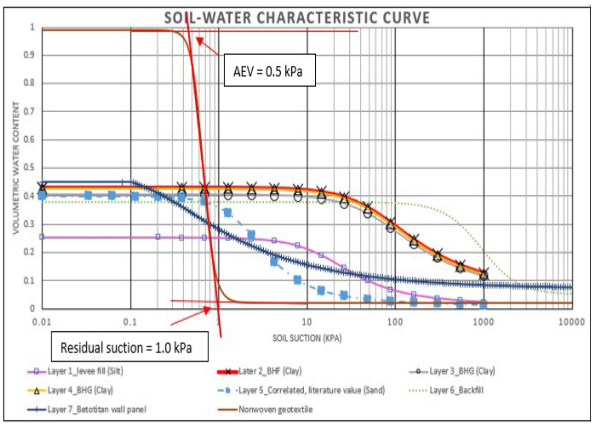


Figure 1: Soil and geotextile hydraulic characteristics: Soil water characteristic curve

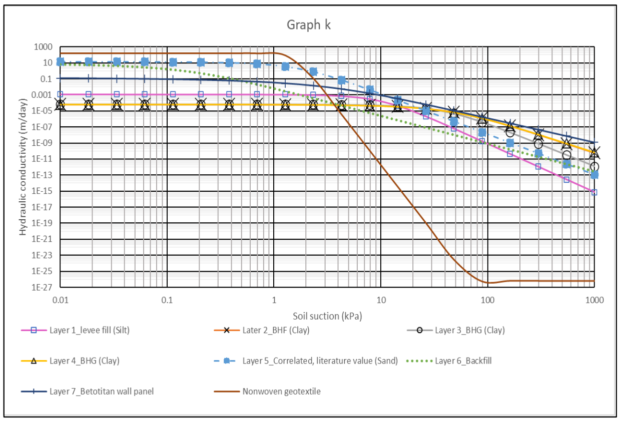


Figure 2: Soil and geotextile hydraulic characteristics: Hydraulic conductivity

Table 4: Riverwater level data adopted in creating boundary conditions [10]

No	Date	Time	River water level, H (masl)	Variation (m)
1	1/8/2018	1.15 am	2.28	-
2	1/8/2018	7.14 am	0.87	-1.41
3	1/8/2018	1.07 pm	2.66 (2.51*)	+1.64
4	1/8/2018	7.55 pm	0.36	-2.30
5	2/8/2018	1.58 am	2.40	+2.04
6	2/8/2018	7.59 am	0.82	-1.58
7	2/8/2018	1.49 pm	2.69 (2.51*)	+1.69
8	2/8/2018	8.35 pm	0.30	-2.21
9	3/8/2018	2.40 am	2.47	+2.17
10	3/8/2018	8.44 am	0.81	-1.66
11	3/8/2018	2.30 pm	2.66 (2.51*)	+1.70
12	3/8/2018	9.15 pm	0.31	-2.20
13	4/8/2018	3.22 am	2.49	+2.18
14	4/8/2018	9.28 am	0.85	-1.64
15	4/8/2018	3.12 pm	2.56 (2.51*)	+1.66
16	4/8/2018	9.55 pm	0.38	-2.13
17	5/8/2018	4.05 am	2.45	+2.07
18	5/8/2018	10.14 am	0.93	-1.52
19	5/8/2018	3.54 pm	2.41	+1.48
20	5/8/2018	10.35 pm	0.52	-1.89
21	6/8/2018	4.50 am	2.37	+1.85
22	6/8/2018	11.03 am	1.04	-1.33
23	6/8/2018	4.38 pm	2.21	+1.17
24	6/8/2018	11.18 pm	0.70	-1.51
25	7/8/2018	5.39 am	2.26	+1.56
26	7/8/2018	12.00 pm	1.17	-1.09
27	7/8/2018	5.28 pm	1.99	+0.82

