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Analysis of the Utilization of Concrete Mat with Different Configuration on Settlement Behaviour of Soft Soil Via PLAXIS 2D

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Abstract: Problematic soil found along the local coastal plains has low shear strength and high compressibility, causing road failures such as settlement. However, it is often treated in way that the subgrade strength is neglected which causes failure to repeat in an unending cycle. The aim of this study is to model the soft soil improvement using PLAXIS 2D to calculate the vertical settlement and lateral displacement of soft soil when a different configuration of concrete mat is laid and further deduce the best configuration out of it. The configuration of the concrete mat for the analysis is diversified into four categories, material, spacing, shape, and the presence of geotextile. A plane strain condition is adopted and the embankment is assumed to be symmetrical in its cross section. A Hardening Soil (HS) model is used to model the embankment, a Soft Soil (SS) model for the soft soil layer, and a Linear Elastic (LE) model for the concrete mat. The outcome of the simulation has a consistent trend in terms of all the manipulative variables of this study. Shape-wise, the rectangular ConcMatt is preferred over the trapezoidal ConcMatt. Meanwhile, conventional concrete mats are much effective in vertical settlement reduction, but lightweight concrete mats contribute to less lateral displacement at the toe of the embankment. Placing the ConcMatt at 10 mm intervals is preferable to 20 mm intervals because it creates a larger reinforced contact area with the embankment. Geotextiles have a significant contribution to both vertical settlement reduction and lateral displacement reduction. As a result, the rectangular conventional ConcMatt with 10 mm spacing and a layer of geotextile is determined to be the best model set in vertical settlement reduction, while the rectangular lightweight ConcMatt with 10 mm spacing and a layer of geotextile is the best in lateral displacement reduction.

Keywords: Soft Soil, Concrete Mat, Settlement, Embankment

1. Introduction

A growing nation can neither run away from development nor urbanisation. However, the nature of the underlying ground beneath has brought forth countless challenges to the engineers when it comes

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to developing a new place. Stable soil readily to embrace the new development era has been a luxury as its availability is truly limited. Studies have shown that the soil strata in Malaysia is saturated with problematic soil especially in Borneo, meanwhile in the Peninsular, 53% of it is suitable and stable soil, whereas the remaining 47% consists of marginal and unsuitable soil, e.g., peat, acid sulphate soil, sandy beach ridges, sand tailing, etc. [1]. The possibility of a country development to put on a halt due to the absent of stable soil would never be viable as the population growth surge rapidly. Problematic soil or soft soil should be treated and rectify before any form of construction and infrastructure development take place. Professionals from the field of geotechnical engineering is crucial in seizing the problem regarding soft soil as an obstacle in developing the country.

1.1. Problem Statement

Stable soil available for the establishment of a new network of road are scanty. Pavements and embankments are forced to be built on problematic soil to make interstate connections possible. In spite of that, road construction requires a strong foundation to support the entire pavement structure to prevent it from any sort of failure which could damage the road due to the traffic load. Since concrete pavement have higher flexural strength, but not practical to be construct on soft soil due to its low bearing capacity. A pre-cast concrete mat could potentially form a semi-rigid pavement which can be laid readily on soft ground with a sand blanket or geotextile beneath it to prevent immediate settlement. Thus, replicating the concept of rigid pavement on soft ground, yet avoiding the hassle of typical construction methods of cast-in-situ concrete pavement. Costing wise, since the rigid pavement requires comparative lesser maintenance with its capacity to withstand traffic load and harsh weather conditions, less road failure may occur which results in a longer design life. The ConcMatt innovation is believed to cost lesser than conventional method in terms of road maintenance work in the future. Subsequent road maintenance work using the ConcMatt innovation has also proven to be much effective as compared to the conventional method of Cold In-Place Recycling (CIPR) based on the 3-testing sites executed by JKR Kluang. However, published data and relevant testing data are limited for the time being to further commercialize the ConcMatt innovation. Thus, finite element modelling is encouraged to replicate the embankment with ConcMatt treatment to test its effectiveness as a load transfer layer to tackle the differential settlement issue.

