

Parametric Study for Piled Raft Foundations

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ABSTRACT

The piled raft is a geotechnical composite construction consisting of the three elements piles, raft and soil which is applied for the foundation of tall buildings in an increasing number. In this paper a parametric study on pile configuration, pile number, pile length and raft thickness on piled raft foundation behaviour are considered.

It has been found that the maximum bending moment in raft increases with increase raft thickness, decrease pile number and decrease in pile length. Central and differential settlement decreases with increase raft thickness and uniform increase in pile length. It has also been found that pile configuration is very important in pile raft design.

In the scope of this paper, the results of the parametric study are presented and design strategies for piled rafts are discussed.

KEYWORDS: Piled raft; foundation design, numerical analysis, parametric study.

INTRODUCTION

The foundation concept of piled rafts differs from traditional foundation design, where the loads are assumed to be carried either by the raft or by the piles, considering the safety factors in each case. Several methods of analyzing piled rafts have been developed. Three broad classes of analysis method have been identified:

1. Simplified calculation methods
2. Approximate computer-based methods
3. More rigorous computer-based methods.

Simplified methods include those of Poulos and Davis (1980), Randolph (1983,1994) (PDR method), van Impe and Clerq (1995), and Burland (1995). All involve a number of

simplifications in relation to the modelling of the soil profile and the loading conditions on the raft.

The approximate computer-based methods include the following broad approaches:

4. Methods employing a “strip on springs” approach, in which the raft is represented by a series of strip footings, and the piles are represented by springs of appropriate stiffness (e.g. Poulos, 1991)
5. Methods employing a “plate on springs” approach, in which the raft is represented by a plate and the piles as springs (e.g. Clancy and Randolph, 1993; Poulos, 1994; Viggiani, 1998; Anagnostopoulos and Georgiadis, 1998).

The more rigorous methods include:

6. Boundary element methods, in which both the raft and the piles within the system are discretized, and use is made of elastic theory (e.g. Butterfield and Banerjee, 1971; Brown and Wiesner, 1975; Kuwabara, 1989; Sinha, 1997)
7. Methods combining boundary element for the piles and finite element analysis for the raft (e.g. Hain and Lee, 1978; Ta and Small, 1996; Franke et al, 1994; Russo and Viggiani, 1998)
8. Simplified finite element analyses, usually involving the representation of the foundation system as a plane strain problem (Desai, 1974) or an axi-symmetric problem (Hooper, 1974), and corresponding finite difference analyses via the commercial program FLAC (e.g. Hewitt and Gue, 1994)
9. Three-dimensional finite element analyses (e.g. Zhuang et al, 1991; Lee, 1993; Wang, 1995; Katzenbach et al, 1998) and finite difference analyses via the commercial program FLAC 3D.

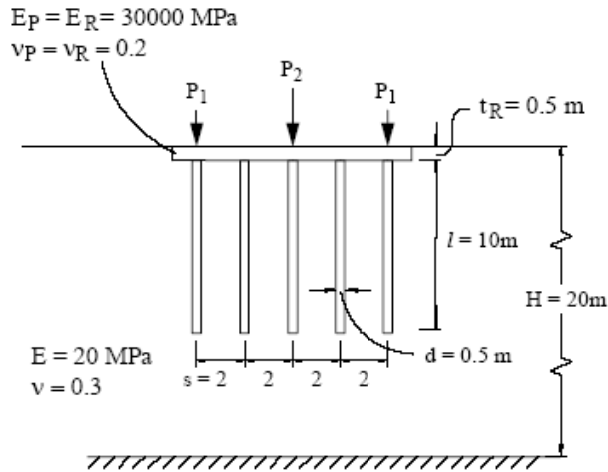
MODELLING AND MODEL VERIFICATION

The parametric study presented in this research work was carried out with a computer program ELPLA. ELPLA is a program for analyzing raft foundations of arbitrary shape with the real subsoil model. The mathematical solution of the raft is based on the finite element method. This program can analyze different types of subsoil models, especially the three-dimensional Continuum model that considers any number of irregular layers. A good advantage of this program is the capability to handle the three analyses of flexible, elastic and rigid foundations. In addition, the mesh of the rigid and flexible foundations can be constructed to be analogous to the finite elements mesh of the elastic foundation.

