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Parametric Study of Under-Reamed Piles in Sand

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***Abstract*— Under-reamed piles are bored cast-in-situ concrete piles having one or more number of bulbs formed by enlarging the pile stem. These piles are best suited in soils where considerable ground movements occur due to seasonal variations, filled up grounds or in soft soil strata. Provision of under reamed bulbs has the advantage of increasing the bearing and uplift capacities. It also provides better anchorage at greater depths. An experimental work was programmed and carried out to understand the behaviour of under-reamed piles subjected to vertical load. The type of soil used in the present laboratory investigation was sand and mild steel under-reamed pile models. This study presents the results of analyses conducted on the influence of geometrical features of the under-reamed pile on its ultimate load carrying capacity. The geometrical features include the length of the pile, number, spacing and position of the bulb.**

Keywords—: Under-reamed pile, Bulb, Geometry, Ultimate bearing capacity, Compressive load

I. INTRODUCTION

Under-reamed piles are of bored cast insitu and bored compaction concrete types having one or more bulbs formed by suitably enlarging the bore hole for the pile stem. With the provision of bulb(s), substantial bearing or anchorage is available. These piles find application in widely varying situations in different types of soils where foundations are required to be taken down to a certain depth in view of considerations like the need (a) to avoid the undesirable effect of seasonal moisture changes as in expansive soils; (b) to reach firm strata; (c) to obtain adequate capacity for downward, upward and lateral loads and moments; or (d) to take the foundations below scour level.

When the ground consists of expansive soil, for example black cotton soil, the bulb of the under-reamed pile provides anchorage against uplift due to swelling pressure apart from the increased bearing. In case of filled-up or otherwise weak strata overlying the firm strata, enlarged base in the form of under-reamed bulb in firm strata provides larger bearing area and piles of greater bearing capacity can be made. In loose to medium pervious sandy and silty strata, bored compaction piles can be used as the process of compaction increases the load bearing capacity of the piles. Under-reamed piles may also be used under situations where the vibration and noise caused during construction of piles are to be avoided. The provision of bulb(s) is of special advantage in under-reamed piles to resist uplift and they can be used as anchors.

Under-reamed piles date back to early 1940s. They were first used in Texas state in USA where smectic clay is abundant. They were intended primarily to resist the uplift forces developed on them due to the heaving of the ground. The first systematic studies on these piles were conducted in South Africa in 1949 by Jenkins and Henkel. The study of Jenkins was followed by the Australian researcher Tusker. In India they are extensively used since the 50’s to anchor building foundations in the expansive black cotton soils, at a depth where ground movements due to changes in moisture content are negligible. These piles have been extensively used in India to support a wide variety of structures in almost all types of soil strata on the basis of safety and economy. Depending on these considerations these piles are being increasingly used for a wide variety of structures, e.g., buildings both residential and industrial, transmission line, TV, antenna and satellite tracking towers, tanks, over bridges, machine foundations and dry docks etc.

Guidelines for design and construction of under-reamed piles are available in a handbook by Sharma et al. (1978). Chummar (1986) and Sharma (1986) discuss the use of under-reamed piles in India, with special reference to construction practices and situations where they are superior to other foundations. In favourable soil conditions such as stiff to hard clays, multi-under-reamed drilled shafts may provide cost savings due to increased capacity when compared with single under-reamed drill shafts. Short bored under-reamed piles have been popularized in India by Central Building Research Institute, Roorkee, primarily for use in ‘black cotton soils’, but they have since found wider application in various soil conditions under a variety of situations. In India, the use of under-reamed pile is governed by the code IS: 2911 (Part III) – 1980.

The load carrying capacity of under-reamed pile depends mainly on the pile dimensions and soil strata. Axial load on a pile is transmitted by point bearing at the toe and the projected area of the bulb and skin friction along the pile stem. Depending upon the nature of soil and pile geometry, in addition to the skin friction on stem, friction can develop on the soil cylinder between the extreme bulbs. In under-reamed compaction piles, the mechanism of load transfer remains the same but soil properties improved by compaction process are considered. In uplift load, point bearing component at toe is absent but unlike other straight shaft piles, point bearing on an annular projection of the bulb is present.

II. LITERATURE REVIEW

A. Studies on Under-reamed pile by Numerical Method

Zahra Mardani and Hamid (2013) numerically studied on tensile bearing capacity of under-reamed pile using finite element method and results was shown that under-reamed piles have a greater bearing capacity comparing to normal piles with uniform stem with the same volume and length. Niroumand et al. (2012) studied uplift capacity of enlarged base piles in sand and found that the ultimate uplift capacity is dependent on the relative undrained/drained shear strength of cohesionless soil, the depth ratio of embedment and soil thickness ratio.