1.2. Objectives

The aim of this study is to model the soft soil improvement with different configurations of concrete mat which would compute its respective vertical settlement and lateral displacement of soft soil. From that, the best configuration that yields the most promising results in terms of reducing soft soil vertical settlement and lateral displacement is determined.

2. Literature Review

2.1. Concrete Mat (ConcMatt)

ConcMatt has been proposed as a solution for maintenance and road construction on soft soil where its idea originated from the road defects that bug the same location over and over again. The ConcMatt solution is said to focus on improving the weakness of subgrade surface and foundation of the road structure [2]. The ConcMatt is designed to distribute load uniformly on the surface of subgrade. It also acts as a transition layer for the difference in contact area between fine particles (soft soil) and granular particles (subbase layer). These could be further proven with trial embankment at 3 locations on Johor, where the ConcMatt is laid to test it efficiencies as its claimed.

2.2. Model Selection

The model of embankment resting on soft ground by [3] is chosen because trial embankment is resting on soft alluvium deposit, whereby its existence as problematic soil along the coastal plains is common according to [4] studies. Besides, the FEM input parameters were verified through back analysis calculations with field measured data vertical deformation (settlement) of a fully instrumented trial embankment at Tokai, Kedah. [3] outcome shows the overall results from both PLAXIS simulation and field measurement are in good agreement.

3. Methodology

This section discusses the model geometry, material properties and model analysis which describes all the necessary information that is required to obtain the results of the study.

3.1. Model Geometry

For the model geometry, its square base, excluding the side slopes, is 5m. The height of the embankment is 1m with 1V:2H side slopes. The model geometry for modelling is as per Figure 1 for model set using rectangular ConcMatt, whereby Figure 2 for model set using trapezoidal ConcMatt. A control set without the ConcMatt and geotextile layer is modelled as reference to compare the settlement reduction of an embankment once traffic load is applied when concrete mat and geotextile are present. The points of observation for settlement are labelled as coordinates A (0 0), B (3.5 0), and C (7 0).