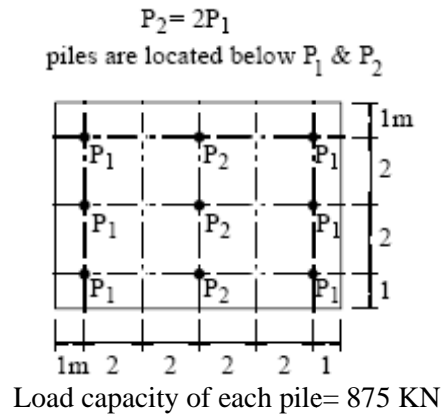
Model verification was carried out for example represented in Figure 1. Figure 2 compares the computed load-settlement relationships (up to a total load of 18 MN) computed from ELPLA with various methods for the centre of the raft with 9 identical piles (Figure 1-b), one under each column.

Variation of maximum positive bending moments, maximum settlement and differential settlement with raft thickness are respectively illustrated on Figure 2-b, Figure 2-c and Figure 2-d.

There is reasonably good agreement between the computed results in this research with results obtained from other researchers.

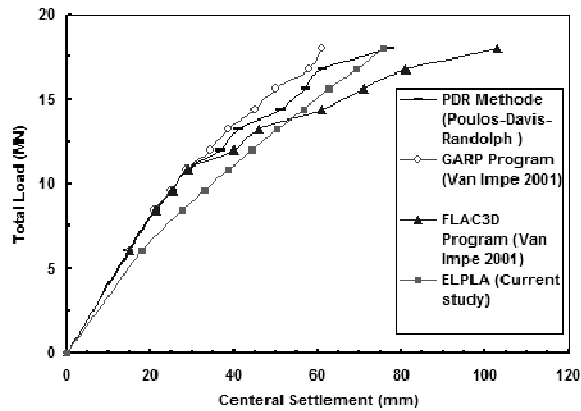


a: Model condition and material properties

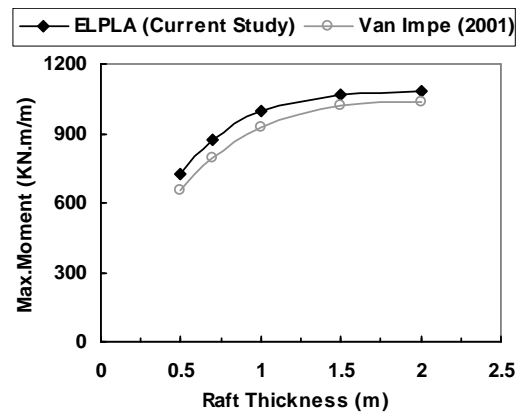


b: Pile and load configuration

Figure 1: Model configuration and properties for results verification



