SETTLEMENT OF PILED-RAFT FOUNDATION FOR 8-STOREY BUILDING ON VERY SOFT CLAY

Ms Khaing Zar Win, Postgraduate student
Department of Civil Engineering
Mandalay Technological University
Myanmar
khinezar80@gmail.com

ABSTRACT In the last few years the number of piled rafts, especially those with few piles, has increased. It was therefore necessary to develop calculation models with sufficient accuracy and cost efficiency for practical use. It will be shown that finite-element analysis can be used to fulfill these requirements. This research aims to study the behavior of piled-raft foundation. Piled-raft foundation is usually designed for buildings to provide adequate load carrying capacity and to limit the overall settlement and hence control differential settlement within tolerable limits. In this study, proposed model of eight-storey reinforced concrete building with piled raft foundation is located Yangon. The proposed model with piled raft foundation is analysed by using STADD Pro software. Firstly, the thickness of raft and soil modulus is estimated. Secondly, the diameter of pile is estimated by Tomlinson's equation, and the bearing capacity of pile foundation is calculated by using the method modified form from the general bearing capacity equations. The vertical displacement or the vertical settlement of pile is considered by using the theoretical approach and the results obtained from analysing the combined structure. The lateral load resistance and maximum moment resistance of pile is calculated by Brom's method. The foundation design is considered 30% of mat and 70% of pile. The research is extended to the pile capacity and bearing capacity of subsoil under the raft in order to verify the appropriate parameters for prediction the settlement of piled-raft foundation of eight-storey building.. Foundation analysis will be carried out by using STAAD Foundation software to predict the settlement of this study.

Keywords: piled-raft foundation, pile capacity, settlement

1 INTRODUCTION

Nowadays, population in Myanmar increases with time. In order to meet for mass housing demands and reduce the landscape used, the construction of high-rise buildings becomes popular. A larger number of high rise buildings and bridges have been constructed during last decade all over the world to fulfill the requirements of the society. In the construction of high-rise buildings, bridges and marine structures, deep foundations especially pile foundations, piled-raft foundations are generally used to transfer the heavy loadings to the soil.

It is common in foundation design to consider first the use of a shallow foundation system, such as raft, to support a structure, and then if this is not adequate, to design a fully piled foundation in which the entire design loads are resisted by the piles. Despite such design assumptions, it is common for a raft to be part of the foundation system (e.g because of the need to provide a basement below the structure). There has been an increasing recognition that the use of piles to reduce raft settlements and differential settlements can lead to considerable economy without compromising the safety and performance of the foundation. Such a foundation makes use of both the raft and the piles, and is referred to here as piled raft. There is reluctance on the part of many foundations designers to consider the use of piled raft foundations in soft clays, for at least two reasons[00Hem].