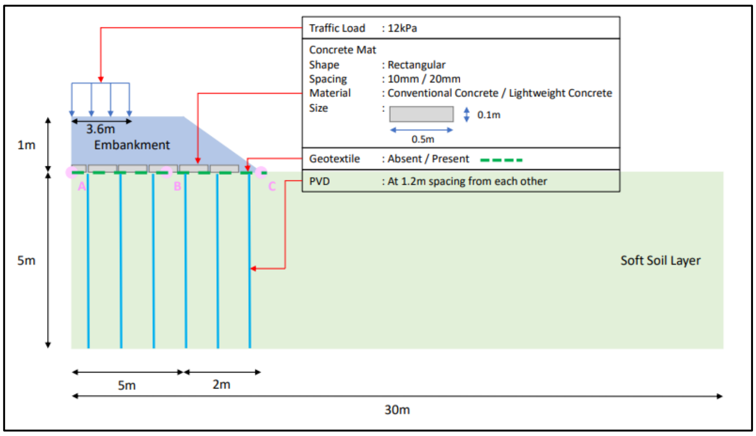

Figure 1: Rectangular shaped concrete mat arrangement

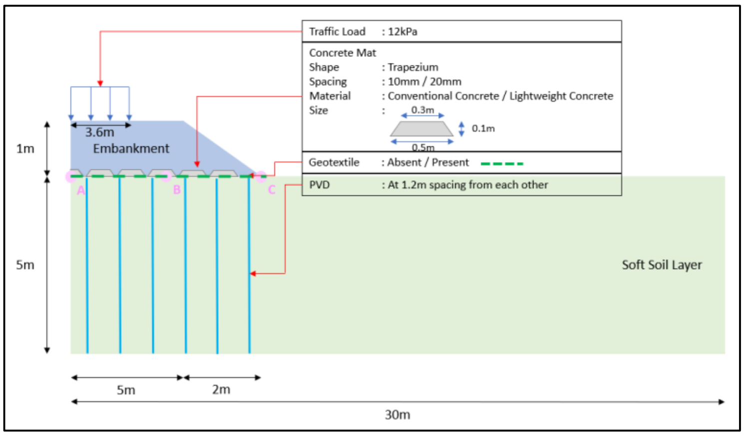

Figure 2: Trapezoidal shaped concrete mat arrangement

3.2. Material Properties

The material properties for embankment and soft soil by [3] is as per Table 1.

Table 1: FEM input parameters for embankment and soft soil by [3]

Parameter	Unit	Embankment	Soft Soil
General			
Material model	-	Hardening Soil (HS)	Soft Soil (SS)
Drainage type	-	Drained	Undrained (A)
Dry unit weight, γ_{unsat}	kN/m^3	16	9
Bulk unit weight, γ_{sat}	kN/m^3	19	13
Initial void ratio, $e_{initial}$	-	0.5	2
Parameters			
Modified compression index, λ^*	-	-	0.109
Modified swelling index, κ^*	-	-	0.026
Secant stiffness in standard drained triaxial test, ${E_{50}}^{ref}$	kN/m^2	30000	-
Tangent stiffness for primary oedometer loading, ${E_{oed}}^{ref}$	kN/m^2	30000	-
Unloading / reloading stiffness, ${E_{oed}}^{ref}$	kN/m^2	90000	-
Cohesion, ${c_{ref}}'$	kN/m^2	5	5
Friction angle, φ'	°	28	21
Dilatancy angle, ψ	°	0	0
Groundwater			
Data set	-	User-defined	User-defined
Model	-	Van Genuchten	Van Genuchten
Horizontal permeability, k_x	m/day	0.08640	1.728 x 10^{-03}
Vertical permeability, k_y	m/day	0.08640	0.864 x 10^{-03}
Interfaces			
Interface Strength	-	Rigid	Rigid
Strength reduction factor, R_{inter}	-	1	1
Initial			
K0 determination	-	Automatic	Automatic
Over consolidation ratio, OCR	-	1.0	1.0
Pre-overburden pressure, POP	kN/m^2	0	0

The material properties of concrete mat to be used in PLAXIS 2D modelling would be as Table 2.

Table 2: Material properties of concrete mat

Parameter	Unit	Concrete Mat	
		Conventional Concrete	**Lightweight Concrete**
General			
Material model	-	Linear Elastic (LE)	Linear Elastic (LE)
Drainage type	-	Non-porous	Non-porous
Dry unit weight, γ_{unsat}	kN/m^3	24	18
Bulk unit weight, γ_{sat}	kN/m^3	24	18
Initial void ratio, $e_{initial}$	-	0.5	0.5
Parameters			
Elastic modulus, E	kN/m^2	3.1 x 10^7	2.19 x 10^7
Poisson's ratio, v	-	0.15	0.25

The material properties of geotextile to be used in the PLAXIS 2D modelling would be as Table 3. The ultimate tensile strength of the basal reinforcement is provided by [3].

Table 3: Material properties of geotextile

Parameter	Unit	Geotextile
Mechanical		
Material type	-	Elastic
Properties	-	Isotropic
EA_1	kN/m	200
EA_2	kN/m	200

3.3. Model Analysis

The embankment is assumed as symmetrical, a halved embankment is modelled in plane strain condition. The staged construction is as per Table 4.