a: Comparison of various methods for load-settlement analysis



b: Effect of raft thickness on maximum bending moment

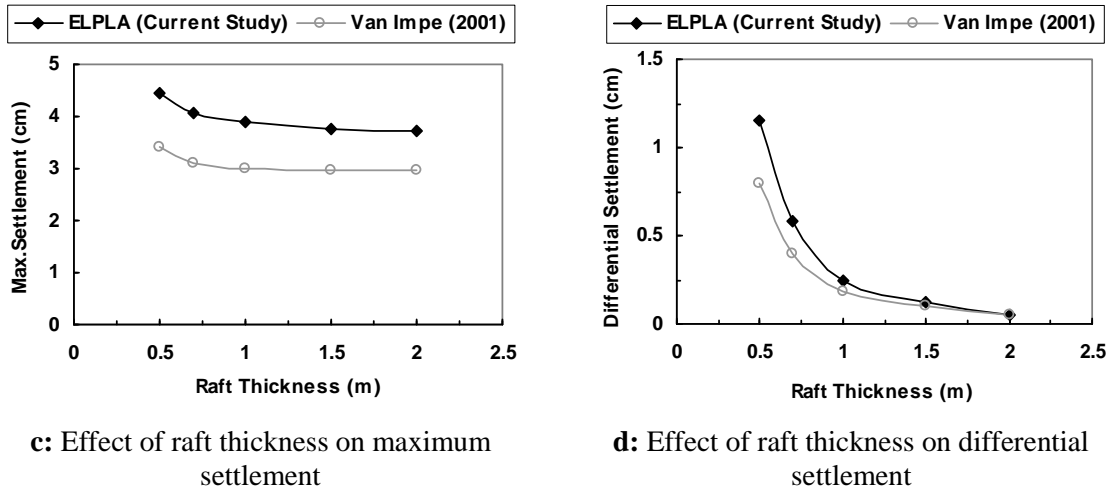


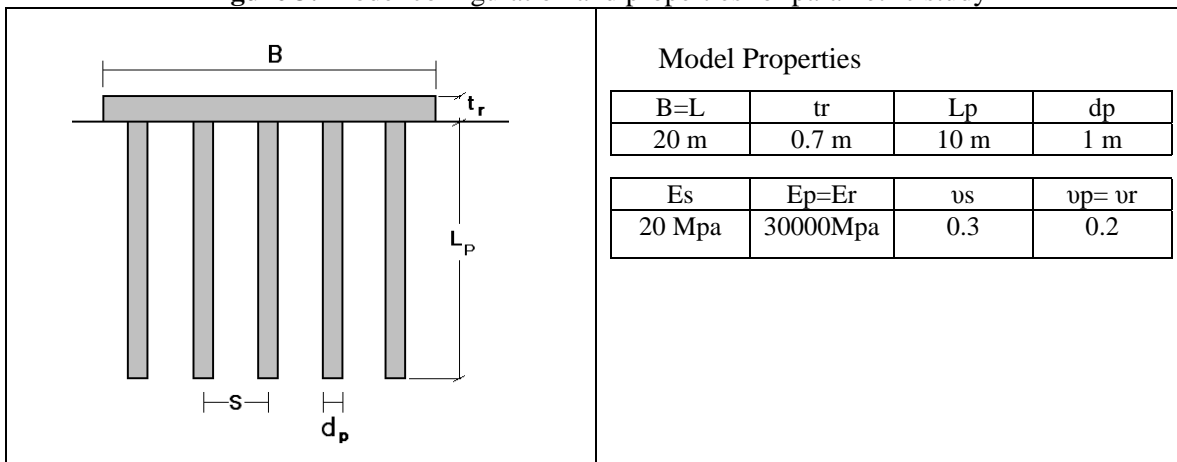
Figure 2: Model verification

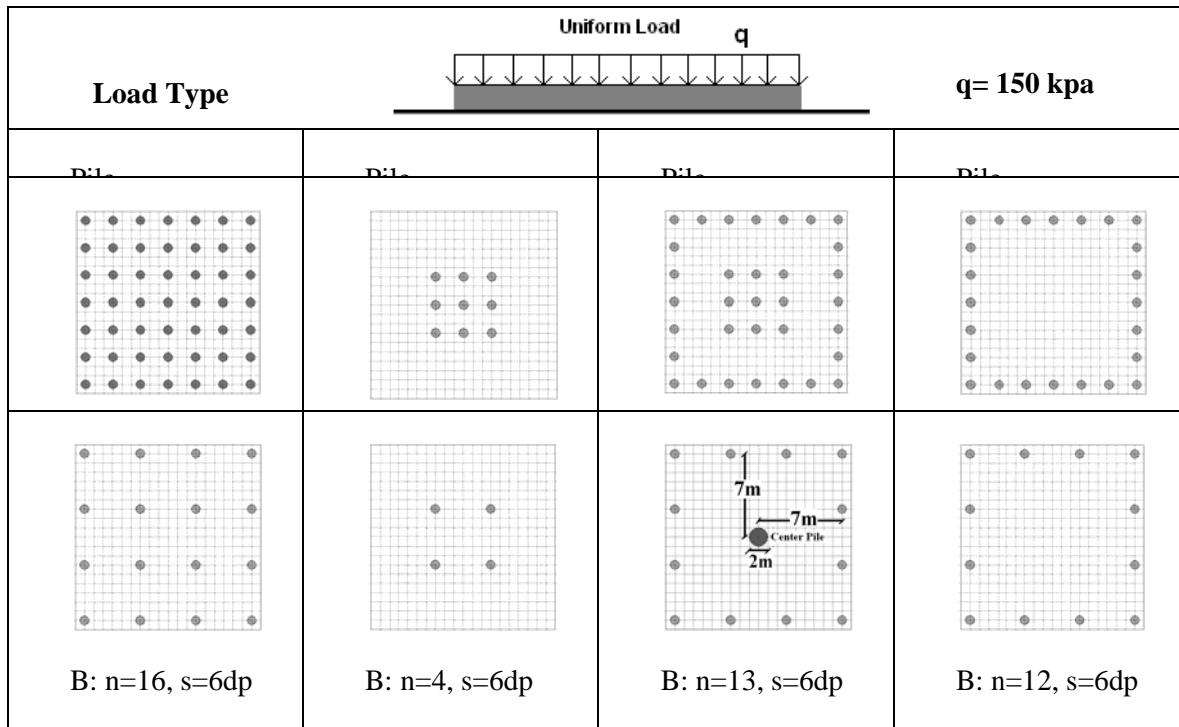
PARAMETRIC STUDY

In the parametric study four basic pile configurations were investigated. Pile configuration and model properties for parametric study are shown in Fig 3. Pile configuration 1 has the pile uniformly distributed under whole raft area. In pile configuration 2 the piles are placed only in the central area of the raft. Pile configuration 3 has piles under central area of the raft as well as under the edges of the raft. In pile configuration 4 the piles are placed only under the edges of the raft.

