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SIMULATION OF PLATE BEARING TEST FOR FRICTION ROOT GROUND SUPPORT SYSTEM IN SAND USING PLAXIS FINITE ELEMENT

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***Abstract*— Predictions of physical characteristics and shear strength properties for friction root ground support system in sands are proposed. This study addresses the significance changes of bearing capacities and settlements of coarse sands with and without Polyurethane foams which precisely dealt with undisturbed soils and stabilized soils, respectively. Furthermore, the study permits a reliable prediction of physical characteristics of the soils via physical properties tests and shear strength behaviors of Polyurethane foams via Unconfined Compression Tests. The evaluated parameters are obtained from field works, site investigation report and previous researches, whilst the simulation is done with Plaxis Finite Element. To anticipate, it is observed that a slight changes in settlements and bearing capacities occurred with respect to the injection of Polyurethane foams.**

Index Terms — **Polyurethane foams, Bearing capacities, Settlements, Coarse sands, Unconfined compression test.**

I. Introduction

Generally, settlement is a major geotechnical problem which caused a massive collapse of structure. This analogy could be best described as the concept of shear strength and effective stress interaction in the course of soil settlement. In light of this, settlements could occur due to the increment of loadings over a long period of time, reduction of mobilized shear strengths with the presence of water and reduction of effective stresses or resisting variables (bearing capacity, compressibility, density, hydraulic conductivity) in soils. [20]. Finite element modeling is a comprehensive software which is commonly used in most of the geotechnical engineering applications. However, it is essential to have in depth understandings of the concept and applications in order to achieve an adequate design and a reliable analysis. Thus, important parameters such as undrained shear strength of the soil, physical properties of the soil and engineering properties of the soil should be identified first. Hence, this study demonstrates on how to define the friction root support system using Plaxis Finite Element. Generally, there are several types of ground improvement methods which are commonly used:i.e. mechanical methods, hydraulic methods, and chemical methods. These methods are implemented in order to enhance and improve the condition of subsurface soil. Each of these methods has their own advantages and disadvantages. However, this study emphasizes only on chemical methods since it dealt with Polyurethane injection approach for soil stabilization.

The goal of this study is to simulate a plate bearing test for friction ground root support system in sand using Plaxis finite element. The prediction of settlement which obtained from the simulation is then verified and validated with the empirical calculation. Basically, empirical method is used to determine the elastic settlement for the sand properties as introduced by De Beer and Martens (1957) and De Beer (1965). The uniqueness relationships by DeBeer and Martens (1957) and De Beer (1965) are adopted in this study due to the elastic settlement of cohesionless soil factor. The empirical relationship is shown in Equation 1 which predicting the elastic settlement of a foundation (Das, 1994). **Table 1** shown value of a and b [7]..

$$S_c = \frac{2.3}{C} \log_{10} \frac{\sigma_o + \Delta\sigma}{\sigma_o} \mathbf{H} \qquad \text{Equation 1}$$

where *C* = a constant of proportionality
σ_o = effective overburden pressure at the depth considered
$\Delta\sigma$ = increase in pressure at that depth due to foundation loading
H = thickness of the layer considered

The value of *C* is governed by Equation 2 :

$$\mathbf{C} = \frac{1.5\, q_c}{\sigma_o} = \mathbf{a(e_o - b)} \qquad \text{Equation 2}$$

where q_c = cone penetration resistance.

Table 1: Values of a and b (after Das, 1994)

Type of soil	Value of constant a	Value of constant b*
Uniform cohesionless material (uniformity coefficient $C_u \leq 2$)		
Clean gravel	0.05	0.50
Coarse sand	0.06	0.50
Medium sand	0.07	0.50
Fine sand	0.08	0.50
Inorganic silt	0.10	0.50
Well-graded cohesionless soil		
Silty sand and gravel	0.09	0.20
Clean, coarse to fine sand	0.12	0.35
Coarse to fine silty sand	0.15	0.25
Sandy silt (inorganic)	0.18	0.25

* The value of the constant *b* should be taken as e_{min} whenever the latter is known or can conveniently be determined. Otherwise, use tablulated values as a rough approximation.