Srilakshmi and Kurian (2010) studied on geometrical features of under-reamed piles using finite element method by ANSYS software, maximum spacing between two piles was reached 1.75 m for bulb diameter of 0.75 m, stem diameter of 0.3 m and pile depth of 3.5 m. C. Y. Lee's research (2007) was about settlement and load distribution analysis of under-reamed piles, also elastic behavior of under-reamed piles in homogeneous soils was presented in the research. The modified boundary element method was used to obtain parametric solutions of under-reamed piles under axial loading. Consideration is given to the effect of pile slenderness ratio, pile-soil relative stiffness, bulb diameter and bearing stratum on response of under-reamed piles. The characteristic of load distribution along the pile length was also studied. It was found that the most efficient means of reducing under-reamed pile settlement occurs when the enlarged base is resting on stiffer soil stratum.

Dilip Kumar, et al. (2004) worked on uplift capacity of pile by finite element method, in the research the load carrying capacity of an individual pile was found more than that of a pile in a group in case of piles under uplift load and of varying cross-section.

B. Studies on Under-reamed pile by Experimental Method

Watanabe, et al. (2011), worked on static axial reciprocal load tests of cast-in-place nodular concrete pile and nodular diaphragm wall. As a result of load tests, the nodular cast-in-place concrete pile and nodular diaphragm wall have large tension and compression resistance. The tension resistance at the nodular part and under-reamed part shows a large value.

Annie Peter et al. (2006), conducted research on concrete under-reamed piles, and performed various loading experiments on these piles. They plotted several stress-strain diagrams indicating higher strength of under-reamed piles under tensile loading in comparison with conventional piles.

From the laboratory study on pile models conducted by A.V.P Kumar and Yagi (1999), there was no significant change in uplift capacity of under-reamed pile with spacing of the bulbs. The theoretical ultimate uplift load predicted by Bureau of Indian Standard Method was compared with the experimental values. The theoretical values were higher than the experimental values. Hence, a modified expression to compute the uplift capacity of under-reamed piles was developed and presented.

Makarchian and Peyman Khademi (1988) , in a laboratory study on effective parameters of uplift force in sandy soil found that the most effective items on increasing tensile bearing capacity is respectively as follow: type of the pile, embedment length, relative density of sand and pile diameter.

Martin et al. (1983), studied under-reamed piles with two bulbs in clay and compared the results with single bulb under-reamed piles, and found that two-bulb under-reamed piles are good alternatives for other piles in over consolidated stiff clay. The distance between the bulbs was considered 1.25 times diameter of the bulb, and it was stated that further studies are required for optimum distance between the bulb and its positive effect upon various factors.

III. OBJECTIVES OF THE STUDY

- To obtain the load settlement variation for conventional pile and under-reamed pile.
- To study the influence of parameters of the under-reamed pile such as length of the pile, number, spacing and position of the bulb on its ultimate load carrying capacity.

IV. MATERIALS USED

A. Sand

The investigation is limited to cohesionless soils. Hence, sand is used in the test bed. The sand used for this investigation was brought from Perumathura beach, Trivandrum, Kerala. The properties of sand are shown in Table 1.

TABLE I. SOIL PROPERTIES

Property	Value
Specific Gravity	2.65
% of fine sand	59%
% of medium sand	41%
Minimum density index	1.48g/cc
Maximum density index	1.76g/cc
Minimum void ratio	0.51
Maximum void ratio	0.788
Density of soil sample	1.63g/cc
Angle of internal friction	25°

B. Model Piles

Two sets of mild steel pile models of length 300 and 350 mm were selected in the present study. The diameter of bulb adopted was 75 mm for 25 mm pile diameter. Model piles used for the study are shown in Figure 1.

Fig. 1. Model steel piles

V. EXPERIMENTAL SET UP AND METHODOLOGY

The pile model tests are quite economical and convenient, because the design, construction and operation of model may be altered several times if necessary until all the defects of the model are eliminated and the most suitable design is obtained. However, the model test results have to be utilized with caution, while predicting the performance of the prototype. In this work an attempt has been made for the experimental determination of ultimate load carrying capacity of model of under-reamed pile with different spacing and location of bulbs. Comparative study of simple pile and multi-under-reamed pile models were also tested.

