The Uncertainties of Using Replacement Soil in Controlling Settlement

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Abstract: The use of replacement soil under shallow foundation may be a cheaper solution than that of using deep foundation to support light buildings over thick layers of soft soil. In the Egyptian Nile Delta, the soil lithology generally consists of thick layers of soft to medium clay that may include highly compressive peat. In this work, the replacement of part of the upper soil layer by dense sand or gravel to support buildings on shallow foundation systems is explored using centrifuge test and numerical modelling. It is found that, the use of replacement soil can reduce settlement and construction cost considerably. Correlations and graphs are deduced to correlate various soil parameters with the external loadings values.

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1. Introduction

In the Egyptian villages and small cities, the population is already dense and is expected to become even denser due to the high rate of population increase. In the meantime, the area allotted for urbanization is virtually constant as the surrounding area must be reserved for agricultural purposes. In the presence of good soil, the use of shallow foundation represents a logical solution (Zeeveart, 1973, Leonard & Frost, 1988).

On the other hand, if the soil is weak and cannot sustain the high superstructure stresses and in addition, the use of deep foundations exceeds the economic ability of the low income population, the only remaining alternative is that of replacement of the upper soil layer, totally or partially, by a layer of stronger soil.

The determination of the replacement soil depth is based on experience which in many cases is questionable. This work aims to study the effect of replacement soil depth in controlling the settlement of footings. It is important to state here that the presence of sand replacement soil over soft clay affects the pressure distribution and approaches the arching condition which in turn overcomes the possibility of occurrence of punching failure.

2. Methods of Analysis

The problem under consideration is treated both numerically and experimentally. The experimental aspects represent the back bone of this work, while the numerical works are treated as a verification process. It is clear that full scale modeling at the site of interest leads to the most reliable results. However, this is not always physically possible or economically. The use of smaller size geotechnical models in the normal gravity field generally leads to erroneous results, especially as far as the stress values is concerned.

Centrifuge modeling has the advantage of producing full scale values of both the stress and strain. Moreover, it can help in changing the time scale from years to hours without influencing the validity of the governing equations, (Schofield, 1980, El Nimr & Abdul Aziz, 2007).

Over the past decades, centrifuge modeling has been accepted in most countries as a reliable means of carrying out geotechnical research work. The scaling factors of centrifuge modeling can be found in many references (Garnier, et al., 2007). The use of centrifuge models to simulate shallow foundation was reported by Leung, et al., as early as 1984.

It is known that the numerical methods attained a real breakthrough after the development of the different forms of the finite element method and following the production of high speed electronic computers with large memories. In soil mechanics, the equilibrium and compatibility equations are combined with the stress strain relation to order to study the problem (Chen & Baladi, 1985)

The different failure modes of soil plasticity such as Tresca, Von Mises, Drucker-Prager, Mohr-Coulomb, etc. may represent certain types of soil under certain conditions but none of them can be applied to simulate all types of soil under all conditions. Even using the most accurate means of calculation, one can’t assume and that the chosen failure criterion will suit the soil under the actual loading conditions.

3. Experimental Work

The soil used in the test was delta clay, which is a soft soil that occupies the top underground layers in most of the Nile Delta provinces.

The clay test samples were prepared to represent average actual field conditions (Stewart & Randolph, 1991). This was done by mixing Delta clay powder with distilled water. The properties of the soil samples are summarized in table 1.

The soil used for replacement consisted of clean medium fine sand. The average grain size distribution curve of this soil is shown Fig.1. Its average angle of internal friction is close to 35^o and thus the angle of dilatancy was taken to be 5^o.

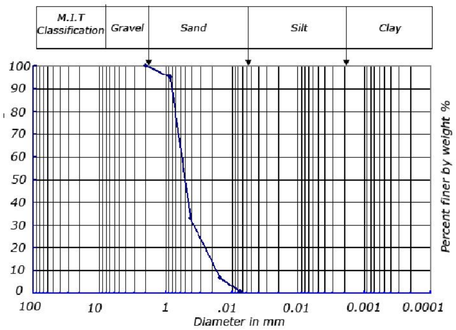

Figure 1. Sieve Analysis of Replacement Soil

The container used for the model has the following dimension: length l = 700mm, width b = 470 mm and Height h = 400 mm, and the depth of the footing base below the ground level D was taken as 50 mm. The tests were conducted for 5 different thickness of replacement soil, namely 0, 25, 50, 75 & 100 mm.

The footing was simulated by a mild steel thin plate with width B = 100 mm and thickness 3 mm. Its modulus of elasticity was 2.1x10^8 kN/m^2.

Table 1 Properties of the soil samples obtained.

