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LATERAL BEHAVIOUR OF PILE UNDER THE EFFECT OF VERTICAL LOAD

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ABSTRACT:
The laboratory and field test data on the response of piles under the combined action of vertical and lateral loads is rather limited. The current practice for design of piles is to consider the vertical and lateral loads independent of each other. This paper presents the effect of vertical load on the behaviour of a single pile under lateral load through laboratory experiments on aluminium pipe piles with outer diameter of 25 mm and internal diameter of 19mm. Pile was driven in poorly graded sand with 60% relative density. Influence of constant magnitude of vertical load (in range of 20%, 40%, 60% and 80% of Experimental Ultimate Vertical Load) on the lateral response of pile under free head condition for slenderness ratio of 10 and 15 was studied and compared. Pile was instrumented with dial gauges to measure deflection at top of pile. The model test results have shown that the influence of vertical loads on the lateral response of piles is to significantly increase the capacity in sandy soil. The test results are compared with the results from the literature and are found to be in favourable agreement.

KEY WORDS: *PILE LOAD TEST, LATERAL LOAD, COMBINED LOAD, LATERAL LOAD TEST.*

1. Introduction

WDM Pile foundations are extensively used to support various structures built on loose/soft soils, where shallow foundations would undergo excessive settlements or shear failure. These piles are used to support vertical loads, lateral loads, or a combination of vertical and lateral loads. However, in view of the complexity involved in analysing the piles under combined loading, the current practice is to analyse the piles independently for vertical loads to determine their bearing capacity and settlement and for the lateral load to determine their flexural behaviour.

The methods of analysis commonly used in predicting the behaviour of piles and pile groups under pure axial loads could be categorized into (1) subgrade reaction method (Coyle and Reese 1966; Kraft et al. 1981; Zhu and Chang 2002); (2) elastic continuum approaches (Poulos 1968; Xu and Poulos 2000); and (3) finite-element methods (Desai 1974; Trochanis et al. 1991; Wang and Sitar 2004). Similarly, the methods to study the behaviour of piles and pile groups under pure lateral loads could be categorized into (1) limit state method (Broms 1964); (2) subgrade reaction method (Matlock and Reese 1960); (3) elastic continuum approach (Poulos 1971; Banerjee and Davis 1978); (4) *p-y* method (Reese et al. 1974); and (5) finite-element methods (Muqtadir and Desai 1986; Brown and Shie 1991; Trochanis et al. 1991; Kimura et al. 1995; Yang and Jeremic 2002; Yang and Jeremic 2005).

Studying the interaction effects on piles under combined loads would no doubt call for a systematic and sophisticated analysis. The literature available in this field is sparse. The limited information on this topic based on analytical investigations (Davisson and Robinson 1965; Ramasamy 1974; Goryunov 1975) reveals that for a given lateral load, the lateral deflection increases with the combination of vertical loads. However, experimental (Pise 1975; Sarochan and Bykov 1976; Jain et al. 1987) and field investigations (McNulty 1956; Bartolomey 1977; Zhukov and Balov 1978) suggest a decrease in lateral deflection with the combination of vertical loads. S. Karthigeyan, V. V. G. S. T. Ramakrishna and K. Rajagopal (2007)[1] attempted to explain this phenomenon by three-dimensional (3D) finite element analysis and reported that (1) the response of the piles in both clayey and sandy soils under lateral loads is influenced by the presence of vertical loads; (2) the presence of vertical loads increases the lateral load capacity of piles in sandy soils by as much as 40% depending on the level of vertical load. Thus experimental model testing would be the most suitable approach to study and analyse the response of pile under lateral load in the presence of vertical load. Since the piles are not often adequately designed to resist lateral loads, the response of piles under lateral load in the presence of vertical loads is more critical and interesting for the design engineers. Besides, the influence of the pile slenderness ratio (*L*/D) is also an important parameter to be considered in pile design. In view of this, the present paper focuses on the study of piles subjected to pure lateral loads and combined vertical and lateral loads through model testing.

2. EXPERIMENTAL INVESTIGATION

Test Programme

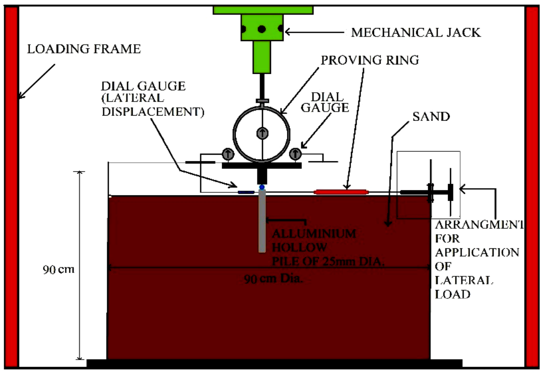

Figure 1. Schematic Diagram of Test Setup

Total 10 number of lateral load tests were conducted on sand with no vertical load and with constant magnitude of vertical load (in range of 20%, 40%, 60% and 80% of Ultimate vertical load). Also a compression test was carried out to determine Ultimate vertical load.

