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Full Length Research Paper

Uplift response of square anchor plates in dense sand

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The behavior of square anchor plates during vertical pullout was studied by experimental data and finite element analyses in dense sand. Validation of the analysis model was also carried out with 100 mm x 100 m square plates in dense sand. Agreement between the uplift capacities from the experimental tests and finite element modeling using PLAXIS 2D, based on 0.2 m computed maximum displacements was excellent for square anchor plates. Numerical analysis using square anchor plates was conducted based on hardening soil model. The research showed that the finite element results were lower than the experimental findings in the dense sand.

Key words: Square anchor plates, finite element, dense sand, uplift responses, PLAXIS 2D.

INTRODUCTION

According to Niroumand and Kassim (2010) the soil anchors are a thin foundation system designed and constructed specifically to resist any uplift force or any overturning moment placed on a structure. Typically, soil anchors are used to transmit different forces from a structure to the soil. Their strength is obtained through the shear strength and the dead weight of the surrounding soil. Niroumand et al. (2010) investigated types of soil anchors using geotechnical engineering such as grouting, helical, anchor plate and soil hook system. The ultimate uplift capacities were investigated due to the last theories and numerical studies were conducted on the horizontal anchor plates in the sand. Numerical analysis and laboratory works were performed to study the performance of the ultimate uplift load capacity of the anchor plate. However, there are relatively few documents in the technical literature which deal with an anchor plate in the sand. For future analysis purposes, the limited ultimate capacity of an anchor plate embedded into the sand can be an assessment based on the numerical and the experimental work.During the last 60 years, various researchers conducted laboratory studies to understand and predict better, the ultimate uplift loading of the anchors in a range of soil types. The analysis was pioneered by Meyerhof and Adams (1968), Murry and Geddes (1987), Sarac (1989), Merifield et al. (2006) and Niroumand and Kassim (2010), which provided numerical and theoretical analysis as an evidence of the influence of the soil packing, size shape of anchors and the embedment ratio on their behavior. Table 1 shows the previous theoretical and numerical analysis on the horizontal square anchor plates, respectively. The results involve the last theories and the numerical studies that were more than just experimental works. In contrast to the variety of experimental results already discussed, very few rigorous numerical analyses have been studied to determine the up-lift loading of the anchor plates in the soil. The research compared the numerical analysis, using the finite element method by PLAXIS 2D, with the experimental results obtained from the work on the experimental model.

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EXPERIMENTAL TEST

Glass box modeling

The glass box is relatively a large container with dimensions of 600 mm in length, 600 mm in width and 500 mm in depth that uses reinforced wood as a frame and it is closed by a plastic with a thickness of 20 mm. For leveling purposes and in order to reduce the influence of the humidity from the floor, the glass was supported by a C-channel of 150 mm in size. A motor displacement with a speed of 60 mm/min and a load cell was employed in the glass box. The sand was packed in dense packing. The research arrangement is shown in Figure 1. The dense packing sand was compacted using an electrical vibrator at every 100 mm thickness for 8 min, covering all the surfaces. From this process, a unit weight of 16.95

Table 1. Soil parameters used in PLAXIS 2D analysis.

Parameters	Dense Sand
Unit weight, γ ($kN.m^{-3}$)	16.95
Friction angle, Ø (°)	42
Poisson's ratio, ν	0.2
Secant stiffness, E_{50}($kN.m^{-2}$)	22000
Initial stiffness, E_{OED}($kN.m^{-2}$)	22000
Reloading stiffness, E_{ur}($kN.m^{-2}$)	64000
Cohesion, c ($kN.m^{-2}$)	0

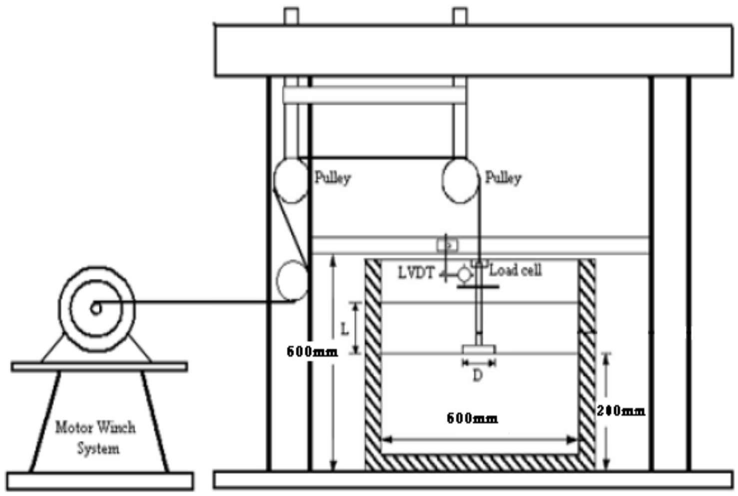

Figure 1. View of pullout test.