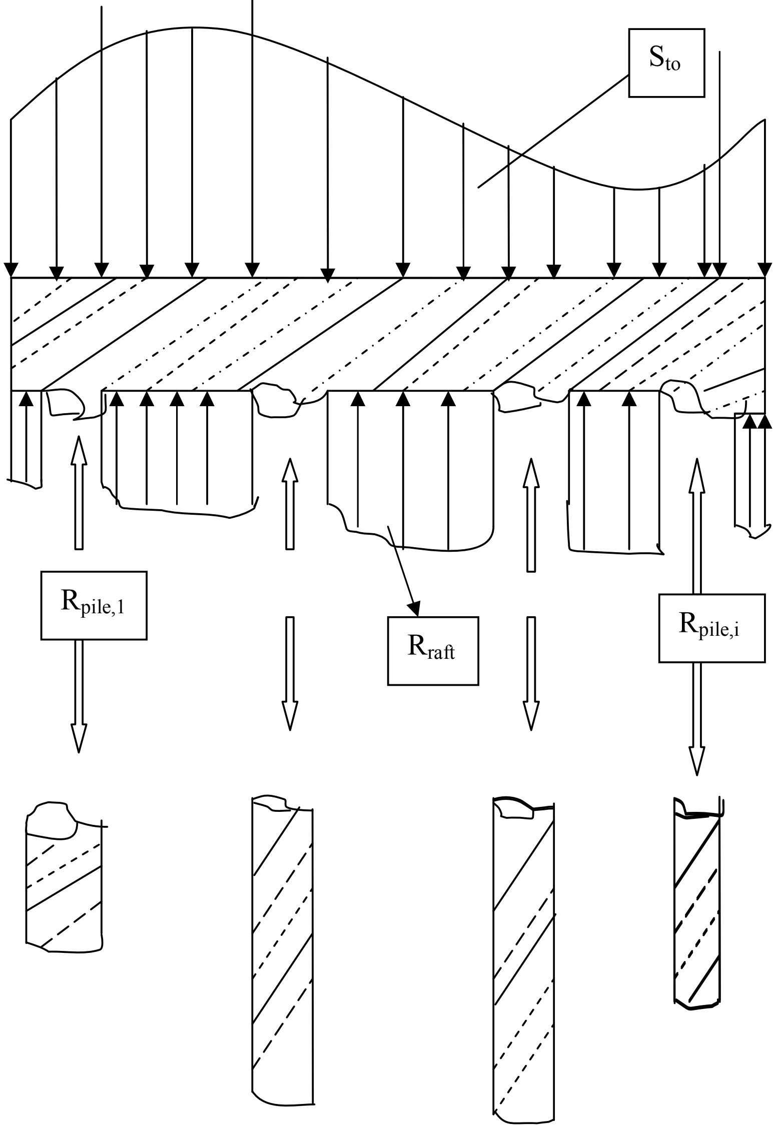

Figure .1. Piled Raft Foundation as a Composite Construction[00Hem]

i. the soft clay often provides only a modest bearing capacity and stiffness for the raft, with the piles having to carry the vast majority of load.

ii. if the soft clay is likely to undergo settlement, for example due to reclamation filling or dewatering, the soil may settle away from the base of the raft, again leaving the piles to carry the load.

The piled raft is a foundation which acts as a composite construction consisting of the three load-bearing elements: piles, raft, and subsoil. According to its stiffness, the raft distributes the total load of the structure S_{tot} as contact pressure, represented by R_{raft}, as well as over the n piles, generally represented by the sum of pile resistance $\sum R_{pilei}$ in the ground (i=1,2,3…), as indicated in Fig. 2.1. Hence the total resistance of the piled raft is given by:

$$R_{tot} = R_{raft} + \sum_{i=1}^{n} R_{pile,i} \geq S_{tot}$$

In cases where the raft is founded below the water table, S_{tot} is replaced by the total effective load of the structure S'_{tot} given by S_{tot} less the ground water buoyancy force. In the same way, R_{tot} is replaced by the total effective resistance of the piled raft R'_{tot}, given by R_{tot} less the groundwater buoyancy force [00Hem].

The design of piled raft foundations required a new understanding of soil-structure interaction because the contribution of both raft and piles is taken into consideration to verify the ultimate bearing capacity and the serviceability of the overall system. Moreover, the interaction between raft and piles makes it possible to use the piles up to a load level which can be significantly higher than the permissible design value for the bearing capacity of a comparable single isolated pile.

The behaviour of a piled raft can be characterized by the coefficient α_{pr}, defined as

$$\alpha_{pr} = \sum_{i=1}^{n} R_{pile,i} \big/ R_{tot} \qquad (2.2)$$

which describes the load sharing between the piles and the raft. A piled raft coefficient of $\alpha_{pr}= 0$ represents the case of a shallow foundation, and a coefficient of unity represents the case of a fully piled foundation without contact pressure beneath the raft. Piled raft foundations cover the range $0 \prec \alpha_{pr} \prec 1$, whereby conventional shallow and piled foundations are the limiting cases of a piled raft.