In parametric study the pile length was varied between $L_p=5m$, $L_p=10m$ and $L_p=20m$. The pile diameter was held constant at $d_p=1m$. Pile spacing was varied between $s=3m$, $s=6m$ and in pile configuration 3-B for center pile $s=7m$ ($d_p=2m$). Ultimate bearing capacity 80kpa for skin friction along the pile and 200kpa for tip of the pile was considered.

Figure 3: Model configuration and properties for parametric study

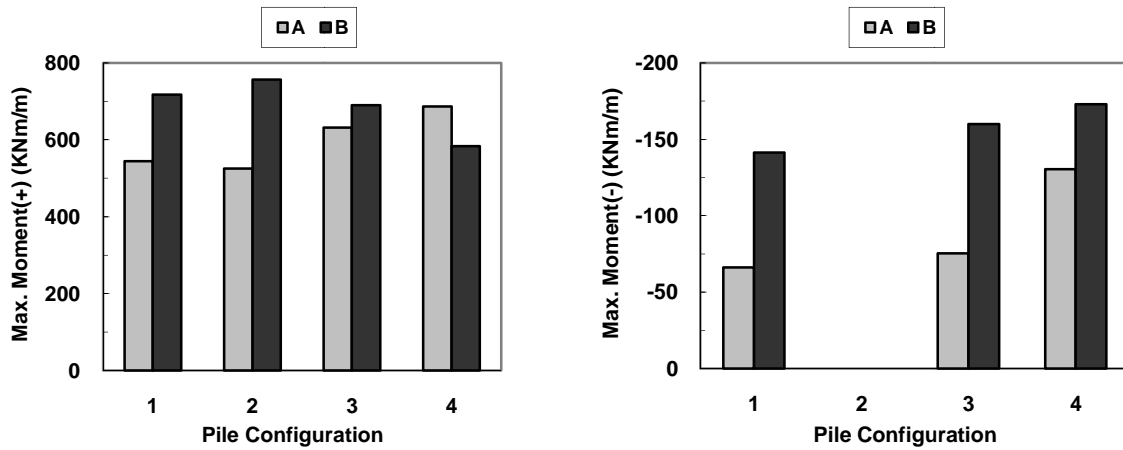




RESULTS AND DISCUSSIONS

Effect of pile configuration and number of piles

Figure 4-a shows the effect of pile configuration on maximum positive bending moment. For pile configuration 1, 2 and 3 by increasing number of piles maximum positive bending moment increased but in pile configuration 4 by increasing pile number maximum positive bending moment reduced. In Figure 4-b can see maximum negative bending moment by increasing number of pile in pile configuration 1, 3 and 4 increased and in pile configuration 2 negative moment not exist.



