Piles and piled raft foundations analyses for Surface Paradise, Gold Coast sub-soil conditions

Piles et radiers empilés analyse pour le Paradis de la surface, Gold Coast conditions du sous-sol

V. Balakumar
Simplex Infrastructures Limited, Chennai, Tamil Nadu, India. vb_kumar2002@yahoo.com
Min Huang
Arup Geotechnics, Australia. m.huang@outlook.com
Der-Wen Chang
Department of Civil Engineering, Tamkang University, Taiwan. dwchang@mail.tku.edu.tw
Erwin Oh
Griffith School of Engineering, Griffith University, Australia. y.oh@griffith.edu.au
San-Shyan Lin
Department of Harbor & River Eng., National Taiwan Ocean University, Taiwan. sslin46@gmail.com
A. S. Balasubramaniam
Griffith School of Engineering, Griffith University, Australia. a.bala@griffith.edu.au

ABSTRACT: Analysis on the behavior of piled raft foundation in the Gold Coast area is presented in this paper. The ground condition is considered as three layers with a very dense sand layer sandwiched between the top medium dense to dense sand layer and the bottom stiff clay layer. This soil profile is simplified from available boreholes of building projects in Surfers Paradise of Gold Coast. A peat layer at deeper depth is not considered in the soil profile used for piled raft analysis in this paper. Parametric studies on varying the thickness and size of the raft, the length and spacing of the piles and the vertical loading magnitudes are main concerns and are presented in detail in this paper.

RÉSUMÉ : Analyse PLAXIS sur le comportement de radier empilés dans la zone Gold Coast est présenté dans le présent document. L'état du sol est considéré comme trois couches avec une couche de sable très dense en sandwich entre la partie supérieure de densité moyenne à couche de sable dense et la couche d'argile raide en bas. Ce profil du sol est simplifiée à partir de forages disponibles des projets de construction à Surfers Paradise Gold Coast. Une couche de tourbe en profondeur plus profonde est pas considérée dans le profil du sol utilisé pour l'analyse de radeau empilés dans cet article. Des études paramétriques sur variation de l'épaisseur et la taille du radeau, la longueur et l'espacement des piles et les grandeurs de chargement verticales sont les principales préoccupations et sont présentés en détail dans le présent document.

KEYWORDS: piled raft foundation, numerical analysis, finite element modeling.

1 INTRODUCTION

The Piled raft foundation is an intelligent geotechnical concept developed for reducing the raft settlement with the introduction of pile elements in a strategic manner. Piled raft concept was developed when the designers recognized the fact that every structure has a permissible settlement depending upon its serviceability requirement and so there is no need to eliminate the settlement in total. Available documentary evidences (Katzenbach etal, 2000; Poulos 2008) have shown that, structures that are tall as well as super tall have been supported on piled raft all over the world. In addition, the effects of raft flexibility on bending moments and differential settlement of the raft as well as axial forces and bending moments of the piles have been emphasized by recent studies of Clancy and Randolph (1993), Poulos et al. (1997) and Ta and Small (1997) in clay soil. Horikoshi and Randolph (1998) have carried out numerous of parametric analysis on performance of piled raft in non-homogenous clay soil. Based on the above many such buildings at Surfers Paradise along the coastal strip of Gold Coast are founded on piled raft foundations. But it appears that no published data relating to their performance is available unlike the cases of structures in Frankfurt. Hence a detailed study is being carried out analytically on the performance of piled raft on the prevailing soil conditions in Gold Coast area by the first author and his team.

The performance of piled raft foundation depends upon the effective interaction among the constituent elements and hence the parameters associated with the raft, pile and the supporting soil play a very important role in the behaviour of piled raft. It is also to be noted that the economics of piled raft design depends upon the cost of piles provided; further the behavior of the pile group is influenced by the properties of the raft and the pile spacing. Keeping the above in mind the present paper has been prepared focusing the attention on the effect of two very important parameters namely raft thickness and pile spacing on the settlement reduction, axial force on the pile and the pile bending moment. The analyses done here although not related to any specific case for the reasons mentioned elsewhere in the paper, the work intends to understand the behavior of piled raft and establish that the behavior is no different from the other cases. In the forthcoming stage the presence of peat will be considered and then in the three dimensional analyses these additional features will be considered along with the validation of the present results.

