Research Article

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Numerical and experimental comparison study of piled raft foundation

Abstract: The piled rafts are expressed as consisting of three geotechnical elements (piles, raft, and soil). As the load can be divided between the piles and the raft, the piles are highly effective in reducing settling and increasing the bearing capacity of the piled rafts, compared to shallow foundations. Civil engineering is witnessing a development in the field of geotechnical engineering, and because the experimental study takes a long time to verify, so the numerical study was conducted by the program MIDAS GTS NX 2020 (v1.1) for comparison with the experimental study. Small-scale models were tested in a sandbox placed in an iron structure containing a hydraulic jack with a capacity of 50 tons, and then, a vertical load was placed in the center of the raft; the bearing capacity was recorded by the load cell, the settlement was recorded by the dial gauge digital and the LVDT, in this study, the number of piles (9) was taken hollow aluminium, the diameter of piles (25) mm, and length of pile (500) mm. They were distributed under the raft by (3 × 3). The distance between the piles was taken by three-dimensional (3D) of the pile, and the dimensions of the raft were 250 mm × 250 mm, with a thickness of 20 mm. Numerical modelling was also used in the MIDAS GTS NX 2020(v1.1) program to solve the problem of the piled raft system for modelling and analysis. 3D models were analyzed using a sandy soil model with a raft of iron 250 mm × 250 mm and a thickness of 20 mm using piles of hollow aluminium with a length of 500 mm and a diameter of 25 mm and the number 3 × 3. As well as taking the criteria (Cullum-Mohr) and (von Mises). It was shown that the numerical study could be relied upon in the field of geotechnical engineering, where the percentages of convergence between the two studies were up to 91% in the piled raft test and 89% in the raft test only.

Keywords: NAE of piled raft, into sand, Thi-Qar

1 Introduction

Piled raft is often utilized for supporting tall structures in foundation design. Analytical approaches and model laboratory studies have been used in several investigations to predict the behaviour of piled raft foundations. Burland et al. [1] initially advocated placing a pile beneath each structure's column to prevent raft settlement. Maharaj and Gandhi [2] used soil as an elastic half-space to examine piled raft foundations numerically. They recommended that piles more giant than the raft might decrease settlement [3]. Furthermore, in traditional piled foundations, lengthy piles have been created that stretch up to the deep strata since the contribution of the raft is overlooked. However, suppose the raft alone is responsible for bearing the weight of the superstructure. In that case, it must be constructed exceptionally thickly. Using tiny models, Bajad and Sahu [4] studied piled raft settlement reduction on soft clay. Test findings showed considerable interaction effects [5]. To distribute the weight of the superstructure, piled raft foundations use a novel method in which the raft makes partial contact with the soil, and the piles make partial contact with the ground via skin friction. Elwakil and Azzam [6] conducted another experimental and computational investigation of piled raft systems using piles as settlement reducers for raft foundations on sand. According to research, pile length, number, and layout affect raft load-bearing ability and settling. Ahmed et al. [7] studied parametric investigation of the effect of the geometry of a piled raft foundation and the stiffness ratio between the pile material and clay on the performance of the foundation system in soft soil. The study indicates the piles' spacing significantly affects the piled raft foundations on soft soils. As the ratio S/D increases, the ultimate carrying capacity of a piled raft foundation decreases. When this ratio exceeds 10 (S/D > 10), piles have little or no effect on the ultimate carrying capacity of this foundation system.
Small experimental tests may provide essential data on the bearing behaviour of the piled raft foundation and reduce settlement by using piles. Lint material is one of the methods used to improve the piled raft behaviour. In this work, piles of aluminium were used in the form of a hollow tube with a diameter of 25 mm and a thickness of 1.3 mm.

2 Methodology

A poorly graded sandy soil was used. Then, model piles were made using steel as a raft and aluminium as a pile. The laboratory work was analyzed using the MIDAS GTS NX finite element software.

2.1 Case study

One of the most successful technologies for engineering analysis is computer-guided finite element numerical modelling of structural response. However, validation must be performed before any experimental study. Thus, two validation examples are chosen between the results of the GTS NX and those of the experimental effort, lending credence to the computer program results.

2.1.1 Experimental study

In small-scale laboratory testing with the raft size of 250 mm × 250 mm × 20 mm, the pile dimensions are embedding length, $L = 500$ mm, and pedestal diameter, $D_p = 25$ mm, with the ratio, $L/D_p = 20$.

2.1.2 Numerical study

The numerical model study was performed on GTS NX software. The raft size is 250 mm × 250 mm × 20 mm, and the pile dimensions are embedding length, $L = 500$ mm, and pile diameter, $D_p = 25$ mm.

