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Studies on the Performance of Under-reamed Piles in Sandy Soil through Model Tests

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Abstract

Predicting pile behavior and estimating pile capacity in different soil conditions are critical in building industry. This paper describes an experimental study which is aimed to comprehend some factors affecting the under-reamed pile capacity in sand i.e. the bulb angle and bulb spacing. It also compares the variation of capacities of these piles in sand in both loose and dense state. A total of 9 model piles were tested, which included four single under-reamed piles, four double under-reamed piles and a normal pile. From the experimental studies, load–settlement curves are obtained and the pile capacities are determined using various criteria reported in the literatures. The capacity increased to at least twice the value when an under-ream bulb was introduced to a normal pile. The pile with bulb angle of 45^0 and with bulb spacing of 1.25 times the bulb diameter showed maximum capacity for single under-reamed and double under-reamed piles, respectively. The pile capacity increased with increase in sand density. The test results are in agreement with the relevant Indian Standards.

Keywords

Bulb angle, Bulb spacing, Under-reamed piles

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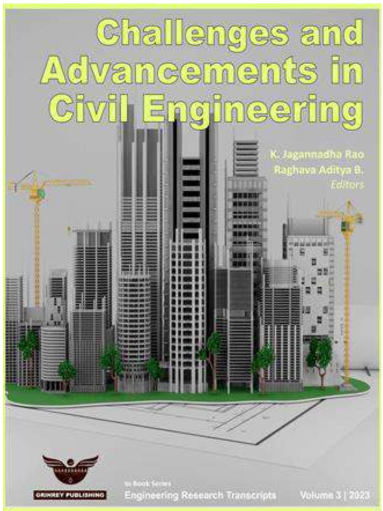

1. Introduction

Pile foundations are frequently used to effectively transmit load from the superstructure to greater depths if some weak strata overlie a firm stratum. Under-reamed pile foundations are those among such deep foundations which are used when the subsurface soil has inadequate strength. They can be either bored compaction piles or cast in place piles. The 1940s saw the introduction to the practice of employing under-reamed piles and since the 1950s, they have been widely used in India, where there was a lot of expansive black cotton soil.

Under-reamed piles are cast-in-place concrete piles having one or more under-ream bulbs along their stems, which enhances pile capacity under compression and tension loads [1]. These piles can lessen the impact of negative skin friction and enhance tip resistance and pile shaft friction [2]. Under-reamed piles which have projections known as bulbs or under-reams which increases its load-carrying capacity under compression, tension, and lateral loading [3-12]. Nazir et al. [13] concluded that the ultimate load could be worked out using time-settlement plot from the pile load test results. According to results of the studies by Harris et al. [14], the uplift capacity declined as the angle of the under-reams increased. The safe pile capacity as determined by subsoil parameters differs from that specified in the IS 2911- Part 3 [15], according to a research done on multiple under-reamed piles of variable diameter and length at various sites by Pakrashi [16]. The results of a numerical study by Jebur et al. [17] on the geometrical form of bulbs revealed that the ream's cone shape is preferred over other under-reamed bulb shapes in terms of reducing vertical displacement. These reams, according to Jebur and Ahmed [18], improve both friction and bearing surface, as well as pile capacity in compressive stress. Therefore, these type of piles are successfully employed for machine foundations and electrical transmission tower foundations. The capacity of the piles in compression and tension was significantly impacted by the number, size, shape, and position of the bulbs [19]. Various studies were also conducted to understand the influence of geometrical features of the under-reamed pile on its ultimate capacity by Christopher and Gopinath [20], Shetty et al. [21] and Shrivastava and Bhatia [22].