The ground condition at the Surfer Paradise, Gold Coast generally consists of alluviums, followed by residual soils and underlying by bedrock. A generalized subsoil profile based on the geotechnical investigation data available from four projects site located at the central Surfer Paradise was studied. The geotechnical parameters were derived based on the in-situ test data.

2 SUBSOIL CONDITIO

The subsoil conditions at Surfers Paradise consist of alluvium materials underlying residual soil and overlying bedrock. Some 25 or more borehole data at four project sites extended to 50m below the ground surface have been collected to study the general subsoil condition at Surface Paradise, Gold Coast.

A layer of dense to very dense alluvial sand continued till a compressible peat was encountered. The peat layer was embedded within the alluvial dense sand and was not met with on every project site. The properties of this peat layer also appeared to vary on different project locations. Hence in the present analyses the peat layer has been omitted. Moreover, obtaining realistic parameters for such layers is very difficult with the conventional methods of soil investigation. Many times this peat layer exhibits brittle nature and so in this first part of our extensive programme this layer has not been considered in our analyses.

The soil profile generally returned to dense to very dense alluvial sand extended to approximate 25m below the ground surface. Beneath the alluvial dense sand layer, residual soils consist of stiff to very stiff clay and dense to very dense gravelly sand was encountered overly bedrock. The sedimentary type bedrock and was encountered at depth range from 32m to 40m below the ground surface. A typical profile is presented in Figure 1.

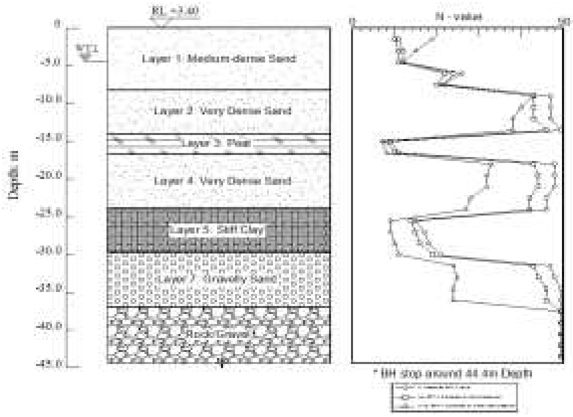

Figure 1. SPT N vs. Depth for Project site 3

3 GEOTECHNICAL PARAMETERS

The complex interaction between raft, pile and ground in the piled raft system could be investigated using the numerical modelling tool. Considering the difficulties involved in obtaining realistic parameter from the conventional soil investigation process an easier approach has been used with simple parameters which most of the geotechnical engineers can understand and recognize in a successful manner which has produced results of acceptable standards.

SPT test results are useful for processing of geotechnical profile, soil classification and deriving the geotechnical strength and stiffness parameters. Well established correlations of SPT with the engineering properties of soils are now available as shown by Schmertmann (1975), Poulos and Davis (1980). Numbers of Standard Penetration Test (SPT) test have been carried out for design of pile raft foundation. The geotechnical parameters adopted for the analysis is summarized in Table 1 and 1a.

4. PILED RAFT FOUNDATIONS ANALYSES

There are number of analytical methods to study the performance of piled raft, but considering the difficulties involved in obtaining such realistic parameter from the conventional soil investigation process, a simpler approach has been used with simple parameters which most of the geotechnical engineers can understand and recognize in a successful manner which has produced results of acceptable standards. For the purpose of simplicity in the analysis, a generalized three-layer subsoil profile for Surfers Paradise area consisting of medium dense sand, very dense sand and stiff clay have been adopted for the FEM analysis and the model is presented in Figure 2.