2.1 Model validation

The present study was validated with one of the published literatures done by Nordin & Mohamad & Alarifi (2021) whom conducting a back analysis using SEEP/W to examine the effect of river water drawdown in affecting the levee slope stability. [10] The slope geometry, material properties, river water level data and boundary conditions were considered according to Nordin et al. [10]

i. Seepage analysis
   a. Slope geometry

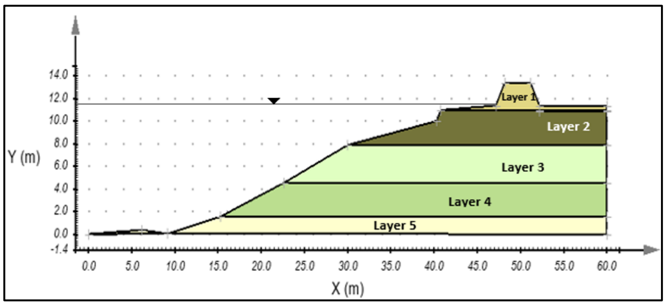


Figure 3: Model geometry of the study area utilized in PLAXIS LE - Groundwater Module and Slope Stability Module

   b. Material properties - Refer to Table 1.
   c. Boundary conditions

For steady state analysis, initial boundary condition of constant head, h = 11.77m (2.28 masl) was applied along the upstream face of layer 1, 2, 3, 4 and 5 which represent the initial water level of river. Boundary condition of zero pressure (pore pressure head, h = 0 m) was set at 500 mm near the toe of downstream levee to prevent the development of pore water pressure near the downstream face of levee. A review boundary condition was applied along the downstream side of levee to study the seepage developed within the levee system. For transient state analysis, similar boundary condition of zero pressure and review boundary was applied. The fluctuation of river water level was defined using a head function boundary condition. This boundary condition was applied along the upstream slope of the levee structure, starting from the bottom of the layer 2 to the point of layer 1 which is the highest level of water level. Refer to Table 4 for water level data. Since the layer 3, 4 and 5 were not affected by water level fluctuation, therefore, a constant head boundary of 7.86m was applied along the upstream face of the soil layer 3, 4 and 5 which represent the river water level.

ii. Slope stability analysis
   a. Material properties - Refer to Table 2.
   b. Calculation method – Morgenstern price
   c. Slope searching method – Entry and exit method in the right to left direction.

2.2 Numerical simulation of reinforced soil wall

The reinforced soil wall was designed based on BS 8006:1995 Code of practice for strengthened/reinforced soils and other fills and Design and Installation Guide for Betotitan retaining wall [16] [14]. TenCate Polyfelt® TS nonwoven geotextile (TS 40) was laid against the levee fill embankment face. It functions as a drainage layer with the aid of toe drain, thus allow water to filter freely from the levee fill embankment to the backfill and flow to the toe drain. [11] As such, it will not prohibit the friction developed within the slope. It also can act as a separating layer to prevent the mixture of reinforced backfill sand and original levee fill soil [11]Whereas Mirafi® PET High-Strength Woven Polyester Geotextiles shows good reinforcement material was laid in every vertical spacing of 0.4m to strengthen the soil strata. [15] Further, Betotitan facing element is a precast concrete cellular retaining wall block to reduce the wall deformation significantly and retaining the backfill soil and hence minimizing the transferred loads to reinforcement layers. [14]

i. Seepage analysis

A. Slope geometry

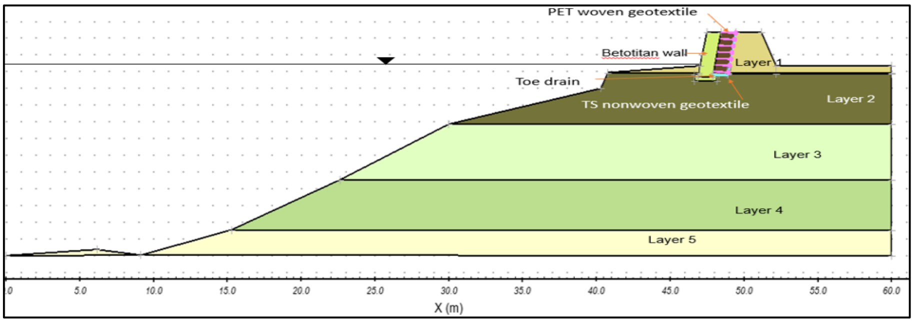


Figure 4: Model geometry for geotextile reinforced soil wall

B. Material properties – Refer to Table 1.

C. Boundary conditions

For steady state analysis, initial boundary condition of constant head, h = 11.77m (2.28 masl) was applied along the wall facing and upstream face of layer 1, 2, 3, 4 and 5. Boundary condition of zero pressure (pore pressure head, h = 0 m) was set at toe of the backfill to represent toe drain to discharge excess water from the retained soil. Zero pressure also applied at the base of wall facing panel to prevent the prevent the development of pore water pressure near the facing element. A review boundary condition was applied along the wall facing to study to simulate the seeping out of water through gaps between the facing panels. For transient state analysis, similar boundary condition of zero pressure and review boundary was applied. The head data boundary condition was applied along the wall facing and layer 2. Refer to Table 4 for water level data. Constant head boundary condition in which h = 7.86m was applied along the upstream face of layer 3, 4 and 5.

