Investigation of Pile Behaviour using Rotary-Jacking Method

N S Hassan¹ and A Ibrahim²
¹Centre for Graduate Studies, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, 57000 Kuala Lumpur.
²Civil Engineering Department, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, 57000 Kuala Lumpur.
Email: aniza@upnm.edu.my

Abstract. This research investigates the installation of a new pile using the rotary and jacking method. The use of hydraulic ram to apply static jacking force does not produce the noise and ground vibration produced by the traditional percussion and vibro-hammer methods. The pile jacking process can increase the bearing capacity and stiff base response but may occasionally cause excessive installation resistance. An innovative rotary jacking method can overcome these problems and enhance pile performance. The research seeks to determine the effect of pile loading and the pile response under axial loading. The laboratory experiment uses a 25-mm circular pile and a screw pile together with a large container filled with silica sand attached to a rotary jacking machine. The installed piles are subjected to the installation and static load tests. The results show that the rotary jacking method successfully installed the pile with less resistance between the sand and pile surface, which allows the piles to penetrate the required depth with less loading. The experimental results proved that the rotary jacking method reduced soil settlement and the time taken to drive the pile into the soil. This new innovative method will enhance pile installation in the construction industry.

1. Introduction
Pile driving is an essential part of building constructions. Piles transfer the load from structures to the ground and strengthen the structure foundation. Pile foundation is defined as installation of pile to transfer the load to the ground when upper structure is not strong enough due to soil weakness [1]. Two types of foundation are classified which are deep and shallow foundation. Deep foundation is widely used because its large bearing capacity, low distortion, and high reliability [2]. The cost of building a foundation on loose soil is very high, particularly in urban areas. Piles provide support to the retaining wall, bridge piers, and machinery foundations which carry the combined vertical and horizontal loads [3]. Pile driving into the ground of a construction site generates vibration as the pile penetrates the soil. Even though the natural vibration of the earth and human activities generate ground vibration [4], the vibration generated during pile driving can cause discomfort to people and damage the nearby structures [5]. Some pile installations, such as hammering installation, have an adverse impact on the environment. The overload force exerted during pile installation may cause underground cracking and damage the water and sewer pipes, power lines, and communications cables [6]. The current pile installation methods take longer to drive the pile into the ground. Longer construction time means higher costs. Malaysia has been using a jack-in piling with a working load of up to 3000 kN since the late 1990s [7]. Jacking method is the most familiar method used at construction site to install the pile into the ground.

It is essential to use a suitable pile for a structure to ensure structural stiffness. The type of pile used is dependent on several factors, including soil type, corrosion, local availability and cost, contractor
preference, and the load-bearing requirement of the foundation [8]. The friction between the soil and pile surface during pile installation can produce resistance. Pile resistance is one of the factors that affecting the performance of pile behaviour. Previous study states that, the ground resistance of single pile is determined by stress distribution under pile base and skin surface [9]. Stainless steel piles are used in construction work. The friction generated between the steel and soil may exceed 35-50% of the total draft resistance [10].

The rotary jacking method is an innovative method for installing pile in the ground developed from the traditional axial jacking method. It uses rotation movement to drive the pile to a particular depth. During the installation, the pile is simultaneously rotated and jacked into the ground. Pile installation by rotation movement reduces the required axial loading [11]. However, the pile response under subsequent loading of the jacking and rotation method is not yet understood.

This paper seeks to determine the impact of using different pile installation methods, the resistance of different pile shapes and sizes, and the subsequent response under axial working loading by rotary jacking method.

2. Materials and Method

2.1. Materials

This experiment used a 25-mm diameter and 600-mm long stainless-steel pile and screw pile, as shown in figure 1 and figure 2. The silica sand passed a 600-μm sieve but retained in a 300-μm sieve. The sand was compacted for ten minutes to reduce the pore volume containing water or air. The piles were driven into the silica sand. The experiment followed the BS 1377: PART 2:1990: Clause 9.2 [12].

![Figure 1. 25 mm circular pile](image1)

![Figure 2. screw pile](image2)

2.2. Apparatus Set-up

2.2.1 Custom Rotary Jacking Machine. The rotary jacking machine in this experiment comprises several components, as shown in figure 3. The custom machine is 0.8 meters high and 0.8 metre in diameter and has a large, circular container to hold the silica sand. The rotary jacking machine has a control panel with three operation switches for penetration, rotation, and vibration. The penetration and rotation switch controls two pile movements, forward and reverse. The machine also connects directly to the data logger that collects the data.
Figure 3. Rotary-jacking machine

2.2.2 Data logger. This research used the Campbell Scientific Datalogger (CR800) to measure the electrical signals and convert the measurements into engineering units. The data logger is connected to the LoggerNet software used to analyse the collected data.

2.2.3 Motors. The mechanism system comprises two (2) motors, the jacking motor and the rotating motor. The maximum speed of the rotating motor is 1 min/rev and 0.0043 mm/s for the jacking motor.

2.2.4 Load Cell. The load cell is a transducer for producing an electrical signal that measures the magnitude directly proportional to the force. The maximum capacity of the load cell is 2000 pounds, which is equivalent to 8.90 kN. The vertical pile displacement was measured using the linear transducer, and the data was displayed on the computer.