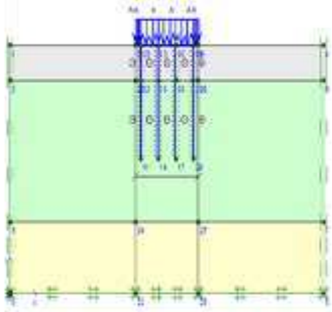

Figure 2 Diagrammatic view of boundary condition using for modeling

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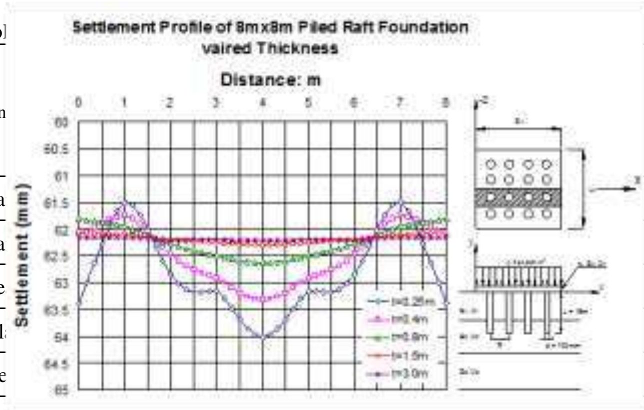

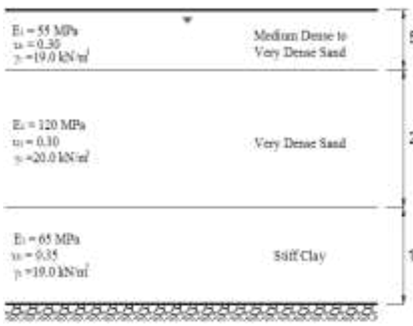

Table 1a. Generalized Soil Profile Adopted for Analysis

5 EFFECT OF RAFT THICKNESS

The effect of raft thickness was studied by varying the thickness of the raft from 0.25m to 3m. For the present the results of 8mx8m raft has been presented.

5.1 *Effect on the settlement*

Figure 3 presents the settlement profile of unpiled raft for a loading of 215kN/m^2. In studying the settlement profile rafts of thickness upto 0,8m is treated is treated as flexible raft and thickness larger than 0.8m is treated as rigid raft.

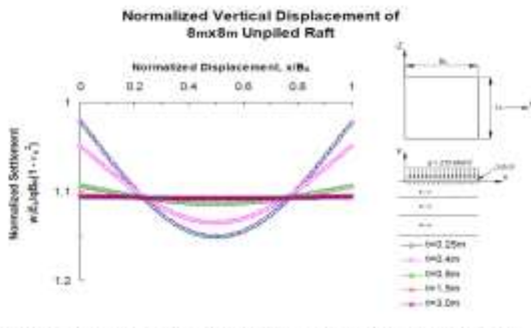

Figure 3 Vertical Displacement of a Raft w/o Pile

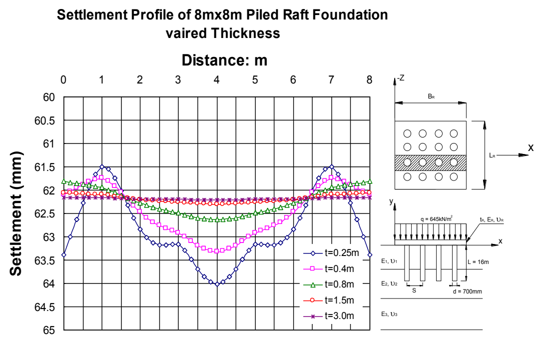

Figure 4 Effect of raft thickness on Computed Settlement of piled raft

Figure 4 presents the settlement profile of the piled raft. Comparing both the figures it is clearly seen that the addition of piles has not only reduced the settlement but in the case of flexible raft, it has altered the settlement profile also similar to that of rigid raft. The settlement reduction achieved is of the order of 43% and in addition the pile group adds rigidity to the flexible raft.

5.2 *Effect on the pile axial force distribution*

Figure 5 presents the effect of raft thickness on the axial force distribution on the pile. It is seen that the variation in the axial force is more pronounced in the case of outer pile than in the case of inner pile. In the case of outer pile in addition to the enhanced confining pressure with depth the loading from the overhang also gets added up. At the same time, due to the reduction in the enhanced confining pressure the reduction in the axial force is more rapid with depth. In the case of inner piles, the effect of increased confining stress is around the pile and so the variation in the axial force is small.