Liquid limit	74.1%
Plastic limit	24.2 %
Specific Gravity	2.66
Compression Index for loading	0.535
Compression Index for Unloading	0.051
Initial Water Content	55.80 %
Initial Void Ratio	1.692

The test was conducted in the Mansoura University 130g-ton geotechnical centrifuge, and the dynamic load was applied by a corresponding dynamic actuator, P67-20 dynamic loading system, which can apply a constant load as well as one according to predefined time-dependent factor. The actuator is remotely controlled from the main centrifuge and its associated operating P.C. The setup of the testing system is presented in Figure 2, and Figure 3 includes a photo of the loading system on the centrifuge basket.

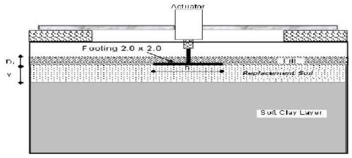

Figure 2. Setup of the Testing System

Figure 3. Loading system with tested container on the centrifuge basket

The test was conducted several times under 20g gravity for different stress values and variable thickness of replacement soil. The stress/settlement correlations for the different cases are shown in Figure 4.

Numerical Work

The numerical work was carried out in three dimensions using the software Plaxis (2005). The Mohr-Coulomb failure mode was chosen for soil behavior.

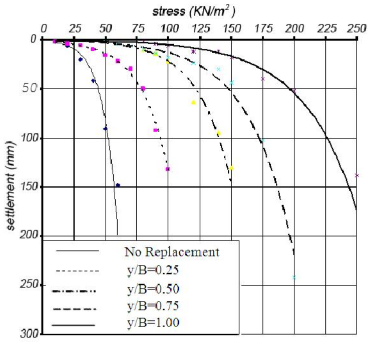

Figure 4. Stress/ Settlement Curves from Experimental Results

The mechanical and physical properties of the soil were taken to be the same as those used in the experimental tests. The dimensions of the domain of study were chosen to be equivalent to those of a 1g domain which corresponds to the 20g model. In other words, it has the following dimensions length = 14.00 m, width = 9.40 m with a square foundation base with side length = 2.00 m. The EI value of a vertical section in the base which is parallel to one of its sides was chosen to be equivalent to that in the model, including scaling factor. Thus, in the numerical work, EI = $2.1 \times 10^8 \times 0.003^3 \times 0.1/12$ kNm^2 = 0.4725 kNm^2.

The study domain was divided into 17500 parallelepiped elements with 16 nodes each. Each element was 0.2 m x 0.2 m in plan while the thickness of the replacement soil, with a maximum value of 0.20 m. Figure 5 presents the plan of the finite element model at the level of the foundation base.

The boundary conditions on the sides and bottom of study domain were assumed to be similar to those of the test, i.e. the strain in all directions equals zero. The stress on the base is assumed to be uniform. Similar to the experimental work carried out, the calculation was repeated for different values starting from 0 to 200 kN/m^2 with 25 kN/m^2 intervals. The obtained results are presented in Figure 6.

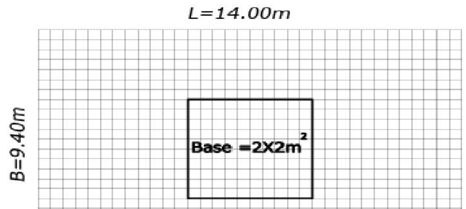

Figure 5. Plans of Finite Elements on Base Level

DS

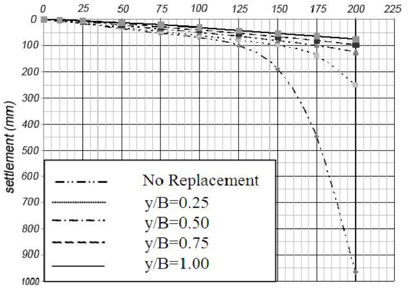

Figure 6. Stress/Settlement Curves from Results of Numerical Modeling

Comparison between Experimental and Numerical Work

The comparison between the experimental and numerical results clearly indicates that the strain differ greatly for the same soil and foundation conditions. The settlement curves for different replacement soil thickness under uniform loadings 50 kN/m^2 & 100 kN/m^2 on the foundation base are presented in Figure 7 & Figure 8 respectively.

Generally, the experimental work yielded higher settlement values in the case of applying no or thin replacement soil layers. On the other hand, for thicker soil replacement layers, the settlement calculated from the numerical model tended to exceed that obtained experimentally.

Specifically, if the uniform load was 50 kN/m^2, and the replacement soil had a thickness less than 0.18 B, the settlement obtained from the experimental works was higher than that obtained from the numerical model and for thicknesses greater than this value, the case was reversed and the settlement calculated from numerical model become the larger one.

