Assessment of Ultimate Bearing Capacity of the Pile for Jacking & Rotary Piling Method

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Abstract. Selecting method of pile installation is one of the most factors which affect progress of a construction project. During the installation process, using command methods was discovered to have some weaknesses, such as high friction resistance and high settlements, which could lead the structure to fail. To overcome these problems, this study introduces new method of pile installation which is Jacking and Rotary method (J&R). The objective of this study is to determine pile behavior for static load test when utilizing a common method namely jacking (J), and a new method of pile installation, J&R through the ultimate pile capacity achieved by both methods. A stainless steel 25 mm circular pile, a 50 mm circular pile and a screw pile were used as test piles for this investigation. To achieve the objectives, this study employed graphical methods such as Brinch Hansen 80 % and Tangent method to determine the ultimate pile capacity for both piling installation methods. Results revealed that for jacking method, the highest ultimate pile capacity value for the 50 mm circular pile was 1.186 kN, whereas the 25 mm circular pile had the lowest pile capacity reading of 0.539 kN. While for J&R, the highest average for both graphical methods is screw pile with 0.683 kN, while the 50 mm circular pile produced the lowest pile capacity which was 0.491 kN. Results indicated the acceptable of J&R methods and suggest further investigate for this method such as the response of pile under axial loading and other tests.

Keyword: Pile installation; Ultimate pile capacity; Jacking & Rotary; Graphical method.

1. Introduction

Piles are buried in the ground and frequently come into contact with rocks and solid ground. Basically, piles are long and slender structures that are penetrate into the ground mainly purpose to support and transfer the load from the structure to the deeper part of the ground. The retaining wall, bridge piers, and machinery foundations are supported by pilings, which support the combined vertical and horizontal stresses (Letsios et. al., 2014). Pile foundation is the process of installing a pile to transfer weight to the ground when an upper structure is insufficiently stable relative to weak soil (Kim et. al., 2017). Due to its excellent durability, minimal distortion, and high bearing capacity, deep foundation is usually applied (Zhanfang et. al.,2020). Pile driving is one of the most important aspects of building structure. It is an important part of the construction process since it ensures that the structure is strong enough to resist the load. Pile driving methods for displacement piles and boring methods for pile replacement can be used to install and drive piles into the ground. To install displacement piles, most pile driving methods, such as jacking, rely on static hydraulic power. The static jacking force is utilized to decrease ground vibration and noise in neighbouring construction locations by using hydraulic rams. The type of piles chosen is determined by a number of factors, including soil type, erosion, local availability and cost, personnel, and the load-bearing needs of the foundation (Adejumo and Boiko, 2012). Pile resistance is frequently linked to pile installation. When the pile is driven into the sand medium, there is resistance between the pile surface and the sand. According to Norkus & Martinkus (2019), the ground resistance of a single pile is determined at loading sites by the stress distribution under the pile base and the piles skin surface (Norkus and Martinkus, 2019). Because piles are set using static analysis methods and real pile resistance is measured during the building phase, achieving the pile resistance assumed in design might be difficult (Ng and Sritharan, 2014). Excessive settling during pile installation might lead to structural cracks. Failure of settlement, according to Fan et al. (2014), is defined as the event displacement exceeding the corresponding allowable displacement (Fan et. al., 2014). Muthukkumaran et al. (2016) found that 10 key bridges under construction in the Nagapattinam Tiruthuraipoondi B.G trains line failed pile load tests due to excessive pile settlement in a previous study (Muthukkumaran et. al., 2016). It is clear that excessive settlement during pile installation is a problem that can cause structural damage and must be addressed in order for the structure to function effectively.

A new concept of pile installation was introduced in this study. A novel technique for installing piles in the ground, rotary jacking was evolved from the conventional axial jacking technique. The pile is simultaneously turned and jacked into the ground during installation. Pile installation by rotational movement helps in the reduction of axial loading necessary (Hazla, 2013). Due to the change of orientations and the magnitude of the base and shaft resist towards the piles, jacking resistance reduces when the piles rotate. This new technology will allow piles to be driven into the sand with less resistance between the pile's surface and the sand medium.