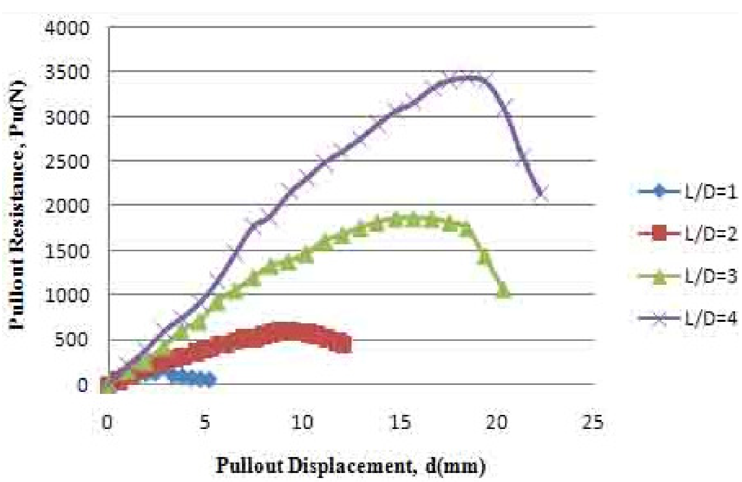

Figure 2. Pullout response on horizontal square anchor plate in dense sand.

kg/m^2 was achieved for the dense packing sand. In addition, the model had an embedment ratio ranging from 1 to 4. A summary of the test results regarding the effect of the embedment ratio on the uplift load capacity in dense sand for the horizontal square anchor model is tabulated in Figure 2. It is evident from the data that the uplift load increased significantly, while the embedment ratio

Figure 3. Failure mechanism in dense sand at embedment ratio, L/D = 4.

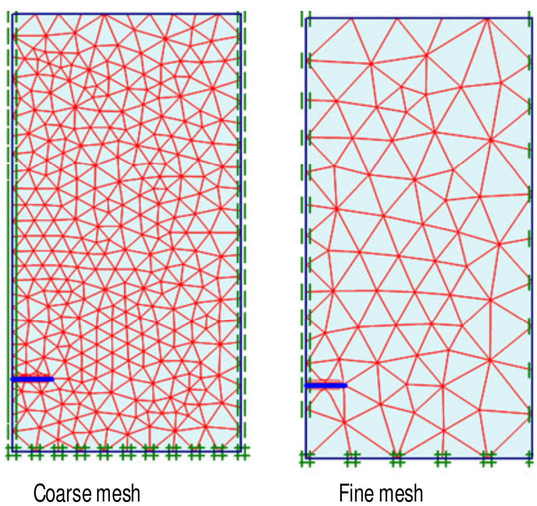

Figure 4. Meshes used in PLAXIS 2D for square anchor plate with embedment ratio L/D = 5.

increased.

Failure mechanism modeling

The failure mechanism tests were performed at the University of Technology Malaysia. In these tests, the patterns were made on the extreme uplift loads and the embedment ratio. The aim of the tests was to show the behavior of the failure mechanism in dense sand around the square anchor plate model due to the uplift loading. The property of the test was applied to a unit weight of16.95 kN/m^2, which was obtained from dense sand. Every 40 mm in vertical intervals contained a layer of 4 mm dyed sand, which was placed in the front face of the failure box in order to visualize the line. The load was applied to the models of the square anchor plate through the loading cable with a constant rate of low. During the test, the failure pattern was shown. The square anchor plate was made to move until a sufficient distance, to ensure the failure pattern was showed. The typical pattern of this zones are shown in Figure 3.

