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ANALYSIS OF LATERALLY LOADED PILE GROUPS

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ABSTRACT: *The analysis of pile groups subjected to lateral load and embedded in cohesionless type of soil strata comprising dry sand is presented in this paper through a parametric study. The complete three dimensional analysis is resorted to the group of two piles and three piles with series arrangement is considered for the purpose of a study. The response of the foundation head is considered in terms of displacement at top of the pile group and bending moment in piles. The study reveals the significant effect of the various parameters of the pile group such as pile spacing, pile size and configuration of the pile group on the behaviour of the pile group.*

Keywords - *Pile Spacing, Pile Size, Series Arrangement, Top Displacement, Bending Moment (B.M.).*

I. INTRODUCTION

Pile foundations are generally preferred when heavy structural loads have to be transferred through weak subsoil to firm strata. Besides vertical loads, these foundations in some situations are subjected to a significant amount of lateral loads. The lateral loads may be due to impact of ships during berthing and wave action in the case off-shore structures. Pile supported foundations of earth retaining and transmission tower structures will also be subjected to lateral loads. Building frames supported by piled foundations exposed to wind forces also fall under the category of the structures subjected to lateral loads. The problem of laterally loaded piles or pile group involves particularly the complex soil-structure interaction between the pile and pile cap.

The conventional approaches available to analyze laterally loaded piles include the elastic continuum approach [1, 2] and the modulus of subgrade reaction approach [3, 4]. The last three decades have witnessed a tremendous growth in the numerical methods and it is now possible to obtain a more realistic and satisfactory solution for any soil-structure related problems. Among the numerical methods the most versatile, prominent and successful procedure is the finite element method, which overcomes the drawbacks of the conventional approaches. Many studies reported in the literature include those by Desai [5], Desai and Abel [6], Banerjee and Driscoll [7] Desai and Appel [8], Desai *et al.* [9], Sawant and Dewaikar [10], Dewaikar *et al* [11], Chore *et al*. [12].

In this paper, 3-D FEA of pile group embedded in a homogenous cohesionless soil- strata comprising of dry sand and subjected to lateral load is presented. The analysis assumes linear elastic behaviour of the soil. It, further, takes into consideration the interaction between the pile gap and the underlying soil, generally the most neglected parameter in the analysis of pile groups. The member of the pile foundation such as the pile and the soil are discretized using 20 node iso-parametric continuum elements. Three degree of freedom is considered at each node, i.e., displacement in three directions in X, Y and Z. The interface between the pile and soil is modelled using 16 noded iso-parametric surface elements as proposed by Buragohain and Shah [13]. In the proposed study, the effect of various parameters of the pile foundation such as spacing between the piles in a group, size of the piles along with number of piles in a group is evaluated on the response of the foundation head. The response of the foundation head is considered in terms of the displacement at the top of the pile group and the bending moment in the piles.

II. PROBLEM DESCRIPTION

The two pile groups consisting of two and three piles respectively in the group are considered. Further, *series arrangement* of piles in the groups is considered for each pile group. When the direction of loading is parallel to the line joining piles, it is referred to as the series arrangement. In each case, the spacing between the piles is varied from 2D to 5D. Further, the piles are connected at their heads pile cap of concrete. The piles are connected at the heads by a pile cap of concrete. The analysis of the pile foundation is carried out for the lateral force (F_H) of magnitude of 1000 kN applied to the pile gap. The properties of the materials (Pile, soil and interface) are reported below.

Pile and Pile Cap : Young Modulus 0.3605×10^8 kPa, Poisson's Ratio 0.15

Pile Diameter (mm) : 500, 600, 800and 1000 mm
L/D Ratio : 10
Poisson's Ratio for Soil : 0.3
Young's Modulus of Elasticity : 1078 kPa

The properties of soil and soil-pile interface along the depth of piles are calculated as mentioned further. For cohesion less soil, the modulus of elasticity is considered to be proportional to overburden pressure and given by the following relation.

