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Effect of Pile Spacing on the Soil Structure Interaction of Pile Supported Building Frame Subjected To Lateral Loads

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Abstract: The process, in which the response of soil influences the motion of the structure and the motion of the structure influences the response of soil, is termed as soil structure interaction. The interaction among the structures, their foundations and the soil medium below the foundations alter the actual behavior of the structure considerably than what is obtained from the consideration of the structure alone. Investigations of soil structure interaction have shown that the response of a structure supported on flexible soil may differ significantly from the response of same structure when supported on a rigid base. This paper presents a study on the Soil-structure interaction effect of pile supported building frames embedded in cohesionless soils subjected to lateral loads. Tests were carried out on 2x2 pile groups and at spacing's of 3d, 5d and 7d. The effect of spacing on bending moment, pile head deflection and rotation of pile cap were studied.

Keywords: *Soil-structure interaction, building frames, pile foundations, lateral loads.*

1. Introduction

In the conventional design methodology, the structural engineer assumes that frames are resting on the fixed or unyielding base and the geotechnical engineer neglects the stiffness of the superstructure while calculating the foundation settlements. The actual behavior of the building frame and foundation will alter if one can consider the interaction effect of the building frame, foundation and soil. The foundation constructed on deformable soils undergoes deformation depending on the stiffness of the foundation, superstructure and soil. This interactive analysis is essential to assess the response of the structure accurately. Various researchers reported this interaction effect in their studies (King, G.J.W. and Chandrasekaran, V.S (1974), Noorzaei, J., Viladkar, M.N., Godbole, P.N., (1995), Mandal, A., Moitra, D., Dutta, S.C., (1998), Wood, D.M., Crewe, A. and Taylor, C (2002), Chore, H.S and R.K. Ingle (2008), Chandrasekaran, S.S, Boominadhan, A (2010), D. Thangaraj and K. Ilamparuthi (2010), Ravi Kumar Reddy C and Gunneswara Rao T D (2012)). Several studies of numerical work and the comparative studies were reported on pile foundations. However, little experimental work has been reported on the soil-structure interaction (SSI) analysis of the pile supported building frames subjected to static lateral load.

In the present study experiments were carried out for a building frame resting on pile foundations embedded in sandy soil subjected to static lateral loads. An attempt is made to study the effect of SSI on the response of the foundation in terms of pile head displacements, pile cap rotation and bending moments along the length of the pile through experimental investigations.

2. Materials Used

2.1. Soil

Sandy soil used in the present study was collected from the Godavari river basin, Andhra Pradesh, India. The Properties of the sand were Cu = 3.33, Cc = 1.134, classification – SP and Specific Gravity = 2.66.

2.2. Plane Frame, Pile Cap and Piles

To select the model pile material and its dimensions the scaling law (eqn.1) given by Wood et.al, (2002) was used in this study.

$$\frac{E_m}{E_p}\frac{I_m}{I_p} = \frac{1}{n^5} \quad (1)$$

Where, E_m= modulus of elasticity of model pile; E_p= modulus of elasticity of prototype pile; I_m= moment of inertia of model pile; I_p= moment of inertia of prototype pile; and 1/n= scale factor for length.

An aluminium rod of 16mm diameter was selected to simulate the prototype pile. The scaling factors used in the study are presented in Table 1.

Table 1: *Scaling factors used in the study*

Variable	Scaling Factors
Stiffness	1/10
Stress	1/10
Strain	1

Length	1/10
Density	1
Force	$1/10^5$

Aluminium plates of 20mm thickness were used as pile caps. The pile cap was attached to the top of piles such that a free standing length of 50 mm is available above the ground level. Columns of height 3.2 m and beam of span 5m of the plane frame were scaled in the similar manner. To maintain the fixed condition, beam column junctions were welded together. Piles were fixed to the pile cap by the system of screwing the pile heads into the pile cap.

3. Experimental Program

3.1. Experimental Setup

The schematic diagram of the experimental setup is shown in Fig. 1. Experiments were conducted on model pile groups entrenched in sand in a rectangular mild steel tank of 1.2m x 0.6m x 0.8m The piles were fixed with strain gauges along the length to study the bending behavior of the piles. The load is applied manually at the top of the frame in lateral direction with increments of 2kgs. LVDTs were used to measure the pile head deflections. By using dial gauges the rotation of the pile cap were measured. A 8 channel data acquisition system, comprising HBM make MGC Plus carrier frequency amplifier with Catman Easy Professional software, was used to monitor and store the data automatically.

