SIMPLIFIED DESIGN METHOD FOR PILED RAFT FOUNDATION

J.M. Raut[1], Dr. S.R.Khadeshwar [2], Dr. S.P.Bajad [3],Dr. M.S.Kadu[4]

[1] Assistant Professor & Ph.D Scholar, Yeshwantrao Chavan College of Engineering,Wanadongari Nagpur-441110 ,Maharashtra,INDIA.
[2]Professor, Yeshwantrao Chavan College of Engineering,Wanadongari Nagpur,Maharashtra,INDIA.
[3]Lecturer Government Polytechnic,Amravati,Maharashtra-444603,INDIA.
[4] Head of civil engineering department ,Shri Ramdeobaba College of Engineering & management Nagpur-440013

ABSTRACT: Raft foundations is the favorite choice for most of the designers but now days due to constrains of cost increment, decreasing availability of land because of rapid industrialization & urbanization there is growth in vertical direction resulting in many high rise building coming up. This has resulted in heavy load, complicated stress conditions and limitation of bearing capacity of soil. This results in settlement of high rise buildings. As a solution to the settlement problem of high rise buildings number of piles are used and new type of foundation called as piled raft foundation is coming up in a big way. In some design approach piles are used for reducing the settlement and load is carried by raft only, another design methods still concentrate on providing adequate axial capacity from the piles to carry the structural load and bearing capacity of raft neglected. In both the design approach piled raft foundation becomes uneconomical as bearing capacity of raft and pile is not utilized in single design approach. This shows that , design rules and standards for piled-raft foundations are not well established. The interesting observation in the Poulos-Davis-Randolph (PDR) design methodology for piled Raft but using simple stiffness formula piled raft foundation can be designed and analyzed. It is observed that increase in pile length leads to increase in the settlement which is contrary to the practical observation. It is because, the stiffness of any structural member in our case pile decreases with increase in length for given diameter. This can be avoided by using length of pile up to depth of fixity. The length of pile below fixity due to surrounding soil can be neglected .This length of pile above depth of fixity is also called free standing length of pile. This free standing length can be calculated using Indian standard on pile. By using simple stiffness formulae in PDR methodology piled raft design can be simplified.

INTRODUCTION

Now a day due to rapid urbanization all over the world has led to increase in the number and height of high-rise and super high-rise buildings because of limitation of space. This situation leads to growing use of combined piled-raft foundation all over the world. World's tallest building Burj-Dubai is also resting on the piled-raft foundation. However, design rules and standards for piled-raft foundations are not well established and hence it remained an area of interest for many researchers. Initially, piles were used as settlement reducers in piled-raft foundation. This traditional capacity based design Approach for piled-raft is popular and significant applications are observed. This may be due to impositions made by prevailing codes and regulations in many countries. It is also observed that most of the countries, including India, do not have standard codes of design for piled-raft. In situations where in an un-piled-raft does not satisfy the design requirements with respect to settlement, the piled-rafts are provided. Under these circumstances, the addition of a limited number of piles will also improve the ultimate load bearing capacity along with improving the settlement performance. There have been an increasing number of structures using piled raft as the foundation to reduce the overall and differential settlement. In much of the available literature, emphasis has been placed on the use of piles as settlements reducers; while less attention has been paid to the bearing capacity of the overall foundation.

The present work is inspired with the general opinion that piles can share some load due to either friction or bearing in addition to reducing the settlement. The paper deals with effect of geometric parameters of the pile on the load settlement of the piled-raft. In addition, it describes the generalized design of piled raft considering the capacity of pile in sharing the load and the ability to reduce the settlement which in turn would lead to a cost effective design of piled raft, especially for high rise buildings. Following the Poulos-Davis-Randolph (PDR) design methodology for piled raft but using simple stiffness formula piled raft foundation can be designed and analyzed. Interestingly, it is observed that increase in pile length leads to increase in the settlement which is contrary to the practical observation. It is because, the stiffness of any structural member in our case pile decreases with increase in length for given diameter. This can be avoided by using length of pile up to depth of fixity. The length of pile below fixity due to surrounding soil can be neglected .This length of pile above depth of fixity is also called free standing length of pile. This free standing length can be calculated using Indian standard on pile. By using simple stiffness formulae in PDR design methodology design method for piled – Raft can be simplified. There are following design approaches found in the recent literature.