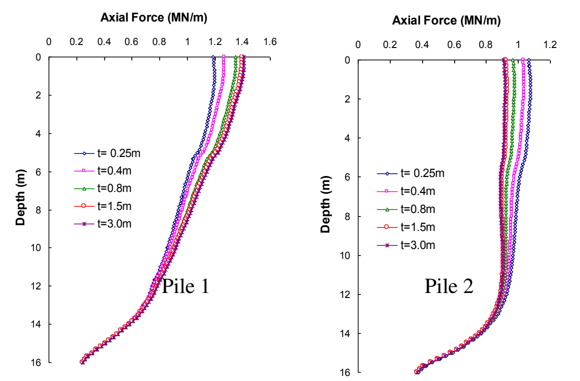

Figure 5 Effect of Raft Thickness on Pile Axial Force

But it is seen that beyond 10m level the reduction is more rapid and the magnitude of the axial force remains the same irrespective of the raft thickness. This feature indicates that the effective length of the pile remains as 0.8L. One very interesting feature exhibited by this study is that The effect of enhanced confining pressure is only upto a level 5m to 6mfrom the top.

5.3 *Effect on pile bending moment*

Figure 6 present the variation of pile bending moment. The figures indicate that the bending moment transferred on the outer pile is more than the inner pile. This may be due to the frame action and also due to the overhang. But the raft thickness appears to have no significant effect on the moment value on the outer pile and the inner pile.

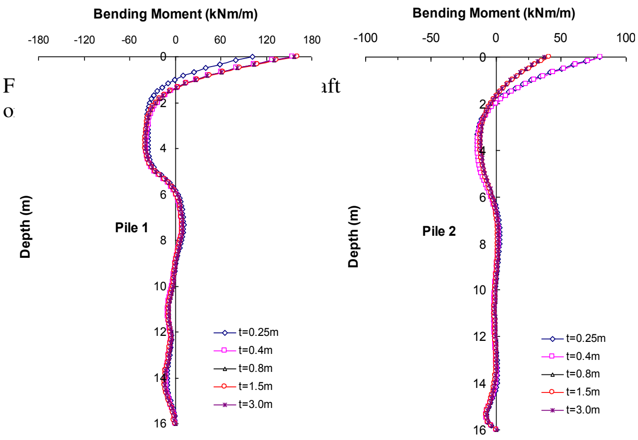

Figure 6 Effect of raft Thickness on Pile Bending Moment

The above study is significant for two reasons. The outer piles must have higher moment resistant capacity particularly when flexible raft is used. Also, the locations has some significance in the sense that the piles have to be more strategically placed keeping the settlement profile and bending moment variation of the unpiled raft depending upon whether the raft is rigid or flexible.

6 EFFECT OF PILE SPACING

6.1 *Effect on raft settlement*

The pile spacing becomes an important aspect mainly because it influences the raft bending moment. The study was done on a 0,8m thick raft adopting 0.7m dia piles. The lengths of the piles have been kept as 16m.The spacing of piles were varied from 3d to 7d where d is the diameter of the pile.

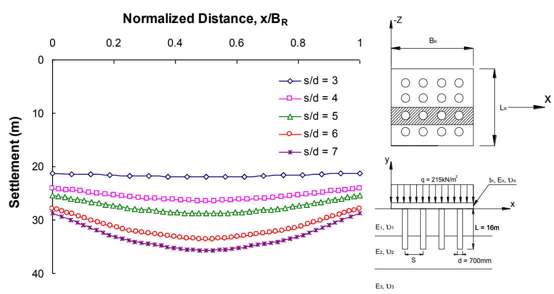

Figure 7 Comparison of Settlement Response for Different Spacing of Piles. Q = 215 kN/m^2

The Figure 7 presents the variation of pile spacing on raft settlement. When the spacing is 3d there is hardly any variation in the settlement profile. The settlement pattern is almost a straight line indicating the system behaves as a fully piled foundation. When the spacing is increased to 4d and 5d small differential settlement was observed but the difference between the edge and the center is negligible. But when the spacing gets more than 5d then the differential settlement becomes appreciable, indicating that 4d to 6d is an ideal spacing for the raft design to be economical.

