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Numerical Analysis of Piled Raft Foundations in Alluvial soil

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Abstract

In this age of rapid urbanization, population is rapidly increasing in urban area, therefore a new concept of vertical cities has been introduced in form of high-rise building, and there are many conventional methods for design of foundation systems for high rise buildings. In most of the conventional methods pile foundations have been given preference for high rise buildings, all the loads of the building are transferred to the soil by piles. Some of the pressure of the building can also be transfer by raft directly to the soil by contact pressure which is neglected in most of the conventional designs of pile raft foundation system. But from last decades, optimised way of designing of pile raft foundation system have been started by engineers, in which raft foundation is allowed to transfer some of the total load directly to the ground by contact pressure. So, in this paper, we are going to use one of the numerical methods for numerical analysis of pile raft foundation system. There are various factors that influence the behaviour of pile raft foundation, some of the important factor that we are going to see in this paper are raft thickness, pile length, pile spacing and number of piles. From the result obtain, with variation in raft thickness the differential settlement can be reduced to certain extent. All these factors are very important for optimize and economical design of pile raft foundation system. In this paper, numerical analysis has been done by using finite element software that is GEOTECH 3D Foundation to find out the influence of above factors on pile raft foundation system in alluvial soil.

Keywords

Raft, Piled raft foundation, Numerical Analysis, Alluvial soil, GEOTECH 3D Foundation

1. Introduction

In conventional method of pile foundation design, the pile cap in the pile which acted as a raft was not considered for transferring of load on ground. Pile cap provided on piles also contributes to transferring of superstructure loads on the ground and such foundation systems are called pile raft foundation. concept of pile raft foundation system was very economical as compared to the pile foundation with pile cap on it. There are three load bearing elements in this pile raft foundation system, these are piles, raft, and subsoil. Pile raft foundation concept have helped in the reducing total as well as differential settlement. In alluvial region, when raft foundation was provided for high rise buildings, excessive settlement was seen which is not acceptable for serviceability requirements, but this excessive settlement can be reduced by providing piles under the raft, it not only helps in reducing the excessive settlement but also helps in improving the bearing capacity of whole foundation system. In conventional design methods higher number of piles were used under the raft in foundation system which were not economical. With this new concept of pile raft foundation system, the total number of piles can be reduced as raft also helps in transfer of some of the loads to the ground in this foundation system. Because of this, the foundation system is most economical for high rise buildings in alluvial regions.

There are number of methods to find out the load settlement behaviour of pile raft foundation system. The most important methods are: -

a. Simplified calculation methods
b. Approximate computer-based methods
c. More rigorous computer-based methods

Poulos and Davis (1980), Randolph (1983,1994), Burland's Approach (Burland 1995), they all used simplified calculation methods for their research work. In this method the modelling of soil profile and loading conditions on the raft were used in very simplified way. Poulos (1991) also gave another method that was approximate computer -Based Analysis (GASP). The last method, which is more rigorous computer -based method is a finite element method and this method is most powerful tool among all for analysis of pile raft foundation system. Some of the early examples of the analysis of pile raft foundation system was given by Hooper (1973), Ottaviani (1975), they applied this method for the analysis of rigid raft, which was on the top of piles group in a homogeneous type of soil. A numerical method was used by chow and Teh (1991) to study the behaviour of pile raft foundation in non-homogeneous soil. Liu and Novak (1991) used finite element method to study the behaviour of a raft supported by a single pile at the centre. Maharaj (2003) presented the results of three-dimensional nonlinear finite element analysis of piled raft foundation under uniformly distributed load.

2. Methodology

In this paper, analysis of pile raft foundation system has been done using a finite element-based software. During the study of pile raft foundation system, numbers of parameters were considered some parameters were taken constant and some varied. The parameters which varied in the study were, raft thickness, pile length, pile spacing and number of piles. In this study static analysis of pile raft foundation have been done for high rise building in alluvial soil. The objective of the study was to find out the effect of varied parameters on the overall settlement and differential settlement of the foundation system. During pile group configuration different factors were included like diameter of pile, length of the pile, number of piles, arrangement of piles and centre to centre spacing between the piles. For any high rise building subjected to a definite loading, if any change is made in the above factors, then there will be a change in the total and differential settlement of the foundation system. The following steps have been followed in the analysis through finite element method: -

(a) Model of the structure: first a three-dimensional model of the structure was created; the structure consists of (i) Raft (ii) piles (iii) and soil. The super structure was shown as a uniformly distributed load on the raft, every part of the structure was modelled into large number of finite elements. The depth of the soil mass was taken double of the width of the raft plus length of the pile as zone of influence for the study.