Figure 1: Setup of the laboratory model.
3 Test setup

A test model was prepared in the laboratory to simulate reality, as shown in Figure 1, which consists of a soil tank with the dimensions of $1,000 \text{ mm} \times 1,000 \text{ mm} \times 800 \text{ mm}$. This tank was placed in an iron structure to resist the applied forces. This structure contains a hydraulic jack with a capacity of 50 tons installed at the end of a load cell with a capacity of 10 tons. The cell was connected to a load indicator to measure the load on the raft. Accurate stress gauges with dimensions $7.4 \text{ mm} \times 4.1 \text{ mm}$ were also used, and they were attached to the piles and connected to a stress indicator to measure the strains in the piles. Use (LVDT) 50 mm, and connect it to the settlement indicator to measure the settlement at the centerline of the raft model. A digital indicator, $0.01 \text{ mm}/0.0005"$ ($0-25.4 \text{ mm}/1"$), was used to enhance the accuracy. Figure 2 shows the devices used in the study.

4 Material model (soil, raft, and pile)

Various materials were used to construct the test model: sandy soil, a steel raft, and an aluminium pile. The soil sample was obtained from Thi-Qar Governorate, southern Iraq. Several laboratory tests were carried out on it, as shown in Table 1. The steel raft model and the aluminium pipe of piles model were used. The properties of the two materials are shown in the same Table 2.

5 Piled raft models

Models for the piles in this study were created using smooth aluminium hollow sections with $1.30 \text{ mm}$ thicknesses and a diameter circular 25 mm. When $L$ is the length of the pile, and $D$ is the outside width of the pile, the
embedment ($L/D = 20$). All testing maintains the distance between piles at three-dimensional (3D) ($S = 75$ mm, where $S$ is the distance between piles). Steel with a flat surface and a 20 mm thickness was also used to model the raft used in the test, as shown in Figure 3, representing the models used in this study. The size of the raft $250 \times 250 \times 20$ mm and the pile number is $3 \times 3$.

### 6 Density-proofing methods

After conducting many experiments to find the ideal method for fixing the density and reaching the relative density of 70%, the ideal way to determine the required density was to use an electric vibrator for 60 s with a wooden plate to prevent the sand particles from breaking [8]. as shown in Figure 4 employed a similar technique.

### 7 GTS NX computer program

The Midas GTS NX software is a finite element analysis program used to conduct sophisticated geotechnical rock deformation and stability analyses. In addition, it is used to examine groundwater flow, dynamic vibrations, and the two-dimensional and 3D investigation of soil–structure interaction. Geotechnical, mining, and civil engineers are

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**Table 1:** The physical properties of the tested sand

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain size analysis</td>
<td></td>
</tr>
<tr>
<td>Classification (USCS)*</td>
<td>SP</td>
</tr>
<tr>
<td>Effective size, $D_{10}$</td>
<td>0.215 mm</td>
</tr>
<tr>
<td>Coefficient of curvature, $C_c$</td>
<td>1.01</td>
</tr>
<tr>
<td>Coefficient of uniformity, $C_u$</td>
<td>3.19</td>
</tr>
<tr>
<td>Specific gravity, $G_s$</td>
<td>2.564</td>
</tr>
<tr>
<td>Dry unit weights</td>
<td></td>
</tr>
<tr>
<td>Maximum dry unit weight, $y_d$ (max)</td>
<td>18.96 kN/m$^3$</td>
</tr>
<tr>
<td>Minimum dry unit weight, $y_d$ (min)</td>
<td>15.41 kN/m$^3$</td>
</tr>
<tr>
<td>Test dry unit weight, $y_d$ (test)</td>
<td>17.76 kN/m$^3$</td>
</tr>
<tr>
<td>Relative density, $D_r$</td>
<td>70.73%</td>
</tr>
<tr>
<td>Void ratio</td>
<td></td>
</tr>
<tr>
<td>Maximum void ratio, $e_{max}$</td>
<td>0.664</td>
</tr>
<tr>
<td>Minimum void ratio, $e_{min}$</td>
<td>0.352</td>
</tr>
<tr>
<td>Test void ratio, $e_{test}$</td>
<td>0.444</td>
</tr>
<tr>
<td>The angle of internal friction, $\phi$</td>
<td>$39^\circ$</td>
</tr>
</tbody>
</table>

*USCS refers to Unified Soil Classification System.

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**Table 2:** Material properties for numerical and experimental modelling

<table>
<thead>
<tr>
<th>Material</th>
<th>Type of material behaviour</th>
<th>Size (mm)</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile (aluminium)</td>
<td>Elastic model</td>
<td>$L = 500$, $D = 25$</td>
<td>Density (kN/m$^3$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>26.5</td>
</tr>
<tr>
<td>Raft (steel)</td>
<td>von Mises model</td>
<td>$250 \times 250 \times 20$</td>
<td>78</td>
</tr>
</tbody>
</table>

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**Figure 3:** Piled raft models.