This paper aims to determine pile behaviour for static load test when utilizing a common method, jacking and new method, jacking and rotary through the ultimate pile capacity achieved by both methods.

2. Materials and Equipment

2.1. Materials

This study used a 25-mm diameter, 50-mm diameter and screw pile with 600-mm long stainless-steel pile and, as shown in Fig. 1, Fig. 2 and Fig. 3. The dimension of piles is tabulated in Table 1. The silica sand used in this study 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 (British Standard, 1990).

Fig. 1: 25 mm circular pile

Fig. 2: 50 mm circular pile

Fig. 3: Screw pile

Table 1: Summary of Tested Pile

Dimension	Unit	25 mm Circular pile	50 mm Circular pile	Screw pile
Length, L	mm	600	600	600
Diameter, D	mm	25	50	28
L/D	-	24	12	21
Weight, W	g	2280	9190	2370
Cross section	mm^2	491	1963	616

2.2 Rotary Jacking Machine

The rotary jacking machine in this study comprises several components, as shown in Fig. 4. The machine is 2000 mm in height and consists of circular containers, rotary and jacking motors at the top and bottom and a barrel system with tyres. The machine has large circular container with 800 mm high and 800 mm in diameter to load the silica sand. The rotating motor and the jacking motor are two (2) of the motors that comprise the mechanical system. The spinning motor's maximum speed is 1 min/rev, while the jacking motor's maximum speed is 0.0043 mm/s. Three operating switches for rotation, penetration, and vibration are positioned on the rotary jacking machine's control panel. The forward and reverse pile movements are regulated by the penetration and rotation switch. With the help of load cell, the electrical signal is produced to ease transferring the data. A transducer for generating an electrical signal that measures the magnitude inversely proportional to the force is a load cell. The load cell can sustain a maximum weight of 2000 pounds, or 8.90 kN. The linear transducer measures the vertical pile displacement, and the computer displays the data. Additionally, the device has a direct connection to the data logger, which can retrieve data and analyse it using Loggernet software. The electrical signals were measured in this investigation using the Campbell Scientific Datalogger (CR800), and the measurements were then converted into engineering units. The software used to analyse the gathered data, Loggernet, is connected to the data logger.

3. Testing Procedures

3.1. Pile Installation

The test consists of two processes, installation of pile and axial working load for all piles. Pile installation process involves Jacking (J) and Jacking and Rotary (J&R) methods. In this study, before the piles are installed, the sand is compacted (vibrating at 30Hz) for 10 minutes. Jacking installation method is used for first round. For this installation procedure, a vertical force was delivered directly to the pile and the jacking motor was turned on. A switch on the jacking button triggered the test. The pile is penetrated and driven into the sand for 300 mm of settlements, which half of actual length of pile. This due to the machine limitation that can only handle up to that point. When the jacking method installation is done, the static load test is continually performed on the same pile. The installation of pile is continued with jacking and rotary method using same process as previously.

