Compressive Capacity of Conventional and Under Reamed Piles in Soft Clay

H O Abbas
Department of Civil Engineering, College of Engineering, University of Diyala, Baquba, Iraq
Email: temimi71@yahoo.com

Abstract. Under reamed pile is a well-known solution for carrying roads, light structures, walk sides, communication and electrical tower and rail. In this laboratory study, the compression conduct of conventional pile and undreamed pile with single and double bulbs models with shaft diameter of 10 mm embedded in soft clay soil layer overlaying sand soil was investigated. The sand layer with a depth of 300mm was compacted into six sub layers to relative density 70% in a steel container of a diameter 300mm in size. The depth of soft clay was 250mm and undrained shear strength (Cu) 35 kPa which compacted into five sub layers on sandy soil layer. A series of tests of model are performed on conventional and underreamed pile. Different lengths of piles are manufactured like 250mm, 290mm, 330mm, 370mm and 410mm and with bulb of a diameter 20mm. Moreover, single bulb and dual bulbs were utilized for these piles, a comparison in behaviour between underreamed pile and conventional pile (without bulb) is fulfilled. This study appeared finalize the ultimate compressive capacity of underreamed pile of single bulb is (1.9, 2.6, 3.3, 3.4 and 3.2) times greater than conventional pile while the underreamed of double bulbs is (4.1, 3.7, 4.3, 4.1 and 3.7) times greater than conventional pile for ratios of L/ D (25, 29, 33, 37 and 41) respectively. A proposed relationship used to estimate ultimate compressive capacity for conventional pile and underreamed pile with single and double bulbs when dimensions of pile are known or used to estimate dimensions of pile for specified load capacity.

Keywords. Pile, Soft soil, Settlement, Compressive capacity.

1. Introduction
One of solution for stability anti uplift tension and compression in a different engineering applications is utilized underreamed piles. The end bearing resistance of shallow underreamed anchors gives clearly peak value. On the contrary, a deep underreamed anchor cannot display the peak value in the end resistant, the friction resistance presents peak [1]. The shapes of enlarge bulbs of under-ream pile are usually have important effects on the underreamed pile failure in soil mass. The geometrical complexion of underreamed piles may change pile soil interaction and failure type of soil mass to local or general failure which surrounding the underreamed piles [2]. Finite element methods used for computation ultimate capacity of underreamed pile of single bulb in different layers of soil. This study gave equations for determining capacity of underreamed piles for different soils such as: soft clay, stiff clay, dense and loose sand and silt [3]. Different results of laboratory study are produced by performing different compressive and tensile tests on underreamed. The results indicated that the underreamed piles in clay have proper capacity to compression and tension [4]. The uplift capacity of enlarged underreamed piles depend on several parameters like: sandy soil relative density, depth of pile embedded in cohesion less soil, number and shape of bulbs [5]. The economic cost is considered in design bulb of underreamed pile. The bulb is constructed as full-bulb double-cone or half-bulb single. Most of expropriated, the
degree angle between bulb and stem of pile is 45°. The cost of semi bulb of underreamed piles construction is lower than that of a complete-bulb one [5]. Compressive capacity of underreamed pile of semi-bulb about 13% and 73% has higher than that of complete bulb and pile of uniform cross section respectively of the same volume and length for the same volume and length [6]. There are many of soil profiles exists in the center and south of Iraq which consist from upper layer of soft clay with depth ranged (2-15) m and dense sand or stiff clay of depth ranged (5-20) m [7]. There are several solutions suggested to construct structures on this soft clay soil such as using screw piles [8-11]. In this study an attempt to use underreamed piles in this soil. Many parameters are investigated such as length of pile, number of bulbs, and extended length of pile in sand layer. Also, a comparison these parameters effect with conventional pile is carried out. In addition, a proposed relationship is suggested to predict dimensions or compressive capacity of pile.

2. Experimental work
The total work is carried out in laboratory, and no field model is used, although the full scale model will provide a better-close to reality data.

1.1. Soft clay soil
The soft clay soil (top layer) utilized in the test models is sampling from a region near to Baquba city. The samples are drilled from a depth (2-3) m below natural ground level. A trial tests were carried out prior of testing models to control the boundary of experiments such as the change in shear strength at various water contents. The results of these trials were achieved and introduced in Figure 1. The whole results of essential properties for this soil are illustrated in Table 1. The soft clay soil is classified as CL depending on the ASTM classification.