**Figure 4:** A machine that proves density with vibration technology.
the primary users of GTS NX. Its primary functions include analysis, testing, and design. The application has various sophisticated modelling capabilities, enabling users to model challenging and intricate issues with unprecedented simplicity and accuracy [9].

The analysis guide manuals in the GTS NX documentation set describe specific procedures for performing analyses for different engineering disciplines. A typical GTS NX analysis has three distinct steps:
1. Build the model,
2. Apply loads and obtain the solution, and
3. Review the results.

7.1 Mesh generation

Both the ground and the raft are modelled using a 3D hybrid mesh. Pile parameters, including the pile-to-soil contact and the pile tip, are determined, creating a one-dimensional fine mesh. The GTS NX hybrid meshes allow users to create meshes using a mix of hexahedral and tetrahedral pieces. While tetrahedral elements are advantageous for modelling complicated geometry with sharper curves and corners, hexahedral elements have the advantage of providing stress estimates that are more precise than those obtained using tetrahedra. Without sacrificing speed in modelling or analysis, GTS NX uses a hybrid Mesher that combines tetrahedral and hexahedral components.

7.1.1 Meshing

Mesh creation, or Meshing, is constructing continuous geometric forms (such as 3D models) by combining shapes in one, two, and three dimensions (mesh faces). The more detailed the mesh, the more precise the 3D model will be, as shown in Figure 5.

7.2 Boundary conditions

According to the boundary conditions, all degrees of freedom towards x, y, and z are fixed at the bottom sides, while at the other four sides, the degrees of freedom are fixed towards the normal axis for all the models, as shown in Figure 6. The pressure is uniformly distributed on the top surface of the raft adjacent to the piston at an area equal to the cross-sectional area of the piston.

7.3 Load carrying capacity of piled raft

When applying a load of 60 kN on the piled raft of the dimensions 250 mm × 250 mm × 20 mm and the piles of dimensions 500 mm length and 25 mm diameter in the Midas GTS NX programmer. The settlement in the z direction was 33.31 mm, as shown in Figure 7.

7.4 Load carrying capacity of raft

Applying a load of 30 kN on the raft of the dimensions 250 mm × 250 mm × 20 mm dimensions in the Midas GTS NX programmer. The settlement in the z-direction was 26.16 mm as shown in Figure 8.
8 Application of vertical load

A vertical load was applied using a mechanical jack. The test was continued recording a continuous settlement of the piled raft under variable load incremental at 10 kN/min. The value of the applied load was read using a load cell, while the central settlement of the raft was measured using LVDT of LI: ±0.01% resolution. The above steps were repeated for each test. Figure 9 shows the piled raft model ready to be tested.

9 Results and discussion

After examining the model of the piled raft, the raft, in the experimental study, was recorded, load and settlement. The data were entered into the Excel program, and a curve drawing was obtained, as shown in Figure 10, and represented the results of the experimental study. In the numerical study, a model was prepared in the GTS NX program. This model is similar to experimental modelling regarding material induction and dimensions. The results were also obtained, as shown in Figure 11, representing the results of

![Figure 8: Settlement of the raft in the z-direction under a load of 30 kN.](image)

![Figure 7: Settlement of the piled raft in z-direction under a load of 60 kN.](image)

![Figure 9: Piled raft model ready to be tested.](image)

![Figure 10: Load–settlement curve for 3 × 3 piled raft 250 mm × 250 mm × 20 mm, the experimental study.](image)
the numerical study. The results of the two studies were compared in Figure 12.

The experimental and numerical study results were obtained as shown in Figures 10 and 11. To accurately present the results, Figure 12 was drawn, and after using the tangent method, the loading capacity of the piled raft is 49 kN, corresponding to a settlement of 5 mm in the experimental study, and 45 kN, corresponding to a settlement of 10 mm in the numerical study. The raft carrying capacity of 26 kN corresponds to a settlement of 10 mm in the experimental study and that of 23 kN corresponds to a settlement of 13 mm in the numerical study.

10 Conclusions

After conducting experimental studies in the laboratory and numerical studies by the program MIDAS GTS NX 2020 (v1.1), the following conclusions can be noted:

1. The addition of piles to the raft improved its bearing capacity by 89% in the experimental study and 95% in the numerical study and decreased settlement by 50–23%, respectively.

2. The bearing capacity of the piled raft depends on the length of the piles, as the settlement decreases and the bearing capacity increases with the increase in the length of the pile. The reason is due to the increase in skin friction along the length of the pile and the soil hardness at the depths.

3. The GTS NX program can be adopted in the numerical study of geotechnical engineering case studies due to the convergence of results between numerical and experimental studies.

4. The accuracy of the results in the numerical study depends on the accuracy of the information entered into the computer program.

11 Recommendations for future studies

1. Study the effect of the diameter of the piles and the distance between them.

3. Conducting a numerical study of the effect of groundwater on pile performance.

Conflict of interest: Authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

References