Bulbs are regarded as the most significant advantage of under-reamed piles over other types of piles because appropriate performance may be attained with smaller stem diameters and lengths. They can be utilized instead of long and broad piles for bearing heavy loads. This implies that the economic properties of under-reamed piles are also taken into account throughout the design process. This study examined the efficiency of the single and double under-reamed pile installed in loose and dense sand and compared the results with that of a normal pile. Single under-reamed piles of various under-ream angles and double under-reamed piles with different under-ream spacings were analyzed and the most efficient one was found out. The study also compared the variation in capacity of piles at different sand density.

2. Materials

2.1. Soil

The accessible local river sand is used for the model test. Laboratory investigations are done to find out the basic soil parameters of river sand. The tank is filled with particles that passed through an IS sieve with size of 4.75mm. Model tests are carried out on both dense and loose sand. Table 1 summarizes the basic properties of the sand.

2.2. Under-reamed Pile Models

Timber (Mahogany) was used to construct the pile models. A total of 9 distinct pile models were made, each having a length of 450 mm and stem diameter of 40 mm. The bulb diameter (D_u) of the under-reamed piles were taken as 100 mm which was 2.5 times the stem diameter. Four piles were single under-reamed piles with various bulb angles of 15^0, 30^0, 45^0, and 60^0. Then, there were four double under-reamed piles with different bulb spacings: $1.0D_u$, $1.25D_u$, $1.5D_u$, and $1.75D_u$ with a constant bulb angle of 45^0. And the final pile created was a normal pile with no bulbs or projections. The images of the pile models used in the study are given in Figure 1 and 2.

Table 1. Properties of Sand

Properties		**Capacity**
Dry Unit Weight (kN/m^3)	Loose Sand	13.9
	Dense Sand	16
Angle of Internal Friction (degrees)	Loose Sand	28
	Dense Sand	37
Uniformity Coefficient		2.86
Fineness Modulus		3
Particle Size Distribution (%)	Gravel Size (4.75 mm – 80 mm)	0
	Sand Size (0.075 mm -4.75 mm)	100
	Silt Size (0.002 mm - 0.075 mm)	0

Fig. 1. Models of normal and single under-reamed piles.

Fig. 2. Models of double under-reamed piles.

2.3. Metal Tank

The pile model tests were conducted in a metal tank with measurements of 450 mm x 450 mm x 600 mm whose size was set based on the pile diameter. Boundary effects were thought to be insignificant considering the size of the tank.

3. Methodology

3.1. Filling the Tank

In loose state, a pouring device filled with sand wass moved spirally from outside towards centre, while maintaining a height of fall of 250 mm. The model pile for testing was positioned vertically and lined up with the loading mechanism after the tank's bottom 150 mm of space had been filled. The remaining portion of the tank was filled similarly without disturbing the model pile. For sand in dense state, the depth of the tank was divided into layers of 50 mm. Sand was filled in layers, and each layer was thoroughly tamped with a cylindrical weight (30 N). To achieve adequate compaction of the sand layers, each layer received around 60 strikes from the weight. The appropriate model pile was installed after filling the bottom 150 mm (3 layers), and the remaining tank was filled using the same method without moving the model pile. Once the tank was filled, the top surface was levelled, and the experimental setup was established.

3.2. Loading Mechanism

A hydraulic loading mechanism was used for this study. By pumping oil, load was applied, and a proving ring with a capacity of 10 kN was used to measure the load. The tank was placed on the loading frame and load was applied using a hydraulic jack. Figure 3 shows the test setup used for the study.

3.3. Test Procedure

Based on the procedures described in the preceding section, the metal tank was filled with sand. Using a hydraulic jack, an external compressive load was applied gradually. Such manually controlled hydraulic jack has been employed for compressive loading in past studies [23]. A proving ring connected to the test setup was used to measure the external load that has been imposed. To measure the settlement, two dial gauges were employed. Load was applied until the displacement exceeded 12 mm or the proving ring began to produce a steady reading with continuous settling. Finally, the ultimate capacities corresponding to 12 mm, 7.5 mm (7.5% of D_u), and 4 mm (10% of D) settlements were calculated using the load-settlement curves plotted from the recorded data.