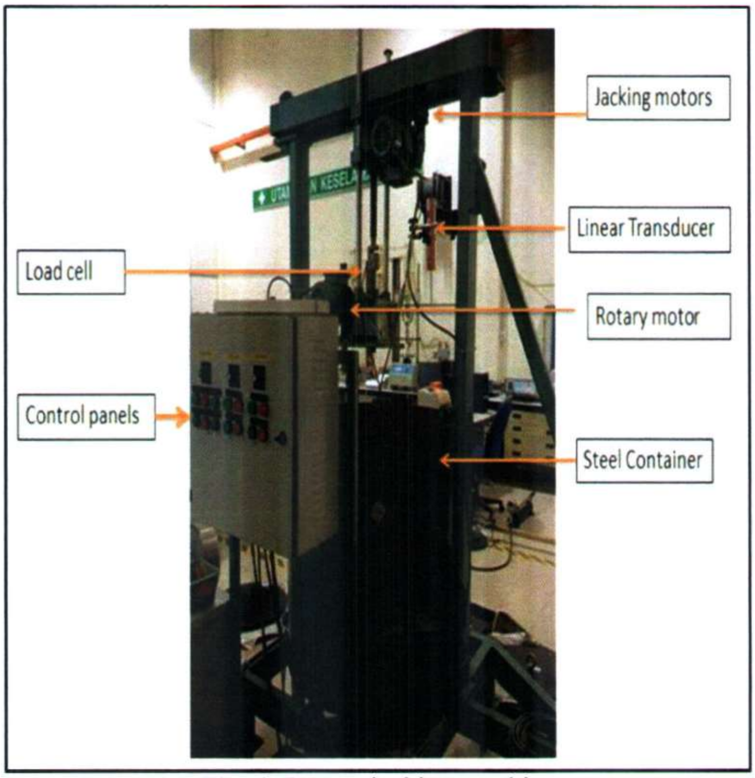

Fig. 4: Rotary-jacking machine

3.2. *Static Load Test*

Static load test is performed to determine pile capacity in order to meet the objective of this study. The load tests are carried out to determine the relationship between the load and the displacements of the pile head, according to Krasinski & Wisaniew (2017). Pile capacity is vital for determining the maximum load that the piles can support without failure or severe ground settling. The pile is removed after the static load test, and the second pile is installed using the same process. Table 2 list the summary of the tested pile.

Table 2: Summary of Tested Pile with Different Sizes of Piles

Installation Method		Jacking		Jacking and Rotary	
Size of Pile	L/D	Installation of Pile	Static Load Test	Installation of Pile	Static Load Test
25 mm Circular	24	√	√	√	√
50 mm Circular	12	√	√	√	√
Screw Pile	21	√	√	√	√

3.3. Graphical Methods

The graphical method is used in this study to determine the pile's bearing capacity. The Brinch Hansen 80% is calculated as referred to Eq. 1 and Tangent methods is determine using two intersection lines are used for graphical method interpolation. The Factor of Safety (FOS) is estimated for both the graphical method. In Malaysia, the Factor of Safety is used to calculate the static pile capacity on the shaft and base (Chow & Tan, 2009). The formula for calculating FOS is found in Eq. 2.

$$Q_U = \frac{1}{2\sqrt{C_1.C_2}} \quad (1)$$

$$Q_U = \frac{Q_s + Q_b}{F_g} \quad (2)$$

4. Result and Discussion

4.1. Installation Method

The pile installation used the jacking method and the jacking and rotary method. Figure 5 shows the combination of graph using both methods for all piles. Table 3 summarises the results from both methods utilised during the installation phase for all piles. The loading necessary for the pile to be driven into the sand can be determined as a comparison between the two methods utilised based on the results achieved. The result demonstrates that the pile depth increased as the loading applied to the pile increased. This clearly shows that the jacking and rotary approach has the best performance behaviour due to the loading required, which means that this method requires less loading to install the piles at a given depth than the jacking method. This indicates that the less load the pile was required to carry, the less resistance was faced during installation. When the load needed of the pile is bigger, the resistance increases. When utilising the jacking method to drive a 25 mm circular pile into the sand at 150 mm depth, the loading necessary was 0.600 kN, but when using the jacking and rotary methods to drive the pile into the same depth, the loading required was 0.300 kN. This demonstrates that the new jacking and rotating procedure, which requires less loading, helps to reduce resistance during pile placement.