TRADITIONAL DESIGN APPROACH:

The traditional design approach for piled-raft foundation is to adjusting diameter, length and number of piles to carry the vertical component of the total load transferred by the superstructure with adequate safety. The load carrying capacity or the contact between raft & soil is neglected.

Innovative Design Approach

The Piled-raft foundation load carrying capacity of pile as well as raft is considered in this design approach. The basic aim in this design approach is to balance the stiffness of piles and raft. The stiffness of pile and raft determines the load sharing between raft and pile.

FAVOURABLE CIRCUMSTANCES FOR PILED RAFTS:

The most effective application of piled-raft occurs when the raft can provide adequate load capacity, but the total of the raft alone exceed the allowable values. Poulos (1991) has examined a number of idealized soil profiles; and found that the following situations may be favourable.

a) Soil profiles consisting of relatively stiff clays.
b) Soil profiles consisting of relatively dense sands.

In both these circumstances, the raft can provide a significant proportion of the required load capacity and stiffness, while the piles boost the performance of the foundation rather than providing the major means of support.

UNFAVOURABLE CIRCUMSTANCES FOR PILED RAFTS:

There are some situations which may be unfavourable for piled-raft, such as,

a) Soil profiles containing soft clays near the surface.
b) Soil profiles containing loose sands near the surface.
c)Soil profiles which contain soft compressible layers at relatively shallow depths.
d) Soil profile which is likely to undergo consolidation settlements due to external causes.
e) Soil profiles which are likely to undergo swelling movement due to external causes.

In the first two cases, the piled-raft may not be able to provide significant load capacity and stiffness, while in the third case, long term settlement of the compressible layers may reduce the contribution of the raft to the long-term stiffness of the foundation. The last two cases should be treated with considerable caution. Consolidation settlements, such as those due to dewatering or shrinking of an active clay-soil, may result in a loss of contact between the raft and the soil, thus increasing the load on the piles leading to increased settlement of the foundation. In case of swelling soils, substantial additional tensile forces may be induced in the pile because of the action of the swelling soil on the raft. Theoretical studies of these situations have been described by Poulos and Sinha (1997).

ADVANTAGES OF PILED-RAFT FOUNDATION:

The advantages of piled-raft can be summarized as:

a) Reduction of maximum and differential settlements leads to improvement of serviceability o a foundation.
b) A significant reduction in the required number and length of piles in comparison to fully piled foundation.
c) Reduction in the internal stress and bending moment in a raft.
d) Improvement in the bearing capacity of a shallow foundation using the load sharing between raft and piles.
e) For eccentrically loaded rafts, centralization of the resistance of the foundation by concentrating piles under the eccentrically loaded area of the raft.

METHODS OF ANALYSIS:

Many methods of analyzing piled-rafts have been developed and some of these have been summarized by Poulos et al. (1997). Three broad classes of methods of analysis have been identified as:

SIMPLIFIED CALCULATION METHODS:

Simplified Method includes those presented by Poulos and Davis (1980), Randolph (1983, 1994), Van Impe and Clerq (1995), and Burland (1995). All these methods involve a number of simplifications in relation to the modeling of the soil profile and the loading conditions on the raft.

APPROXIMATE COMPUTER–BASED METHODS:

The approximate computer-based methods include the following broad approaches.
Methods employing a "strip on springs'' approach in which the raft is represented by a series of strip footing, and the piles are represented by springs of appropriate stiffness (Poulos, 1991)

Methods employing a "plate on springs'' approach in which the raft is represented by a plate and the piles as spring (Clancy and Randolph, 1993; Poulos, 1994; Viggiani, 1998; Anagnastopoulos and Georgiadis, 1998).

More rigorous computer –based methods: The more rigorous methods include:

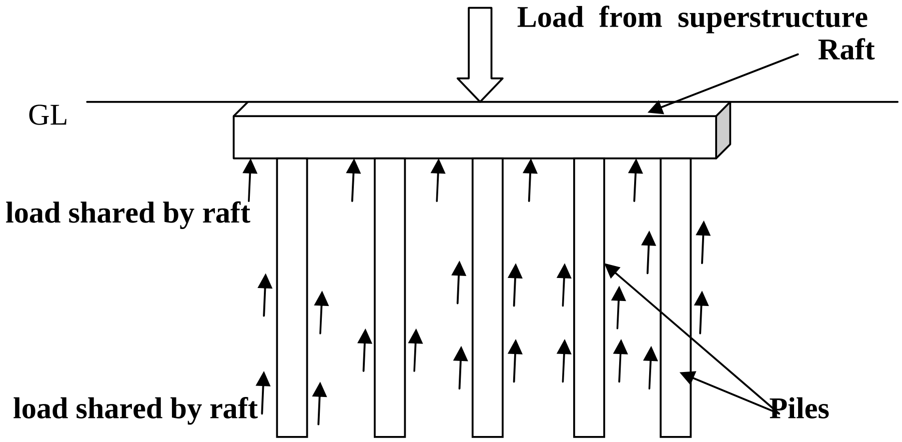
Boundary element method in which both the raft and the piles within the system are discredited, and use elastic theory is used. (Butterfield and Banerjee, 1971; Brown and Wisner, 1975; Kuwabara, 1989; Sinha, 1997).