Fig. 3. Test Setup

4. Results and Discussions

4.1. Tests in Loose Sand

4.1.1 Single Under-reamed Pile

From figure 4, it can be seen that for varying bulb angles, the capacity is maximum for the pile with 45^0 bulb angle. Single under-reamed pile with bulb angle 45^0 has clearly the maximum ultimate capacity corresponding to all the settlements considered and the minimum capacity was obtained for the pile with 60^0 bulb angle. The introduction of under-reams increased the capacity significantly and for the pile with 45^0 bulb angle, the capacity increased to nearly 4.5 times the capacity of normal pile for 12 mm settlement. The maximum capacity observed for 45^0 bulb angle agrees with the suggestions of IS 2911- Part 3: 1980 [15].

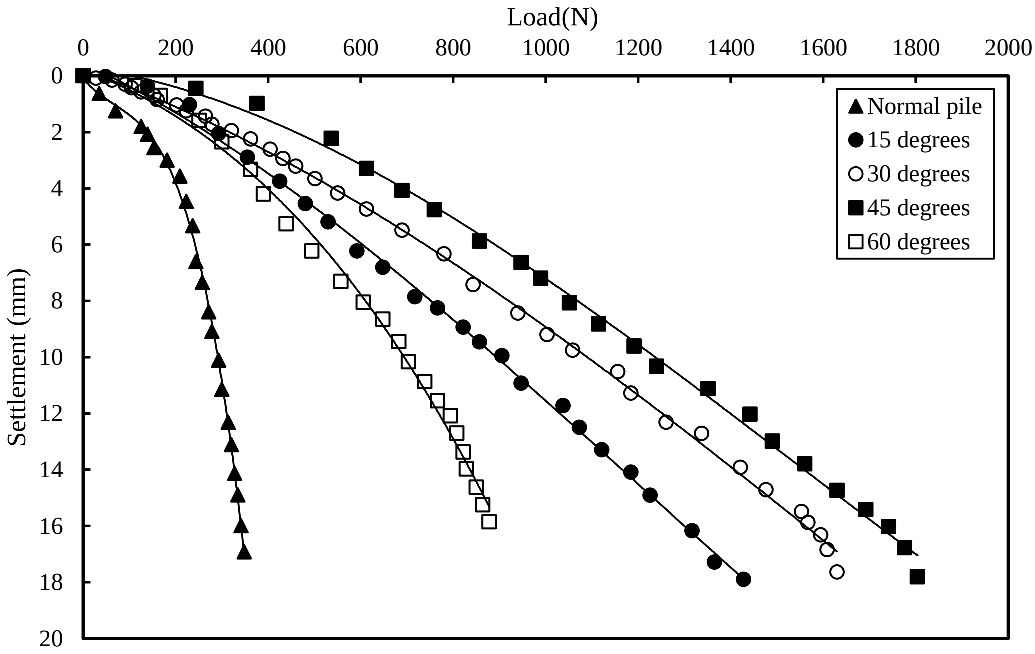

Fig. 4. Load-settlement curves for single under-reamed piles tested in loose sand.

4.1.2 Double Under-reamed Pile

From the load settlement curves as shown in figure 5, it can be seen that the double under-reamed pile with an under-ream spacing of $1.25D_u$ has a slightly higher capacity as compared to others. The capacity of pile with bulb spacing $1.5D_u$ is comparable to that of the pile with $1.25D_u$ bulb spacing at 12 mm settlement and the pile with $1.0D_u$ bulb spacing has the least capacity as compared to all other double under-reamed piles. Also, it should be noted that the capacity of the pile with $1.25D_u$ bulb spacing is nearly 7 times higher in comparison with a normal uniform diameter pile and nearly 1.5 times higher in comparison with single under-reamed pile with 45^0 bulb angle. These maximum capacity observed for $1.25D_u$ bulb spacing is in agreement with the suggestions given by IS 2911 – Part 3: 1980 [15].