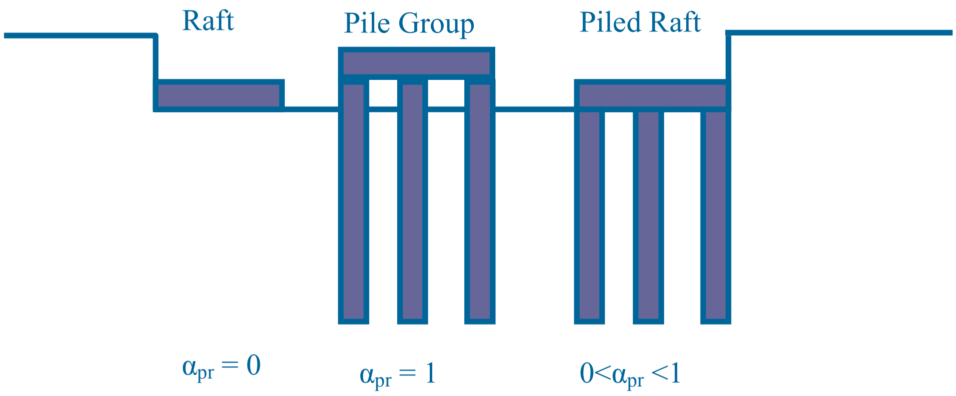

Figure 2 Types of Foundation [00Hem]

The influence of the piles to reduce the settlements of a raft depends on the piled raft coefficient, which in turn depends on the subsoil conditions and the geometric proportions of the piled raft. For the same subsoil conditions and the same area of the raft, the piled raft coefficient is a function of the number and length of the piles as shown in Fig. 2.

1.1. Soil-Structure Interaction of Piled Raft Foundations

The load-bearing behaviour of a piled raft is characterized by complex soil-structure interaction between the elements of the foundation and the subsoil, as illustrated in Figure 2.3.The interaction effects between adjacent piles and between the piles and the raft indicate that the load-bearing behaviour of the piles as part of a piled raft differs substantially from that of a comparable single isolated pile. An awareness of these interaction effects, and the development of an adequate calculation method to take account of them, are the main requirements for the reliable design of piled raft.

In most cases, piled-raft foundations are generally used the effective way of minimizing both total and differential settlements, of improving the bearing capacity of a shallow foundation, and of reducing in an economic way the internal stress levels and bending moments within a raft. The behaviour of piled rafts is determined by complex soil-structure interaction effects, and an understanding of these effects is indispensable for the reliable design of such foundations. In most building design offices, design of the buildings is generally performed with substructuring techniques. It means superstructure of the building system is analyzed and designed first and then foundation system is analyzed and designed to satisfy the resultants of the superstructure analysis whether it is static or dynamic and limitation of foundation deformations according to codes.

Settlement is very important in structural analysis. Behavior of structure will be changed when support settlement occurs. Continuous or fixed-ended beams are quite sensitive to support settlements while not in simply supported beam. Rigid frames are also quite sensitive to differential support settlements. Support settlements can occur from a variety of reasons and the most common type is consolidation of the soil beneath a support. The larger the load on the soil, the more likely is consolidation to occur. The amount of settlement is rarely exactly the same beneath all support points of a structure.