Model pile load test was conducted on sand in the Geotechnical Laboratory, Applied Mechanics department, L.D. College of Engineering, Ahmedabad. The experimental tests are performed on model piles in a RCC circular tank of Internal diameter = 0.9 m, external diameter = 1.0 m and Height of tank = 0.9 m as shown in Fig. 1. The boundaries of the tank affects the stress and displacement fields in the soil therefore general clearance of minimum five times the pile-diameter was maintained between the bottom of tank and bottom surface of steel hollow pile, also dimensions of the tank provides a minimum lateral clearance of five times the pile-diameter. The soil model was prepared by compacting the sand in layers, each of 100 mm thick up to 750 mm height. The sand was compacted at a relative density of 60%.

Figure 2. Experimental setup for the test

Properties of Sand

The dry sand used was clean and poorly graded, with the gradation shown in Fig. 3. The index and engineering properties of silty sand used for the study are shown in Table 1.

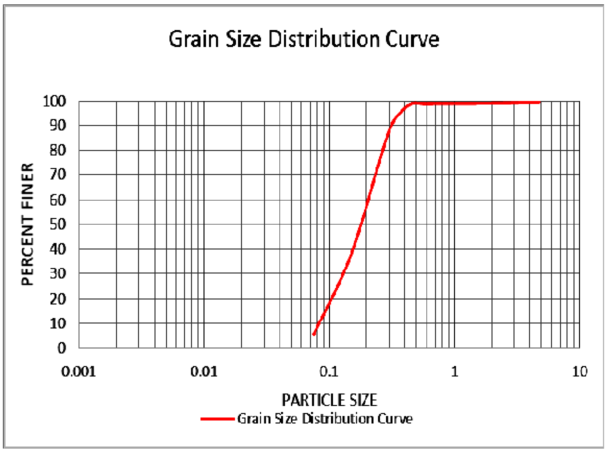

Figure 3. Grain size distribution graph

Table 1: Physical properties of sand

Test	Symbol	Determination	IS Code
Soil classification as per IS		Poorly Graded Sand(SP) $C_u = 2.5$ $C_c = 1.314$	IS :2720 (Part 4)-1985
Specific Gravity	G	2.637	IS :2720 (Part 3)-1980
Relative density	I_d	$I_d = 60\%$ ρmin = 16.78KN/ m^3 ρmax = 18.18KN/ m^3	IS :2720 (Part 4)-1983
Φ of sand	Φ	32.42^0	IS :2720 (Part 13)-1997

For all tests, the sand was placed with a relative density of 60%. To achieve uniform density, the surface vibration technique, with the surface vibrator device was used.

Model Piles and Instrumentation

Aluminium pipes with outer diameters of 25 mm and wall thicknesses of 3 mm were used as model piles. L/D ratio was 10 and 15 so the length of pile was 250 mm and 375 mm. Piles were instrumented for measuring displacement at the top of the pile. The bottom of the pile was closed by a 60° conical shoe. The dial gauge was kept on pile surface by chipping off uneven surface of the side. The dial gauge tip rested on the central portion of the chipped plain surface.

Pile Installation

The pile was placed with the tip resting on the sand surface in the test tank. A pile cushion consisting of a thick geotextile layer and a 6-mm-thick steel plate was placed over the pile. The pile was slowly driven into the sand by gentle blows with a small weight on the steel plate. The verticality of the pile group was checked with a plumb after every 50 mm penetration. The pile of 250 mm and 375 mm length was driven to a depth of 220 mm and 245 mm respectively from the sand surface. The pile head was free and the pile head was kept 30 mm above the sand surface to make provision for application of lateral load.