Methods combining boundary element for the piles and finite element analysis for the raft (Hain and Lee,1978; Ta and Small, 1996; Franke et al. 1994; Russo and Viggiani, 1998)

Simplified finite element analysis usually involving the representation of the foundation system as a plane strain problem (Desai, 1974) or an ax-symmetric problem (Hooper, 1974) and corresponding finite difference analysis via the commercial program FLAC (Hewitt and Gue, 1994). Three-dimensional finite element analysis(e.g. Zhuang et al. 1991;Lee, 1993; Wang, 1995; Katzenbach et al., 1998) and finite difference analysis via the commercial program FLAC3D.

In piled-raft foundation the use of piles was intended to reduce the total and differential settlement of raft to a considerable degree. This helps in achieving large scale economy of the structure without compromising the safety and performance of the foundation. Over the quarter of a century, piles are used as settlement reducers in piled raft. The main focus is on reducing the average settlement while reducing the differential settlement using the piles. However, an approach to these concerns is not well developed. Conceptually, it is thought that there is possibility of taking advantage of load sharing between piles and rafts. Thus, the piled-raft designed with the conceptual approach may achieve a substantial economy and improve performance of the foundation especially when an un-piled raft does not satisfy the settlement criterion.

DESIGN METHODOLOGY:



The piled raft is foundation formed due to combination of raft & piles. Primarily when the settlement in the raft foundation is more then pile are used as settlement reducers. The load bearing capacity of pile is neglected and total load is taken by raft only. This leads to uneconomical design; Another design methods still concentrate on providing adequate axial capacity from the piles to carry the structural load and bearing capacity of raft neglected. in both the design approach piled raft foundation becomes uneconomical as bearing capacity of raft and pile is not utilized in single design approach. This shows that, design rules and standards for piled-raft foundations are not well established. The interesting observation in the poulos-davis-randolph (pdr) design methodology for piled raft but using simple stiffness formula piled raft foundation can be designed and analyzed. This methodology is based on distribution of load between pile and raft on the basis of stiffness.

The piled-raft design problem was solved as per calculations were given by H.G.Poulos for simplified design analysis PDR (Poulos-Davis-Randolph) method. Following the Poulos-Davis-Randolph methodology and using simple stiffness formula,

Stiffness $K = AE/L$, A= area of structural member , E = Modulus of elasticity, L= length of structural member

The effect of variation in length, diameter and number of piles on the load settlement curve is studied and presented. Interestingly, it is observed that increase in length leads to increase in the settlement which is contrary to the practical observation. It is because, the stiffness of any structural member decreases with increase in length for given diameter. The most of research work is based on simple stiffness formula and do not consider effect of depth of fixity of the pile while calculating the stiffness.

