Experimental Investigation of Under Reamed Pile Subjected to Dynamic Loading in Sandy Soil

Maher M. Jebur\textsuperscript{1a} and Mahmood D. Ahmed\textsuperscript{1b}

\textsuperscript{1}Department of Civil Engineering, University of Baghdad, Baghdad, Iraq.
\textsuperscript{a}mmg.maher@yahoo.com, \textsuperscript{b}mahmoud_baghdad@yahoo.com

Abstract. This paper presents an experimental study between uniform pile and different types of underreamed pile, single bulb. The underreamed piles are piles with enlarged bases that are suitable to resist considerable movement of the ground, filled up ground, soft clay, and loose sand which have advantages to increase the soil strength, uplift capacity, and decrease the displacement. In the present study, there are experimental analyze to performance the suitable underreamed type under sinusoidal load from vertical vibration (motor-oscillator was mounted directly on the pile cap). The main finding of this work is that the pile capacity increases with the ream and that all stress values of soil-structure interaction beneath the pile tip and underreamed pile bulb due to external load can be founded. The underreamed pile is made of reinforced concrete and the bulb is located at different positions of the embedded length of the pile. The type of soil used in the present work was loose sand and obtained from Karbala city. The Dynamic time-settlement curve has been obtained from the analysis and it was showed that the reduction in settlement is about 223\% in case of using a single bulb from L/2 from pile tip which is the best results in comparison with the uniform pile.

Keywords. Underreamed pile, dynamic load, machines foundation, sandy soil.

1. Introduction

The present-day trend of modern civil engineering structures tends to rise high into the sky i.e., skyscrapers, transmission tower of electricity, water tanks and tall structures subjected to high axial loads combined with large bending moments due to lateral forces such as wind, have needed superior types of foundation such as deep foundation. Underreamed piles are cast in-situ and made of concrete piles with one or more bulbs in their stems. The bulbs help to distribute the loads in soil and then lead to an increase in the carrying capacity of the piles in both pull-out and compressive loadings. Also, underreamed piles provide better anchoring along the embedded depth of the pile. The first methodical studies on underreamed piles were conducted in South Africa in 1949 by Jenkins and Henkel. Qian et al. [1] presented that the behavior of under reamed piles inserted in sandy soils. The authors determined the pull-out and axial static loading carrying capacity of the piles, which description and calculation the stresses of soil mass and provide a theoretical basis for a future study of this type of pile. Bharathi and Dubey [2] implemented 2D linear finite element analyses of vertical piles (with and without under-ream) subjected to vertical sinusoidal dynamic load using ABAQUS software.

The soil was silty sand (SM) has an angle of internal friction ($\phi = 32^\circ$) and dry unit weight ($\gamma = 15.38$ kN/m$^3$). Based on the results of the numerical study, it was observed that; as the eccentricity of the oscillator (i.e. force level) increases, the vertical displacement amplitude increases. It was also found that the maximum vertical displacement amplitude of the underreamed pile is less than that of a vertical pile. Hence, it is favorable to use underreamed pile in situations where the system is subjected to heavy
vertical dynamic sinusoidal loads. Jebur et al. [3] studied the influence of the geometrical shape of bulbs and subjected to machine load on the carrying capacity of under reamed piles by PLAXIS 3D software-2013 version. The result show that shapes of bulbs have significant effects on the failure of the underreamed pile in the soil mass. The geometrical shape of the reamed pile can be changing the soil pile interaction and change the type of soil mass failure from punching occurred in a pile of uniform cross-section to local failure or general shear failure which occurred in under-reamed piles.

Christopher and Gopinath [4] carried out two sets of mild steel under reamed piles models in sand soil to study the behavior of under-reamed piles subjected to vertical loads by an experimental work, the pile, and under-reamed diameter equal to 25 and 75 mm respectively. From the tests, the results show that, the load capacity of piles with ream is higher in comparison with the straight shaft. In the case of a prismatic pile of diameter 25 mm the ultimate capacity increased about 305% in compression, when the pile is under-reamed. Al-Suhaily et al. [5] used an open pile, which consists of a square steel section for a pile of square with dimensions of (24×24) mm with 480 mm in length and 1.5 mm in thickness. A steel frame was planned to be used in motivating the piles, the steel structure was located above the pile. The results showed that gates are opening at an angles ranged from 20–80°. The changed types of substrates, thus increasing the loading area from (B2 to 9.8 B2) by an increase of 880% and increasing the increment ratio in pull out resistance from (53 N to 430 N) by an increase of 711%.

