An Evaluation of Carrying Capacity of Jack-in Piles with Base Enlargement in Soft Clay

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Abstract. The enhancement of the carrying capacity of the single pile can be achieved by improving the roughness of the pile shaft and/or enlarging the tip of the pile. This paper presents the results of a laboratory experiment of a modeled steel pipe pile with and without the enlargement of the pile base. The pile base was made separately from the pile shaft and was inserted using jacking pressures into an artificial and homogenous soft clay soils. The soil media used is classified as high plasticity clayey-silt is compacted in the concrete container with 600 mm in diameter and 1000 mm in depth. This study shows that the technique of pile tip enlargement works properly, and the carrying capacity of the pile is higher than a pile without base enlargement by increasing of up to ± 270%.

1. Introduction

The foundation of a structure is defined as an integrated part of the structure in direct contact with the ground and which transmits the load of the structure into the ground. There are two types of foundation namely, shallow foundation and deep foundation, where the shallow foundation is used when the soil near the ground surface has an adequate bearing capacity, and the working load is not too heavy. In some cases, shallow foundations are inadequate to support the structural loads, so deep foundations or pile foundations are required. Piles are columnar elements in a foundation which have the function of transferring load from the superstructure through weakly compressible strata or through water, onto stiffer or more compact and less compressible soils or onto a granular rock. The mechanism of bearing capacity of the pile foundation consisting of, the friction of the surrounding soils along the pile and the bearing capacity under the tip of the pile. To increase the carrying capacity of the single pile, various efforts have been done including increase the carrying capacity of the tip and or around the surface of the pile skin, by means of modifying the physical shape of the pile, for example, increase the pile roughness and or enlarge the dimensions of the pile tip cross-section.

There are several types of pile foundation with base enlargement, two of them are Franki Piles and Mac-Arthur Piles. Was developed in 1909 by Belgian Engineer Edgard Frankignoul, the Franki piling system (also called pressure-injected footing) is a method used to drive expanded base cast-in-situ concrete piles (Figure 1), where the installation method of this piling system is explained clearly in ref. [1]. This method can be applied to different site conditions and is still widely used due to its high tensile load capacity, and relatively low noise and ground vibration levels.

Franki piles can be used as high-capacity deep foundation elements without the necessity of excavation or dewatering. They are useful in conditions where a sufficient bearing soil can only be reached deeper in the ground, and are best suited to the granular soil where the rising bearing is primarily achieved from the densification of the soil around the base. They are not recommended for use
in cohesive soils where compaction of the base is not possible. The Franki piling system is the quietest of the driven cast-in-place systems, and so is used in conditions where high noise levels could cause environmental problems.

The next type of pile with the enlargement on the base was developed by the MacArthur Concrete Pile Corp. (1950). A temporary steel tube is driven into the ground to the desired depth, then fill the tubes with concrete one-third the length of the tube, followed by raising and lowering the tube to produce bulb at the pile base. Once the bulb is formed, then drawn the tube gradually while filling the hole with concrete until completely fill the hole (Figure 2).

Both methods described above have a limitation if applied on a layer of soft clay because the bulb at the base of the pile cannot be formed perfectly. Therefore, to overcome this drawback, researchers from University of Christian Petra Surabaya has proposed a new method namely Preloaded Bulb Cast in-situ [2]. Although their research was successful to increase the carrying capacity of the pile tip, the bulb produced by this method is still less than the maximum. This paper describes a new method proposed
by the authors which deal with the techniques to create a pile bulb in soft clay layer and will explain more detail in the next sections.

2. Model Description
In general, this research was a laboratory experiment consist of a model of steel tube in a scale of 1:10, that pushed into soft clays soil that compacted on the concrete container with a diameter of 600 mm and a height of 1000 mm.

2.1. Characteristics of soil media
A laboratory testing program was designed to determine the geotechnical and physical properties of the artificial clay soil as shown in Table 1. All of the tests are carried out based on Indonesian Standards SNI [3]. The grain-size distribution curves of the studied soils indicated that it is composed of predominantly clay and silt-sized particles. The Atterberg limit test revealed that examined soil would be classified as high plasticity clayey-silt.

| Table 1. Properties of soft clay soil |
|--------------------------------------|
| Parameters                            | Values       |
| The depth of sampling (m)             | 1.00         |
| Colour                               | dark grey    |
| Specific gravity                     | 2.55         |
| Natural water content (%)             | 42.23        |
| Bulk density (kN/m³)                  | 1.56         |
| Percent smaller than 75μm             | 85.12        |
| Liquid limit (%)                      | 68.00        |
| Plastic limit (%)                     | 42.66        |
| Plasticity Index (%)                  | 25.34        |
| Unified soil classification           | CH           |
| Compaction (Proctor) test            |              |
| γd(max. (kN/m³)                       | 11.50        |
| OMC (%)                              | 34           |
| Internal friction angle (φ), degree   | 0.0          |
| Cohesion (c), (kN/m²)                 | 6.0          |