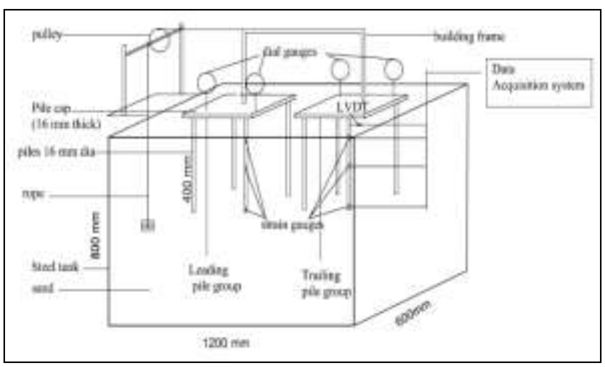

Fig. 1 *Experimental setup*

3.2. Sand Bed Preparation and Pile Installation

3.2.1. Test Procedure

Entire Sand bed of 750 mm thickness was prepared by Pluviation method. The static lateral load was applied to the model piles by inserting weights on a hanger connected to a steel rope set up over a pulley supported by the loading frame. The loads were applied in increments and to stabilize the deflection, each load was applied for 30 min. During the application of static loads, pile head displacement, and strains along the pile length were measured using the data acquisition system described earlier and dial gauges were used to measure the rotation of the pile cap.

3.3. Testing Phases

Static lateral load tests were conducted on model building frame supported with pile foundations embedded in sand with relative density of 75%. Tests were conducted on the 2x2 pile configuration at different spacing of 3d, 5d and 7d for an aspect ratio of 25.

4. Discussion on Test Results

4.1. Load –Deflection Behavior

The average load per pile V/s pile head deflection curves for 2 x 2 pile group with L/D of 25 is depicted in fig 2.

As shown in the figure, the pile head deflection increases non-linearly with applied lateral load and at smaller loads, it found that the variation of pile head deflection is smaller with variation in pile spacing. The variation for all the three spacing's is almost similar at smaller deflection of about 1.5 mm. But at higher loads, there is large variation with larger deflection for the piles with closer spacing's i.e., 3d spacing.

For an average load of 30N, the pile head deflection decreases by 34% and 56% when the spacing increases from 3d to 5d and 3d to 7d respectively. This larger deflection at lower spacing is due to soil-structure interaction. It can also be observed that at relatively large deflections, the average load carried by each pile reduces with a decrease in spacing.

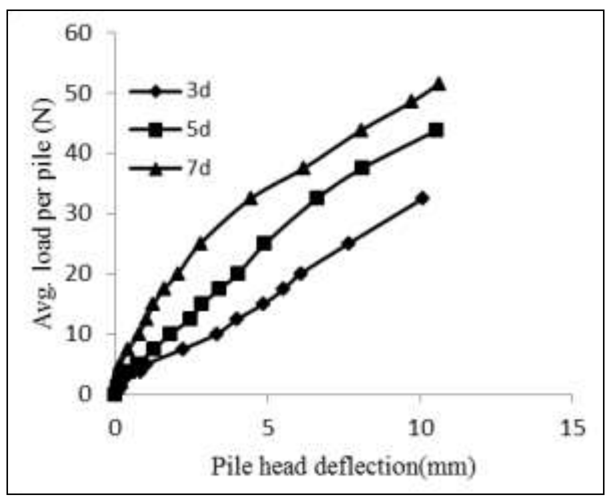

Fig. 2 *Measured load-deflection curves for piles in 2 x 2 pile group*

At larger deflections, there is more overlap of stress zones that results in reduction in load carrying capacity. It is found that at lower loads the deflection is varying linearly but as the load increases there is large variation in the deflection with the spacing.

4.2. Bending Moment Curve

The bending moment is calculated from the bending strain measurement at various points along the length of the model pile using the equation 2.

$$M= (E I \epsilon/r) \qquad (2)$$

Where, E= young's modulus of the model pile material; I= moment of inertia of the model pile; Є= measured bending strain; r= horizontal distance between the strain gauge position and neutral axis.

Fig. 3 shows the variation of bending moment along the length of the pile for various spacing's of 3d, 5d and 7d and for 2x2 pile group for an average load of 25 N per pile.

For a given load, the magnitude of maximum bending moment of the pile at closer spacing (3d) is found to be more when compared to larger spacing's of 5d and 7d. This difference in the bending moment for 3D spacing is attributed to the pile-soil interaction due to the shadowing effect. This shadowing effect becomes less significant as the spacing between the piles increases.

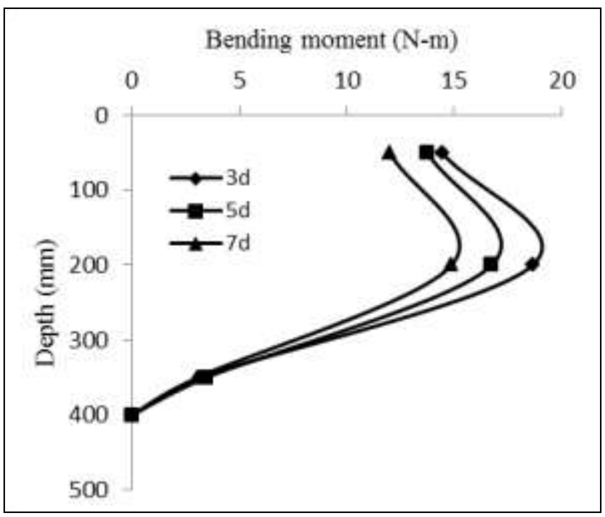

Fig. 3 *Measured bending moment profiles of 2 x 2 pile groups.*

For the present tested pile configuration of 2 x 2, the percentage reduction in maximum bending moment is 10% and 20% when the spacing increases from 3d to 5d and 3d to 7d respectively. It is also found that as the average load per pile increases, the variation in maximum bending moment with spacing also increases.