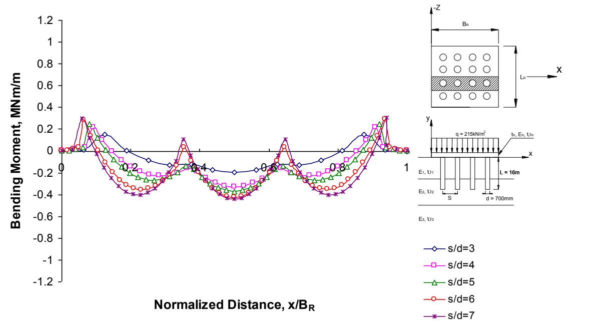

Figure 8 Comparison of Piled Raft Bending Moment Response - Variation of pile spacing

Refer to Figure 8. The variation of raft bending moment is more pronounced when the spacing becomes more than 5d. It was observed that the difference in the raft bending moment between the case of 4d spacing and 5d spacing is less than 5d to 6d and 6d to 7d. At higher pile spacing the raft has a tendency to behave as continuous beam.

6.2 Effect *on axial force and bending moment on the piles*

Refer to Figure 9, it is seen that the axial force variation is more pronounce in the case of outer pile than in the case of inner pile. Beyond 5d spacing the fall in the axial force is more rapid compared to the smaller spacing. It was also observed that the axial force at the pile head is more in the case of outer pile than in the case of inner pile. The variation between the outer pile and inner pile is more when the spacing is more than 5d indicating that when the spacing is larger the outer pile must have a higher capacity than the inner pile. But it is seen that beyond 0.8L irrespective of the spacing the axial load variation is negligible and the rate of fall of axial load is more rapid beyond 10 m or say 0.6L.

The trend of the variation in the bending moment is same as in the previous cases (Refer Figure 10). The outer pile is subjected to a higher bending moment than the inner pile. Beyond 6m level the bending moment was becoming nil as in all the earlier cases.

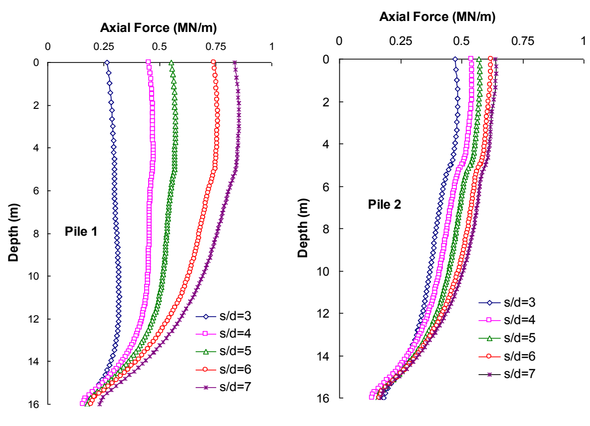

Figure 9 Effect of Pile Spacing on Pile Axial Load. q = 215kN/m^2

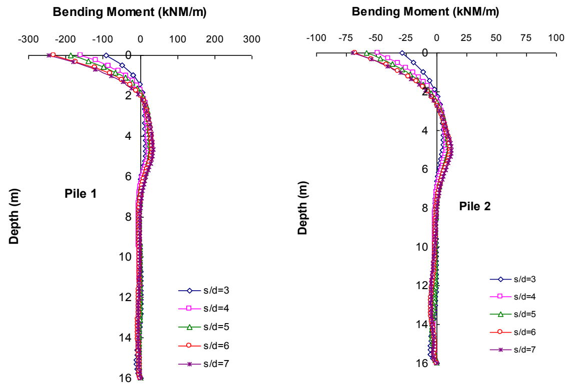

Figure 10 Effect of Pile Spacing on Pile Bending Moment.q = 215kN/m^2

7 SUMMARY AND CONCLUSIONS

The present study has established that simpler approach with simple parameters which most of the geotechnical engineers can understand and recognize can be used in a successful manner to get results of acceptable standards. An overall study of the axial stress and bending moment distribution indicates that the effect of increase in the confining stress is not felt beyond the pile length of 0.6L, when the raft width is less than the pile length.

The importance of locating the piles in a strategic manner is established by the change in the raft bending moment, settlement value and the profile compared to the plain raft behaviour. The variation in pile length and diameter can also be attempted. The study has shown that the unpiled raft design plays a very important role in designing the piled raft in an effective manner.

8 ACKNOWLEDGEMENT

Constructive and most valued critical comments were kindly provided by Prof. Harry G Poulos and many practicing engineers. The authors have tried to accommodate refinements and in particular 3 D analyses are now being performed in this continuous research at Griffith University under Dr. Erwin Oh's, leadership with additional parameters collected.

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