The test bed was prepared in a cylindrical mould of diameter 600 mm and height 900 mm. The size of the mould was chosen keeping in view that the influence of boundary resistant on the load is very marginal. Sand was filled in layers of 50mm and each layer was compacted using a plate vibrator. The test tank is emptied and refilled for each test to ensure that controlled conditions are maintained throughout the investigation. At required depth, the pile was positioned on the bed. The loading tests were carried out in a loading frame fabricated in the Department of Civil Engineering. The load is applied using a hydraulic jack of capacity 50kN. The settlement of the pile is measured using two dial gauges kept diametrically opposite to each other. The model pile is placed exactly beneath the centre of loading jack to avoid eccentric loading. The test set up is shown in Figure 2.

Fig. 2. Loading Arrangement

The model pile is kept embedded in the soil such that the pile top is 50 mm above the soil surface. A known load was applied on the pile carefully and the corresponding settlement of pile was recorded from the dial gauges. The next incremental load was applied when the settlement is completely stopped. The load settlement response was observed till the settlement reached 25 mm and the load corresponding to 25 mm deflection on load-deflection curve is taken as the ultimate load in compression.

VI. RESULTS AND DISCUSSIONS

A. *Length of the pile without bulb and with bulb*

In this study a bulb of diameter 75 mm is provided on the stem at standard height from the tip whose length is made to vary. Two sets of data, one with bulb and one without, have been used. The results from the tests are entered in Table 2 which shows that ultimate load is generally insensitive to change in length. The ultimate loads, however, are substantially in favour of the under-reamed pile when compared to prismatic pile.

TABLE II. LENGTH OF PILE : ULTIMATE LOAD IN COMPRESSION

Length of Pile (mm)	Ultimate Load in Compression (kg)			
	Prismatic (without bulb)	*Under-reamed (with bulb)*		
		One bulb	*Two bulbs*	*Three bulbs*
300	62.19	111.11	208.99	251.76
350	63.95	116.56	212.18	257.32

B. *Location of the bulb*

A pile of length 300 mm with diameter of pile 25mm and bulb diameter 75 mm has been used for these studies, with the height of the centre of the bulb from the tip as the parameter. The results pertaining to the location of the bulb on the stem are given in Table 3 and the load settlement graph is shown in Figure 3. It is seen that the ultimate capacity is highest for the bottom-most location of the bulb, decreasing thereafter to a constant value after some height.

TABLE III. LOCATION OF BULB ON STEM : ULTIMATE LOAD IN COMPRESSION

Height of Under-ream from Bottom of Pile, h (mm)	Ultimate Load in Compression
25	156.01
75	111.11
125	100.58
175	66.93
225	66.73

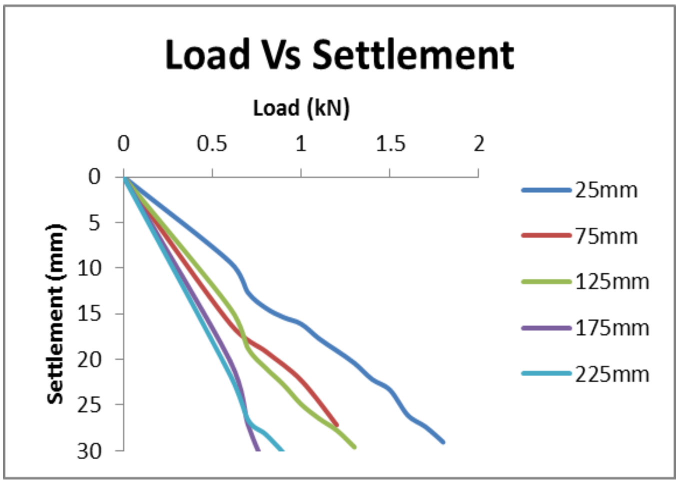

Fig. 3. Load-Settlement Profile of Under-reamed pile with different bulb location

C. *Spacing between bulbs*

A pile of length 300mm with diameter of pile 25 mm and bulb diameter 75 mm has been used for these studies, with the spacing between the centre of the bulbs as the parameter. Here, two bulbs were used for the analysis. The results from the above analyses are presented in Table 4. It is seen that the effect of increasing the spacing between the bulbs increased the ultimate load carrying capacity.

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It is to be pointed out that the load carrying capacity does not go on increasing with an increasing in the spacing. For a certain increase in the spacing, the increase in load carrying capacity becomes smaller. Load-settlement diagram for under-reamed piles with different spacing of bulbs is given in Figure 4.

