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Development of Interaction Factors Charts for Piled Raft Foundation

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***Abstract*—**This study aims at analysing the load settlement behavior and predict the bearing capacity of piled raft foundation a series of finite element models with different foundation configurations and stiffness were established. Numerical modeling is used to study the behavior of the piled raft foundation due to the complexity of piles, raft, and soil interaction and also due to the lack of reliable analytical method that can predict the behavior of the piled raft foundation system. Simple analytical models are developed to predict the average settlement and the load sharing between the piles and the raft in piled raft foundation system. A simple example to demonstrate the applications of these charts is included.

***Keywords*—**Finite element, pile-raft foundation, method, PLAXIS software, settlement.

I. Introduction

IN pile raft foundation, piles provide support to control settlement and the raft delivers additional capacity at ultimate loading, which reduces the required number of piles. Also the raft may provide redundancy to the piles and thus reduces the potential influence of affected piles (if any) on the foundation performance. In this situation, the raft allows re-distribution of the load from "the affected piles to those that are not affected" [1]. Piles may also reduce the differential settlement when the raft alone exceeds the allowable settlement. The raft may "increase the lateral stress between the underlying piles and the soil, and thus can increase the ultimate load capacity of a pile as compared to free-standing piles" [2]. The general concept of pile raft foundation using settlement reducing piles was first proposed by [3], who stated that the idealized condition of uniform loading of the settlement; is where the largest load is in the centre and the smallest load at the edge. The settlement reducing piles are therefore introduced in the centre of the raft to reduce differential settlement. Pile and pile raft foundations have been extensively studied and significant contributions have been made by many authors [4]. In clay soil, the interaction properties between soil and structure are very important because of its deformation characteristic. [5] studied the interaction behaviour of pile–soil-raft under vertical loading, combined with the model of optimizing design. For high loads on the new structure, the risk of tilts and settlements of the new buildings have to be taken into account as well as the adjacent structures [6].

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Through the investigation of a high rise building in Australia, [7] showed that Pile Raft Foundation can become an economical alternative to conventional Pile Group Foundation. Reference [8] did an experimental study on Pile Raft Foundation; their study revealed that the total bearing capacity of a piled raft system is not significantly affected by the raft thickness, while the total load carried by piles is slightly reduced.

II. Settlement of Piled Raft

Stiffness of the piled raft can be obtained from the equation proposed by [9] as

$$K_{pr} = \frac{K_p + K_r(1 - 2\alpha_{rp})}{1 - \alpha_{rp}^2(\frac{K_r}{K_p})} \tag{1}$$

The pile raft interaction factor, α_{rp}, can be obtained from

$$\alpha_{rp} = 1 - \frac{\ln(\frac{r_c}{r_0})}{\zeta} \tag{2}$$

$$\zeta = \ln(\frac{r_m}{r_0}) \tag{3}$$

$$r_m = 2.5\rho(1 - v)L \tag{4}$$

where K_{pr} = stiffness of the piled raft; K_r = stiffness of the raft; K_p = stiffness of the pile group; α_{rp}= pile raft interaction factor; E_r = raft modulus of elasticity; E_p = Elastic modulus of pile material; E_s = soil modulus of elasticity; v_v = soil Poisson's ratio; t = raft thickness; a = raft radius; A_1 = area of pile section; A_2 = area of pile outer-circumference; r_c = average radius of pile cap; r_0 = radius of pile; P_r = percentage of the load carried by the raft; P_t = Total applied load; ζ = Influence of pile geometry; r_m= Maximum radius of influence of pile; ρ = Degree of homogeneity of the soil.

The raft stiffness K_r and pile group stiffness can be estimated from elastic theory. The single pile stiffness is computed from elastic theory, and then multiplied by a group stiffness efficiency factor which is estimated approximately from elastic solutions.