ii. Slope stability analysis

A. Material properties – Refer to table 2 and 3.

B. Calculation method – Morgenstern price

C. Slope searching method – Entry and exit method in the right to left direction.

2.3 Parametric study of reinforced soil wall

Parametric study was carried out on the reinforced soil wall by varying the material properties to delimit the critical slip surface. The stability of reinforced soil wall is analyzed with changing the unit weight of backfill, saturated hydraulic conductivity of nonwoven geotextile reinforcement, and tensile strength of nonwoven geotextile reinforcement. The purpose of this study is to determine the factor affect stability of reinforced soil wall on the resulting factor of safety (FOS).

Table 5: Simulation scheme in parametric study

Simulation scheme	Variables	Parameters
1	Saturated hydraulic conductivity of TenCate Polyfelt® TS nonwoven geotextile	k_{sat} = 0.0019 m/s k_{sat} = 0.115 m/s k_{sat} = 0.50 m/s k_{sat} = 0.75 m/s
2	Tensile strength of TenCate Polyfelt® TS nonwoven geotextile	T = 13.5 kN/m T = 35 kN/m T = 50 kN/m T = 80 kN/m
3	Unit weight of backfill	$\gamma = 18\ \mathrm{kN/m^3}$ $\gamma = 22\ \mathrm{kN/m^3}$ $\gamma = 25\ \mathrm{kN/m^3}$ $\gamma = 28\ \mathrm{kN/m^3}$

3. Results and Discussion

3.1 Model validation

i. Seepage analysis

From the results, there seems the results of the present study were found to be in close agreement with the results of Nordin et al. The observed deviation was attributed to the difference in mesh properties and tolerances in time step increments.

The presence of seepage at the upstream face of levee slope could reduce the shear strength of soil due to the existence of pore water pressure, which in turn would cause failure on the levee structure. Thus, the levee structure failed due to the seepage force. If this exerted seepage force is strong enough, it is able to displace the soil particles in its way and particles may washed away by the flowing water. This phenomenon also known as "piping"; it is a form of the seepage erosion.

Based on the numerical simulation that was done, the results showed that there was presence of the excess pore water pressure in soils above the river water level during drawdown. The lowering rate of the phreatic line within the levee structure was not concurrent with the decreasing river water level. For instance, the river water level in 3.9 days has been reduced to 10.4m, but the phreatic line in the levee structure was still higher than the river water level. Henceforth, the buildup of excess pore pressure could reduce the shear strength of soil and lastly cause the instability of levee.

ii. Slope stability analysis

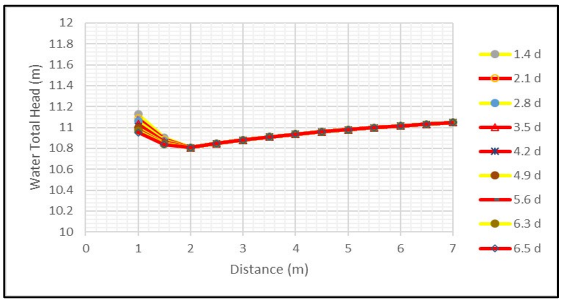
Based on the results, the slope failure mode occurred at levee structure is toe slide. The results shows that the FOS in drawdown models were ranged from 1.47 to 1.48, while the FOS in the water increment models were ranged from 1.47 to 1.63. According to the slope design guideline by Jabatan Kerja Raya (JKR), the minimum global Factor of Safety (FOS) for treated fill slope shall be 1.5. [17] In this case, it was clearly presented that the levee system did not meet the minimum requirement of FOS set by JKR. Thus, necessary action shall be taken to reduce the effect of water fluctuation and seepage on the stability of levee structure and to prevent the levee failure. Appropriate remedial measure which is geotextile reinforced soil wall was proposed to address this problem.