(b) Loads: The total load of the super structure is considered as uniformly distributed load on the surface of the raft in pile raft foundation system. This type of uniformly distribution of load is only possible if raft is flexible in nature. When load is applied on a flexible type of raft it undergoes differential settlement and due to flexible nature of raft the assumed uniform load will become non uniform. But this uniform distribution of load is acceptable for practical purposes.

(c) Result: The above model that has been created is then analysed by using finite element software, GEOTECH 3D Foundation, to find out the settlement.

A three-dimensional model of the piled raft generated using GEOTECH 3D foundation is shown in Figure 1

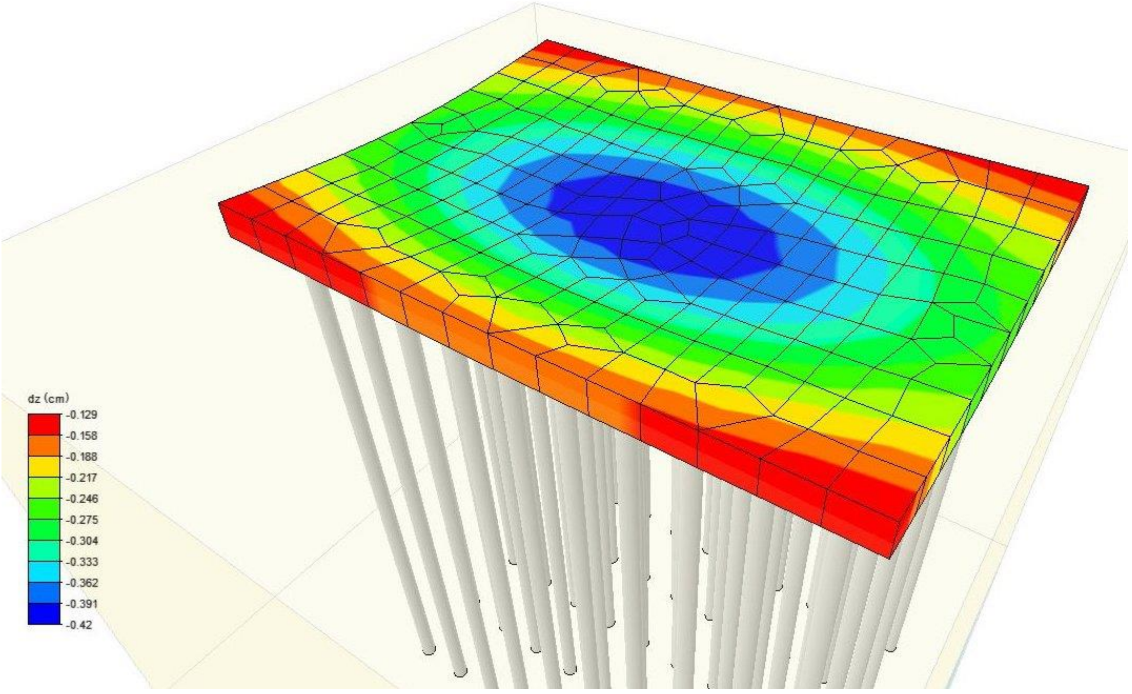

Figure 1: Three-dimensional model of the piled raft

3. Analysis Method

(a) Soil mass: a rectangular cross- section of large soil mass has been considered for study, the depth of the soil mass is taken double the depth of the raft and width is taken five times the width of the raft. The pile raft foundation system is assumed to be placed in alluvial soil deposits just below the ground surface. The properties of the alluvial soil that has been used for the analysis has been shown in the Table -1.