Table 4: Staged construction for model simulation

Staged Construction	Calculation Type	Loading Type	Duration (day)
Initial Phase	K0 procedure	Staged construction	-
PVD, geotextile, ConcMatt	Consolidation	Staged construction	7
Embankment Construction	Consolidation	Staged construction	7
Consolidation	Consolidation	Staged construction	60
Apply Load	Consolidation	Staged construction	0.1
End of Consolidation	Consolidation	Minimum excess pore pressure	-

4. Results and Discussion

As per the objective of this study, the soft soil settlement at points A (0 0), B (3.5 0) and C (7 0) of all the models will be observed and presented in the form of graph. Meanwhile, lateral displacement will be observed at the toe of embankment. From that, the best model set out of all different configuration would be chosen.

4.1. Soft Soil Vertical Settlement of All Models

The graph of soft soil settlement against time is plotted for all model sets. It is then categorised and merged into 4 different graphs placed side by side, with the first graph being when only conventional ConcMatt is used; the second, lightweight ConcMatt; the third, a combination of conventional ConcMatt with geotextile; and lastly, a combination of lightweight ConcMatt with geotextile. Since the observation points for settlement are differentiated into 3 points, 3 merged graphs would be presented. The percentage difference of each improved model would be calculated against the control model. Hence, the greater the percentage difference, the greater the settlement reduction, which also indicates a better improved model with lesser settlement experienced by embankment.

At point A (0 0), also the midpoint of a full embankment, the settlement of embankment is said to be most critical at the midpoint. The overall results can be seen in Figure 3. Meanwhile, at point B (3.5 0), referring to Figure 4, the overall final settlement for all models is expected to be lesser than that in previous point A. This is because as load is applied onto the embankment, the embankment tends to settle and curve into a "outspread-U-shape". Thus, the further the observation point is located from the midpoint, the lesser the tendency of it to experience a greater settlement than that of the midpoint of embankment. At point C (7 0), the overall final vertical settlement for all models is expected to be the least among all three observation points. However, as the embankment deformed into a "outspread-U-shape", the soft subsoil tends to squeeze out through the toe [5], causing a slight positive settlement at the start of the graph as shown in Figure 5.