Friction root support system using polyurethane injection for ground improvement is implemented in order to enhance the bearing capacity and shear strength of the soil. This support system is modeled using Plaxis Finite Element and the prediction results are compared with the empirical calculation.

II. MATERIALS AND METHODS

The properties of coarse grained soil and polyurethane foam are identified first. These data are used in both approaches, numerical (Plaxis) and empirical analyses. The basic properties of various soils are tabulated in **Table 2.**

Table 2: Typical Properties of Various Soils (after Das, 1994)

Soil Type	Void Ratio, e	Dry Density, γ (kN/m³)	Saturated Unit weight, γs (kg/m³)	Elastic Modulus, E MPa	Poisson's Ratio, υ	Friction Angle, ϕ
Loose uniform sand	0.8	16.5	18.5	10.5 – 24	0.20 – 0.40	35°
Dense uniform sand	0.45	20.0	21.5	17.25 – 27.60	0.25 – 0.40	40°
Silty sand	0.65	17.0	20.0	10.35 – 17.25	0.30 – 0.45	30°
Sand and Gravel	0.2	21.0	23.0	69 – 172.50	0.15 – 0.35	40°
Soft Clay	0.9 – 1.4	17.0	17.0	4.1 – 20.7	0.20 – 0.50	
Stiff Clay	0.6	19.0	19.0	41.4 – 96.6	0.20 – 0.50	

Polyurethane is produced by the reaction of a polyol (R-OH) and isocyanate (R1-NCO) in the presence of catalyst and additives. Chemical solutions used in the study are shown in **Fig. 1**[20].

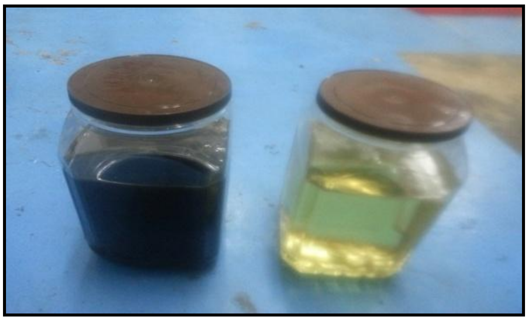

Fig. 1: Polyol and isocynate chemical solutions

The design specifications of the Polyurethane foam or resins are listed in **Table 3**. These properties are determined from the laboratory tests using the liquid polyol and isocynate designed for heavy usages. These parameters are used for the designs and analyses of the remediation works using applied engineering mechanics and sophisticated software in predicting and analyzing the existing ground settlements and movements of the grounds after remediations works. [21].

Table 3: Design properties of the polyurethane foams and resins [21].

Description	**Value**	**Unit**
Unit weight of the polyurethane foam/resin, γ	3	kN/m^3
Stiffness modulus, E	15,000	kN/m^2
Poisson's ratio, ν	0.3	
Compressive strength, σ	2.2	MPa
Permeability, k	1×10^{-12}	m/s
Ultimate load capacity	57	kN

The types of modeling used for this study are Mohr Coulomb Model for polyurethane foams and Hardening Soil Model for the soil layers. The evaluated parameters are obtained from the site investigation reports and correlation interpolations of typical soil properties in the principles of foundation engineering handbook.
The distance between BH1 Borehole 1(BH1) and Borehole 2(BH2) is approximately 64m. The plate load test is conducted at the center whereby the dimension of the plate is 1m by 1m. The plate load test is modeled on the ground level which is above the granular fill layer. The construction stages for the simulation is divided into 5 main stages.

III. NUMERICAL RESULTS AND DISCUSSION

This section represents the numerical results of settlement and bearing capacity levels via Plaxis Finite Element

Modeling (Plaxis FEM) which utilized Mohr Coulomb and Hardening Soil Models as aforementioned above.

3.1 Prediction of settlement and bearing capacity

The types of models used in this study are Mohr Coulomb Model and Hardening Soil Model wherein the model are used to monitor the settlement level of the model during the stabilization process. The procedures of the model simulation are as follows;

i) Initialization of loads.
ii) Failure monitoring test (without the PU injection)
iii) Injection of PU (after load release)
iv) Initialization of loads (with injection of PU).
v) Failure monitoring test (with PU injection).