(b) Raft: a flat slab type of raft having uniform thickness is used for analysis, the raft is assumed to be resting on the ground surface. For the analysis purpose a raft of 50 m by 30 m has been used which is rectangular in shape. All the properties of raft that have been used for the analysis is shown in Table -1.

(c) Piles: Modelling of the piles have been done like that of raft, the piles are having higher young's modulus as compared to that of soil. All the properties of the piles used for analysis have been given in Table -1

Table 1: Properties of soil, raft, and Pile

Description	Soil	Raft	Piles
Type	**Alluvial soil**	**Concrete**	**Concrete**
FE Model	Mohr-Coulomb	Linear Isotropic	Linear Isotropic
Unit Weight	γsat = 18KN/m3	γ = 24KN/m3	γ = 24KN/m3
Modulus of Elasticity	Es = 8.0 MPa	E = 3 X 10^7 KN/m2	E = 3 X 10^7 KN/m2
Poisson's Ratio (ν)	0.3	0.2	0.2
Friction angle (Θ')	20	-	-
Cohesion (C')	10 KN/m2	-	-
Dilatancy angle (Ψ)	0	-	-

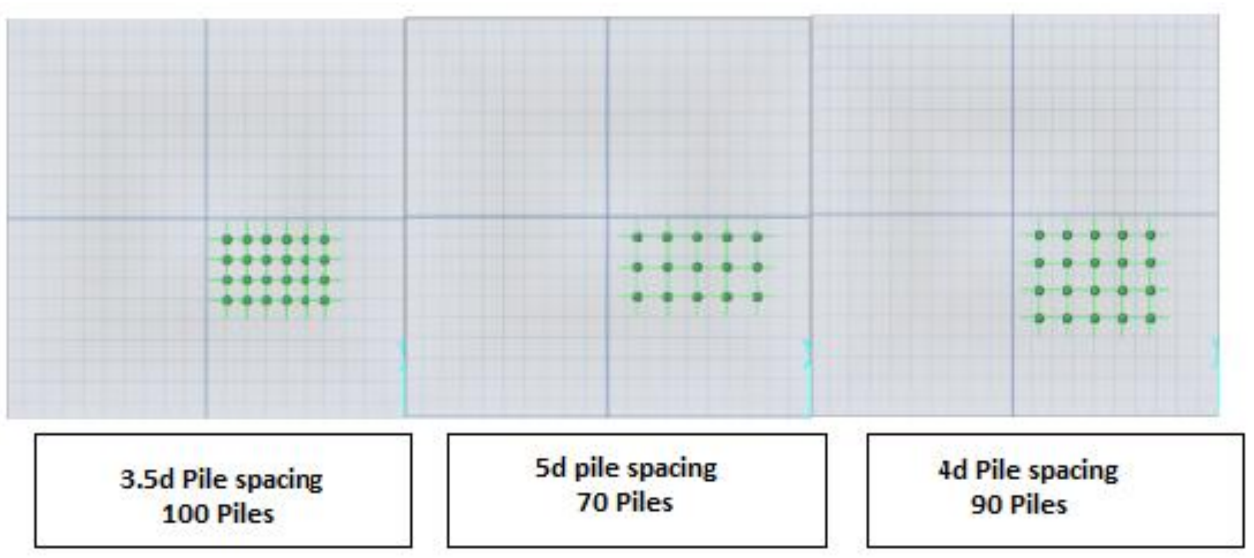

Figure 2: Three typical Pile configuration for study

4. Results of Analysis

In this study, number of alternative arrangements of piles have been used and, on this basis, the comparison criteria for ultimate design have been set for total and differential settlement.

4.1 Raft: Variation in Thickness of raft.

In Figure -3, effect of thickness of raft on total settlement and differential settlement have been shown.