3.2 Numerical simulation of reinforced soil wall

i. Seepage analysis

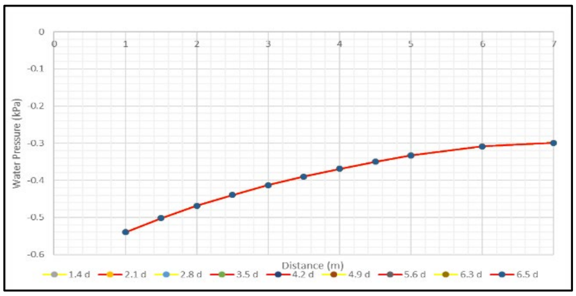
Phreatic line of levee structure remained approximately constant in both water increment and drawdown models. This indicated that the phreatic line within the levee structure was not affected by water level fluctuation. Negative pore water pressure was observed in both water level increment and drawdown models. This indicated the groundwater table was below the retaining structure and the retained soil was unsaturated. Negative pore pressure could increase the shear strength of soil, resulting the reinforced levee structure is more stable than the unreinforced levee slope. the magnitude of pore water pressure distribution in both models were similar too. This showcases the function of nonwoven geotextile and toe drain as a drainage system to drain out the water from the levee structure. Thus, the pore water pressure in the levee structure was approximately constant at all time. Numerical simulation of water increment and drawdown throughout the geotextile reinforced levee structure (from toe of backfill slope to toe of levee slope) is presented in Figure 5 and 6.

Seepage vectors only acted along the nonwoven geotextile (TS 40) and moved towards the toe drain. Thus, the capability of combination of nonwoven geotextile and toe drain as a drainage system to remove the water from the retaining structure. On top of that, the seepage vectors were acting downward as illustrated in Figure 7, the downward seepage in the soil could increase the effective stress or inter-particle forces. This additional stress is due to seepage pressure which acts in the direction of flow of water. When water flows down the soil mass, water tends to push soil particles downwards. Consequently, soil particles push each other cause the increment of inter-particle forces and increase in effective stress.



(Notes: Red line = water level increase; Yellow line = water level decrease)

Figure 5: Water total head



(Notes: Red line = water level increase; Yellow line = water level decrease)

Figure 6: Pore water pressure

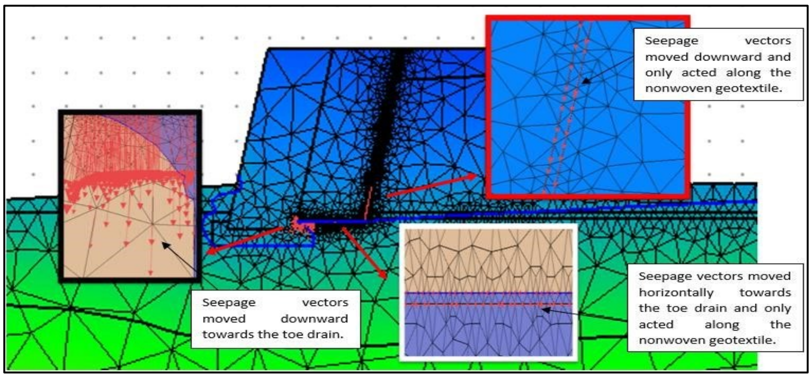


Figure 7: Seepage vectors in Geotextile Reinforced Soil Wall

ii. Slope stability analysis

Based on the analysis results, the slope failure modes experienced by the geotextile reinforced soil wall was rotational slide. The FOS for geotextile reinforced soil wall were ranged from 2.52 to 2.92, this indicated the stability of levee has risen after the application of geotextile reinforced soil wall. According to the slope design guideline by Jabatan Kerja Raya (JKR), the minimum global Factor of Safety (FOS) for treated fill slope shall be 1.5. [17] In this case, it is clearly shows that the geotextile reinforced levee structure has met the minimum requirement of FOS set by JKR. This prove that the application of geotextile reinforced soil wall is able to avoid the levee failure due to water level fluctuation.