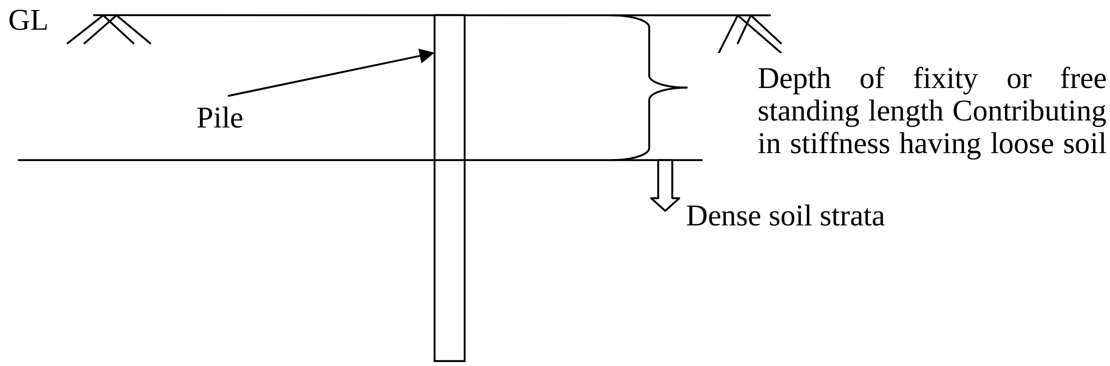


Fig :2 Free standing Length

The depth of fixity and equivalent length of cantilever is calculated as per Standard IS: 2911 (Part 1/sec2).This depth of fixity is used for calculating the stiffness of pile. Using this methodology design problem is stated as follows.

DESIGN PROBLEM:

To design & study the effect of pile configuration on load settlement of piled-raft having raft size of 18m x 8m x0.5m is considered for soil having Cohesion of Soil of 50 KN/m2 and angle of internal friction of 20 degree is considered.

Raft dimensions = 18m x 8m x 0.5m
Soil Cohesion, C = 50 KN/m2
Angle for internal friction for soil = 200
The following combinations were studied.
Number of piles, N = 12 m to 16 m
Length of piles, L= 12m to 30m with length increment each of 3m.
Diameter of pile, D=0.5m to 0.8m with diameter increment of 0.05m.

Sensitivity analysis of each one parameter is carried out for all the possible combinations. Design analysis was done as per PDR (Poulos-Davis-Randolph) methodology. Pile stiffness is calculated by taking length of pile equals to depth to fixity. Load–settlement curves were studied for load varying from 0 KN to failure load with increment of 1000 KN. There are seven numbers of graph for different diameters of pile while keeping its length & number constant. So, total 7x7x5=245 combinations are studied.

However, for the purpose of simplicity, the observations and the corresponding graphs and tables for 16 piles with 0.6m diameter (D) with length varying from 12m to 30m with an increment of 3 m are presented and elaborated below.

Table 1 show that increase in length of pile increases the ultimate loading capacity of pile. Increase in length reduces the settlement for particular load. For 22000 KN settlement is 61.79mm for 12m pile. Whereas for 15m pile length it reduces to 49.20 mm and so on up to 21m.But after 21m length of pile, there is decrease in settlement but amount is small.

Table 2 shows that there is very little effect of increase in length of pile after 21m and particularly for 27m to 30m effect is very negligible Load- settlement curve is drawn for different lengths for all combinations. Form the above graphical observations and table1, it can be interpreted that load carrying capacity of piled raft increases while increase in length of pile. The increase in length of pile also reduces the settlement of pile raft up to specific length beyond which further increase in length does not help in decreasing settlement.

There is a specific combination of stiffness of raft and pile in a pile-raft foundation for achieving economical design. The optimum combination of diameter (D) of pile and the no of piles (N) for the considered raft is to be calculated. It is the ultimate aim in the pile–raft design methodology. This can be achieved, through calculation of load sharing factor for different combinations of piles with keeping raft dimensions constant in this case. The results of the above iterations are presented below in tabular form.

Table 3 shows that there are some negative figures for load sharing factor for diameter 0.5m and number of piles 12 and 13.This is due to the fact that stiffness of piles is so less as compared raft that there is negative settlement and piles are uplifted by raft . For diameter 0.55m and 12 numbers of piles, load sharing factor is about 50%. This is perfect pile & raft stiffness combinations for piled Raft. As further increase in number and diameter say for 0.8m diameter and 16 numbers of piles this factor is 0.963. So maximum load is taken by piles and negligible load is taken by raft.