TABLE IV. SPACING BETWEEN BULBS : ULTIMATE LOAD IN COMPRESSION

Spacing Between Bulbs (mm)	Ultimate Load in Compression (kg)	% Increase
100	105.71	0.0
150	193.05	82.6
200	208.99	8.3

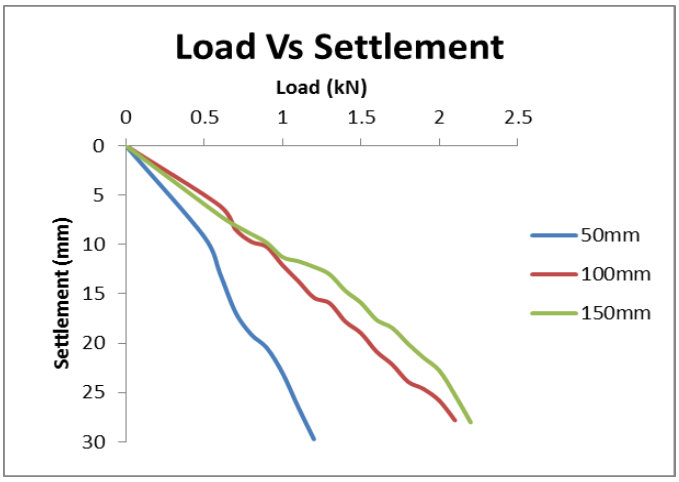

Fig. 4. Load-Settlement Profile of Under-reamed pile with different spacing between bulbs

D. *Number of bulbs*

A pile of length 300 mm with diameter of pile 25mm and bulb diameter 75 mm has been used for these studies. Here, a maximum of three bulbs were used for the study. The results from the above tests are presented in Table 5. It is seen that the ultimate load carrying capacity is increased with the increase in number of bulbs. The effect of increase in number of bulbs in ultimate load carrying capacity is more significant for double under-reamed pile. Load-settlement for multi-under-reamed piles is given in Figure 5.

TABLE V. MULTI-UNDER-REAMED PILES : ULTIMATE LOAD IN COMPRESSION

Number of bulbs	Ultimate Load in Compression (kg)	% Increase
1	111.11	0.0
2	208.99	88.1
3	251.76	20.5

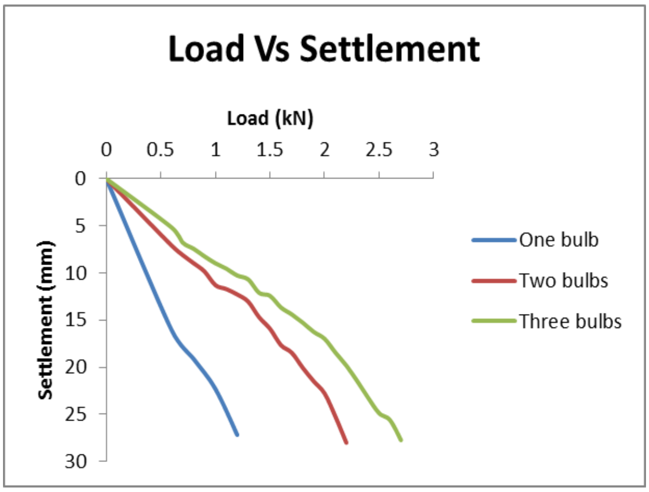

Fig. 5. Load-Settlement Profile of Under-reamed pile with varying number of bulbs

VII. CONCLUSIONS

The conclusions drawn from the above studies have been stated below in a quantitative form to the extent possible.

- The test results obtained in this study clearly shows that the load carrying capacity of under-reamed piles under compression is much higher in comparison with the conventional pile.
- The most valuable conclusion from the case of prismatic pile of diameter 25 mm is the increase in the capacity by 305% in compression, when the pile is under-reamed.
- It was found that the ultimate load is generally insensitive to change in length for both prismatic and under-reamed piles.
- For a given soil and pile, the influence of location of the bulb is not significant beyond the standard height 175 mm from the base of the pile for the location of the under-ream. However this capacity is 57.1% lesser compared to the case of the under-ream located at the bottom of the pile.
- As regards the spacing between two bulbs, there is an increase in capacity by 82.6% when it reached a spacing of 150 mm. It is to be pointed out that the load carrying capacity does not go on increasing with an increasing in the spacing. For a certain increase in the spacing, the increase in load carrying capacity becomes smaller.
- The observation in the case of multi-under-reamed piles is that, the capacity increases by 127% in compression when the number of bulbs increases from one to three. The effect of increase in number of bulbs in ultimate load carrying capacity is more significant for double under-reamed pile.

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