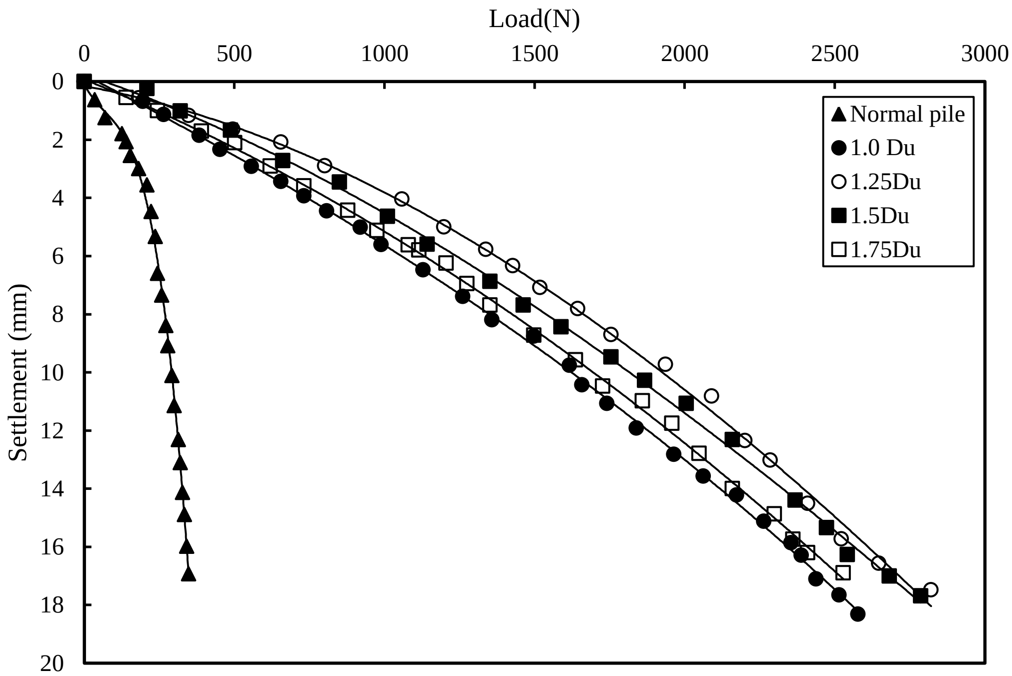

Fig. 5. Load-settlement curves for double under-reamed piles tested in loose sand.

4.2. Tests in Dense Sand

4.2.1 Single Under-reamed Pile

The load settlement plots, as in figure 6, show that under-reamed pile with bulb angle of 45^0 clearly has the maximum capacity corresponding to all the settlements considered. Minimum capacity was obtained for the pile with 60^0 bulb angle. The introduction of under-reams increased the capacity significantly and for the pile with 45^0 bulb angle the capacity increased to nearly 4 times the capacity of normal pile for 12 mm settlement. So, ,it is quite evident that the trends are similar to that in loose sand. Also, the results agree with the suggestions in IS 2911- Part 3: 1980 [15] for providing an under-ream angle of 45^0.