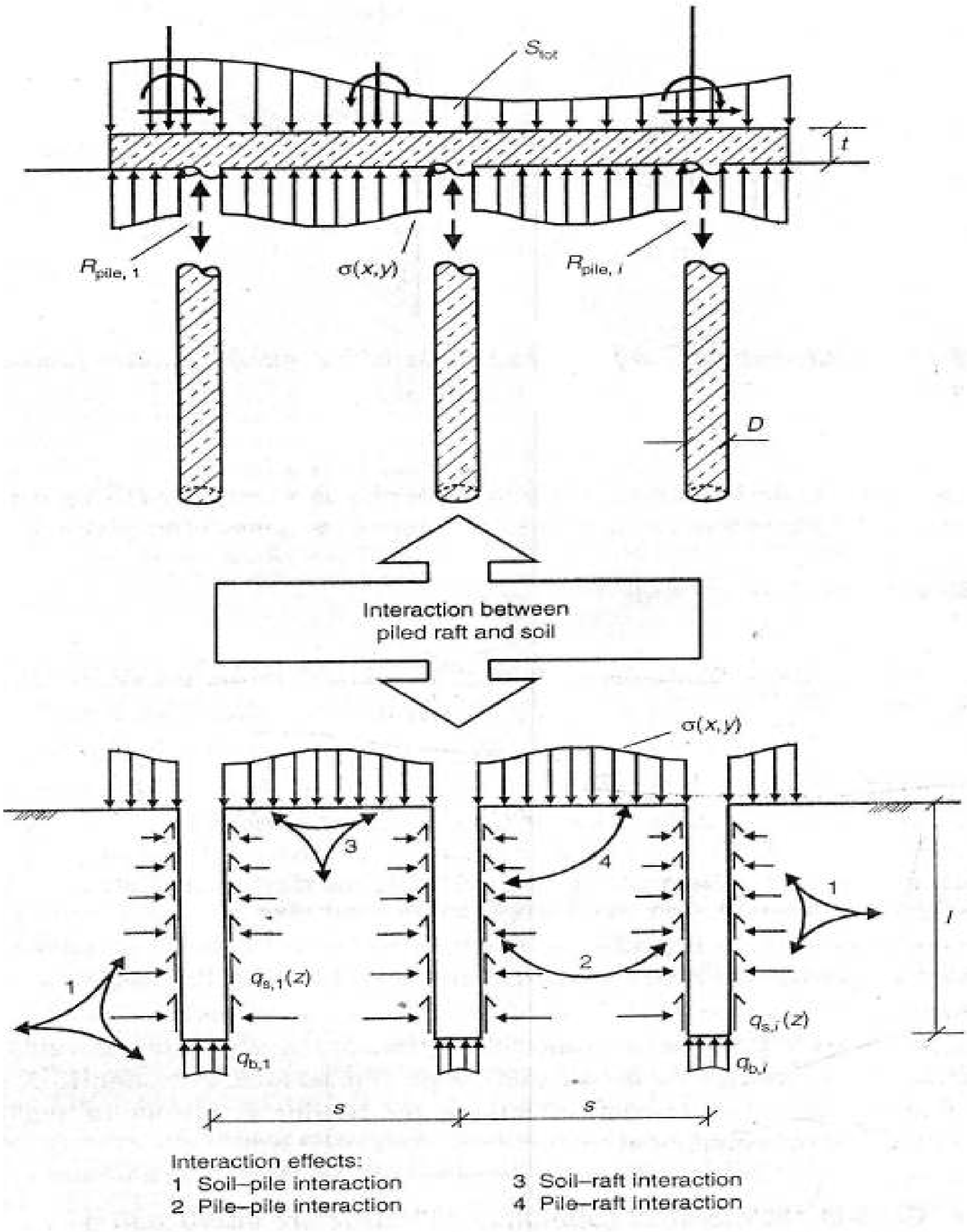

Figure 3. Soil-structure Interaction Effects for Piled Raft Foundations [00Hem]

2 SITE LOCATION AND STRUCTURAL SYSTEM

Location : Yangon
Type of structure : Eight storied reinforced concrete building
Type of occupancy : Official

Area of structure	:	Maximum length - 67 ft Maximum width -29 ft
Height of structure	:	Overall height-112.5ft Height above ground level – 95.5 ft
Shape of building	:	Rectangular shape

3 LOAD ON THE MODEL

Three kinds of load such as gravity load, wind load and earthquake load are considered essentially in the design.

3.1.Gravity Load

Gravity Load is considered as dead load and live load. During earthquake motion, the following differences between dead load and live load are occurred.

(1) Dead loads are defined as gravity loads that will be accelerated laterally with the structural frame under earthquake motion. Dead load results from the weight of the structure and all other permanently attached materials.

(2) Live loads are defined as gravity loads that do not accelerate laterally at the same rate as the structural frame when the structure undergoes earthquake motion.

3.2.. Wind Load

Static approach based on UBC Method is used to estimate wind load. The suggestions of UBC for wind load are as follows:

(1) Wind shall be assumed to come from any horizontal direction.

(2) No reduction in wind pressure shall be taken for the shielding effect of adjacent structure.

(3) Three types of exposures B, C, D are considered:

Data used for calculation of wind loading are:

- Exposure type = B
- Effective height = 103.5 ft
- Basic wind speed = 85mph
- Importance factor = 1

3.3. Earthquake Load

The magnitude of earthquake load is a result of the dynamic response of the building to the ground motion. In this study, the UBC Method of analysis is used for earthquake analysis.

The following are used as data for UBC method of analysis to match local condition.