$$k = \frac{0.65\,E_s}{B\left(1-\nu^2\right)} \quad and \quad k = n_h\, z \quad from\ which$$

$$E_s = \frac{B\left(1-\nu^2\right) n_h\, z}{0.65}$$

In the above expression, k is subgrade modulus, E_s is modulus of elasticity, B is diameter of pile, z is depth from ground level, and ν is Poisson's ratio for sand which is taken as 0.3.In the present study, n_h is taken as 7700 for medium dry sand (IS 2911-Part I and Section I). Pursuant to this, the interface properties are defined by following relation.

$$k_s = E_s/10 \quad and \quad k_n = 10\,E_s$$

The values of Poisson's ratio (μ) and the values of the Young's modulus of elasticity (Es) deduced and further, that of the interface properties (k_s and k_n) along the depth of the pile are deduced using afore-mentioned relations.

III. RESULTS AND DISCUSSION

Effect on displacement

Displacement at the top of the pile group and bending moment in the pile are considered for the purpose of the comparison. The effect of the pile spacing, number of piles and the pile diameter is evaluated on the top displacement of the pile groups in the parametric study. The effect of the pile spacing on the horizontal displacement at the top of the pile group for different diameters and spacing considered in the present study is shown in Fig. 1.

For either pile group, i.e., G2PS and G3PS, displacements are found to decrease with increase in pile spacing indicating increase in the resistance to lateral loads. Displacements are, further, found to decrease with increase in number of piles. The displacements for various spacing are observed on higher side in respect of the group of two piles (G2PS) as compared to that in respect of the group of three piles (G3PS). With increase in number of piles, the stiffness of the pile group increases with increase in number of piles in a group.

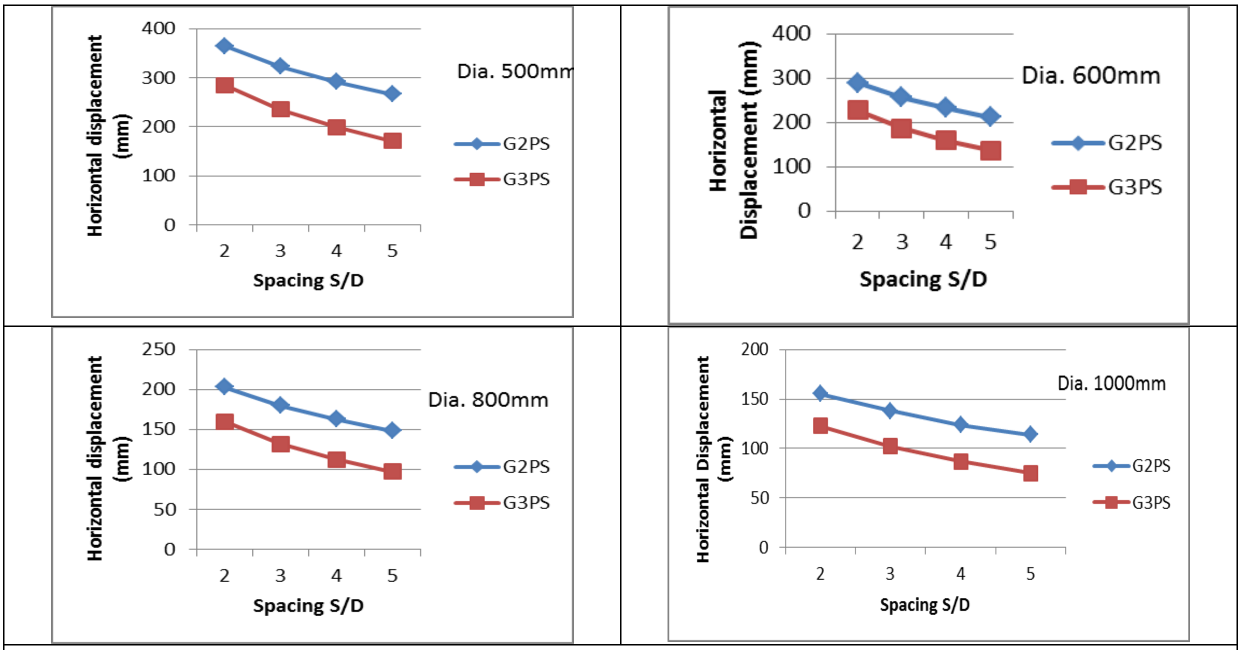

Fig.1: Variation of displacements (mm) at the top of the pile group for different diameters

The displacements for various pile sizes corresponding to different spacing considered in the present study in respect of group of two and three piles are shown in Table 1 and indicated graphically in Fig.2.

