International Journal of Structural Analysis & Design – IJSAD
Volume 1 : Issue 3 [ISSN : 2372-4102]
Publication Date : 30 September,2014

Effect of Multi-Storey Building Structure Sequential Loading on Soil-Foundation Interactions

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***Abstract*—The analysis of multi-storey building structure founded on the soils involves an interactive process starting with the construction stage and ending with a state of balance between stresses and strains developed within the soil field as well as within the structure. The interaction effect becomes more complex when the structure analysis considers the construction phasing of multistory building on composite foundation system. The study considers the complete interaction between the foundation structure and soil, and between the foundation-soil and the super-structure. The soil-structure interaction of combined Piled-Raft Foundation with the foundation soil and superstructure of the building is evaluated through nonlinear 3D-Finite Element Analyses using PLAXIS3D FOUNDATION code. The multi-storey building with construction stages and Hardening Soil for non-cohesive soil is taken in the analysis. The effect of the soil-foundation-structure response with construction phasing and different floors loading is investigated and discussed.**

Keywords—Piled-raft foundation, Sequential loading, construction stages, Finite Element Method, Soil Settlement

I. Introduction

The analysis of multi-storey buildings having composite pile-raft foundation system is challenging because it involves interactive process starting with the construction phase and ending with a state of balance between stresses and strains developed within the soil field as well as within the structure. There are important interactions between the pile, the raft and the soil to support the forces from the upper structure. The interaction characteristics of structural system and foundation system are further enhanced by the tallness of the building. In this interaction, deformations in the soils are the key factor which will affect forces and deformation in foundation and superstructure. Considerable attention has been paid to analyze, design and construction of combined piled-raft foundation (CPRF) system. Arslan (2007) has discussed geo-technical aspects of the planning and construction of high-rise buildings, and use of innovative CPRF system for high-rise buildings. Ahmed et al (2013) has pointed out the recent advances in the piled-raft foundation system. Lin and Feng (2006) have presented piled-raft analysis output for settlement, bending moment both in pile and raft, and effects of raft flexibility for vertical uniform loading in the subsoil. For the case of piled raft placed over soft clay layer, the contact pressure is merely 4-6%, whereas it is 15-25% if the piled raft resting on sand layer at ground surface. Rabiei (2009) have carried out the parametric study of piled-raft foundation. The parameter studied were pile length and spacing, number of piles, raft thickness, pile-soil and raft-soil stiffness ratio and pile-raft interaction. They concluded that by ignoring the interactions involved in the piled raft system, may lead to serious underestimates of settlement and may also lead to inaccurate estimates of raft bending moments and pile loads. Singh and Singh (2008) demonstrated that ignoring the interactions between the piled raft foundations elements will lead to a very serious over-estimate of the stiffness of the foundation. The case studies on optimized piled-raft foundation performance with connected and non-connected piles are presented by Eslami et al. (2012).

From the literature survey it is clear that the interaction of the superstructure and its construction stages in the analysis of soil-foundation has been ignored in most of the previous research work and load from the super structure in considered acting directly on the raft as a uniform or concentrated load. Present study considers the complete interaction between the foundation structure and soil, and between the foundation-soil and the super-structure. The soil-structure interaction of composite Piled-Raft Foundation with the soil and superstructure of the building is evaluated through nonlinear 3D-Finite Element Analyses using PLAXIS3D FOUNDATION code. The multi-storey building with construction stages and Hardening Soil for non-cohesive soil is taken in the analysis. The effect of the soil-foundation-structure response with different floors loading and multi-layers soil stratum is investigated.