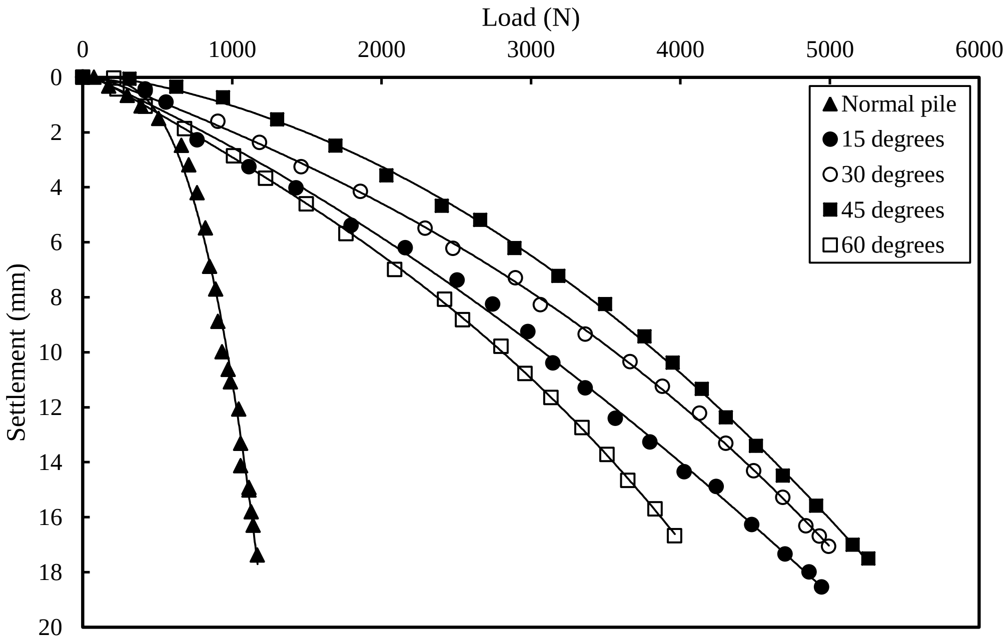

Fig. 6. Load-settlement curves for single under-reamed piles tested in dense sand.

4.2.2 Double Under-reamed Pile

From the load-settlement plot shown in figure 7, it can be inferred that the capacity of double under-reamed pile with bulb spacing $1.0D_u$ has the least capacity. Corresponding to all the three settlements considered, the ultimate capacity of double under-reamed pile with bulb spacing $1.25D_u$ has the maximum value, which is in agreement with the suggestion by IS 2911- Part 3. Another important observation is, that the capacity of the pile with $1.25D_u$ bulb spacing is nearly 7 times higher in comparison with a normal uniform diameter pile and nearly 1.5 times higher in comparison with single under-reamed pile with 45^0 bulb angle.

4.3. Variation in Capacity with Density of Sand and Number of Bulbs

In this study the tests were conducted in two densities of sand. Table 2 shows the capacities of normal piles, single under-reamed piles (with 45^0 bulb angle) and double under-reamed piles (with $1.25D_u$ bulb spacing and 45^0 bulb angle) in both these densities i.e. loose state and dense state. From this data it is evident that, as the density of sand increases the capacity of the pile also increases. Here, for the change in density from 13.9 to 16 kN/m^3, the capacity of the all the piles, i.e. normal, single under-reamed and double under-reamed piles, increased to almost 3 times. This is due to the higher angle of internal friction which increases the surface interaction between the pile and sand. Also, from the table 2 it is evident that as the number of bulbs increased the capacity of piles increased by quite a margin, as we have discussed in the preceding sections.