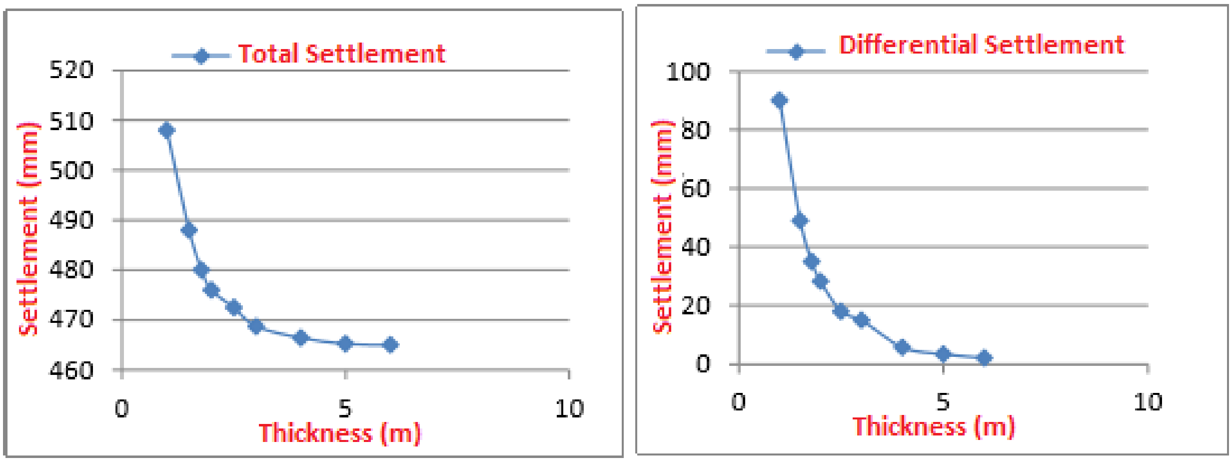

Figure 3: Total and Differential settlement against thickness of raft

In the Figure -3 above, as the thickness of the raft is increasing both total settlement and differential settlement of the pile raft foundation is also decreasing, but after certain point if thickness of raft is further increased then there is no effect on settlement. In the above figure after 3m thickness of raft, if thickness is further increased then there is no reduction in settlement.

This analysis on thickness of raft on settlement of foundation has also been shown in the Table -2 below

Table 2: In the three- dimensional Finite element model

Raft thickness (m)	Differential settlement (mm)	% Decrease of differential settlement
1	90.0	16.32
1.5	51.54	44.91
2.0	42.32	63.47
2.5	35.21	74.65
3.0	21.91	81.32
3.5	11.87	87.65
4.0	07.42	95.45
4.5	04.21	98.32
5.0	01.91	99.61

From Table 2 , it can be said that by increasing the thickness of the raft ,the differential settlement can be reduced by 70% .but for economical foundation system the raft thickness should be kept below 3m as there is no or very little effect on settlement if thickness is further increased.it can also be seen from the above table that settlement can be reduced up to 100% if thickness is increased to 6m ,but then the foundation system will become uneconomical.

4.2 Piled Raft: Variation of Spacing between piles and Number of piles used in pile raft foundation

Another analysis was done with variation of spacing between piles and by using different numbers of piles under raft as it can be seen in Figure -2. The results from this variation have been shown in Figure-4 and Figure -5.