The present study devoted to studying the behavior of under-reamed piles inserted in sandy soil and subjected to vibrating loading through obtaining the settlement-dynamic time variation for conventional pile and under-reamed pile; understanding the behavior of reamed position under sinusoidal load, and to investigate the relationship between net pile friction force and bulb position and bearing pile tip.

2. Materials Used

2.1. Sand

The soil used in the model tests is natural sand but passing through sieve No. 10 and retaining on sieve No. 100 obtained from Karbala city. The site is located in station (0+0) km for Al-Rufae road which leads to Razaza lake. The useful physical and mechanical properties of used sandy soil are listed in Table 1

| Property                           | Unit | Value   | Specification               |
|-----------------------------------|------|---------|-----------------------------|
| Specific gravity, Gs              | -    | 2.66    | ASTM (D854)                 |
| Coefficient of uniformity, Cu     | -    | 2.0     | ASTM (D422)                 |
| Coefficient of curvature, Cc      | -    | 0.96    | ASTM (D422)                 |
| Classification (USCS)             | -    | SP      |                             |
| Maximum, γd,max.                  | kN/m³| 16.80   | ASTM (D4253)                |
| Minimum, γd,min.                  | kN/m³| 14.90   | ASTM (D4254)                |
| Dry unit weight (Used)            | kN/m³| 15.21   | -                           |
| Young’s modulus, E                | kPa  | 1200    | ASTM (D4253)                |
| Poisson’s ratio, ν                 | -    | 0.3     | Assumed                     |
| Angle of internal friction, φ     | degree | 32    | ASTM D 3080)               |
| Dilation angle, ψ                 | degree | 2.0   | ASTM (D3080)               |

2.2. Model Pile

A pile length 570 mm with a diameter 23 mm, the pile is kept embedded in the sand so that the pile top is 20 mm above the soil surface. The model piles used in this study are made of an admixture of reactive powder concrete. This reactive powder allows producing a high performance and workability mortar, increase mortar toughness, ductility, and impact resistance Mohammed et al. [6]. To construct the under reamed bulb at specific locations of the model pile, the wall of uniform circular cross-sectional area pile is coated with a structural epoxy bonding agent (Sikadur-23) which is a moisture tolerant to bond the
surface of the pile at the desired level of reamed with new mortar of under reamed bulb. Figure 1 shows the plastic molds of cone shape have diameter equals 23 mm at top and diameters equal to 46 mm at the bottom are used to construct the form of under reamed and filed by mortar slurry by special injection needle.

![Figure 1. Under reamed construction.](image)

2.3. Piled Cap Models
The piled cap used in this study is made from steel plate of dimensions (150×150×10) mm

3. Experimental Setup and Methodology
The test was arranged in a steel container (1000×1000×1000 mm), these dimensions were chosen to meet the boundary effects of physical models subjected to harmonic vertical vibration. Sand was filled in layers using the raining system which was manufactured to obtain a relatively homogeneous sand bed depending on the falling rate and height. Several trials with different heights of fall were performed to achieve the desired relative density as shown in Fig 2.

![Figure 2. Density calibration curve for sand used.](image)
The sinusoidal excitation load reciprocating machines and unwell balanced rotating equipment cause periodic dynamic forces. The maximum amplitude of the vertical dynamic force produced \( F_{\text{max}} \) is:

\[
F_{\text{max}} = m_e \, e \, \omega_r^2 \quad (N)
\]  

(1)

Where \( \omega_r \) is the circular operating frequency of the machine, r/s; \( e \) is the eccentric distance from the center of shaft to the unbalanced mass \( m_e \); and \( m_e \) is the unbalanced mass, g. Small motor was used to simulate a rotary machine with a total mass of 2.11 kg while the eccentric mass was 0.0145 kg and the eccentric distance was 22 mm, from the above data and for (30 Hz) operating frequency, the induced dynamic load for the machine from the above formula is 11.3 N. The corresponding settlement of pile was recorded by Computerize linear variable differential transducer (LVDT). The force sensor is used to measure the forces directly beneath under reamed pile (pile tip and bulbs), and the number of load sensors has been used equal to the number of pile bulbs plus 1 Fig. 3.