![Figure 1. Change of undrained shear strength with water content for the remoulded clay after two days.](image)

1.2. Sandy soil
The bottom layer below soft clay layer used in test models is sandy soil. This soil is sampling from site Karbala Governorate, and it is fine clean poorly graded. Different laboratory tests are performed on this soil, the test results are shown in Table 2. The direct shear test used to determine shear strength parameters (C, Ø) for relative density equal to 70% which refer to dry unit weight equal to (16) kN/m³. Depending on the ASTM classification, the soil is categorized as poorly graded sand (SP).

1.3. Models of pile and soil container
Under reamed pile models are manufactured from a solid alluminum material with shaft diameter 10mm. Two types of under reamed piles are used in this study: single bulb and double bulbs as shown in Figure
2. Also, conventional piles without bulb are used in this study for comparing with under reamed piles. In total, fifteen models test are used in this study include five models for each three types of piles (conventional, single bulb, double bulbs). The lengths of piles used in this study are (25, 29, 33, 37 and 41) cm. Plebeianly, test tank dimensions are chosen so as not to stress bulbs touch the boundaries of tank which is result from installation of pile [12]. The cross section of steel container is circular with internal diameter of 30cm and height of 55cm. Soil steel container was made using a 4mm thickness plate with the base of container is supported by four small wheels. Figure 3 illustrates the steel container painted with coats and anti-rusts layers to prevent corrosion.

**Table 1. Soft clay properties.**

| Property                        | Value | Specification               |
|---------------------------------|-------|-----------------------------|
| Specific gravity (Gs)           | 2.78  | ASTM D 854 - 2              |
| Liquid limit (L.L)%             | 37    | ASTM D 4318 - 00            |
| Plastic limit (P.L)%            | 22    | ASTM D 4318 – 00            |
| Plasticity Index (P.I)%         | 15    |                             |
| Sand %                          | 4     | ASTM D 422                  |
| Silt%                           | 45    | ASTM D 422                  |
| Clay%                           | 51    | ASTM D 422                  |
| Unified Soil Classification System (USCS) | CL     | ASTM D 422                  |
| Max. Unit Weight (kN/m$^3$)     | 18    | (ASTM D-1557)               |
| Optimum Moisture Content (O.M.C)% | 18    | (ASTM D-1557)               |

**Table 2. Sandy soil properties.**

| Property                        | Value | Specification               |
|---------------------------------|-------|-----------------------------|
| Coefficient of Uniformity (Cu)  | 2.5   | (ASTM D-422) and ASTM D 2487 (2006) |
| Curvature coefficient (Cc)      | 0.83  | (ASTM D-422), ASTM D 2487 (2006) |
| Unified Soil Classification System (USCS) | SP     | (ASTM D-422), ASTM D 2487 (2006) |
| Specific Gravity (Gs)           | 2.65  |                             |
| Cohesion(kN/m$^3$)              | 0     | ASTM D3040-04(2006)         |
| Internal Friction Angle (φ°)    | 36    | ASTM D3040-04(2006)         |
3. **Testing procedure**