Reference [10] provides the following equation to estimate the pile stiffness

$$K_p = \frac{R_a E_p}{E_s} \tag{5}$$

(6)

$$R_a = \frac{A_1}{A_2}$$

where E_p = Elastic modulus of the pile material; E_s = Elastic modulus of surrounding soil (average deformation modulus of soil along pile shaft); R_a= Ratio of pile base to the area of the pile outer circumference (for rigid pile, R_a = 1); A_1 = Area of the pile shaft; A_2 = Area of the pile section

Reference [11] computed the raft stiffness as:

$$K_r = \frac{4\, E_r B_r t_r^3 (1 - v_s^2)}{3\pi E_s L_r^4 (1 - v_r^2)} \quad (7)$$

where E_r = Elasticity modulus of the raft; L_r = Length of the raft; B_r = Width of the raft; v_r = Poisson's ratio of the raft

The percentage of the load carried by the raft can be determined from:

$$\frac{P_r}{P_p + P_r} = \frac{K_r * (1 - \alpha_{rp})}{K_p + K_r * (1 - 2 * \alpha_{rp})} \quad (8)$$

Then the load carried by the raft is:

$$P_r = \left(\frac{K_r * (1 - \alpha_{rp})}{K_p + K_r * (1 - 2 * \alpha_{rp})} \right) (P_p + P_r) \quad (9)$$

The load sharing by the pile group can be determined from:

$$P_p = P - P_r \quad (10)$$

where P is the total load.

The interaction factor can be determined from its basic definition as;

$$\alpha_{pr} = \frac{k_r}{P_r} (w_{pr} - \frac{P_p}{k_p}) \quad (12)$$

III. Development of Interaction Factors Charts

The interactional charts are developed to illustrate the concept described in previous sections. The finite element method Plaxis software was used to estimate the raft and piles stiffnesses instead of using equations. These charts can be used to predict the load sharing between the piles and raft in preliminary stage of piled raft foundation system.

IV. The Steps Used for the Development of Interaction Factors Charts

The following steps were used to develop the interaction factors charts from finite element method and analytical solution proposed by [12] as;

1. The pile group and raft stiffness are obtained from finite element method.
2. The load sharing between the piles, P_p, and raft, P_r are determined according to finite element analysis.
3. The average settlements of piled raft foundation are obtained from finite element analysis.
4. The interaction factors are calculated using (1).

The data used for development of interaction factors are shown in Table I.

TABLE I
Data Used for Development of Interaction Charts

Parameter	Name	Soil	Raft	Pile	Unit
Young's modulus	E	$100 * 10^3$	$3 * 10^7$	$3 * 10^7, 3 * 10^8$	kN/m^2
Poisson's ratio	v	0.45	0.15	0.15	–
Unit weight	γ	20	24	24	kN/m^3
Raft length	L_r	–	40	–	m
Raft breadth	B_r	–	40, 20	–	m
Thicknes	t_r	–	1.0	–	m
Pile length	L	–	–	10, 25, 50, 100	m
Pile diameter	d	–	–	1.0	m
Pile spacing	s	–	–	$2d, 3d, 4d, 5d, 6d$	m

The piled raft interaction factors and stiffnesses charts are shown in Figs. 1-5.

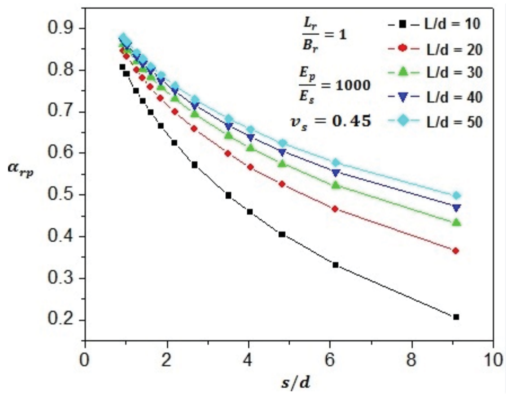


Fig. 1 Piled Raft Interaction Factor for $\frac{E_p}{E_s} = 1000, v_s = 0.45$, and $\frac{L_r}{B_r} = 1$