2.3. Experiment
The experiment consists of pile installation and static loading testing. The jacking method and the jacking and rotary methods were used to install the pile. The first step is vibrating the silica sand in the container for five minutes to compact the sand. The first pile installation used the jacking method and took about 2.5 hours to reach the required length. Because the machine cannot be driven to 600-mm pile length, the maximum length of pile installation is 300 mm. The static load test used a 0.08 kN weighing block. Because the machine was custom-made, the highest loading is ten blocks weighing 0.78 kN. The data was recorded immediately after the completion of the pile installation. The pile was removed after the static load test, and the second pile was installed using the same process. Table 1 lists the experiments.
### Table 1. Experimental schedule

| Shape of Pile | Method of Installation | Static Load Test |
|---------------|------------------------|------------------|
|               | Jacking                | Jacking          |
| 25 mm Circular| √                      | √                |
| Screw Pile    | √                      | √                |
|               | Jacking and Rotary     | Jacking and Rotary |
| 25 mm Circular| √                      | √                |
| Screw Pile    | √                      | √                |

3. Result and Discussion.

3.1. Installation Method

The pile installation used the jacking method and the jacking and rotary method. Figure 4 shows the graph for installing the 25-mm circular pile. The jacking method required 0.60 kN loading to drive the pile to a depth of 150 mm, and the jacking and rotary method required 0.30 kN loading. Figure 5 shows the graph for the installation of the screw pile using both installation methods. It shows that the jacking method required 1.03 kN loading, and the jacking and rotary method required 0.66 kN loading to drive the pile to a depth of 150 mm. The loading required for the jacking method is twice that for the jacking and rotary methods, which proves that the jacking and rotary method required less loading to drive the pile to a particular depth. The lower loading means less resistance between the pile surface and sand, which reduced the time for installing the pile in the sand.

![25 mm Circular Pile Installation](image)

**Figure 4.** Result of 25 mm circular pile installation.
3.2. Static Load Test

The static load test determines the relationship between the load and the pile head displacement [13]. This test was carried out to determine the subsequent response that influences the pile settlement. The linear transducer collects the data under working axial loading. The maximum loading in this experiment is 0.785 kN, and the test is carried out immediately after the completion of the installation. Each test takes about one hour. Figure 6 and figure 7 show the static load test results for the 25-mm circular and screw pile for both installation methods. The 25-mm circular pile shows a 1.4 mm settlement at a point load of 0.6 kN when using the jacking method and a 0.4 mm settlement when using the jacking and rotary method. The screw pile showed 1.02 mm and 0.75 mm settlement for the jacking and jacking rotary method at the same point of load. The graphs show less pile settlement for the jacking and rotary method relative to the jacking method. Therefore, the jacking and rotary method resulted in less structural failure and is safer for the surrounding environment.

Figure 5. Result of screw pile installation.

Figure 6. Result of static load test for 25 mm circular pile.
4. Conclusion
The experimental results showed that the jack and rotary pile installation reduced the friction between the pile and sand, which reduced the resistance. In terms of resistance, bearing capacity, and load carried by the pile (load test), the jacking and rotary method is superior to the jacking method. The time taken for pile installation using the jacking and rotary method is less than for the jacking method. Therefore, the jacking and rotary method is an efficient method for pile installation because it is more eco-friendly and less costly. Future research should use different types of sand to determine the effectiveness of the jack and rotary method on other soil parameters. Also, further research should seek to improve the results of the installation test.

References
[1] Kim S, Whang, S W and Kim S 2017 Pile Foundations Design Through the Increased Bearing Capacity of Extended End Pile Journal of Asian Architecture and Building Engineering, 16 pp 395-402
[2] Zhanfang H, Xiaohong B, Chao Y, and Yanping W 2020 Vertical Bearing Capacity of a Pile-Liquefiable Sandy Soil Foundation Under Horizontal Seismic Force Plos One, 15
[3] Letsios C, Lagaros N D and Papadrakakis M 2014 Optimum design methodology for pile foundation in london Case Study in Structural Engineering, 2 pp 24-32
[4] Athanasopoulos G A and Pelekis P C 2000 Ground vibrations from sheet pile driving in urban environment: measurements, analysis and effects on buildings and occupants Soil Dynamic and Earthquake Engineering. 19 pp 371-387
[5] White D, Finlay T, Bolton M and Bearss G 2002 Press-in piling: Ground vibration and noise during installation Cambridge University Department. 116 pp 363-371
[6] Endres D 2013 Effect of pile driving induced vibrations on nearby structures Geotechnical Services Section Michigan Department of Transportation. RC-1600
[7] Tan. Y C, Chow C M and Gue S S 2011 Jack-in pile in Malaysia: A Malaysia consultant respective Proceedings of the VLA Seminar.
[8] Adejumo T E and Boiko I L 2012 Pile Foundation and Installation Methods in Nigeria Faculty
of Civil Engineering. 17 pp 2613-2621

[9] Norkus A and Martinkus V 2019 Experimental Study on Bearing Capacity Resistance of Short Displacement Pile Groups in Dense Sands. Journals of Civil Engineering and Management, 25 pp 551-558

[10] Vilde A, Rucins A and Sevostjanovs G 2007 Impact of speed on the soil sliding resistance. Jelgava 5 pp 24-25

[11] Hazla E 2013 Rotary press-in piling hard ground. Fourth-Year Undergraduate Project in Group D.

[12] British Standard (BS) 1377: PART 2:1990: Clause 9.2 Methods of test for soils for civil engineering purposes

[13] Krasinski A and Wisaniew M 2017 Static load test on instrumented pile-field data and numerical simulations. Studia Geotechnica et Mechanica, 39