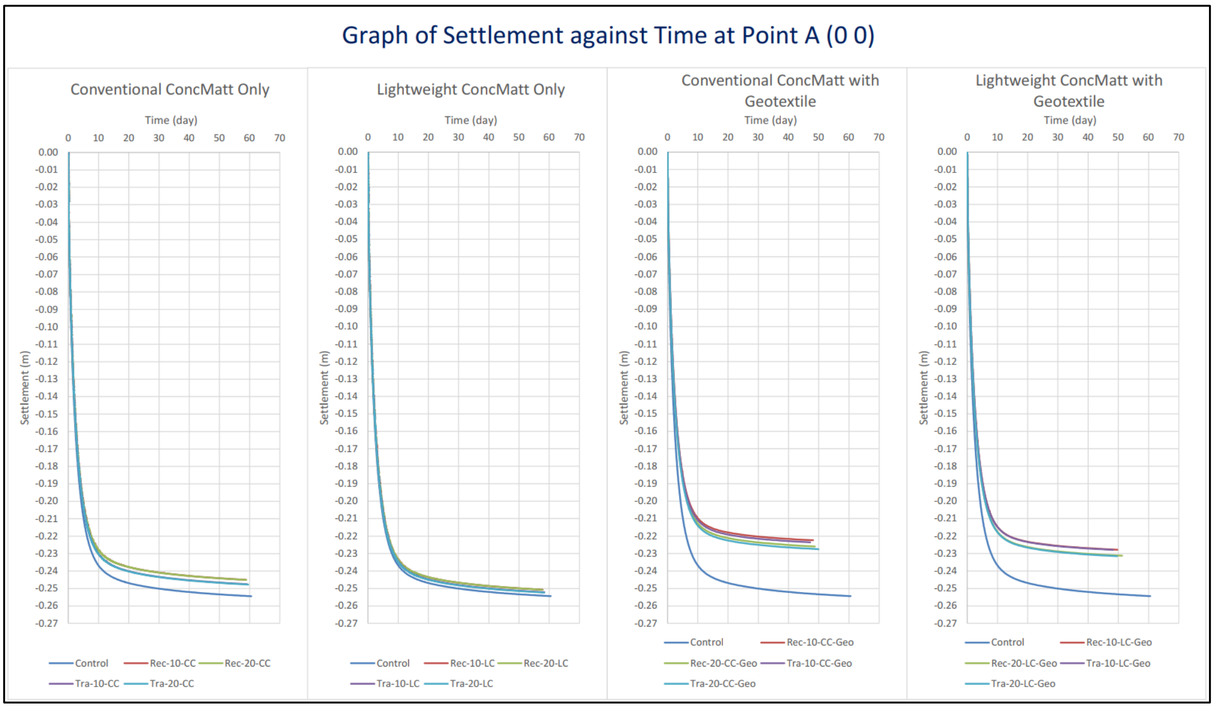

Figure 3: Graph of vertical settlement against time at point A (0 0)

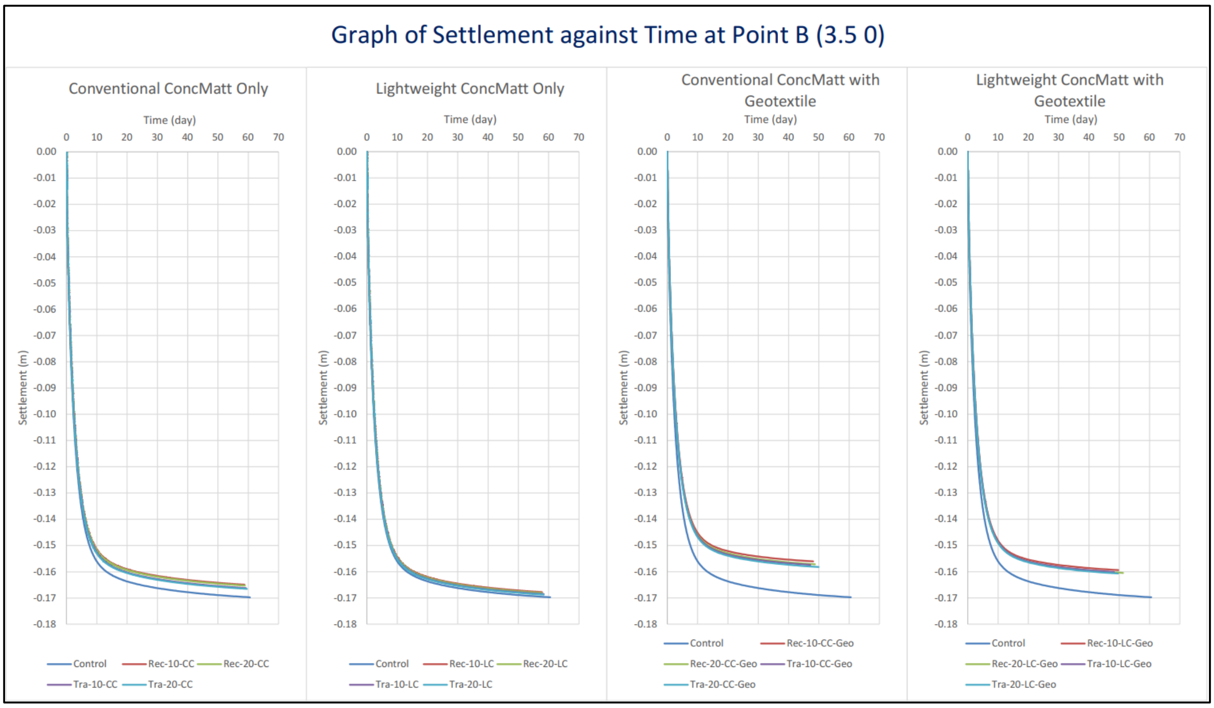

Figure 4: Graph of vertical settlement against time at point B (3.5 0)