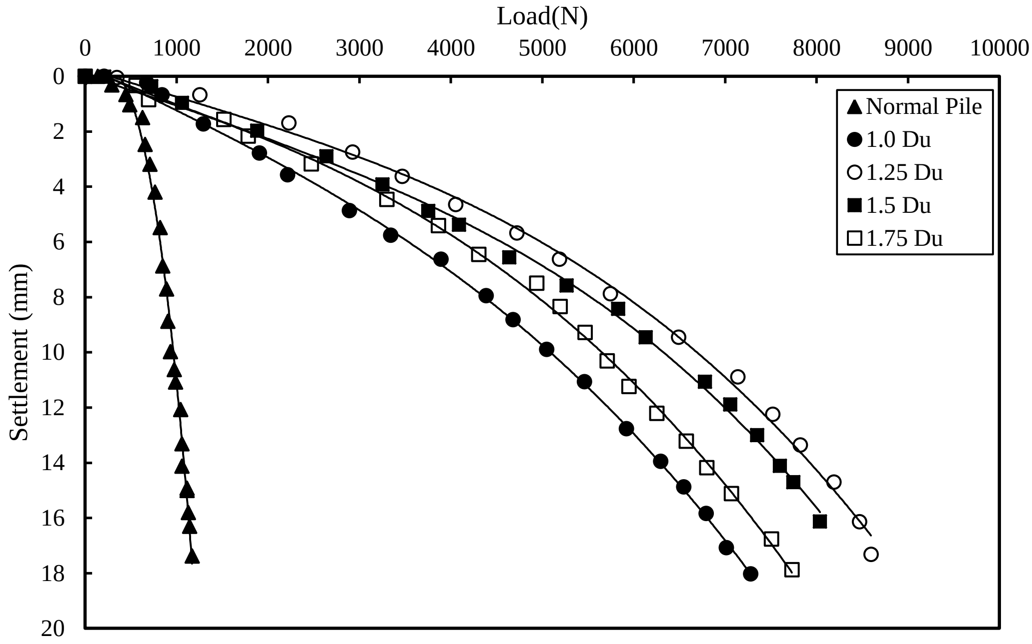

Fig. 7. Load-settlement curves for double under-reamed piles tested in dense sand.

Table 2. Capacities of Piles corresponding to12 mm settlement in different densities of sand

Material	Capacity (N)	
	Loose Sand	**Dense Sand**
Normal Pile	310	1000
Single Under-reamed Pile	1450	4210
Double Under-reamed Pile	2220	7390

5. Conclusions

The current study attempted to understand various parameters that influence the capacity of under-reamed piles, such as bulb angle, bulb spacing, number of bulbs and sand density. A series of model tests revealed that the capacity of under-reamed piles is actually controlled by the aforementioned criteria. In conclusion, the introduction of an under-ream bulb significantly enhances the load-bearing capacity of normal uniform diameter piles, with capacity increasing by at least twice the original value. This study confirms the prevailing practice of using a 45^0 bulb angle for under-reamed piles, both single and double, which yielded the highest capacity. Furthermore, the optimal configuration for double under-reamed piles involves a bulb spacing of $1.25D_u$ and a bulb angle of 45^0. The study demonstrated that increasing the number of bulbs from one to two further enhances capacity, regardless of the sand density. Notably, the findings align with the recommendations outlined in IS 2911 - Part 3: 2010, supporting the practical application of a 45^0 bulb angle and advocating for bulb spacing between $1.25D_u$ and $1.5D_u$ for double under-reamed piles in sandy soil. This comprehensive investigation contributes valuable insights to the field of foundation engineering and reinforces the soundness of existing design guidelines for optimizing the load-bearing performance of under-reamed piles in various sandy soil.

Nomenclature

D : Stem Diameter

D_u : Bulb Diameter

References

[1] Farokhi, A. S., Alielahi, H., and Mardani, Z. (2014). Optimizing the performance of under-reamed piles in clay using numerical method. Electronic Journal of Geotechnical Engineering, 19(Bundle G), 1507-1520.

[2] Chandrasekaran, V., Garg, K. G., and Prakash, C. (1978). Behaviour of isolated bored enlarged base pile under sustained vertical loads. Soils and Foundations, 18(2), 1-15.

[3] Cooke, R. W., and Whitaker, T. (1961). Experiments on model piles with enlarged bases. Geotechnique 11 (1), 1–13.

[4] Prakash, C., and Ramakrishna, V.V.G.S.T. (2004). Lateral load capacity of underreamed piles: an analytical approach. Soils Found. 44 (5), 51–65.

[5] Peter, J. A., Lakshmanan, N., and Manoharan, P. D. (2006). Investigations on the static behavior of self-compacting concrete under-reamed piles. J. Mater. Civ. Eng. 18 (3), 408–414.