- Zone factor for Yangon area, Z =0.15g
  where, g = gravity constant
- Importance factor = 1
- Soil profile type = S_d (stiff soil)
- Response modification factor, R = 5.5
- (Intermediate Moment Resisting Frame, IMRF)

4 DESIGN OF SELECTED PILE

For design of selected pile, the diameter of pile is firstly estimated for design of pile and then bearing capacity of pile is calculated. The calculation results are presented in following sections.

4.1. Estimation of Diameter of Pile

The diameter of single pile is $D = 2.257\sqrt{\frac{P_d}{f'_c}} = 16\,\text{in}$

4.2. Calculation of bearing capacity of single pile in cohesionless soil

The water table is assumed at 2.5 ft depth below ground level.

$Ø = 36^\circ$, c = 0 , γ = 125 lb/ft^3

The average effective angle of friction over the length of the shaft, $\bar{\phi}$, is taken as the angle of pile/soil friction, Ø. For cast-in-place pile from Table 2.3,

$\delta = \bar{\phi} = 36^\circ$

The value of horizontal soil stress, K_s is 0.5 for bored pile.

$$N_q = e^{\pi \tan\phi} \tan^2\left(45^\circ + \frac{\phi}{2}\right) = 37.752$$

. $\gamma' = 125 - 62.4 = 62.6$ lb/ft^3

$$A_b = \pi\frac{D^2}{4} = 1.396\,\text{ft}^2$$

The calculation of skin resistance of pile is described in Table.1.

The ultimate skin resistance of pile in cohesionless soil, Q_s, is calculated as follows:

$$Q_s = \pi D \sum (L_i q_f) = \pi \times 1.333 \times 23.86 = 99.92 \text{ kips}$$

Table.1. Calculation of Skin Resistance of Pile in Cohesionless Soil

Layer	Depth (ft)	L_i (ft)	$\sigma'_{vo} = \gamma'_i L_i$ (kip/ft^2)	K_s	$\tan\delta$	$q_f = \frac{1}{2} K_s \sigma'_{vo} \tan\delta$ (kip/ft^2)	L_i q_f (kip/ft)
1	10	-	-	-	-	-	-
2	10	10	0.626	0.5	0.727	0.113	1.13
3	10	10	0.626	0.5	0.727	0.227	2.27
4	10	10	0.626	0.5	0.727	0.341	3.41
5	10	10	0.626	0.5	0.727	0.455	4.55
6	10	10	0.626	0.5	0.727	0.568	5.68
7	10	10	0.626	0.5	0.727	0.682	6.82
8	10	-	-	-	-	-	-
Total		60	3.756				23.86

The ultimate point resistance of pile, Q_p, is as follows:

$$Q_p = N_q \sigma'_{vo} A_b = (37.752)\ (3.756)\ (1.396) = 197.95 \text{ kips}$$

Total ultimate resistance $(Q_{ult})_S = Q_p + Q_f = 297.87$ kips

The allowable bearing capacity of single pile is calculated with safety factor of 2.5.

$$(Q_{all})_S = \frac{Q_s + Q_p}{2.5} = 119.148 \text{ kips}$$

4.3.. Calculation of bearing capacity of pile in cohesive soil

The water table is assumed at 2.5 ft depth below ground level. The value of adhesion factor, α is taken from Fig. 2.12.

$$\Phi = 0^\circ ,\ c = 3.2 \text{ kip/ft}^2 ,\ \gamma = 120 \text{ lb/ft}^3.$$

The calculation of skin resistance of pile is described in Table.2.