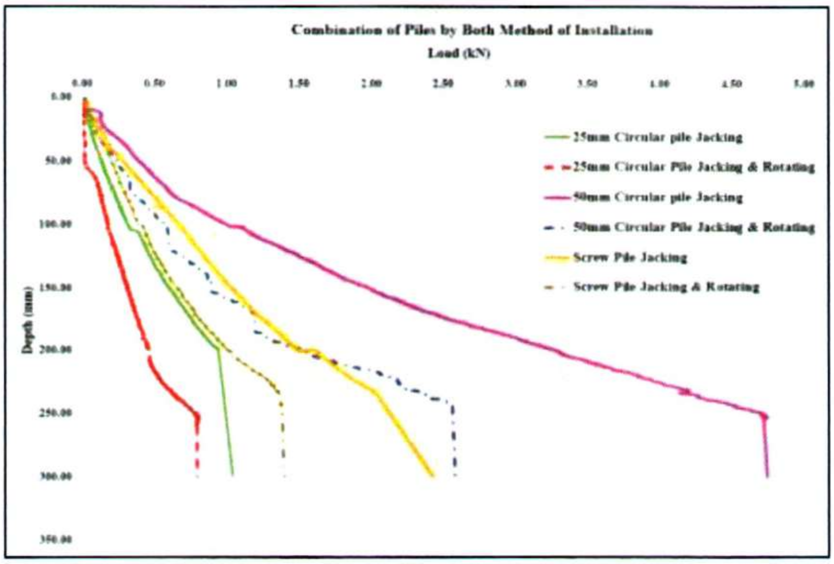

Fig. 5: Combination of Piles by Using Jacking Method and Jacking and Rotary Method

4.2. Static Load Test

After completing the pile tests, the rotary condition used in the jacking and rotary method helped reduce pile settlements, according to the results obtained from the jacking and jacking and rotary method. According to Sato et al. (2018), shaft rotation lowered penetration resistance, as evidenced by the rotation ratio. The piles are easier to penetrate the earth when the rotating action was used during pile installation because the resistance was minimised. The graph of pile settlements for both methods are shown in Fig. 6 and Fig. 7. The 50 mm circular pile demonstrated the feasibility of using the jacking and rotary methods in pile placement, as opposed to the jacking method, where the load settlement reading was substantially smaller. This was demonstrated by static load tests, which revealed that the 50 mm circular pile had a lower settlement reduction when static stress tests were performed as shown in Table 4.

Table 3: Summary of Load Require for Pile Installation

Size of Pile	25 mm Circular		50 mm Circular		Screw Pile	
Depth of Penetration (mm)	150	300	150	300	150	300
Jacking Method (kN)	0.600	1.041	1.985	4.742	1.028	2.424
Jacking and Rotary Method (kN)	0.300	0.794	0.894	2.580	0.660	1.391