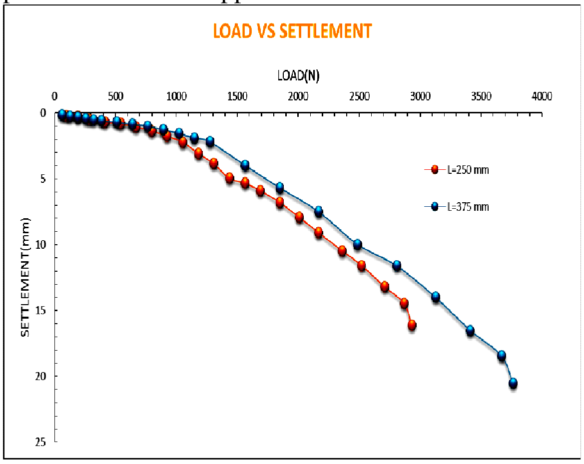

Figure. 4. Load vs Settlement graph for compression test

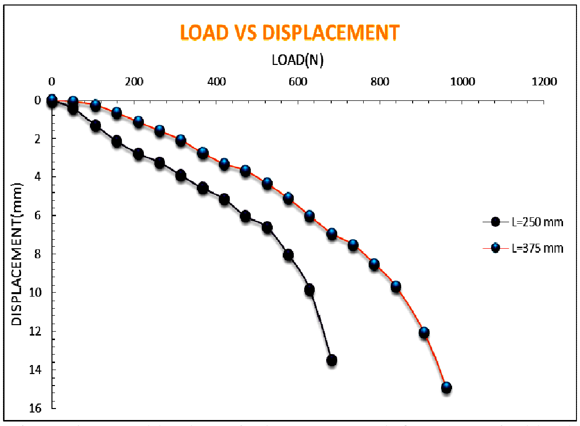

Figure 5. Lateral load vs Displacement graph for NO vertical load

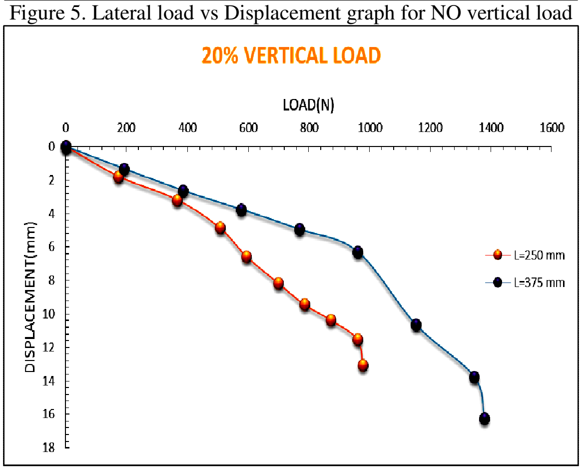

Figure 6. Lateral load vs Displacement graph for 20% vertical load

Test Procedure

A series of 10 tests were carried out on piles under free head condition with the different magnitude of constant vertical load. Lateral load tests were carried out on single pile for no vertical load and for 20%, 40%, 60% and 80% of the Experimental Ultimate Vertical Load. A compression test was also conducted for pile having L/D 10 and 15 to calculate the Ultimate Vertical Load for free head pile. The lateral load was applied by about 10 equal increments. The horizontal displacement of the pile head was measured using mechanical dial gauges. Each load increment was maintained for a minimum of 10 min till the displacement stabilized with no movement.

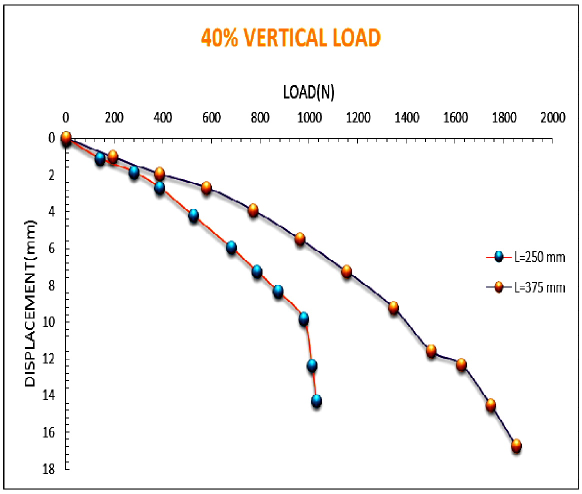

Figure 7. Lateral load vs Displacement graph for 40% vertical load

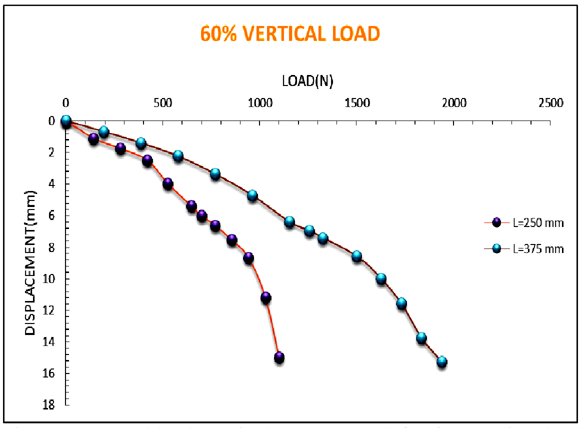

Figure. 8. Lateral load vs Displacement graph for 60% vertical load

The combined loads are applied in two stages. In the first stage, vertical loads were applied and then in the second stage, lateral loads were applied while the vertical load was kept constant. This type of loading is similar to that in field situations such as pile jetties, transmission line towers, and overhead water tanks, etc. Here, the piles are first subjected to vertical loading from the weight of the deck or superstructure. The lateral loading may be caused by wind, wave loading, ship impact, etc. while the piles are subjected to vertical loads.