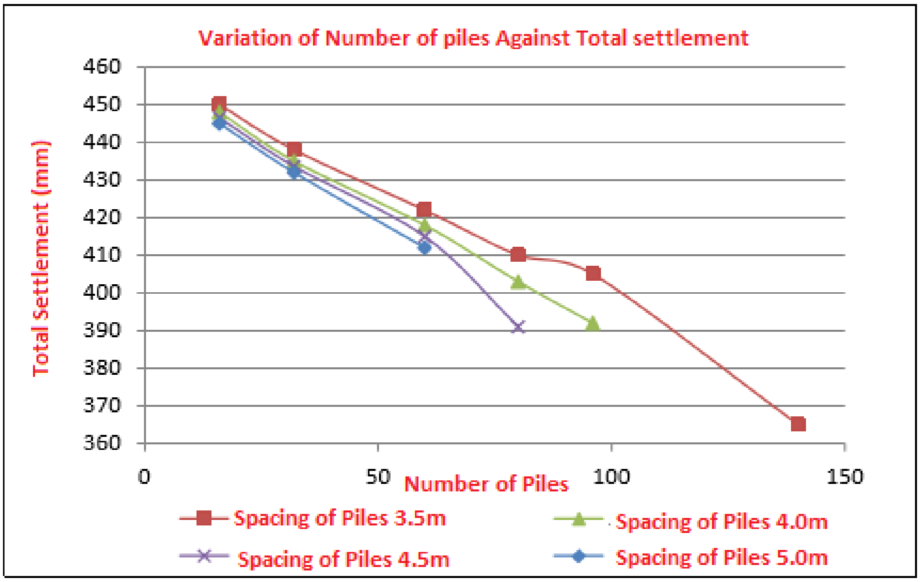

Figure 4: Total Settlement of pile raft foundation system against number of Pile

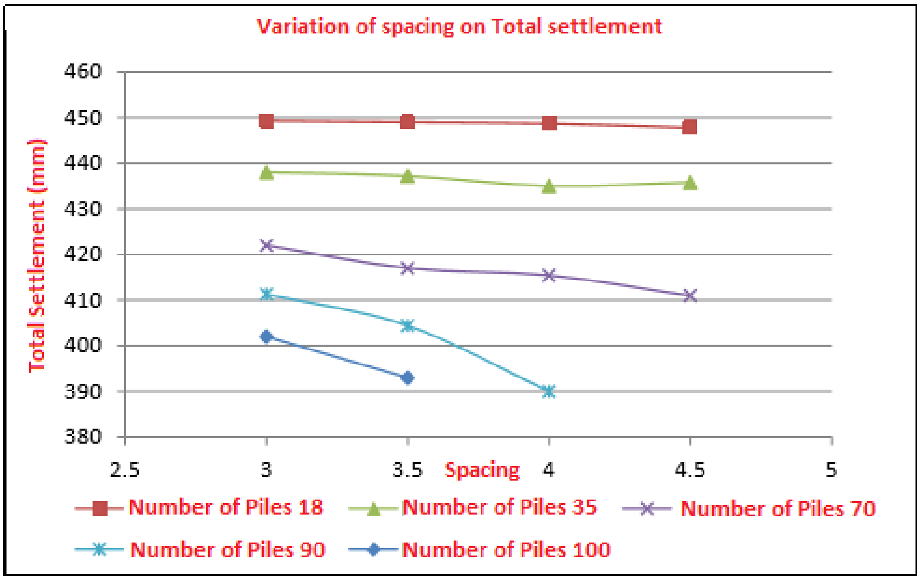

Figure 5: Total settlement of Pile raft foundation against spacing of Piles

From the above Figures 4 and 5, it can be said that a significant decrease in total settlement of the foundation system can be achieved by increasing the total number of piles and if spacing between the piles are increased then also certain amount of decrease in the settlement can be seen in the foundation system. The total settlement can be reduced by 50 mm if spacing between the piles and number of piles are increased. In this study, number of piles were increased from 20 to 100, and reduction in settlement was seen.

Similarly, analysis was done for differential settlement that can be seen in Figure 6 and 7. From these Figures it can be seen that, for spacing of 3.5 ,4 and 4.5 m there is minimum differential settlement for a given loading of 180 KN/m2.