Sandy soil is prepared at dry unit weight equal to 16kN/m³ after drying in the oven and passing sieve No.40. The dense state of this soil is performed and prepared by compacting soil with manual steel plate hammer of weight equal to 9.87kg and diameter of 15cm. The soft clay soil is prepared with undrained shear strength Cu=35kPa at moisture water content of 28%. The preparation process is started by weighting 30 kg of natural soil and mixed thoroughly with enough quantity of water to acquire the required consistency. The mixing process is conducted by using electrical mixing. After complete mixing, the soil is placed in a steel container in five sub layers which is settled carefully usage a wooden tamper to eliminate any entrapped air until reaching the required thickness. After supplementing the final levelled flat surface layer, polythen sheet is covered the surface for a period of two days to get uniform homogeneous moisture content and prevent any loss of moisture. A cylinder with diameter 22mm is driven into center of layers in container to require depth after complete preparation of layers. After that installation pile to the required depth and pull out the cylinder. A strain control test was performed, since the loads were applied by a hydraulic hand jack over the pile cap. The load was recorded in relation with each 0.5mm incremental displacement. The test was kept until no significant change in displacement occurred at the pile head. Figure 4 shows the pile test device.
4. Discussion of results
The ultimate capacity of under reamed pile can be calculated from load - settlement curve by using double tangent method or see any clear break is available in load - settlement curve. The clear break point is the ultimate load. In double tangent method, draw a tangent to initial straight-line portion and draw an tangent line to the second straight line portion, the meeting points of two line is the ultimate capacity of an under reamed pile. The under reamed pile may fail by larger settlement or due to excessive shear and also it may fail if the pile does in have enough capacity to resist uplift force. The double tangent method is adopted to determine ultimate capacity load of all models pile. Model tests are accomplished on a conventional pile and two types of under reamed piles single and double bulbs. All of these model piles possess the shaft diameter of (10) mm. It is obvious from Figure 5 the effect of the length of conventional pile and under reamed pile (L/ D) on its capacity. Plebeianly, the ultimate capacity of all piles battened with battening its length (L/ D) regardless the different factors like pile geometry and number of bulbs. The rate of increase of the ultimate pile capacity for underreamed pile is steep as compared to conventional pile. The precents of increase in ultimate compressive capacity are (433, 786 and 379) for conventional pile and underreamed pile of single and double bulbs respectively when ratio of L/ D changed from 25 to 41. In addition, it is noticed that the ultimate compressive capacity of underreamed pile of single bulb is (1.9, 2.6, 3.3, 3.4 and 3.2) times greater than conventional pile while the underreamed of double bulbs is (4.1, 3.7, 4.3, 4.1 and 3.7) times greater than conventional pile for ratios of L/ D (25, 29, 33, 39 and 41) respectively. Also, the ultimate compressive capacity of underreamed pile of double bulbs is (2.2, 1.4,1.3, 1.2 and 1.17) times more than that of single bulb for ratios of L/ D (25, 29, 33, 37 and 41) respectively. Figure 6 illustrates the active length of anchorage of pile in sand layer to the ultimate compressive capacity of conventional and underreamed pile of single and double bulbs. It is clear that the increase of anchorage length in sand layer lead to increase in the ultimate compressive capacity. When the conventional pile and underreamed pile of single and double bulbs embedded in soft clay only, the values of ultimate compressive capacity are small, while when the length of piles extended to sand layer, the ultimate compressive capacity begins to increase largely especially for underreamed pile. This behavior may be attributed to augment shaft resistance and bearing resistance of underreamed piles in the region of sand soil. The presence of enlarged bulbs in this soil performs to augment the surface area and acts as anchor. This result is agreed with [3, 6, and 13].

Figure 4. Device used for testing models.
Figure 5. Change in ultimate capacity of conventional pile and underreamed piles against L/D ratios.

Figure 6. Change in ultimate capacity of conventional pile and underreamed piles against Ls/ H ratio.

Figure 7 depicts the proposed dimensionless relation between ratios of \((Ls^2/H.Dp)\) and \((Qu/ Cu.d^2)\), where: \(Qu\): ultimate compressive capacity, \(Cu\): undrained shear strength of soft clay, \(d\): shaft diameter of pile, \(Ls\): embedded length of pile in sand layer, \(H\): thickness of soft clay layer, \(Dp\): bulb diameter. This relation may be used to estimate ultimate compressive capacity for conventional pile and underreamed pile with single and double bulbs when dimensions of pile are known or used to estimate dimensions of pile for specified load capacity. The following example illustrates the using of this Figure 7. Example: Find the ultimate compressive capacity of conventional and underreamed pile of single and double bulbs using the following information: Length of pile \((L) = 5\) m, diameter of shaft pile \((D) = 0.25\) m, undrained shear strength of soft clay=35kPa, soft clay layer depth overlaying thick sand layer=3m. Solution: \(Ls=5-3=2\) m, \(Dp=2D=2x0.25=0.5\) m \(Ls^2/H.Dp=5.33\) for conventional pile and \(Ls^2/H.Dp=2.67\) for underreamed pile of single and double bulbs, after that intersect these values with curve of Figure 7 and then determine: \(Qu/ Cu.d^2\) = 60 for conventional pile, \(Qu/ Cu.d^2\) = 200 for underreamed
pile of single bulb and \( Qu / Cu.d^2 = 250 \) for underreamed pile of double bulbs. Substitute values of \( Cu, d \) and find \( Qu = 131kN \) for conventional pile, \( Qu = 438kN \) for underreamed pile of single bulb and \( Qu = 547kN \) for underreamed pile of double bulbs. It is obvious that underreamed pile of single and double bulbs give higher values than conventional pile for the same length and shaft diameter. The range of using the proposed dimensionless relationship is for soft clay overlaying dense sand.

\[ \text{Figure 7. Proposed dimensionless relationship for conventional pile and underreamed piles of single and double bulbs.} \]