The ultimate skin resistance of pile in cohesive soil, Q_s, is calculated as follows:

$$Q_s = \pi D \sum (L_i q_f) = \pi \times 1.333 \times 96 = 402.02 \text{ kips}$$

The ultimate point resistance of pile, Q_p, is calculated as follows:

$$Q_p = N_c\, c_b\, A_b = (9)\ (3.2)\ (1.396) = 40.205 \text{ kips}$$

Total ultimate resistance $(Q_{ult})_S = Q_p + Q_f = 442.23$ kips

The allowable bearing capacity of single pile is calculated with safety factor of 2.5.

$$(Q_{all})_S = \frac{Q_s + Q_p}{2.5} = 176.892 \text{ kips}$$

Table.2. Calculation of Skin Resistance of Pile in Cohesive Soil

Layer	Depth (ft)	L_i (ft)	c_u (kip/ft^2)	α	$q_f = \alpha c_u$ (kip/ft^2)	$L_i q_f$ (kip/ft)
1	10	-	-	-	-	-
2	10	10	3.2	0.5	1.6	16
3	10	10	3.2	0.5	1.6	16
4	10	10	3.2	0.5	1.6	16
5	10	10	3.2	0.5	1.6	16
6	10	10	3.2	0.5	1.6	16
7	10	10	3.2	0.5	1.6	16
8	10	-	-	-	-	-
Total		60				96

5 VERTICAL DISPLACEMENT OR SETTLEMENT OF PILE FOUNDATION

The vertical displacement or settlement of pile foundation is estimated by:

$$S_t = \frac{B}{100} + \frac{(Q_{va}/L)}{A_p E_p} = 0.03 \text{ ft} = 0.36 \text{ in}$$

which is less than the allowable vertical displacement or settlement 1 in.

6 ESTIMATION OF BEARING CAPACITY OF SOIL

To analyse and design the combined structure with the help of STADD Pro software, the bearing capacity of soil is estimated from three method. The results of ultimate bearing capacity of soil obtained by using Hansen's method, Meyerhof's method, and Vesic's method are 3863 ksf, 814 ksf, 815 ksf, respectively. In this study, the average value of ultimate bearing capacity, 1831 ksf, is used. To get the allowable bearing of soil, the ultimate bearing capacity of soil is divided by the factor of safety. In this study, the factor of safety is taken as '2.5'.

7 ESTIMATION OF MODULUS OF SUBGRADE REACTION

The lateral modulus of subgrade reaction is obtained from the following equations:

$$k_s = A_s + B_s Z^n$$

$$A_s = F_{w1} C_m C (c N_c + 0.5 \gamma B_p N_r)$$

$$B_s Z^n = F_{w2} C_m C (\gamma N_q Z^n)$$

In this calculation, the shape factor F_{w1} is assumed as 1.3, the size factor, C_m is taken as 2, and the constant, C is supposed as 12. The results of subgrade reaction for each soil layer for bored hole 1 is expressed in Table.3.

Table.3. Results of Subgrade Reaction for Bored Hole 1

Layer Depth (ft)	k_s (kip/ft³)
	D = 1.33 ft
10	60
20	105
30	175
40	280
50	418
60	400

8 COMPARATIVE STUDY

In this study, the composite structure is designed by using STADD Pro. The design of piled raft foundation is calculated from empirical methods. In this section, the analysis results are compared with reduced various pile stiffness, 90%, 80%, 70%, 60% and 50%. Especially, the vertical displacements of pile near coluimn and away from column are described.