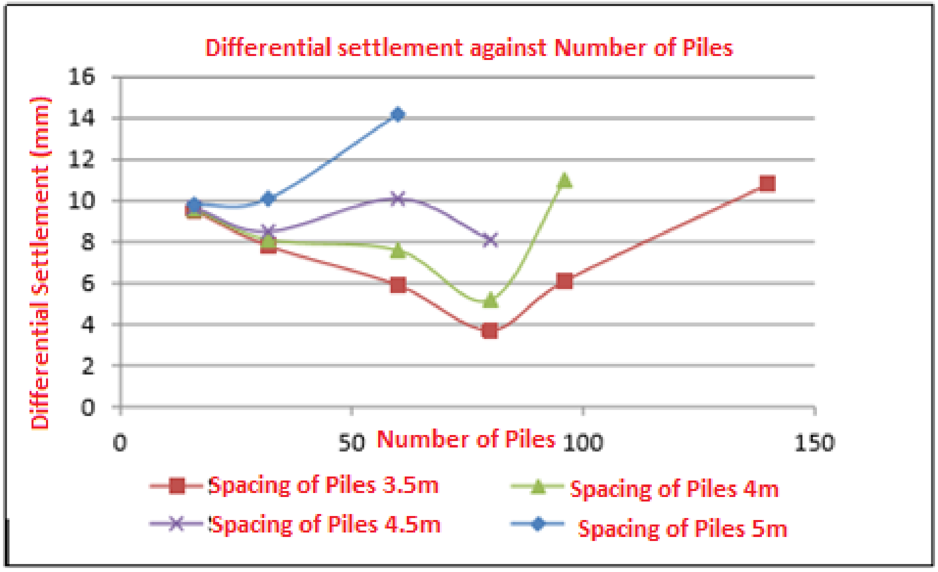

Figure 6: Differential settlement against Number of Piles

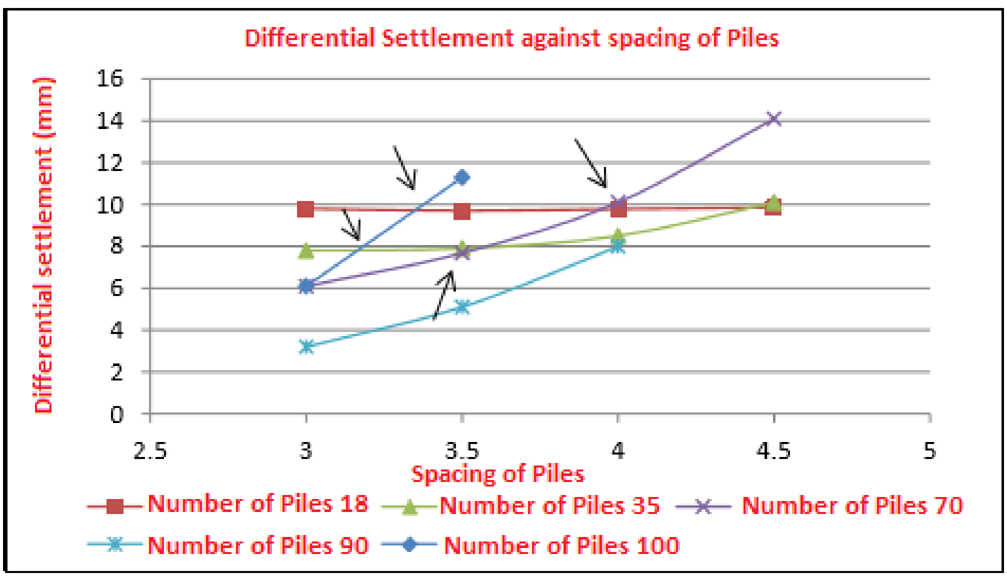

Figure 7: Differential settlement against spacing for constant Pile Numbers

In conventional methods of design of pile raft foundation system, the designers use to provide higher numbers of piles under the raft to achieve the differential settlement requirements of the code. The reduction in total and differential settlement can simply be achieved by just providing piles under raft but for optimised design, optimum number of piles should be used for economical foundation system.

4.3 Piled Raft Foundation: Variation of Length of piles

For analysis of variation of length of piles on settlement of foundation, the maximum spacing between piles have been taken 5m and minimum as 3m, the number of piles has been taken between 50 to 80 piles and the length of the piles are taken between 10m to 60m. The results obtain this analysis have been shown in the figure 8 and 9, given below.