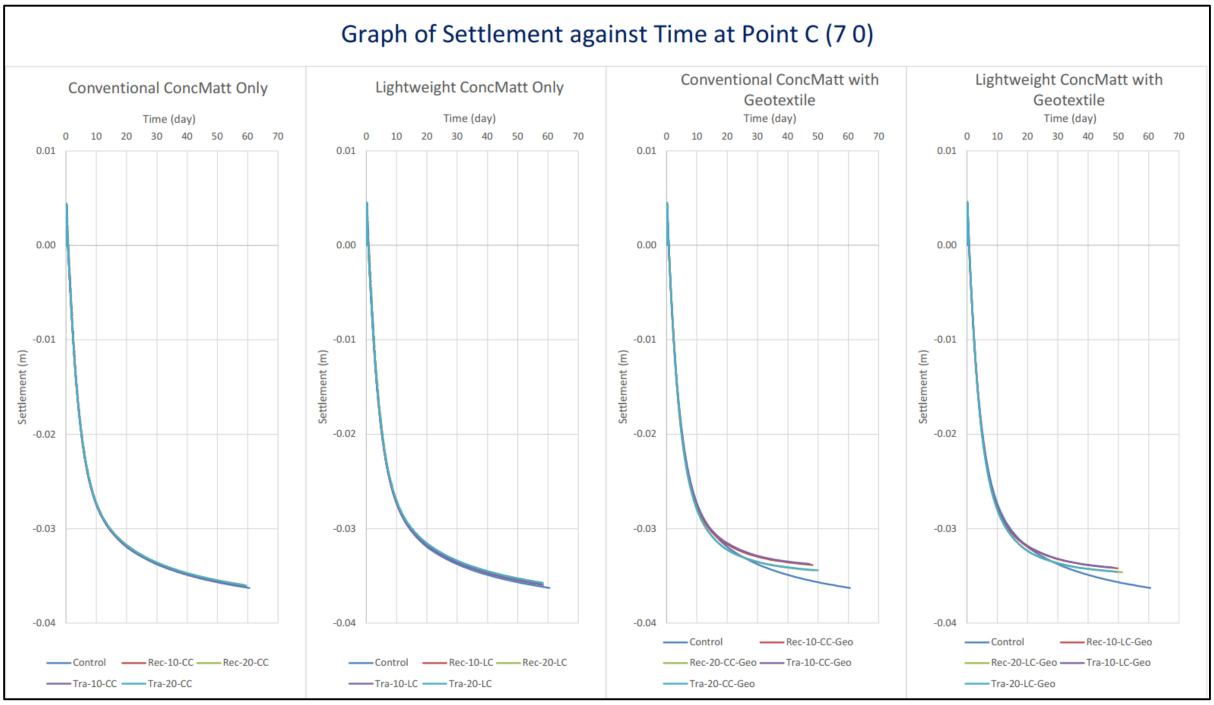

Figure 5: Graph of vertical settlement against time at point C (7 0)

4.2. Soft Soil Lateral Displacement of All Models at Toe of Embankment

Lateral displacement will only be observed at point C (7 0), which is positioned at the toe of the embankment. This is because the construction of the embankment which begins on a levelled platform would impose stress on the soft alluvium subsoil foundation. The soft alluvium subsoil with merely negligible shear strength will starts to squeeze out through the toe, causing a lateral spreading at the toe of embankment [5]. This phenomenon will only stop when both the active and passive forces come to equilibrium. From Figure 6, it is obvious enough to prove that ConcMatt itself do not contribute much in the lateral displacement reduction. However, when ConcMatt is combined with geotextile, the lateral displacement reduction surge up to around 69.60% to 84.48%.