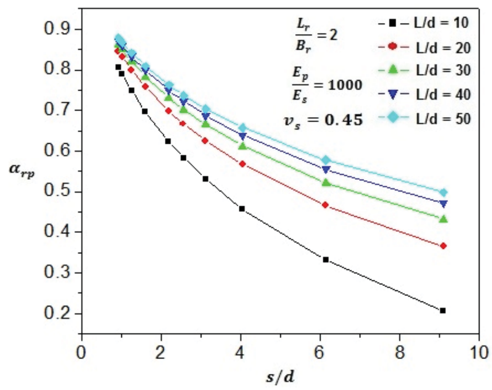


Fig. 2 Piled Raft Interaction Factor for $\frac{E_p}{E_s} = 1000, v_s = 0.45$, and $\frac{L_r}{B_r} = 2$

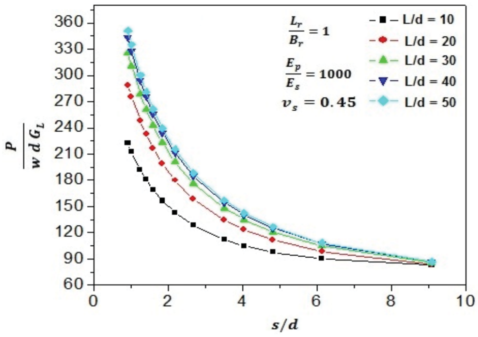


Fig. 3 Piled Raft Stiffness for $\frac{E_p}{E_s} = 1000, v_s = 0.45$, and $\frac{L_r}{B_r} = 1$.

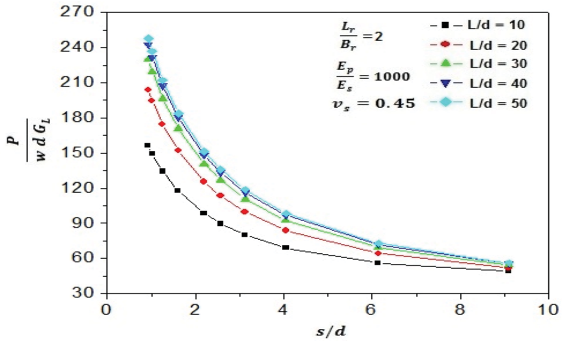


Fig. 4 Piled Raft Stiffness for $\frac{E_p}{E_s} = 1000, v_s = 0.45$, and $\frac{L_r}{B_r} = 2$

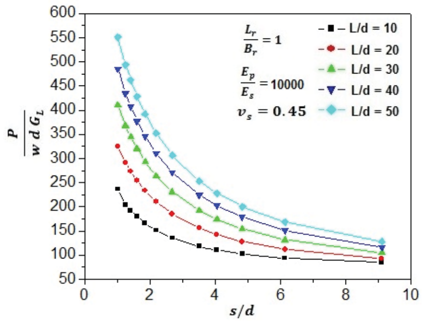


Fig. 5 Piled Raft Stiffness for $\frac{E_p}{E_s} = 10000$ and $\frac{L_r}{B_r} = 1$

V. Worked out Example

As an example, to demonstrate the application of the developed charts, a building transmitted a load of 100 MN to the Piled raft foundation is considered. The geometry and material properties of piles, raft and soil are shown in Table II.

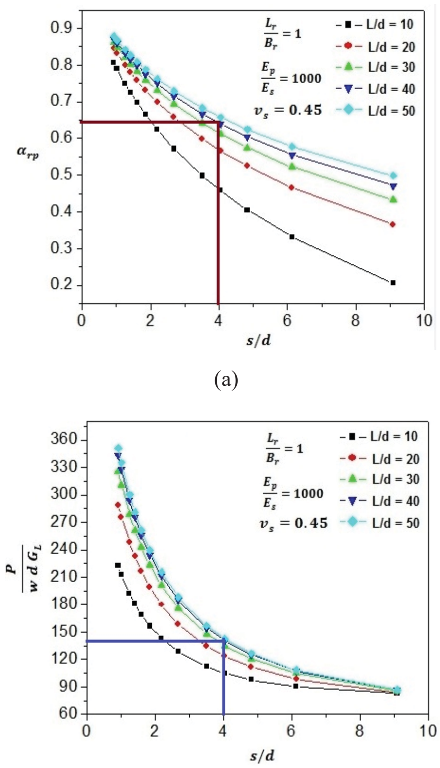
From Fig. 6, the value of interaction factor, α_{pr}, and the dimensionless vale $\frac{P}{w\,d\,G_L}$ are equal to 0.65 and 140 respectively.