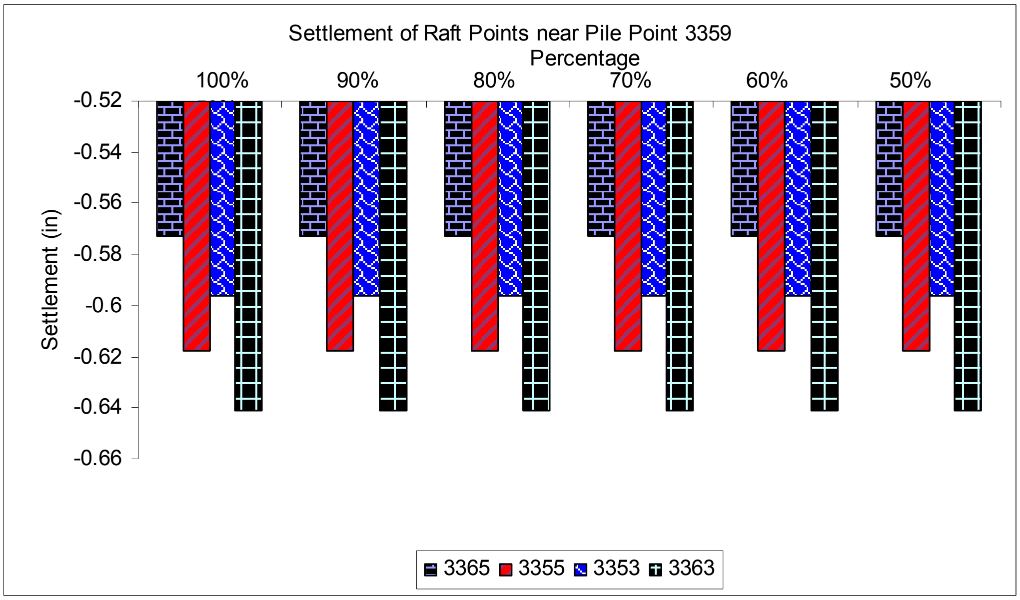

Figure 4 Comparison of Settlements of Raft Points near Pile Point 3359 between 100% Pile Stiffness and Various Percentage of Pile Stiffness (away column)

From Fig..1 to Fig.3 illustrate the comparison of displacement results for 90% pile stiffness, 80% pile stiffness, 70%, 60% and 50% pile stiffness. According to Figures, the vertical displacements obtained from full pile capacity of piled raft foundation are the same those obtained from 90%, 80%, 70%, 60% and 50% of pile stiffness according to pile point.The settlement of piled raft does not exceed allowable limit when the capacity of piles supporting piles reduces to various percentage according to result charts. The settlements of away column are more variable than those of near column but the settlement is under allowable limit for all considered cases.

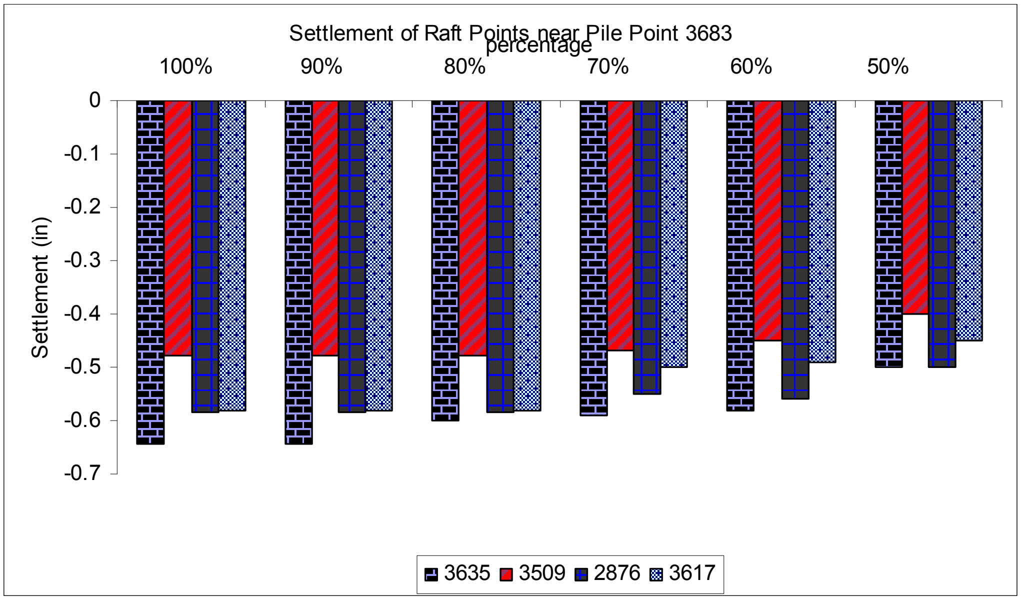

Figure 5 Comparison of Settlements of Raft near Pile Point 3683 between 100% Pile Stiffness and Various Percentage of Pile Stiffness (near Column)