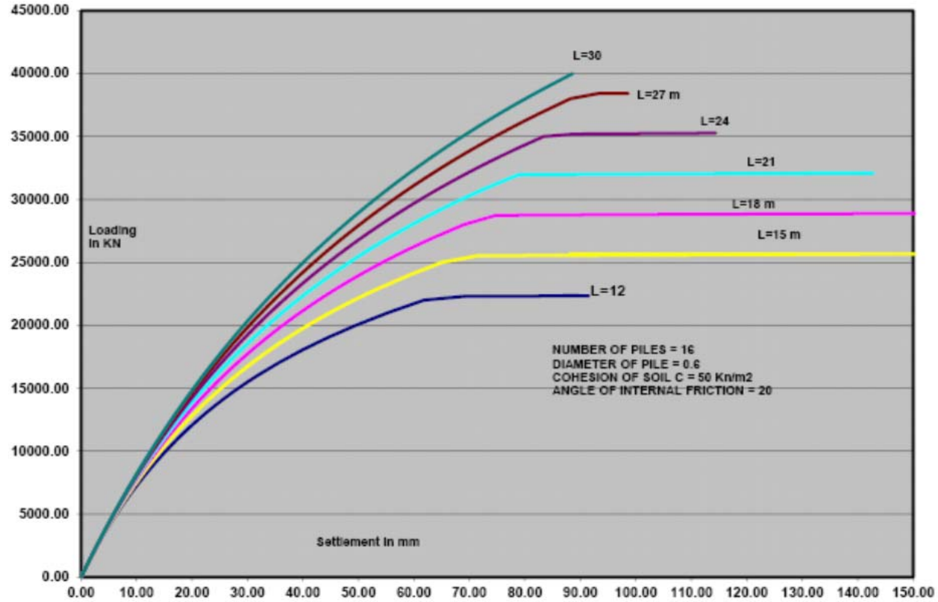
CONCLUSION:

The Conclusion drawn from the present study is summarizes as:

1. It is observed in the Poulos-Davis-Randolph (PDR) design methodology for piled Raft but using simple stiffness formula increase in pile length leads to increase in the settlement which is contrary to the practical observation. It is because, the stiffness of any structural member in our case pile decreases with increase in length for given diameter. This can be avoided by using length of pile up to depth of fixity. The length of pile below fixity due to surrounding soil can be neglected .This length of pile above depth of fixity is also called free standing length of pile. This free standing length can be calculated using Indian standard on pile. By using simple stiffness formulae in PDR methodology piled raft design can be simplified.
2. There is an optimum combination of stiffness of raft and pile in a pile raft foundation for achieving economical design. Beyond which further increase in stiffness of raft and pile makes the foundation uneconomical. It is suggested that while going for design and construction of piled-raft foundation, the limiting combination of stiffness of raft and pile must be considered.
3. Load carrying capacity of piled-raft increases with increase in length of pile. The increase in length of pile reduces the settlement of pile raft up to specific length beyond which further increase in length does not help in decreasing settlement.
4. Load carrying capacity of piled-raft increases with increase in diameter of pile in general however, the increase in diameter of pile reduces the settlement up to specific diameter beyond which further increase in diameter does not help in decreasing settlement.

Table1: Settlement in mm for different length up to failure.

Load KN	**Length of pile in meter**						
	12	15	18	21	24	27	30
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1000	1.13	1.12	1.12	1.11	1.11	1.11	1.11
2000	2.32	2.29	2.28	2.27	2.26	2.25	2.24
3000	3.58	3.53	3.49	3.46	3.44	3.42	3.41
4000	4.93	4.82	4.75	4.70	4.66	4.63	4.61
5000	6.37	6.19	6.07	5.99	5.93	5.88	5.84
6000	7.90	7.63	7.45	7.33	7.23	7.16	7.10
7000	9.54	9.15	8.90	8.72	8.59	8.48	8.40
8000	11.30	10.76	10.41	10.17	9.99	9.85	9.74
9000	13.19	12.46	11.99	11.67	11.44	11.26	11.11
10000	15.22	14.26	13.66	13.24	12.94	12.71	12.53
11000	17.42	16.18	15.41	14.88	14.50	14.21	13.98
120000	19.81	18.22	17.25	16.59	16.12	15.76	15.48
13000	22.41	20.40	19.19	18.38	17.80	17.37	17.03
14000	25.24	22.72	21.23	20.25	19.55	19.03	18.62
15000	28.34	25.22	23.39	22.20	21.36	20.74	20.26
16000	31.75	27.89	25.68	24.25	23.26	22.52	21.96
17000	35.51	30.77	28.10	26.41	25.23	24.37	23.71
18000	39.68	33.88	30.68	28.67	27.28	26.28	25.51
19000	44.32	37.24	33.42	31.04	29.43	28.26	27.38
20000	49.50	40.89	36.33	33.55	31.67	30.33	29.31
21000	55.29	44.86	39.45	36.19	34.02	32.47	31.31
22000	**61.79**	49.20	42.78	38.98	36.47	34.70	33.37
23000		53.96	46.36	41.93	39.04	37.01	35.51
24000		59.20	50.20	45.05	41.74	39.43	37.73
25000		**65.00**	54.35	48.37	44.57	41.95	40.03
26000			58.83	51.90	47.55	44.58	42.42
27000			63.69	55.65	50.68	47.32	44.90
28000			**68.98**	59.66	53.99	50.19	47.47
29000				63.95	57.48	53.19	50.15
30000				68.54	61.17	56.34	52.93
31000				**73.48**	65.08	59.64	55.84
32000					69.23	63.10	58.86
33000					73.63	66.74	62.02
34000					78.32	70.58	65.31
35000					**83.33**	74.62	68.75
36000						78.88	72.36
37000						83.39	76.13
38000						**88.16**	80.09
39000							84.24
40000							**88.61**