3. RESULTS AND DISCUSSION

Fig. 4 shows the Load-Settlement curve of the compression test. The ultimate load carrying capacity of the pile having L/D 10 and 15 for the compression test is 2933 N and 3762 N respectively, which is similar to that expected from theory. Lateral load-

Displacement curves from 10 tests carried out on single pile embedded in sand with and without vertical load shown in Fig. 5 to Fig. 9. Soil failure occurs before the failure of pile. Hence, the lateral response of pile will be governed by the ultimate lateral load carrying capacity of the soil. The ultimate lateral resistance of pile subjected to constant magnitude of vertical load was obtained from the lateral load-displacement curves.

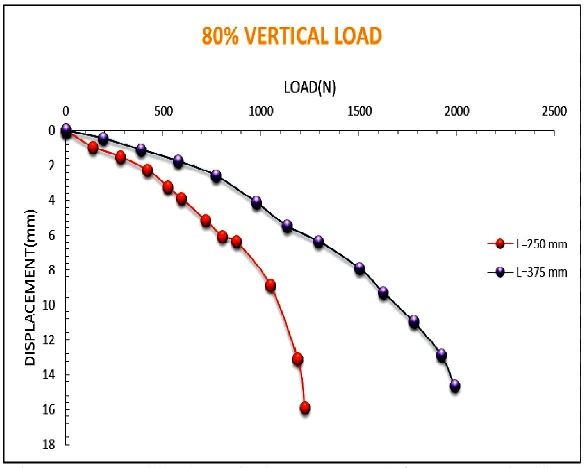

Figure 9. Lateral load vs Displacement graph for 80% vertical load

The ultimate lateral resistance of pile having L/D 10 and 15 subjected to pure lateral load is 681 N and 960 N respectively.

The lateral load carrying capacity of pile is increased when it is subjected to vertical load. The increase in ultimate resistance of pile for slenderness ratio 10 is 43.59%, 51.28%, 61.54% and 79.49% for pile subjected to 20%, 40%, 60% and 80% vertical load respectively w.r.t. pile subjected to no vertical load.

The increase in ultimate resistance of pile for slenderness ratio 15 is 43.64%, 92.73%, 45.59% and 107.27% for pile subjected to 20%, 40%, 60% and 80% vertical load respectively w.r.t. pile subjected to no vertical load.

The increase in safe lateral load of pile for slenderness ratio 10 corresponding to 12mm displacement for 20%, 40%, 60% and 80% of vertical load with respect to pure lateral load test is 46.80%, 52.57%, 58.48% and 75.15% respectively.

The increase in safe lateral load of pile for slenderness ratio 15 corresponding to 12mm displacement for 20%, 40%, 60% and 80% of vertical load with respect to pure lateral load test is 38.14%, 76.85%, 95.86% and 108.50% respectively.

The application of vertical load clearly shows the increase in the ultimate lateral resistance of pile.

4. CONCLUSION

Model tests were carried out on Aluminium single pile of fixed L/D ratio of 10 and 15. The test results are analysed and presented in here. Based on the foregoing study, the following conclusions are drawn:

1. The vertical load has a significant influence on the lateral response of pile embedded in sand as pile induces complex interaction effects due to simultaneous mobilization of passive earth pressure due to a horizontal load and pile skin friction due to vertical load
2. By increasing the slenderness ratio from 10 to 15, ultimate lateral resistance corresponding to each slenderness ratio showed an increment of about 27% to 80%.
3. By increasing the magnitude of vertical load by 20%, ultimate lateral resistance corresponding to each increment showed an increment of about 35% to 74%.
4. The ultimate lateral load of pile increases with the increase in the magnitude of vertical load up to 49% to 107% w.r.t no vertical load.
5. With the increase in the slenderness ratio the total displacement of pile head shows an increment of 2 mm to 10 mm.
6. With the increase in the magnitude of vertical load by 20% the total displacement of pile shows a decrement of 0.5 mm to 2 mm.

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