Each of these stages is analyzed based on the vertical displacement analysis and the load against displacement curve. Both of these analyses are illustrated in **Fig. 2**, **Fig. 3** and **Fig. 4**.

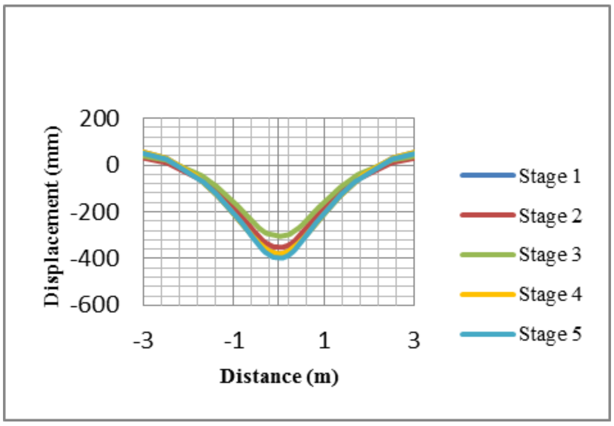

Fig. 2: Vertical Displacement for the Overall Stages

Figure 2 indicates the vertical displacement for the overall stages involved in the modelings. It shows that there is a slight significance change in settlement level due to the injection of PU into the soil composition. It is obvious that a drastic change occurred between stage 2 and 3 with 350 mm and 300mm of settlement level, respectively. In addition, it could be concluded that 15% of settlement reduction is achieved with the presence of PU in soil composition.

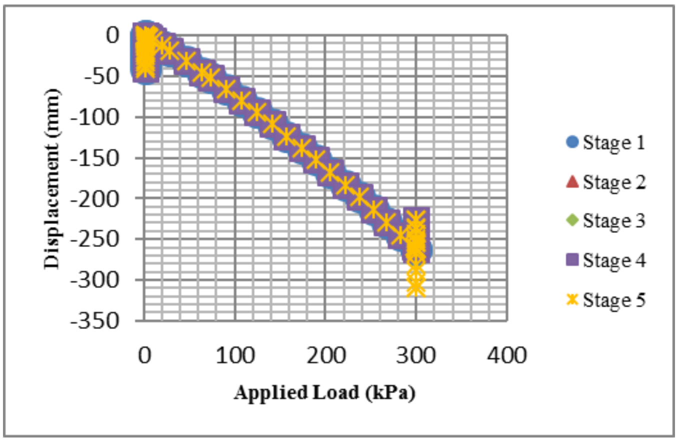

Fig. 3: The load-displacement relationship for Point A in all stages.

Figure 3 represents the load-displacement relationship for overall stages of point A as extracted in Plaxis Finite Element Modeling. There is a slight change of settlement before and after the injection polyurethane in the soil. It is observed that the results are identical for all applied stages in the load-displacement relationships. The settlement initial values of Stage 1 are set to zero and have been reset to zero in Stage 2 as the maximum limit of load is exceeded (300 kPa). This scenario is to replicate the actual fieldwork procedure which could guarantee the reliable and significance outputs. **Fig. 3** also indicates 15% of settlement reduction between stage 2 and 3 as obtained in **Fig. 5** with 260 mm and 220 mm, respectively. The maximum settlement level is achieved at 310mm with the loading application of 300 kPa.

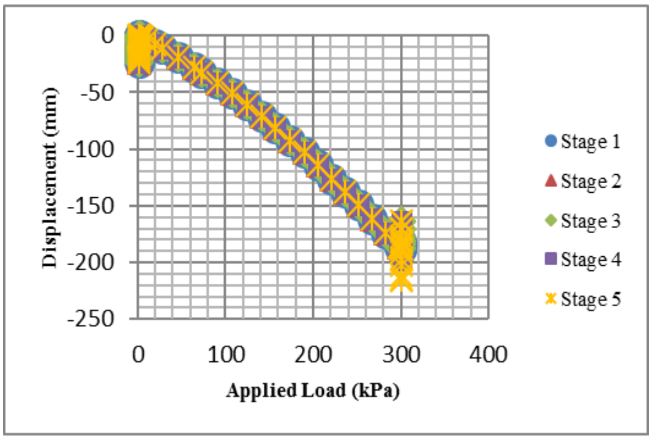

Fig. 4: The load-displacement relationship for Point B in all stages.