a: Effect of pile configuration on maximum positive bending moment

b: Effect of pile configuration on maximum negative bending moment

Figure 4: Effect of pile configuration on maximum bending moment

Figure 5 shows the piled raft settlement on cross sections A-A for different pile configuration. The bending moment per unit length acting on a cross-section perpendicular to the x axis is plotted in Figure 6 for the cross section A-A and in Figure 7 for the cross section B-B.

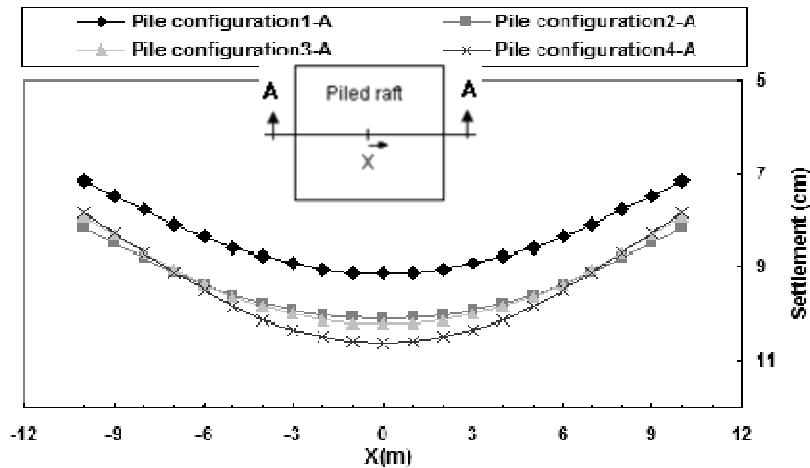


Figure 5: Effect of pile configuration on piled raft settlement

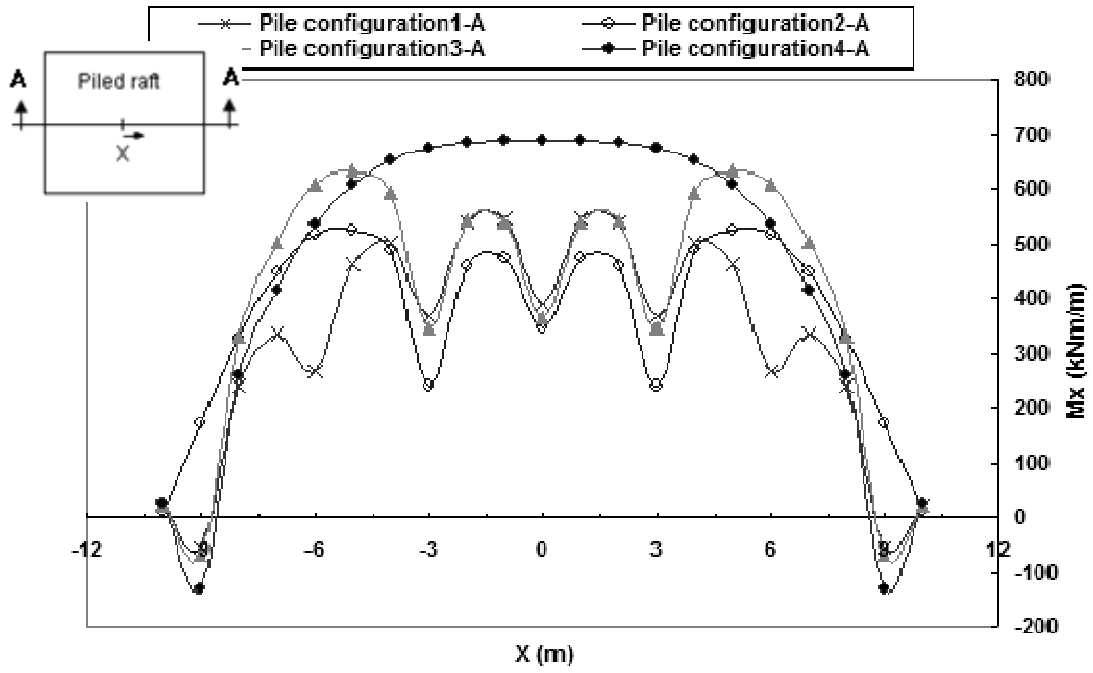


Figure 6: Effect of pile configuration on raft moment