5. Conclusions
Many points of conclusions are founded from this study which is successively:
1. The ultimate capacity of compressive conventional pile and underreamed piles of single and double bulbs augment with the increasing depth extended to sand layer.
2. The ultimate compressive capacity of underreamed pile of single bulb is (1.9, 2.6, 3.3, 3.4 and 3.2) times greater than conventional pile while the undereamed of double bulbs is (4.1, 3.7, 4.3, 4.1 and 3.7) times greater than conventional pile for ratios of \( L/D \) (25, 29, 33, 37 and 41) respectively.
3. The ultimate compressive capacity of underreamed pile of double bulbs is (2.2, 1.4,1.3, 1.2 and 1.17) times more than that of single bulb for ratios of \( L/D \) (25, 29, 33, 37 and 41) respectively.
4. When the conventional pile and underreamed pile of single and double bulbs embedded in soft clay only, the values of ultimate compressive capacity are small, while when the length of piles extended to sand layer, the ultimate compressive capacity begins to increase largely especially for underreamed pile; therefore: piles should be extended to dense or stiff layer to support structures constructed on it.
5. A proposed dimensionless relationship used in this study to estimate ultimate compressive capacity for conventional pile and underreamed pile with single and double bulbs when dimensions of pile are known or used to estimate dimensions of pile for specified load capacity.

References
[1] Shrivastava N and Behatia N 2008 Ultimate bearing capacity of underreamed pile-finite element approach The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG) Goa India.
[2] Majid H, Hanifi C and Omar K 2019 Performance of multi-helix pile embedded in organic soil under pull-out load Transportation Infrastructure Geotechnology https://doi.org/10.1007/s40515-018-00069-0
[3] Tanuja C and Binil G 2016 Parametric study of under-reamed piles in sand  International Journal of Engineering Research and Technology (IJERT) 5(7) pp.577-581 http://www.ijert.org

[4] Watanabe, K, Sei H, Nishiyama T and Ishii Y 2011 Static axial reciprocal load test of cast-in-place nodular concrete pile and nodular diaphragm wall Geotechnical engineering journal of the SEAGS and AGSSEA 42 (2).

[5] Omar K A and Hassan O A 2019 Performance assessment of screw piles embedded in soft clay Civil Engineering Journal 5(8) pp.1788-1798.http://dx.doi.org/10.28991/cej-2019-03091371

[6] Hassan O A and Omar K A 2020 Parameters affecting screw pile capacity embedded in soft clay overlaying dense sandy soil IOP Conference Series: Materials Science and Engineering 745 doi:10.1088/1757-899X/745/1/012117.

[7] Ataollah S F, Hamid A and Zahra M 2014 Optimizing the performance of under-reamed piles in clay using numerical method EJGE journal 19 pp.1507-1520.

[8] Abbase H O 2017 Pullout capacity of screw piles in sandy soil Journal of Geotechnical Engineering 4(1) pp.8–12.

[9] Albusoda B S and Abbase H O 2017 Performance assessment of single and group of helical piles embedded in expansive soil Geo-Engineering, doi: 10.1186/s40703-017-0063-x.

[10] Al-Taie A J 2015 Profiles and geotechnical properties for some Basrah soils Al-Khawarizmi Engineering Journal 11(2) pp.74-85.

[11] Jebur M M, Ahmed M D and Karkush M O 2020 Numerical Analysis of Under-Reamed Pile Subjected to Dynamic Loading in Sandy Soil IOP Conference Series: Materials Science and Engineering 671 doi:10.1088/1757-899X/671/1/012084

[12] Shih T H, Xiang, Y C and Yi-Fan W 2020 A 3-D Analysis on the loading behaviours of an underreamed anchor in cohesion-less soils IOP Conference Series: Materials Science and Engineering 758 pp.1-7 doi:10.1088/1757-899X/758/1/012048

[13] Niroumand H, Kasim K, Ghafooripour A and Nazir R 2012 Uplift Capacity of enlarged base piles in sand Electronic Journal of Geotechnical Engineering (EJGE) 17 pp. 2721-2737.

[14] Watanabe, K, Sei H, Nishiyama T and Ishii Y 2011 Static axial reciprocal load test of cast-in-place nodular concrete pile and nodular diaphragm wall Geotechnical engineering journal of the SEAGS and AGSSEA 42 (2).

Acknowledgements
I would like to thank all staff of Civil engineering department, and the staff of soil mechanics laboratory in the College of Engineering, University of Diyala, Iraq, for their support.