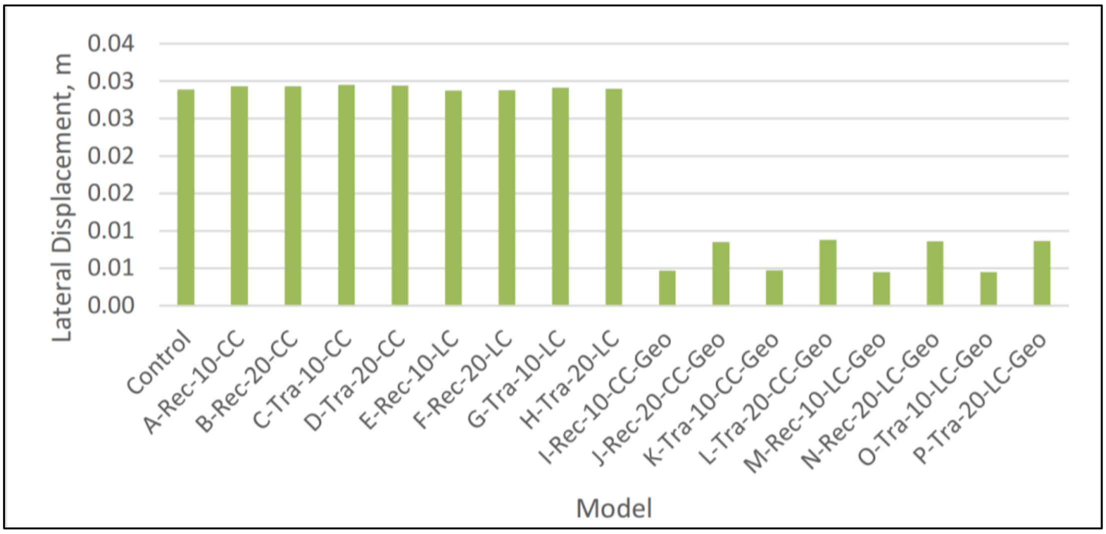

Figure 6: Final lateral displacement at point C (7 0)

4.3. Discussion

Overall, the trend of vertical settlement reduction observed from point A, B and C are quite obvious in terms of material, shape of ConcMatt, spacing between ConcMatt and presence of geotextile. Conventional concrete mat achieved a consistent higher vertical settlement reduction than lightweight concrete mat in all the models simulated even at different observation points. This may be due to the density of the conventional concrete is greater than the lightweight concrete. As the ConcMatt is laid along with the PVD and geotextile in PLAXIS staged constructions, ConcMatt somehow acts as a permanent surcharge or preloading on the soft alluvium subsoil before applying the traffic load. The concept of it may be explained by [6] studies that shows a comparatively large surcharge would results in a smaller post construction settlement, since the vertical settlement is observed only after applying the traffic load.

Spacing wise, a smaller spacing between ConcMatt results in better vertical settlement reduction as a closer arrangement provides a larger area of reinforcement to the weak subsoil supporting the embankment. Similarly, geotextile is proven to be an effective load transfer platform which also acts as a basal reinforcement as discussed in previous chapter. It gives sufficient support to the ConcMatt which allows a much uniform settlement. Also, since PVDs are used as pre-treatment for the subsoil, it is acts as a constant variable which complement the geotextile indirectly. [7] studies do show that the PVDs function in combination with geotextile to reduce differential settlement and foundation lateral deformation. When geotextile and PVDs are used together, embankment performance is significantly improved over when either approach of soil improvement is used alone.

In the case of lateral displacement observed at point C, models where geotextile is present significantly decrease the lateral displacement at the toe of embankment. This further shows the simulation is in agreement with past studies by [7] and [8] which agree that lateral displacement is obviously reduced with the presence of geotextile. However, the only difference in the reduction pattern is that lightweight ConcMatt results in a better lateral displacement reduction compared to conventional ConcMatt. This can be explained by the deformation is more critical in vertical direction for lightweight ConcMatt, thus resulting in lesser horizontal movement at the toe.

From the above analysis, the best model in reducing the vertical settlement for all three observation point A, B and C is Model I, where geotextile and conventional rectangular concrete mat is placed in 10mm interval between each other is used together. Meanwhile, in terms of lateral displacement reduction at point C, the best model is Model M, where geotextile and lightweight rectangular concrete mat is placed in 10mm interval between each other is used together.