NUMERICAL ANALYSIS

PLAXIS modeling

According to Niroumand (2007) a hardening soil model (HSM) was selected from those available in PLAXIS 2D to describe the non-linear sand behavior in this study. During the generation of the mesh, 15-noded triangular elements were selected, in preference to the alternative of the 6-noded versions, in order to provide a greater accuracy in the determination of the displacements. PLAXIS incorporates a fully automatic mesh generation procedure, in which the geometry is divided into the elements of the basic element types, and the compatible structural elements. The analysis was carried out using an axial-symmetrical model for the anchor plates in dense sand.

According to Niroumand (2006) PLAXIS generates full fixity at the base of the geometrical and smooth conditions at the vertical sides. The uplift loads were applied with an increment of 1. The half-width meshes, which were close to the glass box setting and the failure mechanism derived from the research in dense sand, are shown in Figure 4.

Numerical analysis results

The variation of the uplift load with the displacement from the PLAXIS 2D analyses showed generally, a good agreement with the physical model obtained from the experimental results for the anchor depth. The results graphically presented in the figure illustrate the maximum uplift load against the displacement that ranges from 1 to 4 for this model. It is evident that the uplift load increased significantly, while the embedment ratio increased. The maximum uplift load of the model showed almost similar trend when the embedment ratio was at L/D = 4. Figure 5 illustrates the influence of the embedment ratio, L/D on the anchor plate model in the dense sand.

The results of the displacement contours, obtained from PLAXIS 2D on the horizontal square anchor plate embedded in the sand are illustrated in Figure 6. This figure shows that for this anchor plate, the soil displacement and the shear stresses increased up to the sand surface as a shallow anchor plate.

COMPARISON BETWEEN NUMERICAL RESULTS BY PLAXIS AND EXPERIMENTAL RESULTS

Figure 7 illustrates a comparison between the maximum

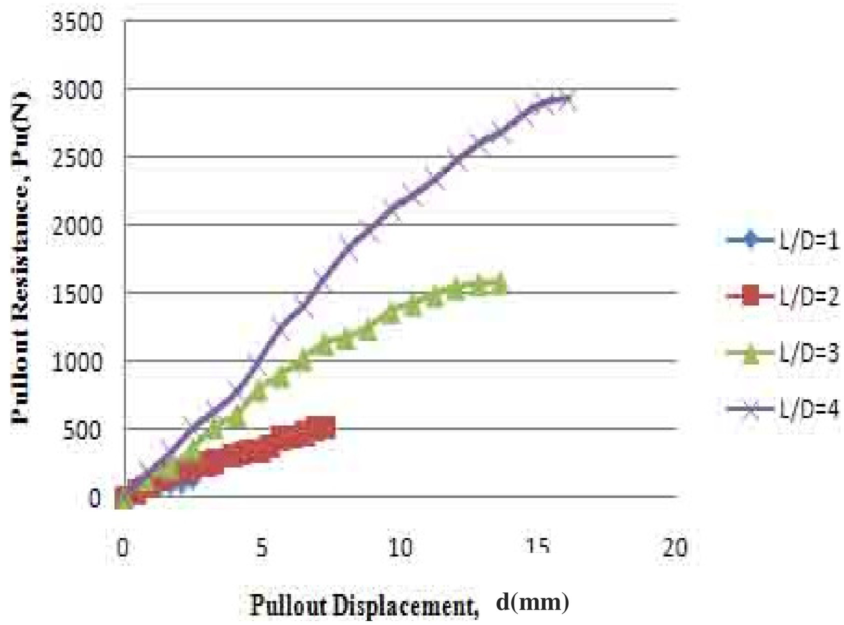

Figure 5. Effect of embedment ratio on pullout response of horizontal square anchor plate in dense sand.