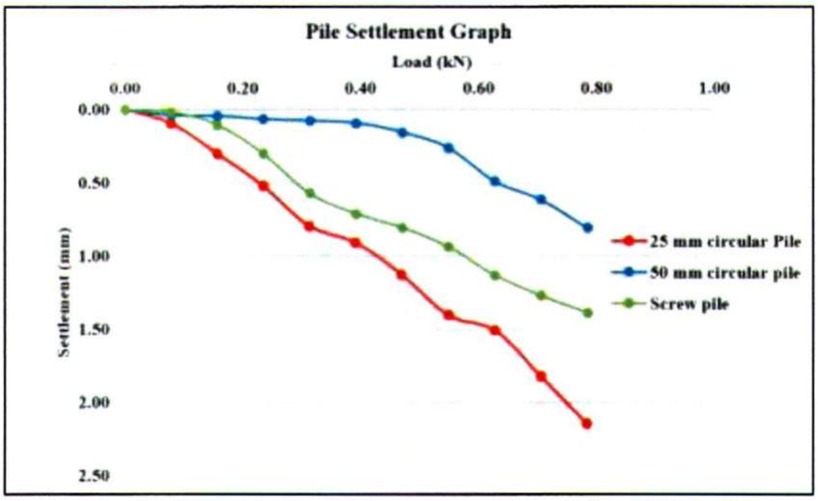

Fig. 6: Comparison of Pile Settlement by Jacking Method

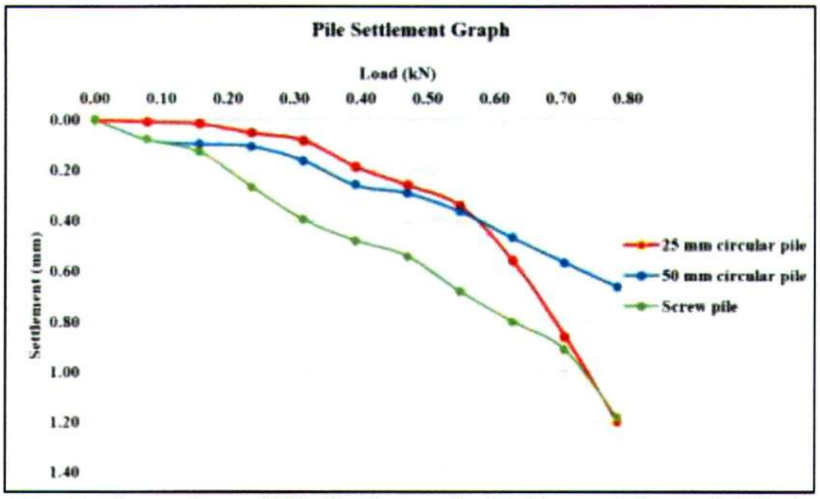

Fig. 7: Comparison of Pile Settlement by Jacking and Rotary Method

Table 4: Design Features of Pile

Size of Pile	25 mm Circular Pile		50 mm Circular Pile		Screw Pile	
Maximum Test Loading (kN)	0.785		0.785		0.785	
	J	JR	J	JR	J	JR
Total Settlement (mm)	2.149	1.201	0.806	0.661	1.385	1.181

4.3. Evaluation of Pile Capacity Using Graphical Methods

The evaluation of the static load tests' results that are performed in the laboratory are made because there were no changes or peak behaviour with the maximum loading that increased with the settlements, 0.785 kN. The graphical method is used to evaluate the ultimate pile capacity as compared with the design load. In this study, two graphical methods are used, the Brinch Hansen 80% and Tangent methods. The ultimate pile capacity for the jacking method for each pile type is displayed in a bar chart, as shown in Fig. 8 The ultimate pile capacity value for the 50 mm circular pile is 1.186 kN, whereas the 25 mm circular pile had the lowest pile capacity reading of 0.539 kN. As referred to Fig. 9, the bar chart shows the graphical evaluation for jacking and rotary method. The screw pile provided the maximum pile capacity reading of 0.683 kN, while the 50 mm circular pile produced the lowest pile capacity of 0.491 kN for this method.