Graph 1 load settlement Curve

Table2: Settlement per unit load & length

Ratio	Length of pile in meter						
	12	15	18	21	24	27	30
Ultimate Loading(KN)	22000	25000	28000	31000	35000	38000	40000
Settlement mm	61.79	65.00	68.98	73.48	83.33	88.1	88.6
Settlemnt/ load	356	384.6	406	421	420	431	454
Settlement /length	5.14	4.33	3.83	3.49	3.47	3.26	2.95

Table3: Load Sharing Factor For Piled-Raft

Sr.No.	Diameter of pile	Number of Piles (N)				
		12	13	14	15	16
1	D=0.50	-1.158	-0.33	0.039	0.248	0.382
2	D=0.55	0.517	0.599	0.657	0.700	0.734
3	D=0.60	0.761	0.791	0.814	0.833	0.848
4	D=0.65	0.855	0.87	0.883	0.893	0.902
5	D=0.70	0.903	0.912	0.92	0.927	0.932
6	D=0.75	0.931	0.937	0.943	0.947	0.951
7	D=0.80	0.949	0.954	0.957	0.961	0.963

REFERENCES

H.G.Poulos "Design applications of Raft foundations" book Published by Thomas Telford Publishing

Dilip Kumar Maharaj (2004)"The Effect of raft size and pile length on load settlement behaviour of axisymmetric piled raft foundation" *Electronic Journal of Geotechnical Engineering.*

Dilip Kumar Maharaj (2004) "Three dimensional nonlinear finite element analysis to study the effect of raft and pile stiffness on the load–settlement behaviour of piled raft foundation" *Electronic Journal of Geotechnical Engineering.*

"Methods of Analysis of piled Raft foundations" A report prepared on Behalf of Technical Committee TC18 on Piled foundations.

Harry G. Poulos() "Piled Rafts In Swelling or Consolidating soils" *Journal of Geotechnical Engineering* ,Vol.119,No.2, February © ASCE.

Y.C.Tan, C.M.Chow & S.S. Gue , Gue & Partners Sdn Bhd, Kuala Lumpur, Malaysia. "A Design Approach for Piled Raft with Short Friction Piles for Low Rise Buildings on Very Soft Clay"

Oliver Reul and Mark F. Randolph. "Design Strategies for Piled Rafts Subjected to Nonuniform Vertical Loading" *Journal of Geotechnical and Geoenvironmental Engineering* Vol, 130 No. 1 January 1,2004 ©ASCE .

Tan,Y.C, Cheah S.W. and Taha M.R. "Methodology for Design of Piled Raft for Five – Storey's Buildings on Very Soft Clays

R.P.Cunha, H.G.Poulos, and J.C. Small "Investigation of Design Alternatives for A Piled Raft Case History". *Journal of Geotechnical Engineering and Geoenvironmental Engineering,* Vol.127,No 8,January,2001, © ASCE.

Luca de Sanctis and Gianpiero Russo "Analysis and Performance of Piled Rafts Designed Using Innovative Criteria" *Journal of Geotechnical Engineering and Geoenvironmental Engineering,* Vol.134, No8, August 1, 2008, © ASCE

Widjojo A. Prakoso student member ASCE and Fred H. Kulhaway Fellow ASCE. "Contribution to Piled Raft Foundation Design" *Journal of Geotechnical Engineering and Geoenvironmental Engineering* Vol.127,No 1,January,2001. © ASCE

Indian Standard "Code of Practice for Design and Construction of Pile Foundation" Part I- Concrete piles, Section – 2 Bored Cast In Situ Piles - IS: 2911(Part I/sec-2)-1979.

Luca de Sanctis and Alessandro Mandolini " Bearing Capacity of Piled Rafts on Soft Clay Soils Vol,132 No. 12 December 1,2006 ©ASCE.