2.2. Pile model design
In this experiment, the author introduces two type of model piles, namely standard pile (pile without base enlargement) and pile equipped with a mechanical system to create the bulb at the pile base. To fit the scale 1:10 ratio conversion, therefore the dimension of model piles is designed with its external diameter by 40 mm, with a wall thickness of 2.0 mm, and a total pile length of 600 mm. Furthermore, in order to form the enlargement of the pile base, then a detachable steel shoe is designed at the end of the pile. For a standard pile, a steel shoe diameter was designed as large as the diameter of the pile. Since for the pile with base enlargement, the diameter of the steel shoe is slightly larger than the diameter of the pile, in this case, is determined by 60 mm (Figure 3). The main function of this pile shoe as an artificial supporting layer (artificial bearing stratum) to ensure that the enlargement of the pile base can perfectly be formed, through concrete pressure transferred by the internal pressing rod (internal rod pusher).
2.3. Pile installation method

This type of pile may be driven (jack-in) through a soft clay soil. Furthermore, a steel tube having an external diameter of 40 mm and 2 mm in thickness, is driven into the ground. To facilitate driving of the pile, the steel tube is fitted with a detachable steel shoe with the diameter of 60 mm that completely closes at the bottom of the tube. When the tube has been driven to the required depth, a number of dry concrete is poured at its base, filling the bottom of the tube. Dry concrete is then pushed out of the tube together with a detachable steel shoe until it stops at a certain distance and forming a bulb which is desired. Immediately after the bulb has been perfectly formed, then the tube is gradually withdrawn leaving the concrete below. Thus, reinforce by alternately pouring the fresh concrete and withdrawing the tube, the pile is constructed to its full length. The pile shoe will remain in place and hence a new one is needed for each pile installation. In case the pile is required to be reinforced, the reinforcement cage is lowered into the steel tube prior to the pouring of fresh concrete. Step by step in installing this piling system is depicted in Figure 4.

Furthermore, the pile is loaded statically using hydraulics jack and proving ring to measure the load, which gives a couple of load and the settlement data. To determine the ultimate load of the tested pile is done by analyzing the curve shape of the relationship load-net settlement, which is described in [4] as follows: net settlement is equal of total settlement minus the elastic settlement. In the special case when the relationship between the load and displacement curve does not show a clear ultimate capacity of the pile, then in practice the ultimate pile capacity can be defined as the load which causes the pile settlement of 10% times the diameter of the pile [5].

Figure 3. Components of detachable of pile shoe
a. Push the tube down to its design depth.
b. Holding the top part of the tube and followed by pushing the dry concrete inside the tube consequently, the pile shoe will move down and terminate to its desire distance.
c. Create the bulb (base enlargement) at the pile base by continually pushing the dry concrete, add some dry concrete if needed.
d. Once the bulb was perfectly formed, then start to release the temporary tube from the pile shoe. Insert the reinforce cage according to the design requirements.
e. Lift up the tube gently, while pouring fresh concrete and compacted by using tremi pipe.

Figure 4. Stages in installing an artificial hard stratum

3. Result and discussion

Figure 5 below shows the relationship between the load and the total displacement curve of a standard pile (curve 1), while the curve 2 and 3 are the two series of testing of the pile with the enlargement at the pile base. In the curve 1 the peak value of the ultimate bearing capacity of the pile is not realized, therefore the ultimate bearing capacity is determined based on the settlement of the pile by 10% times the diameter of the pile, that is equal to 0.75 kN.

Figure 5. Load settlement curve

In the same way, the piles 2 and 3 successively obtained the ultimate load capacity of 1.95 kN and 2.05 kN, it means that carrying capacity has increased by 270%. In addition, from the visual observation of the shape of the enlargement of the pile base which is produced by using a system of pile shoe separate
from the body of the pile, give a very effective result. Additional research still needs to be done especially to improve the method to separate the pile shoe from the temporary steel pipe after the formation of the enlargement of the pile base, to be more practical and effective.

4. Conclusion
The paper deals with the improving method to create a bulb or pile base enlargement in soft to very soft clay deposit. The result indicated that the proposed method works properly, where the ultimate pile capacity is increased up to 270%. It is noticed we cannot get all information with small-scale models, therefore in compliment to model test, it is necessary to continue to carry out tests on large-scale models and real structures.

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