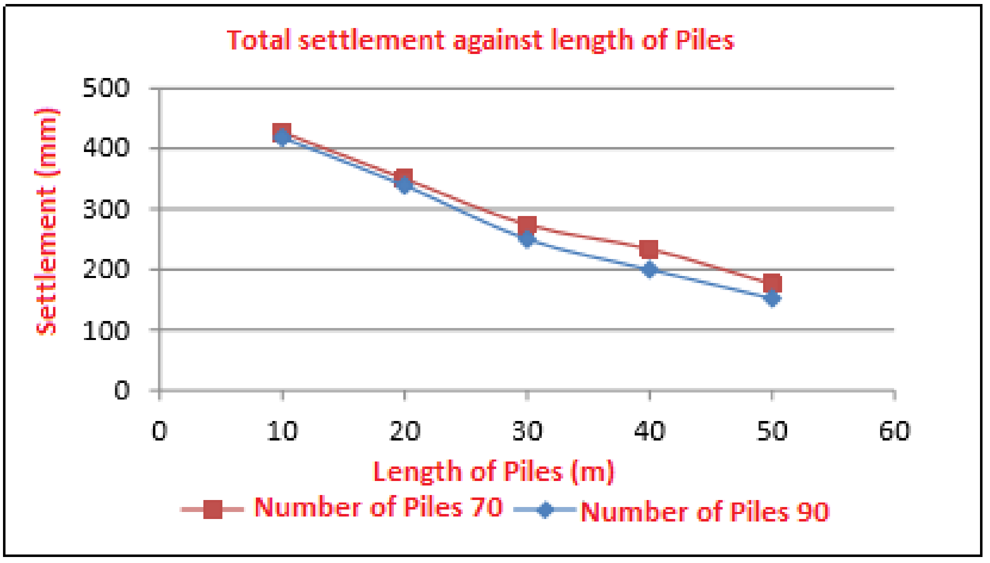

Figure 8: Variation of Total settlement with Pile Length

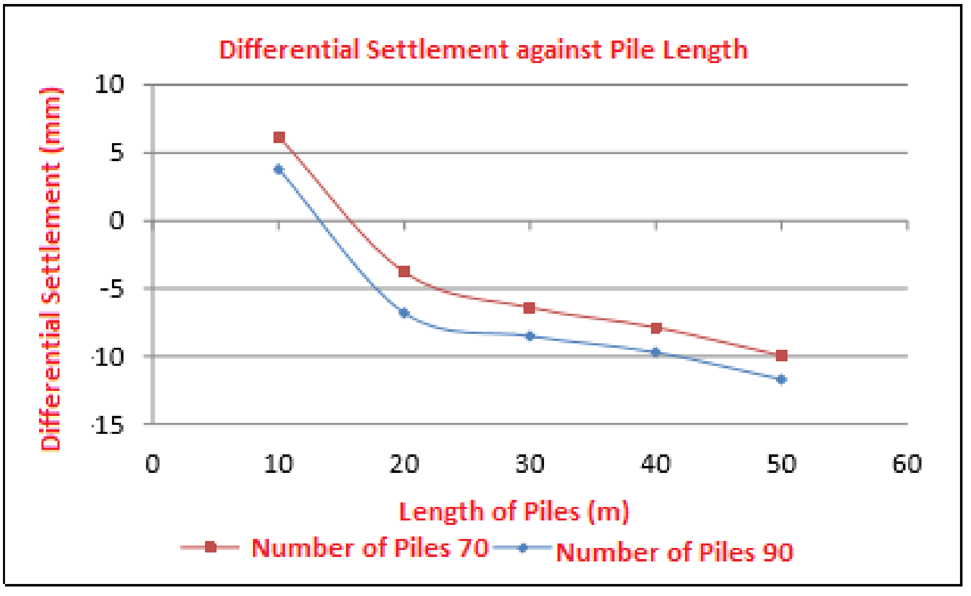

Figure 9: Variation of Differential Settlement with Pile length

As it can be seen in the above figures that an increase in the length of piles has decreased the total and differential settlement to a higher amount. For total settlement a similar kind of pattern can be seen for spacing of 3m and 4.5m in Figure 8 and figure 10. If the length of the pile is increased above 20m, then there is no change in the differential settlement this can be seen from Figure 9 and 11.