Figure 4 indicates the load-displacement relationship of point B for all stages involved. Point B is located at the bottom of the first layer which consists of compacted granular fill soil. Therefore, the settlement level at this point is lower than point A. Appraisingly, the presence of PU at point B shows an intended result for stage 2 and 3 of settlement level changes. This shows that the PU able to penetrate the soil composition at any position of PU bulb located. Furthermore, a quantitatively identical percentage of settlement level changes is obtained at Point B.

3.2 Validation for the numerical analyses

The results of numerical analyses are discussed and validated based on the empirical analyses. It is essential to validate the results to ensure the convergence of the numerical analyses.

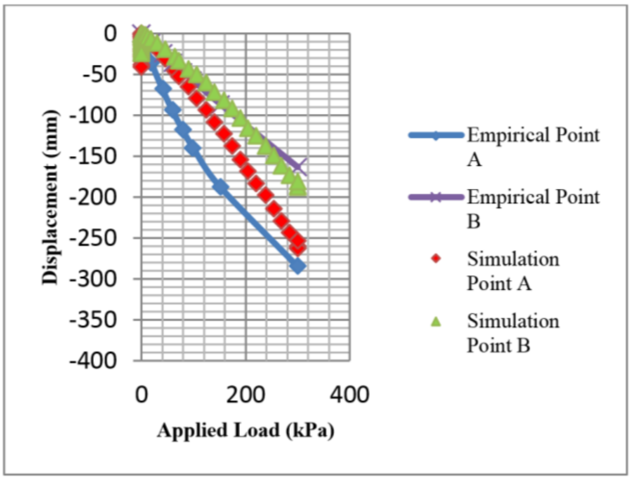

Fig. 5: The convergence of load-displacement relationship between Point A and B.

Figure 5 represents a convergence of load-displacement relationship with PU injection of the evaluated soil composition. The empirical values are obtained using DeBeer and Martens (1957) and DeBeer (1965) formulas as aforementioned above. These numerical results are in a good agreement with the empirical values excepts for the results of Point A. At Point A, it is observed that the predicted settlement level is lower than the empirical value. **Table 4** demonstrates the numerical results are acceptable and reliable according to the percentage differences provided.

Table 4: A validation table between empirical and numerical results for Point A and B

Empirical				Prediction (Simulation)			
Point A		Point B		Point A		Point B	
Applied Load (kPa)	Settlement (mm)	Applied Load (kPa)	Settlement (mm)	Applied Load (kPa)	Settlement (mm)	Applied Load (kPa)	Settlement (mm)
0	0	0	0	0	0	0	0
20	-36.424	20	-11.897	20	-18.218	20	-8.053
40	-67.542	40	-23.631	40	-35.569	40	-17.750
60	-94.705	60	-35.207	60	-51.841	60	-30.508
80	-118.806	80	-46.628	80	-67.224	80	-39.907
100	-140.466	100	-57.899	100	-82.580	100	-49.704
150	-186.613	150	-85.443	150	-146.873	150	-80.091
300	-284.769	300	-163.128	300	-254.564	300	-186.896

IV. CONCLUSION

In general, this study focuses on polyurethane foam as the frictional material for the ground support system to enhance the bearing capacity of the stabilized soil. Plaxis FEM is an ideal software for this analysis which able to monitor the settlement levels and bearing capacity results of the soil with the presence of PU.
A numerical analysis has been conducted to investigate the effect of PU of stabilized soil on the bearing capacity properties and settlement levels of the soil. The empirical and numerical results have been calculated to investigate the convergence of settlement levels and bearing capacity results. With the load-displacement relationships at the selected points, users and manufacturers can better understand the behaviour of stabilized soil with the presence of PU thus make informed decisions during the design process.
Overall, an understanding of the designation mechanism of PU is beneficial for the ground support system, which comprehends investigation of the relationships between the soil properties, structure of the PU, process of modeling and physical properties of the soil.

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