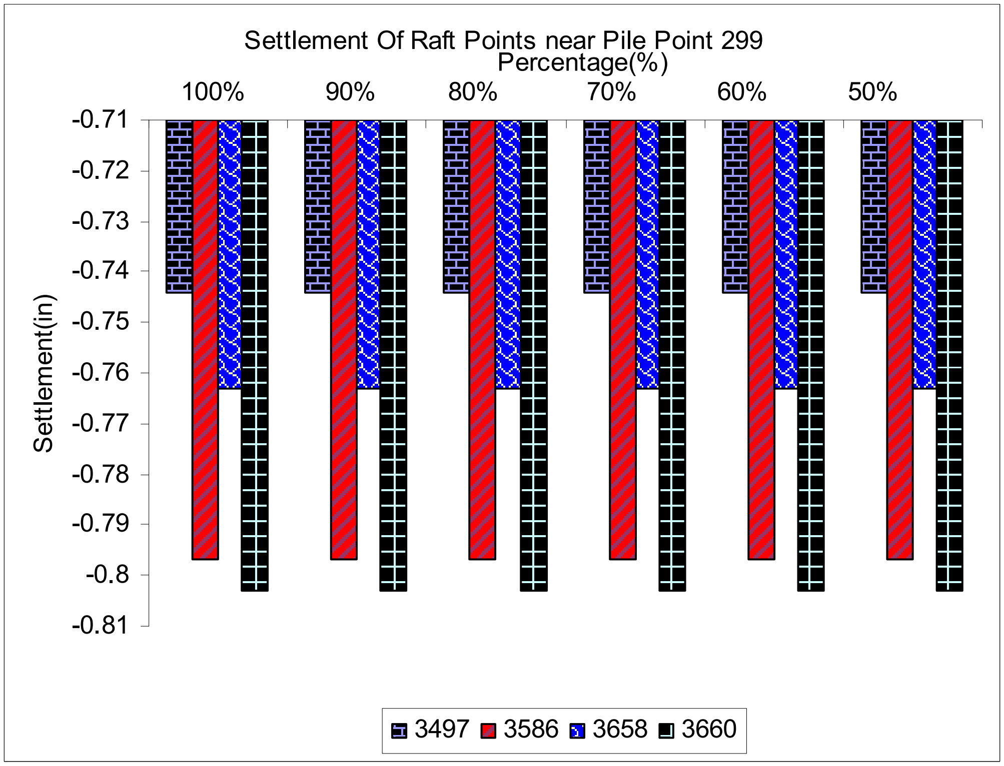

Figure 6 Comparison of Settlements of Raft Points near Pile Point 299(Column) between 100% Pile Stiffness and Various Percentage of Pile Stiffness

9 CONCLUSION

From this study the following conclusions can be drawn for the prediction of settlement of piled raft foundation in case of insufficient pile capacity.

(1) The result of vertical displacement or settlement of all piles is less than the allowable settlement, 1.0 in.

(2) Base pressure under raft exceeds allowable bearing capacity of soil when capacity of supporting piles reduces to 60%.

(3) Load sharing between raft and pile is found to be proportionally on pile capacity.

(4) Therefore, the thickness of raft is estimated 2.5 ft and soil modulus is 38.2 lb/in^3.

(5) Axial forces in piles are different at various locations.

(6) Therefore, the thickness of raft is estimated 2.5 ft and soil modulus is 38.2 lb/in^3.

(7) The result of displacement of raft near pile point and away from pile point are same those of fully pile capacity compared with reduced various percentage of pile stiffness.

(8) The base pressure of pier exerted from soil obtained from analyzing is less than the allowable bearing capacity of soil but greater than that of 70% reduced pile capacity.

Finally, it can be concluded that more accurate approach presented in this study should be used for foundation response prediction for sensitive engineering structural buildings such as nuclear reactor and tall and slender structure.

10 REFERENCES

Poulos, H.G.: (2005) Technical References Paper Analysis And Deisgn of Pile Raft Foundation, Civil Park Interntional Conference, Part 1& 2,.

Braja, M. D.: (1999) Principals of foundation Engineering. 4th Edition. Brooks/Cole Publishing Company,.

Tomlinson, M. J.: (2001) Foundation Design And Construction.7th Edition.UK: E & FN Spon, An Imprint of Chapman & Hall,.

Hemsley, J.A.: (2000) Design Applications of Raft Foundations. Proceedings, Geotechnical Practice in Offshore Engineering. American Society of Civil Engineers,. 536-545.

Bowels, J. E. (1996) : Foundation Analysis And Design. 5th Edition. U.S.A: McGraw Hill Co,