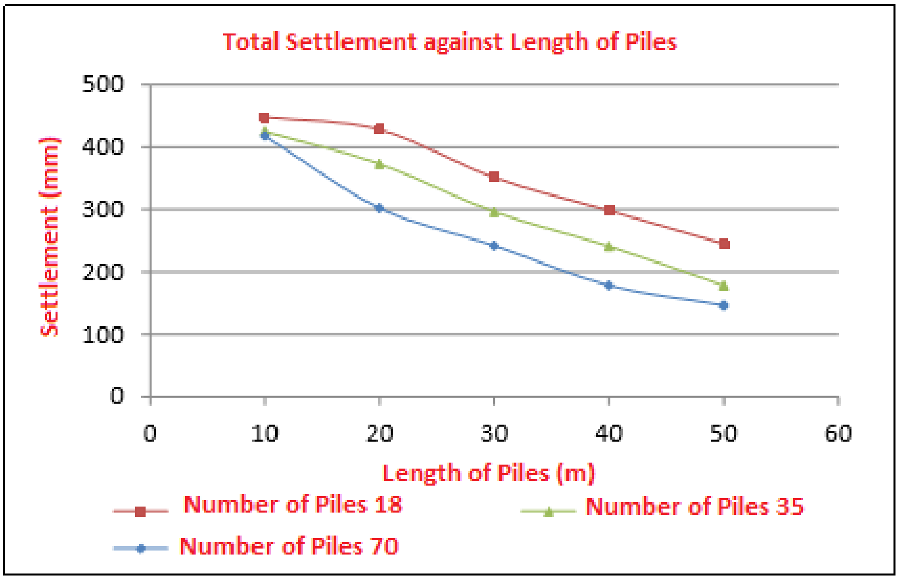

Figure 10: Variation of Total Settlement with Length of the pile

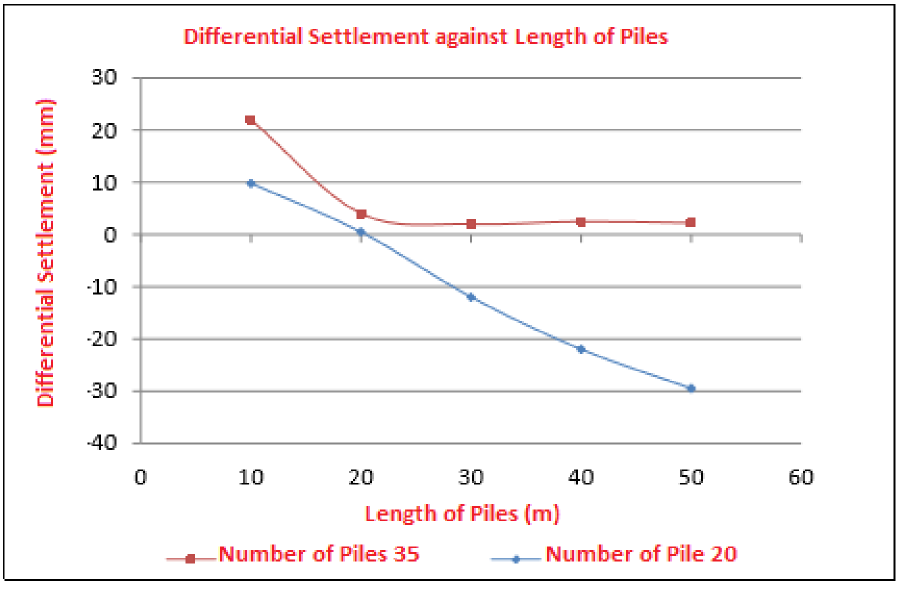

Figure 11: Variation of Differential Settlement with length of Pile

A negative value of differential settlement can be seen in spacing of 3.5m with 60 to 80 numbers of piles this can be seen from figure 9, this is only because of stiffness of pile and raft. The raft area where piles are located become stiffer when the pile length increases. If the spacing between the piles are very less and have significant length, then the raft which is unsupported around the edge acts like a cantilever and because of this settlement of the raft at the edges are more as compared to the central part.

5. Conclusions

Pile raft foundation system can be proven to be most economical type of foundation system for high rise buildings if thickness of the raft, length of the piles, spacing of the pile and number of piles in pile raft foundation system are used in most optimised way. This numerical analysis using finite element software-based method gives close results when compared with in-situ values.

a. In alluvial type of soils, total settlement and differential settlements of piled raft decreases when the thickness of raft in pile raft foundation is increased. The effect of variation of raft thickness is more on differential settlement then total settlement.
b. In determining the total settlement and differential settlement, stiffness of pile and stiffness of raft plays a very important role.
c. Increasing the thickness of raft up to 3m has shown significant reduction in total as well as differential settlement of the foundation system.
d. Above 25m length of pile, there is no change in differential settlement of the foundation, but settlement at the centre decreases with increase in pile length.

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