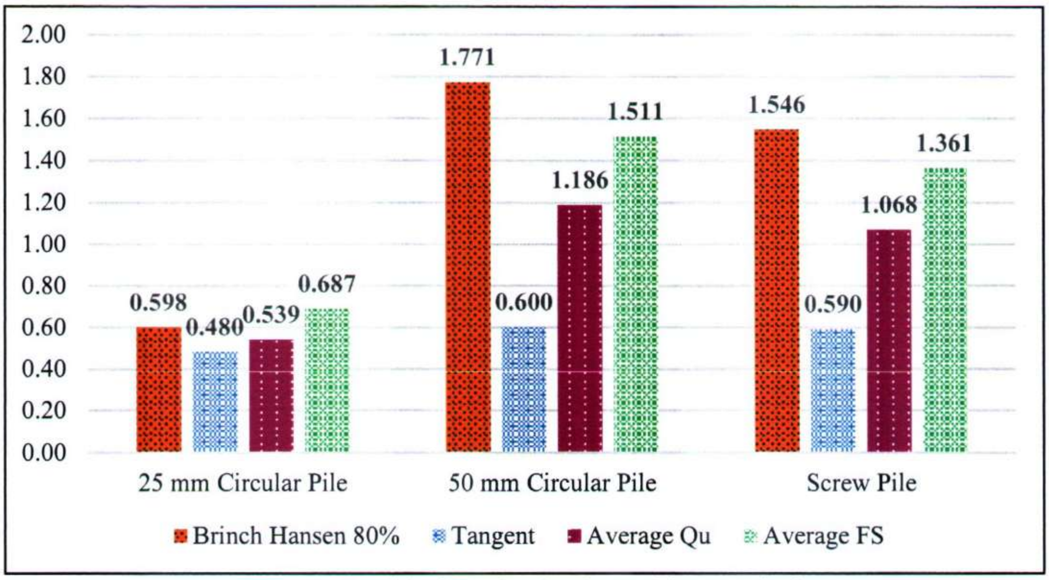

Fig. 8: Graphical Evaluation by Jacking Method

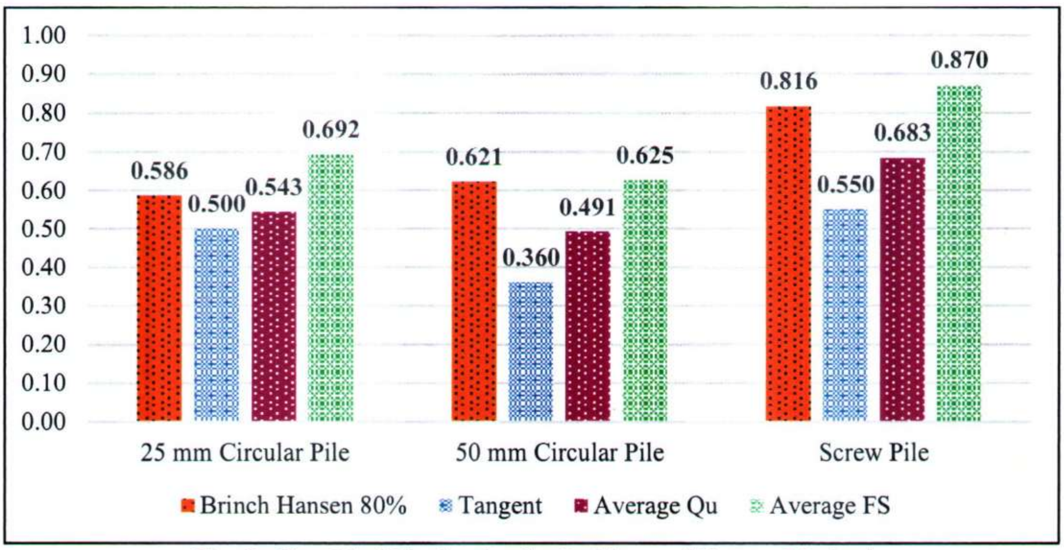

Fig. 9: Graphical Evaluation by Jacking and Rotary Method

5. Conclusion and Recommendation Works

The results showed that the new pile installation technique is the greatest alternative for driving piles in the future. It can be concluded that the jacking and rotating method is used to install the 25 mm circular pile and the 50 mm circular pile, demonstrating that this method is capable of resolving issues at the construction site such as reduced pile settlement, which can result in structural damage and failure load. As a result, if this new approach is implemented, this knowledge about its application can provide useful information about the optimum strategy for installing piles for future work. As for recommendation at future, the piles should be made of a variety of materials, such as timber and concrete, since both are often employed in construction works. Other types of soil can be used in place of sand. The pile installation technique can be done with either cohesive or non-cohesive soil. However, the soil must be examined for soil characteristics criteria to verify that the machine can work with the material.

6. References

Adejumo T E and Boiko I L 2012 Pile Foundation and Installation Methods in Nigeria *Faculty of Civil Engineering*. **17** pp 2613-2621

British Standard (BS) 1377: PART 2:1990: Clause 9.2 Methods of test for soils for civil engineering purposesChow, C.M., & Tan, Y.C. (2009). Jack-In Pile in Malaysia: Malaysian Experience and Design Approach to EC7. G&P Geotechnics, Malaysia. *IEM Course on Eurocode 7-Geotechnical Design.*

Fan H., Huang Q., & Liang R. (2014). Realiabilty Analysis of Piles in Spatially Varying Soils Considering Multiple Failure Modes. *Journal of Computers and Geotechnics*, 57. Letsios C,

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

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

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

Lagaros N D and Papadrakakis M 2014 Optimum design methodology for pile foundation in london *Case Study in Structural Engineering.* **2** pp 24-32

Muthukkumaran K., Raaj S.K., & Kumar M.V. (2016). Assessment of Pile Failures Due to Excessive Settlements During Pile Load Test. The 15th Asian Regional Conference On Soil Mechanics and Geotechnical Engineering. *Japanese Geotechnical Society Special Publication,* 2, 2520-2524.

Ng K., & Sritharan S. (2014). Integration of Construction Control and Pile Setup into Load And Resistance Factors Design of Piles. Soils and Foundations, 54, 197-208.

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

Sato, T., Otani, J., Chevalier, B., & Eskisar, T. (2018). Effect of shaft rotation of driven spiral piles on vertical bearing capacity. The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering. *Japanese Geotechnical Society Special Publication.*

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**