II. Statement of The Problem

In this study, a 15 storey square building with 4 bays of 5m in X- and Y- direction and having piled raft foundation in the two layered soil system is selected as shown in Fig. 1. The ground and typical floors are 6.0 m and 3.0 m high respectively. The structural system of all floors is a flat concrete slab type of 200mm thickness subjected to a total uniform load of 10, 15 and 20 kN/m2. The three columns sizes i.e. 65, 75, 90cm has been provided in the building. The concrete raft is assumed to be at a depth 2.0 (m) beneath the ground surface and has 1.0 m thicknesses. The plan dimension of raft is 25m x 25m with overhang of 2.5m. The estimated total vertical load on rafts is 138.810 MN. A total of 25 circular concrete piles of 1.5 m diameter are located under the raft as shown in Fig. 1. The piles slenderness ratio (L/D) is taken as 36.0. Modulus of elasticity of pile material is taken as 2.35×10^7kN/m2 while its density is considered as 25kN/m3. The soil profile is of two layer systems with upper layer of loose sand and lower layer of dense sand. The assigned soil parameters for the two layers are given in Table 1.2. The water level is assumed at the ground surface. Modulus of elasticity of concrete is assumed as 3.4×10^7kN/m2 while concrete Poisson's ratio and density is considered in structural models as 0.2 and 25kN/m3 respectively.

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III. Finite Element Modelling Methodology

The finite element method based software PLAXIS 3D is used for 3D- modelling of 15-storey building structure having piled-raft foundation in layered soil field. The columns and piles are modelled as frame elements with linear elastic properties. The floor slab and raft is discretized using 6-node triangular plate elements with linear elastic properties. The soil field with two layers of non-cohesive soils namely loose and dense sand is modelled as 15-node wedge triangular continuum elements.

IV. Results and Discussion

Based on the methodology described in previous sections, 3D- finite element models of piled-raft foundations-soils using the PLAXIS 3D software considering hardening soil (HS) failure model along with super structure of building have been developed and analyzed for the complete structure-foundation-soil interactions study considering construction phase and floor loading. The analysis results of the models are presented at two levels, one at raft level and other at the pile end point level. The contours of soil settlements along vertical and horizontal cross-sections are also presented.

A. Interaction effect on Foundation system of the building

Table 2 shows the predicted soil settlements with the mode of super structure loading to the foundation soil. It is evident from the results that there is clear interaction of building structure with the foundation soil. The predicted maximum soil settlements vary with the mode of application of loading on the foundation soil. The analysis of piled-raft foundation along with phasing of loading will indicate soil to be flexible. The maximum soil settlements at all levels are increased when loading is applied through the sequential loading of the building structure. The maximum soil settlements are 26.16cm and 27.36cm respectively at loading applied in one phase and through sequential loading while on similar conditions of loading, the soil settlements at bottom pile end are 3.34cm, and 3.56cm. The contours of soil settlements along the vertical and horizontal cross-section of the soil field shown in Fig. 3 and 4 clearly depict that dissipation of loading in the soil field vary with the mode of super structure loading on the foundation.

The predicted soil settlements with the different floor loading are given in Table 3. The results show that the soil settlements have not been increased is same ratio similar to increase in the floor loading ratio. The percentage increase in the soil settlements decreases with the increase of building floor loading. The maximum soil settlements are 22.2cm, 27.36cm and 29.11 respectively at 10, 15 and 20 kN/m2 floor loading while on similar floor loading, the soil settlements at bottom pile end are 2.6cm, 3.56cm and 3.91.

B. Foundation-Structure Interaction Effect on Piled-Raft Footing

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include ACKNOWLEDGMENTS and REFERENCES and, for these, the correct style to use is “Heading 5”. Use “figure caption” for your Figure captions, and “table head” for your table title. Run-in heads, such as “Abstract”, will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced. Styles named “Heading 1”, “Heading 2”, “Heading 3”, and “Heading 4” are prescribed.

C. Figures and Tables

1) **Positioning Figures and Tables:** ***Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation “Fig. 1”, even at the beginning of a sentence.***

TABLE I. TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
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a. Sample of a Table footnote. *(Table footnote)*

We suggest that you use a text box to insert a graphic (which is ideally a 300 dpi TIFF or EPS file, with all fonts embedded) because, in an MSW document, this method is somewhat more stable than directly inserting a picture.

To have non-visible rules on your frame, use the MSWord "Format" pull-down menu, select Text Box > Colors and Lines to choose No Fill and No Line.

Figure 1. Example of a figure caption. *(figure caption)*

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

Acknowledgment (Heading 5)

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression, "One of us (R. B. G.) thanks . . ." Instead, try "R. B. G. thanks". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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