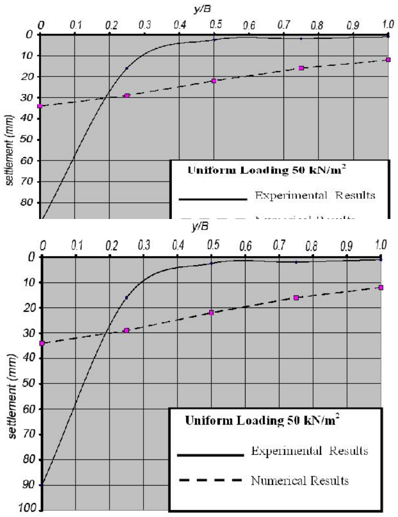

Figure 7. Settlement under a uniform stress 50 kN/m^2

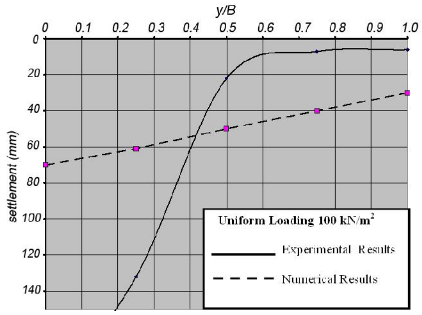

Figure 8 Settlement under a uniform stress 100 kN/m^2

The same thing occurred, for uniform load equal to 100 kN/m^2. However in this case, the phenomenon occurred when the replacement soil equaled 0.42 kN/m^2.

It was also observed that during the experiment, under a uniform load exceeding 100 kN/m, the soil suffered complete failure if the soil replacement was less than 0.2B. However, the numerical model results indicated no signs of failure for the whole range of loads and soil replacement thicknesses.

Another important observation is that the settlement resulting from the tests approached a constant, small value as the thickness of the soil replacement exceeded 0.5B and 0.6B for uniform load equaling 50 kN/m^2 and 100 kN/m^2, respectively. However, the settlement results of the numerical model decreased almost linearly for all load conditions without showing any indication of approaching a constant value.

Conclusions

The effect of replacing the upper soft soil layer or part of it by a relatively stronger soil was investigated both experimentally using centrifuge modeling and numerically adopting the Mohr-Coulomb soil behavior model.

In this work, all soft soil parameters, as well those of the replacement soil, were assumed identical for both the experimental and numerical models.

Regarding the dimensioning, it would have been more realistic to extend the domain boundary of the numerical model far enough from the foundation base edges in order to avoid boundary effects.

However, in order to avoid any difference in boundary conditions, the process of defining the dimensions for the two models was conducted exactly according to the scaling rules of centrifuge testing. Thus, the boundary locations and conditions of the numerical model were kept equivalent to those of the experimental model.

Despite the complete similarity in the parameters and dimensions, the results obtained from the two methods differ greatly. To investigate this two factors were considered:

a) The validity of the Mohr-Coulomb model to simulate the chosen types of layered soils

b) The assumption in the numerical model that the soil properties remain unchanged after the loading process.

The major differences between the results of the two models are analyzed as follows:

a) It was found that the experiments generally led to high settlement values in the case of thin replacement layers, while the opposite occurred in thicker replacement layers as the numerical model settlement value become higher than those obtained from the centrifuge model. This means, at least for this particular case (sand overlaying soft soil), the validity of Mohr-Coulomb failure criterion is suspect. Whether this is due to the failure of this model in the case of such multilayered soil or due to the variation of the soil parameters due to loading remains to be investigated.

b) The numerical model failed to reach failure when the uniform load was 100 kN/m^2 for a thin sand layer on soft soil or even if the soft soil was loaded directly (no replacement soil). This does not seem logical, as the soft soil used must reach failure under such a loading condition. A variation in soil properties must have taken place during the loading process in the centrifuge. This change is not taken into consideration in the numerical model.

c) The settlement values increase almost linearly and do not trend towards a constant value. This also does not seem logical, as there is a minimum limit to the void ratio of any soil. This may be due to the fact that no lower limit condition is assigned for the void ratio in the Mohr-Coulomb failure surface.

The work presented here is restricted to a very special case of footings and soil conditions. The conclusions presented here do not necessarily applied to other cases of replacement soil with different properties on soft soil, even with properties as those presented here.

The foundation dimensions and its material properties may also play a role in testing the validity of the conclusions obtained.

Finally, the tank used in centrifuge testing and consequently, the corresponding numerical model, had limited dimensions and hence the boundary effect on the results may not be negligible. This may be one of the disadvantages of centrifuge modeling.

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