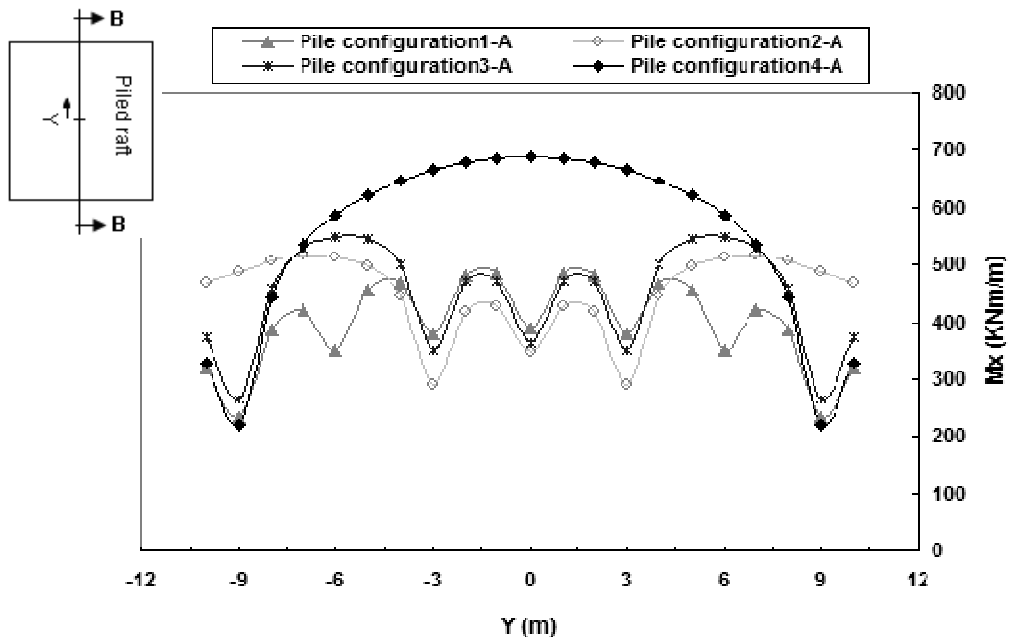


Figure 7: Effect of pile configuration on raft moment

Effect of varying pile length

For pile configuration 3-A illustrated in Figure 8, shows the effect of varying the pile length ($L_1=L_2$) on the maximum settlement, the differential settlement (between the centre and outer piles), the maximum positive moment in the raft, and the maximum negative moment in the raft in Figure 9. As would be expected, the settlement, differential settlement and maximum positive moment all decrease and maximum negative moment increase with uniform increasing pile length, while the proportion of load carried by the piles increases.