Table 1: Displacement (mm) for various pile sizes

Configuration/ Spacing	G2PS				G3PS			
	500 Size	**600 Size**	**800 Size**	**1000 Size**	**500 Size**	**600 Size**	**800 Size**	**1000 Size**
2D	365	289	203	155	285	227	160	123
3D	323	256	180	138	235	187	132	102
4D	292	232	163	124	199	159	112	86.7
5D	266	211	148	114	171	137	97.2	75.3

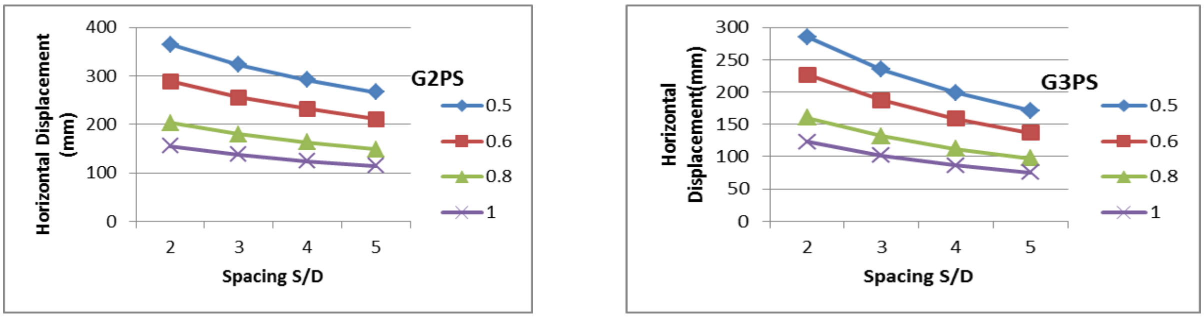

Fig.2: Variation of displacement with spacing for various pile sizes

Further, it is observed that with increase in the size of the pile, the displacement goes on decreasing with spacing for the group having similar number of piles therein in respect of either pile groups considered in the present study. The increase in pile size enhances the stiffness of the pile group as a result of which the displacement decreases for higher pile size.

Effect on capacity

The capacity of the pile group is considered as load corresponding to displacement of 10% of pile diameter. The horizontal capacity of pile groups for different pile diameters is indicated in Table 2. It is seen that with increase in pile spacing the capacity is found to increase. Further, the capacity is observed to increase with number of piles in a group under identical arrangement. The increase in pile size is, further, found to increase the capacity of the pile group.

Table 2: Horizontal capacity of the pile groups (kN)

Spacing / Configuration	Pile Size 500 mm				Pile Size 600 mm			
	2D	3D	4D	5D	2D	3D	4D	5D
G2PS	136.98	154.80	171.23	187.97	207.61	234.38	258.62	284.36
G3PS	175.44	212.77	251.26	292.40	264.32	320.86	377.36	437.96
Spacing / Configuration	Pile Size 800 mm				Pile Size 1000 mm			
	2D	3D	4D	5D	2D	3D	4D	5D
G2PS	394.09	444.44	490.80	540.54	645.16	724.64	806.45	877.19
G3PS	500	606.06	714.29	823.05	813.00	980.39	1153.4	1328.02

Effect on bending moment (BM)

The bending moment (B.M.) is evaluated along the depth of pile for different pile spacing and pile diameters in respect of the group of piles considered in the present study (G2PS and G3PS). The comparison of moments between the individual piles in the group of two piles is shown in Table 3.