![Image](image.png)

**Figure 3.** Schematic diagram of the physical model.

| 4. Results and Discussion |
|---------------------------|
| In this study, the position of reamed from the pile tip used was 0, L/4, L/2, and 3L/4 as shown in Fig. 4. Figure 5 shows the relation between bulbs position and maximum settlement whit the time, therefore, it can be noted that when bulb position equal to L/2 from pile tip, there is minimum settlement 0.55 mm compare with uniform pile 1.8 mm see Fig. 6, the motive of reducing the settlement return to there is a good interaction between bulb position and confined soil pressure against external dynamic force. |
Figure 4. The different positions of the bulb.

Figure 5. Time-Settlement for (30 HZ-RD 35%).
Figures 7 to 11 display the relationship of dynamic bearing force in (pile tip and bulb)-time curve with RD 35% and 30 Hz that means dynamic load put on pile cap was 11.13 N. From these Figures, it is intended to study the average friction force along under-reamed pile (F), the average force under bulbs (BU) and the pile tip force in time (120) sec motor stop (PT).

Figure 6. Settlement-Bulb position for (30 HZ-RD 35%).

Figure 7. Force-Time Curve for (30 HZ-RD 35%- Uniform).

Figure 8. Force-Time Curve for (30 HZ-RD 35%- L=0).
Figure 9. Force-Time Curve for (30 HZ-RD 35%- L/4).

Figure 10. Force-Time Curve for (30 HZ-RD 35%- L/2).

Figure 11. Force-Time Curve for (30 HZ-RD 35%- 3L/4).

Figure 12 shows that (F) value in (L/4, L/2 and 3L/4) was more than (Uniform and L=0) because bulb position makes its work together with the pile to encourage soil particular around bulb for involvement in total friction force, which is opposite to what happened in bearing force under bulb (BU) Fig. 13.
Figure 12. Friction force-blub position for (30 HZ-RD 35%).

Figure 13. BU%-blub position for (30 HZ-RD 35%).

Finally, Fig. 14 shows that under-reamed pile can be reduced pile tip force under machine vibration compare with uniform pile at the final time which the demising vibration was stopped due to stick reamed with surround sand.

Figure 14. PT-Blub position for (30 HZ-RD 35%).
5. Conclusions

- In dynamic loading, the factor of safety against bearing failure increased during machine operation. During operation, the skin friction resistance mobilized along pile length led to decrease the bearing load.
- At time 120 sec for all cases of under-reamer pile end bearing less than initial time 0 sec and the minimum values appear in the position L/2.
- Using a single under-reamed pile can be increasing friction force instead of uniform pile, the maximum friction force was in position of reamed L/4 in loose sand.
- Finally, the optimum position of the reamed pile under dynamic load was at the position L/2 where it can be caring about 10.9% of total loading (external and dead load) and the settlement equal to 0.55 mm.

References

[1] Y.M. Qian, D.P. Zhao, and X.W. Xie, The research on the ultimate bearing capacity of soil around the push-extend multi-under-reamed pile at sliding failure state, Applied Mechanics and Materials 578-579 2014 232–235
[2] M. Bharathi and R.N. Dubey, Dynamic lateral response of under-reamed vertical and batter piles Construction and Building Materials 158 2018 910-920
[3] M.M. Jebur, M.D. Ahmed, and M.O. Karkush, numerical analysis of under-reamed pile subjected to dynamic loading in sandy soil, In IOP Conference Series: Materials Science and Engineering, 671(1) 2020 p. 012084.
[4] T. Christopher and M.B. Gopinath, Parametric study of under-reamed piles in sand, International Journal of Engineering Research & Technology (IJERT), 5(7) 2016 577-581.
[5] A.S. Al-Suhailey, A.S. Abood, and M.Y. Fattah, M. Y., (2018), Bearing capacity of uplift piles with end gates, Proceedings of China-Europe Conference on Geotechnical Engineering, 2018 893–897.
[6] S.D. Mohammed, W.Z. Majeed, N.B. Naji, and N.M. Fawzi, Investigating the influence of gamma ray energies and steel fiber on attenuation properties of reactive powder concrete. Nuclear Science and Techniques, 28(10) 2017 153.