The FOS during the drawdown is relatively lower than the FOS during water increment as illustrated in Figure 8. This is because the passive earth pressure increased when the water level was risen. When the passive earth pressure is high, the Betotitan wall is pushed towards the backfill, hence the passive earth pressure tends to stabilize the slope.

3.3 Parametric study of reinforced soil wall

The outputs of parametric study have revealed that:

- The factor of safety (FOS) of reinforced soil wall is significantly changing with the variation in the saturated hydraulic conductivity of nonwoven geotextile. Thus, the nonwoven geotextile in reinforced soil wall performs dominantly as a drainage material under unsaturated conditions.
- The factor of safety (FOS) of reinforced soil wall is no significantly changing with the variation in the tensile strength of nonwoven geotextile. Thus, the nonwoven geotextile in soil wall does not performs dominantly as a reinforced material under unsaturated conditions.
- The higher the unit weight for the backfill, the lower the factor of safety (FOS) of reinforced soil wall. Because the total vertical force also increases due to increase in unit weight, this causes increase the total weight of a slice and then reduce the FOS.

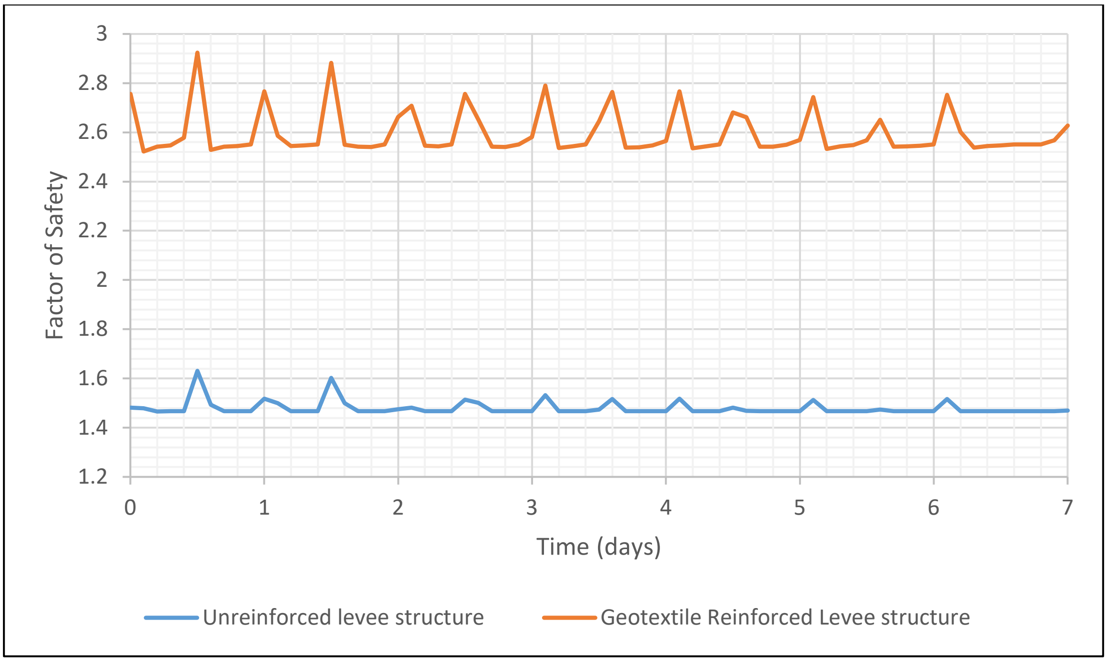


Figure 8: Comparison between the FOS achieved by geotextile reinforced soil wall and unreinforced levee structure

4. Conclusion & Recommendations

This project investigated the effect of water level fluctuation on the stability of reinforced soil wall. Numerical simulation on selected case study which is flood mitigation project at Kerian River was done to simulate the effect of fluctuation on the stability of the levee slope. The slope is more stable during the water level increment because the hydrostatic pressure acting from the seaside of slope has stabilized the slope and increased the factor of safety (FOS). The results showed that water level fluctuation has caused levee failure especially in water drawdown. In order to address the problem, geotextile reinforced soil wall was proposed to stabilize the soil. The FOS for geotextile reinforced soil wall is between 2.52 to 2.92, this indicated the stability of levee has been risen after the application of geotextile reinforced soil wall. According to the slope design guideline by Jabatan Kerja Raya (JKR), the minimum global FOS for treated fill slope shall be 1.5. In this case, it is clearly shows that the geotextile reinforced levee structure has met the minimum requirement of FOS set by JKR. This proves that the application of geotextile reinforced soil wall is able to avoid the levee failure due to water level fluctuation. Use of low unit weight backfill soil is able to increase the active earth pressure and help to increase the stability of reinforced soil wall. The design can be improved by checking the design of geotextile reinforced soil wall in terms of internal stability and external stability. Also, consider the structural behavior of Betotitan wall facing element and the effect of rainfall infiltration into the slope.