Table 3: Comparison of moments (kN-m) in group of two piles for different pile sizes

500mm Pile Size *(Maximum)*					500 mm Pile Size *(Minimum)*			
	2D	3D	4D	5D	2D	3D	4D	5D
Front	414.97	358	295.22	232.76	9.52	8.12	-1.36	-86.62
Rear	413.95	413.94	356.76	229.75	9.66	8.17	4.62	-82.86
600mm Pile Size *(Maximum)*					600mm Pile Size *(Minimum)*			
Front	463.44	396.56	323.54	256.52	12.08	10.33	-42.1	-140.29
Rear	461.98	394.15	318.82	250.06	12.25	10.39	-38.92	-141.69

800 mm Pile Size (*Maximum*)					800 mm Pile Size (*Minimum*)			
Front	559.04	472.37	384.25	304.78	17.512	-1.88	-121.21	-241.80
Rear	556.38	466.84	373.64	287.46	17.781	6.00	-130.27	-263.36
1000 mm Pile Size (*Maximum*)					1000 mm Pile Size (*Minimum*)			
Front	653.17	548.35	448.75	354.71	23.26	-54.45	-196.62	335.84
Rear	648.82	535.41	428.71	321.99	23.63	-59.24	-225.95	-388.13

It is observed that the moments in the front and the rear pile are near about the same. It indicates that the either pile shares equal proportion of load. In respect of group of two piles, the maximum positive bending moment is found to decrease with increase in pile spacing. However, the same is found to increase with increase in pile size. The fixing moment, i.e., negative moment at pile head is increasing with increase in pile spacing and pile size.

Similarly, the comparison of moments between the individual piles in the group of three piles is shown in Table 4. From the values of the maximum moments mentioned in the table, it is observed that in respect of group of three piles for all the pile sizes, positive moments in the front and rear piles, i.e., corner piles, are almost same whereas the moments in central piles are different. It indicates that the corner piles are subjected to higher positive bending moment. Further, the moment is found to increase with pile size.

However, the fixing moment (negative moment) at the pile head is higher in the corner pile than that in central pile at lower spacing. But at the higher spacing fixing moments in corner piles are smaller than that in central pile. This indicates that large portion of load is shared by corner piles than central piles.

Table 4: Comparison of moments (kN-m) in group of three piles for different pile sizes

500mm Pile Size (*Maximum*)					500 mm Pile Size (*Minimum*)			
	2D	3D	4D	5D	2D	3D	4D	5D
Front	235.01	160.29	96.19	51.92	0.86	-93.96	-9.386	-30.76
Central	181.59	125.26	70.87	31.54	5.41	-48.08	-18.08	-51.74
Rear	235.43	160.75	96.22	51.57	6.92	-86.05	-7.59	-30.33
600mm Pile Size (*Maximum*)					600mm Pile Size (*Minimum*)			
Front	259.99	176.76	106.03	55.55	-28.87	-138.023	-243.322	-337.602
Central	195.45	131.69	71.581	29.212	6.708	-87.258	-214.74	-332.017
Rear	260.76	177.30	105.58	54.443	-20.314	-128.028	-236.586	-332.975
800 mm Pile Size (*Maximum*)					800 mm Pile Size (*Minimum*)			
Front	313.4	211.48	128.37	68.033	-84.949	-219.861	-345.712	-454.75
Central	217.37	137.47	66.85	23.029	-4.765	-180.566	-352.16	-508.461
Rear	314.62	212.94	126.96	65.787	-71.13	-197.41	-340.827	-452.989
1000 mm Pile Size (*Maximum*)					1000 mm Pile Size (*Minimum*)			
Front	371.14	249.77	154.85	85.737	-135.148	-290.746	-432.443	-550.466
Central	236.71	142.09	63.478	17.94	-64.332	-289.279	-511.339	-708.501
Rear	373.50	245.53	152.83	81.348	-115.586	-274.805	-432.113	-553.35

IV. CONCLUSIONS

The typical results emerging out of the parametric study presented in this paper brings out the following broad conclusions:

- With the increase in pile spacing, resistance to lateral load increases.
- With increase in number of piles in a group, resistance to lateral load increases.
- The capacity of a pile group increases with pile spacing and pile size.
- The capacity increases with number of piles.
- The moment at the pile head increases with increase in pile spacing.
- While front and rear piles in group of two piles shares near about equal load, large portion of the load is shared by corner piles than central piles in group of three piles.

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