[6] Khatri, V. N., Kumar, A., Gupta, S. K., Dutta, R. K., and Gnananandarao, T. (2019). Numerical study on the uplift capacity of under-reamed piles in clay with linearly increasing cohesion. Int. J. Geotech. Eng. 1–12. https://doi.org/10.1080/ 19386362.2019.1660527.

[7] Kumar, A., Khatri, V. N., and Gupta, S. K. (2020). Effect of linearly increasing cohesion on the compression and uplift capacity of the under-reamed pile in clay. SN Appl. Sci. 2 (2), 1–17.

[8] Kumar, A., Khatri, V. N., and Gupta, S. K. (2021). Numerical and analytical study on uplift capacity of under-reamed piles in sand. Mar. Georesour. Geotechnol. 1–38. https:// doi.org/10.1080/1064119X.2021.1871689.

[9] Majumder, M., and Chakraborty, D. (2021). Three-dimensional numerical analysis of under-reamed pile in clay under lateral loading. Innovative Infrastructure Solutions 6 (2), 1–17.

[10] Majumder, M., and Chakraborty, D. (2021). Bearing and uplift capacities of under-reamed piles in soft clay underlaid by stiff clay using lower-bound finite element limit analysis. Front. Struct. Civ. Eng. 15 (2), 537–551.

[11] Majumder, M., and Chakraborty, D. (2021). Effects of scour-hole depth on the bearing and uplift capacities of under-reamed pile in clay. Ocean Eng. 240, 109927.

[12] Majumder, M., and Chakraborty, D. (2021). Effects of scour-hole dimensions and bulb positions on the lateral response of under-reamed pile in soft clay. Appl. Ocean Res. 117, 102942.

[13] Nazir, R., Moayedi, H., Mosallanezhad, M., and Tourtiz, A. (2015). Appraisal of reliable skin friction variation in a bored pile. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 168(1), 75-86.

[14] Harris, D. E., and Madabhushi, G. S. P. (2015). Uplift capacity of an under-reamed pile foundation. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 168(6), 526-538. https://doi.org/10.1680/jgeen.14.00154

[15] IS: 2911 Part III. (1980). Code of Practice for Design and Construction of Pile Foundations: Underreamed Piles. New Delhi, India: Bureau of Indian Standard.

[16] Pakrashi, S. (2017). A Comparative Study on Safe Pile Capacity as Shown in Table 1 of IS 2911 (Part III): 1980. Journal of The Institution of Engineers (India): Series A, 98(1), 185-199.

[17] Jebur, M. M., Ahmed, M. D., and Karkush, M. O. (2020). Numerical analysis of under-reamed pile subjected to dynamic loading in sandy soil. In IOP conference series: materials science and engineering (Vol. 671, No. 1, p. 012084). IOP Publishing.

[18] Jebur, M. M., and Ahmed, M. D. (2020). Experimental investigation of under reamed pile subjected to dynamic loading in Sandy soil. In IOP conference series: materials science and engineering (Vol. 901, No. 1, p. 012003). IOP Publishing.

[19] Kurian, N. P., and Srilakshmi, G. (2010). Studies on the geometrical features of under-reamed piles by the finite element method. Journal of Karunya University, 2(1), 1-14.

[20] Christopher, T., and Gopinath, M. B. (2016). Parametric study of under-reamed piles in sand. International Journal of Engineering Research & Technology (IJERT), 5(7), 577-581.

[21] Shetty, P., Naveen, B. S., and Kumar, N. B. S. (2015). Analytical study on geometrical of underreamed pile by Ansys. International Journal of Modern Chemistry and Applied Science, 2(3), 174-180.

[22] Shrivastava, N., and Bhatia, N. (2008). Ultimate bearing capacity of under-reamed pile-finite element approach. In The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG) (pp.1-6).

[23] Hegde, A., and Sitharam, T. G. (2015). Experimental and analytical studies on soft clay beds reinforced with bamboo cells and geocells. International Journal of Geosynthetics and Ground Engineering, 1, 1-11.