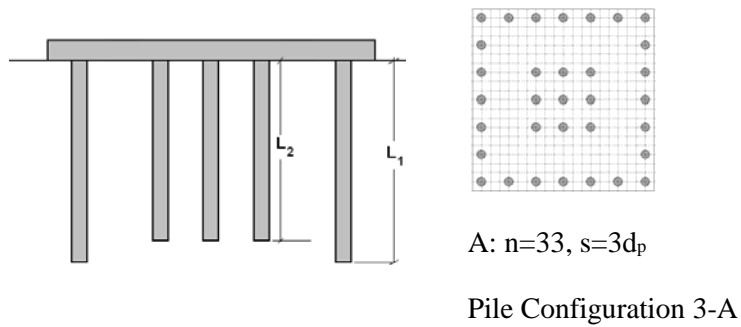
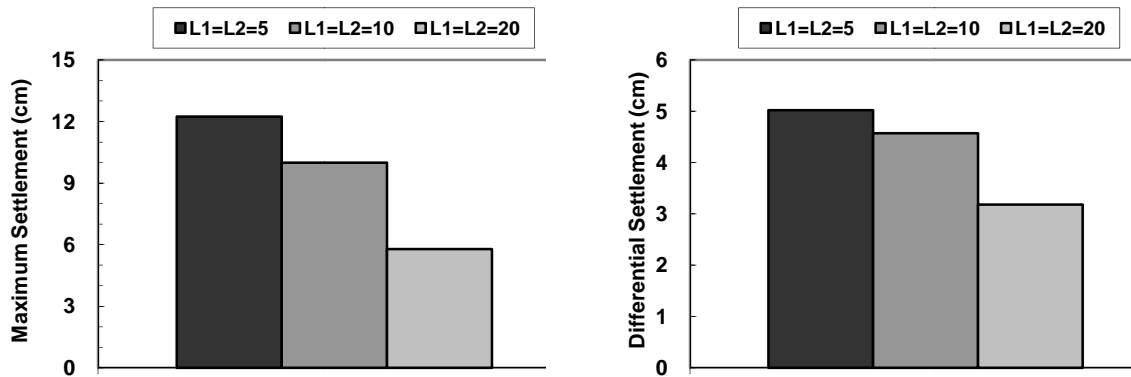


Figure 8: Model for analysis of pile length variation



a: Pile Length-Maximum Settlement chart

b: Pile Length-Differential Settlement chart

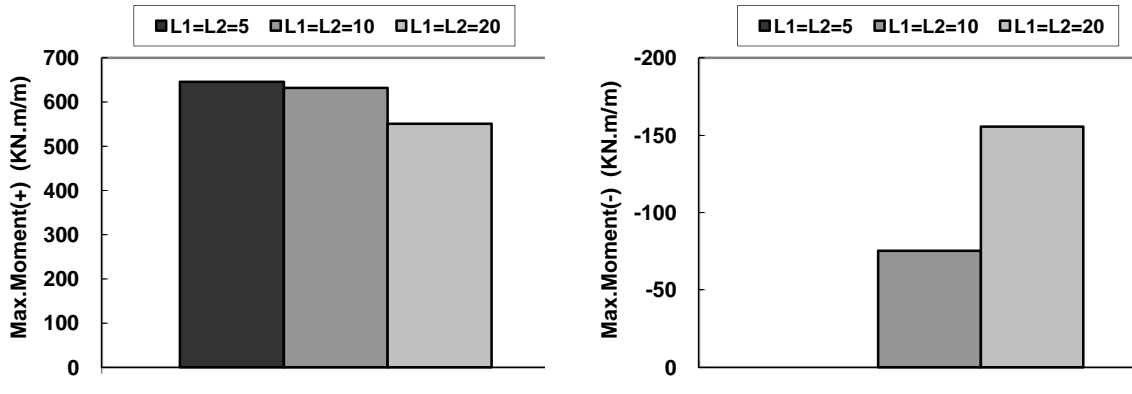


Figure 9: Effect of uniform varying the pile length on piled raft behavior

Figure 10 shows the effect of variation of centre and outer piles length on the maximum settlement, the differential settlement and the maximum positive moment in the raft.