5. Conclusion and Recommendations

Subsequently, from the simulation, the outcome from all model sets is determined, analysed and discussed in which the best model set in terms of vertical settlement reduction and lateral displacement reduction is deduced. The outcome of the simulation has consistent trend in terms of all the manipulative variables of this study. Shape wise, the rectangular ConcMatt is favourable over the trapezoidal ConcMatt. Meanwhile, conventional concrete mat is much effective in vertical settlement reduction, but lightweight concrete mat contributed in lesser lateral displacement at the toe of embankment. Placing the ConcMatt with 10mm spacing from each other is better than 20mm spacing, as to create a larger reinforced contact area to the embankment. Geotextile has significant contribution in both vertical settlement reduction and lateral displacement reduction. Above all, Model I (Rec-10-CC-Geo) is deduced to be the best model set in vertical settlement reduction, while Model M (Rec-10-LC-Geo) is best in lateral displacement reduction.

However, continuous research and studies have to be done in order to find a better solution at all times to counter the soft soil issues imposed towards road construction. With that, the following recommendation is given specifically in relevance with this study:

i. Laboratory testing to be carried out using a prototype model to replicate the on-site implementation of ConcMatt.
ii. Model the soft alluvium soil layer using other material model. For instance, the Soft Soil Creep (SSC) model, Modified Cam-Clay (MCC) model, Hardening Soil (HS) model, etc.
iii. Diversified the combination of improvement towards the ConcMatt innovation to determine its respective effectiveness.

Acknowledgement

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References

[1] A. Hassan, "MALAYSIA Soil Resource Management Paper presented in the Asian Soil Partnership Consultation Workshop on Sustainable Management and Protection of Soil Resources," Bangkok, 2015. Accessed: Apr. 03, 2021. [Online]. Available: https://www.doa.gov.my

[2] O. Matek, "A Slide Present - Concmatt Update 27jun2020." Omamatek Eng. & Trading Sdn Bhd, pp. 1–37, 2020.

[3] Y.-C. Tan, L.-H. Ooi, A. Yeow, P.-T. Lee, and K.-S. Koo, "Instrumented Trial Embankment on Soft Ground at Tokai, State of Kedah, Malaysia," in The 18th International Conference on Soil Mechanics and Geotechnical Engineering, 18th ICSMGE, Paris, France, September 2-6, 2013, pp. 2977–2980.

[4] S. R. Kaniraj and R. R. Joseph, "Geotechnical Behavior of Organic Soils of North Sarawak," in 4th International Conference on Soft Soil Engineering, Vancouver, Canada, October 2-4, 2006, Google Scholar, pp 267–274.

[5] B. Khan and I. Mehmood, "Checking Squeeze-Out Zone Under an Embankment Constructed at Seabed and Its Slope-Stability Analysis," Science Vision, vol. 14, pp. 99–108, 2008.

[6] G. W. Li, T. N. Nguyen, and A. C. Amenuvor, "Settlement Prediction of Surcharge Preloaded Low Embankment on Soft Ground Subjected to Cyclic Loading," Marine Georesources and Geotechnology, vol. 34, no. 2, pp. 154–161, Feb. 2016, doi: 10.1080/1064119X.2014.985860.

[7] R. K. Rowe and C. Taechakumthorn, "Combined Effect of PVDs And Reinforcement on Embankments Over Rate-Sensitive Soils," Geotextiles and Geomembranes, vol. 26, no. 3, pp. 239–249, Jun. 2008, doi: 10.1016/J.GEOTEXMEM.2007.10.001.

[8] J. Liu and J. Liu, "Character of Embankment Reinforced with Geotextile on Sloping Weak Foundation," Advanced Materials Research, vol. 168–170, pp. 1272–1276, December 2010, doi: 10.4028/WWW.SCIENTIFIC.NET/AMR.168-170.1272.