4.3. Rotation of the Pile Cap

As shown in Fig.1, dial gauges are attached to each of the pile groups on both sides of the frame and the variation in vertical movement of both corners of pile caps are noted. Rotation of the pile caps are calculated from the dial gauge readings and the horizontal distance between them.

Fig. 4 shows the variation in rotation of pile caps with pile spacing's of 3d, 5d and 7d with the change in average load per pile.

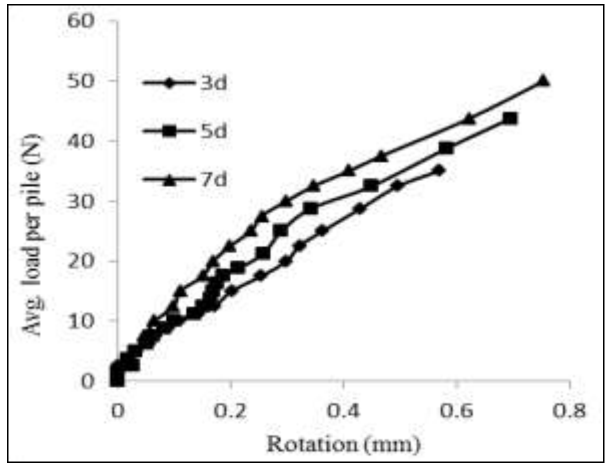

Fig. 4 *measured rotation of pile cap for 2 x 2 pile group*

For a given average load per pile, the rotation in the pile cap is found to decrease with an increase in pile spacing. The variation is very small when the average load per pile is less than 10 N. But as the load increases, the variation also increases. At a load of 30 N, the rotation decreases by 20 % and 33 % as the spacing increases from 3d to 5d and 3d to 7d respectively.

4.3.1. Rotation Variation between Leading and Trailing Group

The Load V/s rotation curves for the leading and trailing group with 3d spacing is shown in fig 5.

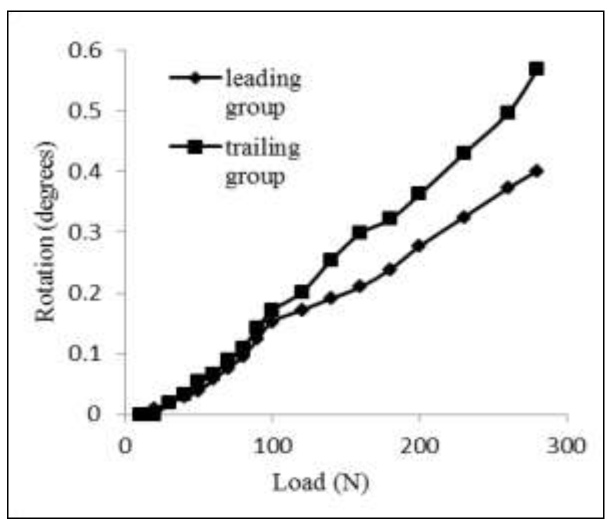

Fig. 5 *Measured rotations at 3D spacing for 2 x 2 configuration*

From this fig. it can be observed that, at loads below 100N, the variation of rotation between the leading and trailing groups is found to be smaller. But at higher loads, there is significant variation in rotation especially for pile spacing of 3d. The variation in rotation decreases as the pile spacing increases. There is as high as 45% variation in rotation between the trailing and leading group for 3D pile spacing at failure.

5. Conclusions

Based on the experimental investigation results, the following conclusions are drawn

1. Soil-structure interaction leads to significant increase in pile head deflection in the pile groups when the pile spacing is decreased. The deflection decreases by 34% and 56% when the spacing increases from 3d to 5d and 3d to 7d respectively. At larger deflections, there is more overlap of stress zones, which result in reduction of load carrying capacity for lower pile spacing's.
2. The magnitude of maximum bending moment at closer spacing of 3d is found to be more than that of larger spacing's. There is a reduction of about 10% and20% in maximum bending moment as the spacing increases from 3d to 5d & 3d to 7d respectively.
3. The rotation in the pile cap is found to decrease with an increase in pile spacing due to the increase in pile cap stiffness and soil-structure interaction. At a load of 30 N, the rotation decreases by 20 % and 33 % as the spacing increases from 3d to 5d and 3d to 7d respectively.
4. There is as high as 45 % variation in rotation between the trailing and leading group for 3d pile spacing at failure.

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