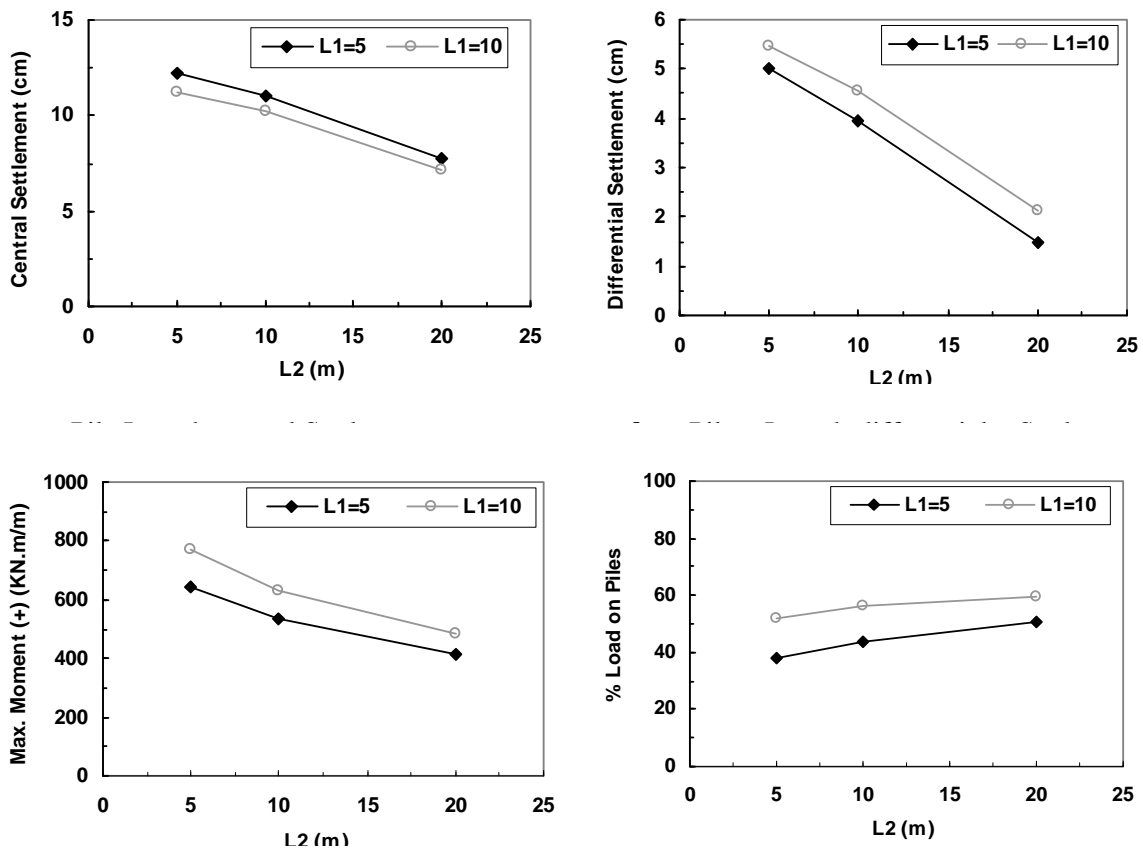


Figure 10: Effect of nonuniform varying the pile length on piled raft performance

In this case, for constant center pile length with increasing outer pile length, maximum positive moment in the raft, differential settlement and percent of load on piles increases and central settlement decrease. for constant outer pile length with increasing center pile length, maximum positive moment in the raft, differential settlement and central settlement decreases and percent of load on piles increase.

Effect of Raft Thickness

Figure 2 (b-c-d) shows solutions from the program ELPLA for a piled raft with 9 piles supporting rafts of varying thicknesses. Except for thin rafts, the maximum settlement is not greatly affected by raft thickness, whereas the differential settlement decreases significantly with increasing raft thickness. Conversely, the maximum moment in the raft increases with increasing raft thickness. For the case considered here, there is little or no benefit in increasing the raft thickness above about 1 m.

From the results presented herein, it can be concluded that increasing the raft thickness is effective primarily in reducing the differential settlement. However, it should also be noted that increasing the raft thickness may be very beneficial in resisting the punching shear from both piles and column loadings.

CONCLUSIONS

Piled raft foundations have the potential to provide economical foundation systems, under the appropriate geotechnical conditions. The design philosophy should be based on both ultimate load capacity and settlement criteria, with the key question to be answered being: “what is the minimum number of piles required to be added to the raft such that the ultimate load, settlement and differential settlement criteria are satisfied?” Use of some of the results outlined in this report can be used to assist the foundation designer to provide a rational answer to this question.

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