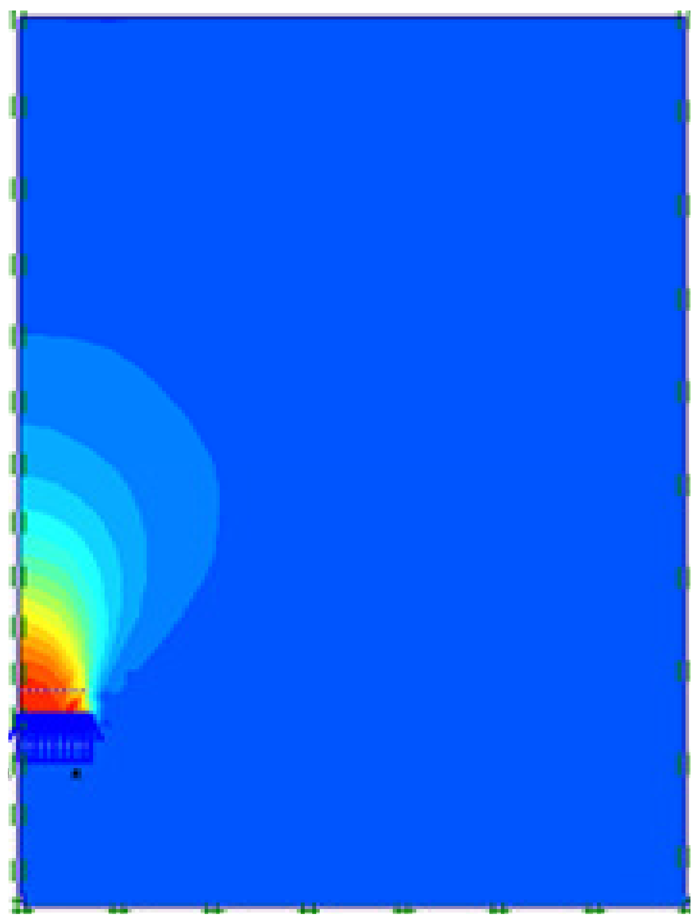

Figure 6. Displacement contours for a square anchor plate at L/D=4.

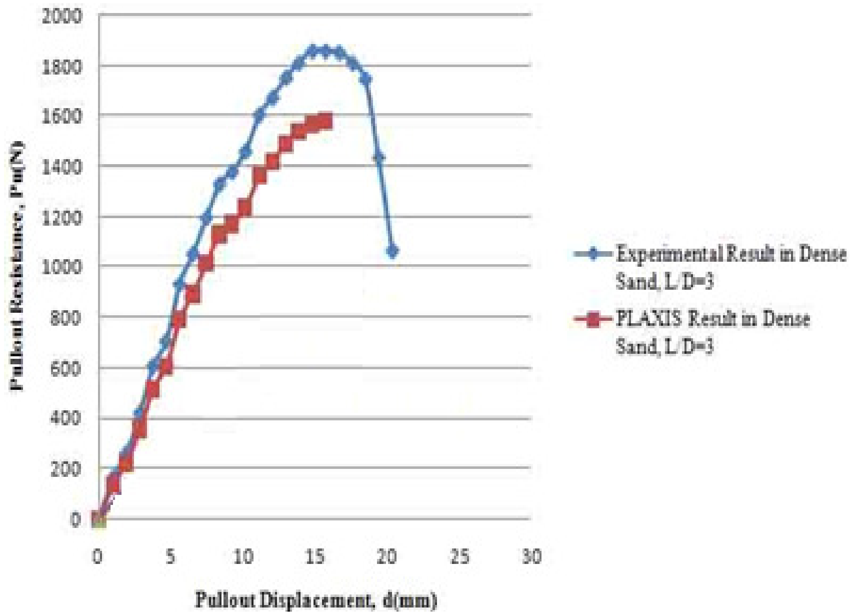

Figure 7. Comparison between uplift load from glass box and numerical modeling by PLAXIS 2D.

uplift loads for the square anchor plate in the dense sand. As a result, it is claimed that, the density of the sand affects the increase of the uplift capacity of the square anchor plate. The experimental and the numerical modeling results of this research were based on the uplift load and the displacement in any condition. The relationship between the uplift load and the displacement derived from the experimental result and the numerical modeling by PLAXIS 2D approaches towards the dense sand is illustrated in Figure 7.

Conclusion

The main purpose of this study was to determine the ultimate uplift capacity and to make a validation of the square anchor plate, based on dense sand. The test performed in the glass box showed that the limited ultimate capacity of the square anchor plate model was influenced by the embedment ratio and the sand density. Typically, the results from PLAXIS had a good agreement with the experimental results obtained from the prediction of the uplift load capacity on the square anchor plate. These can be used to provide the basis for the design of such structures in the sand. There was no overall agreement found between the results in this work and the numerical modeling by PLAXIS 2D regarding the uplift capacity and the embedment ratio. However, close agreements were found with the numerical modeling for particular embedment ratios and the experimental results.

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