Acknowledgement

The author would like to sincerely thank the Faculty of Civil Engineering and Built Environment Universiti Tun Hussein Onn Malaysia for its support.

References

[1] P. Bruun, "The Bruun rule of erosion by sea-level rise: a discussion on large-scale two-and three-dimensional usages.," *Journal of coastal Research,* pp. 627-648, 1988.

[2] S.Ehsan, R. A.Begum, N. G. M.Nor, & K. N. A.Maulud , "Current and potential impacts of sea level rise in the coastal areas of Malaysia.," *In IOP Conference Series: Earth and Environmental Science,* vol. 228, no. 1, p. 012023, 2019.

[3] H.V.Gajjar & V. M.Rotte, "Influence of Reinforcement Pattern on the Performance of Geotextile-Reinforced Slopes.," *In Advances in Computer Methods and Geomechanics: IACMAG Symposium 2019,* vol. 56, p. 397, 2020.

[4] H. Vidal, Reinforced Earth, a New Material for Public Works., Waterways Experiment Station, 1967.

[5] J. Johansson, "Impact of water-level variations on slope stability," Luleå tekniska universitet, 2014.

[6] "Tide," National Geographic Society, [Online]. Available: https://www.nationalgeographic.org/encyclopedia/tide/. [Accessed 2 January 2022].

[7] "King Tides and Climate Change," United States Environmental Protection Agency, 6 August 2021. [Online]. Available: https://www.epa.gov/cre/king-tides-and-climate-change. [Accessed 15 December 2021].

[8] J. Atkinson, "Stress in the ground," UWE Bristol, [Online]. Available: http://environment.uwe.ac.uk/geocal/soilmech/stresses/stresses.htm. [Accessed 15 December 2021].

[9] "River, Basin & Reserve," Perak State Department of Irrigation And Drainage, 2018. [Online]. Available: http://jps.perak.gov.my/index.php/en/about-us-en/section/river-section/general-information/77-about-us/275-river-basin-reserve. [Accessed 1 January 2022].

[10] N. M.Nordin, H.Mohamad & H.Alarifi, "Numerical modelling of seepage analysis using SEEP/W: A case study for the Kerian River Flood Mitigation Project (Phase 3) in Bandar Baharu, Kedah.," *In IOP Conference Series: Materials Science and Engineering,* vol. 1101, no. 1, p. 012007, 2021.

[11] "TenCate Polyfelt® TS," [Online]. Available: https://www.tencategeo.eu/en/products/nonwoven-geotextiles/tencate-polyfelt-ts. [Accessed 11 November 2021].

[12] T.Iryo, & R. K.Rowe, "Hydraulic behaviour of soil–geocomposite layers in slopes.," *Geosynthetics International,* vol. 12, no. 3, pp. 145-155, 2005.

[13] S.Schneider, D.Mallants & D. Jacques, "Determining hydraulic properties of concrete and mortar by inverse modelling.," in *MRS Online Proceedings Library (OPL)*, 2012.

[14] "Betoconcept - Betoflor," Modern Plaza Sdn. Bhd., Johor, 2021.

[15] "TenCate Solutions for Basal Reinforcement," 2021. [Online]. Available: https://www.tencategeo.asia/media/d8fa9ca6-80a9-4c2d-8ecc-7790bf99e195/K902nA/TenCate%20Geosynthetics/Documents%20ASIA/English/Brochures/Application/Gen%20Broc%20-Basal%20Reinforcement%20(100%20300-gb-0412).pdf. [Accessed 10 November 2021].

[16] AC01895560, A. (Ed.), Code of practice for strengthened/reinforced soils and other fills., BSi, 1995.

[17] "Guidelines for slope design.," Jabatan Kerja Raya, Slope Engineering Branch, Selangor, 2010.