The shear modulus can be estimated according to:

$$G_L = \frac{E}{2(1+v)} \tag{32}$$

TABLE II
Data Used for Worked Out Example

Parameter	Soil	Raft	Pile	Units	Group dimensionless value	
E	100	$100x10^3$	$100x10^3$	Mpa	E_p/E_s	1000
v	0.45	0.2	0.2	$-$	L/d	40
d	$-$	$-$	0.5	m	s/d	4
L	$-$	$-$	20	m	L_r/B_r	1
s	$-$	$-$	$4d$	m		
L_r	$-$	40	$-$	m		
B_r	$-$	40	$-$	m		
t_r	$-$	1.0	$-$	m		



(a)

(b)

Fig. 6 The values of Interaction Factor and the Settlement of the Building where P = total load on the foundation, w = average settlement, d = pile diameter and G_L is shear modulus at the end of the pile base

$$G_L = \frac{100}{2(1+0.45)} = 34.4828\,Mpa$$

$$\frac{P}{w\,d\,G_L} = 140$$

$$w = \frac{P}{140 * d * G_L} = \frac{100}{140 * 0.5 * 34.4828} = 0.0414\,m$$

The average settlement = 41.4 mm.

VI. Conclusion

Simple analytical models are developed to predict the average settlement and the load sharing between the piles and the raft in piled raft foundation system. These charts can be used to predict the load sharing between the piles and raft in preliminary stage of piled raft foundation system.

References

[1] H.G. Poulos, Piled raft and compensated piled raft foundations for soft soil sites, Geotechnical Special Publications, No 129, ASCE, pp. 214 – 234.

[2] R. Katzenbach, G. Bachmann, H. Ramm, "Combined Pile Raft Foundation (CPRF): An appropriate solution for foundation of high-rise building" Sloak Journal of Civil Engineering (SJCE), 2005, pp. 19-29.

[3] J.B. Burland, B.B. Brons, V.F.B. Mello, "Behaviour of foundation and structures" Proc. 9th int conf. On Soil Mech. And Foundation Eng., Tokyo, vol. 2, pp. 495-546.

[4] W.G.K. Fleming, A.J. Randolph, and W.K.Elson, Piling engineering. Taylor & Francis Group, London, 1992.

[5] X. Chen, P. Qian, "Research on optimizing design of pile raft foundation in soft soil" Proc. Of third international conference on soft soil engineering, Lee et al (eds), 2006, pp. 181-183.

[6] R. Katzenbach, G. Bachmann, H. Ramm, "Combined Pile Raft Foundation(CPRF): an appropriate solution for foundation of high-rise building" Sloak Journal of Civil Engineering (SJCE), 2005, pp. 19-29.

[7] F. Badelow, H.G. Poulos, J.C. Small, and P. Moyes, "Economic foundation design for tall buildings" Proceedings of International Conference on Piling and Deep Foundation. Amsterdam, 31 May-2 June, 2006, pp. 200-209.

[8] Al-Mosawi, J. Mosa, Fattah, Y. Mohammed, Al-Zayadi, and A. O. Abbas, "Experimental Observation on the Behavior of a Pile Raft Foundation" Journal of Engineering., vol. 17 (4), 2011, pp. 807-828.

[9] M.F. Randloph, "Developments in the Design and Construction of Piles" Discussion in Proc. of Conf. on Recent, London: ICE, 1979, pp. 389–390.

[10] M. F. Randloph, C. P. Worth, "Analysis of deformation of vertically loaded piles" ASCE, vol. 104, No. GT12, 1978, pp. 1485-1488.

[11] S.F. Brown, Practical foundation engineering handbook. New York: McGraw-Hill, 1996.

[12] M.F. Randolph "*Design methods for pile groups and piled rafts*", Proc. 13th Int. Conf. S.M. & Found. Eng., vol. 5, 1994, pp. 61-82.