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Research Paper

Analysis of bearing capacity of bored piles from bi-directional load test: A case study in Quang Ngai province

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ABSTRACT

The paper presents the vertical bearing capacity of bored piles from the bi-directional load test (O-Cell method) at the Tra Khuc dam-bridge project in Quang Ngai province. The dam structure was supported by approximately 400 bored piles with the diameter of D1200 *mm* and the length of 27 *m* to 50 *m*. The ground includes the sand, clay and weathered rock layers with the SPT index (N30) from 8 to 80. The pile's tips were socketed in the granite layer with the average compressive strength of 18.6 *MPa*. Two test piles with the length of 29.1 *m* (T1N) and 42.75 *m* (T8N) were conducted O-Cell test. The side friction of soil layers and pile tip resistance were analyzed. The axial strain obtained from strain gages were used to analyze the axial load distribution along the depth of the pile. The test results show that the side resistance of the piles in the weathered rock mixed is 77.14 *kPa* for the pile T1N and 72.34 *kPa* for the pile T8N (approximately 50% of the total side resistance) which are not the ultimate shaft resistance of the piles in this layer. As its' advantages, the bi-directional load test could be applied widely in the narrow site or on river condition in Vietnam.

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1 Introduction

The bi-directional load test based on O-Cell method has been applied for large diameter bored piles since 1984. This method was developed based on the self-balance principle using pile-soil resistance, pile weight and pile tip resistance. The O-Cell method provides plenty of advantages. For example, it does not require heavyweights as a traditional load test method. Hence, the testing progress is faster and safer. Furthermore, the test is able to conduct in the narrow site in urban areas or for bridge pillars abutment on river condition. Hai, Dao [1] reported the test result at Seabank building, which was the first

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application of the bi-directional load test in Danang. Fellenius, Hai [2] also presented the O-Cell load test results applying in the Mekong Delta area. In Singapore and the Philippines, the O-Cell test was successfully applied for bored piles and barrettes [3, 4]. Besides, some famous bridges over the world were tested the bored piles with high loads by the O-Cell test [5-7]. In addition, based on the O-Cell test results, the side resistance of the pile and the load distribution along depth of the pile were determined [5, 8-10]. Recently, the construction of infrastructure projects such as high-rise buildings, large-span bridges, and dams have been developed significantly in Vietnam. It requires a safety and accurate pile testing solutions. The bi-directional load test method has been developed by domestic engineers and successfully applied to several projects showing economic and technical efficiency. This paper is going to analyze the bi-directional load test results from a case study in Quang Ngai province.

2 Geology profile

The dam – bridge project is located at Tra Khuc, Quang Ngai province. The structure with the length of 414.2 *m* includes eight 41.8 *m* long spans and two 39.9 *m* long spans. Figure 1 illustrates the cross-section of the project. The structure is supported by a deep foundation containing 400 pored piles with a diameter of D1200 *mm*. Two test piles are T1N and T8N with the length of 29.1 *m* and 43.1 *m*, respectively.

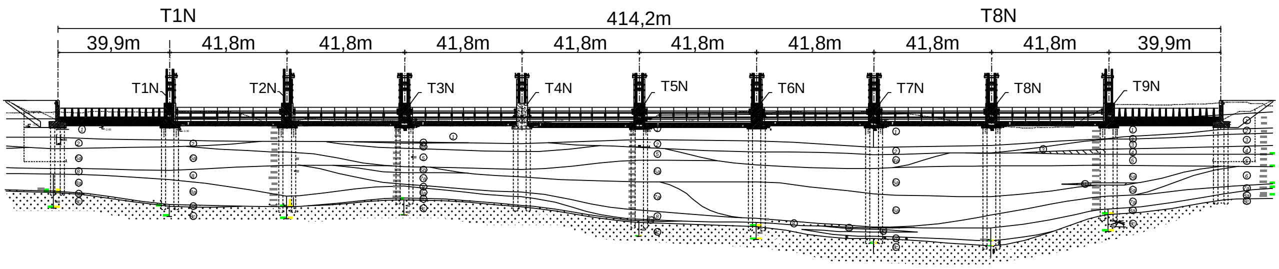

Fig. 1 - The layout of the Tra Khuc dam - bridge

Figures 2 and 3 show the geological cross-section and main properties (N30, c, φ and γ) of soils. Soil layer 1 is the coarse gravel sand; layer 2 is the clay mixed with sand; layer 3 is small to medium sand; layer 4 is the clay mixed with little gravel; layer 5 is the sand mixed with clay; layer 6 is the hard clay is derived from a completely weathered rock; layer 7 is the weathered rock mixed with gravel; layer 8 is the light weathered rock. The ratio of RQD of the rock layer is mainly from 25-100% and the compressive strength is from 18.6 *MPa* and 22.2 *MPa* at T1N and T8N, respectively.

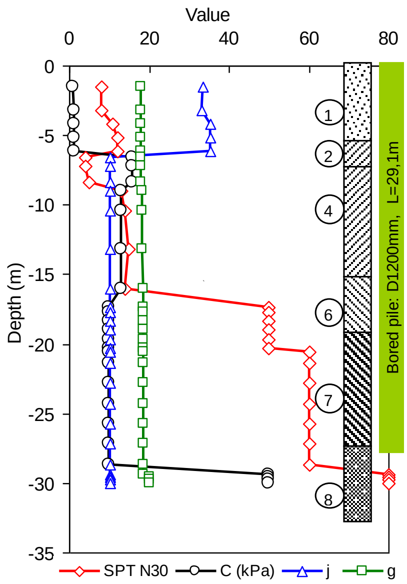

Fig. 2 - Soil profile of test pile T1N

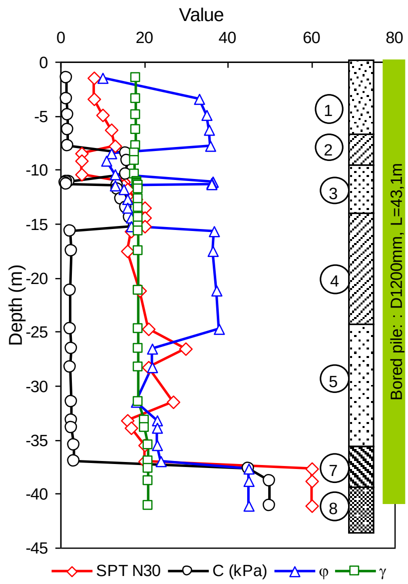

Fig. 3 - Soil profile of test pile T8N

3 Bi-directional load test process

Pile instrumentation: The position of the load box was determined based on the load balance principle of the resistance below and above the load box. According to the designed bearing capacity calculated from AASHTO [11], the O-Cell box was located at 1m from the tip of the pile (Figure 4). The load box uses 03 hydraulic jacks with the capacity of 1700 *kN/jack*. Thus, the loading capacity of each load box is 10800 *kN*. The strain gages were used to observe the strain and load distribution along with the depth of the piles. Location details and elevations of the strain gages are shown in Figure 4. The pile T1N concluded 03 strain gages (ST1-3) at the elevations of -9.0 *m*, -15 *m*, and -21 *m*; while the pile T8N used 04 strain gages at the elevations of -8 *m*, -15 *m*, -25 *m*, and -36 *m*. At each elevation, a pair of strain gages were used to measure the average value at each section. The recorded data from strain gages will be used to analyze the load transfer in the pile and the side resistance. Figure 5 shows the pile installation with the load box and the testing process.

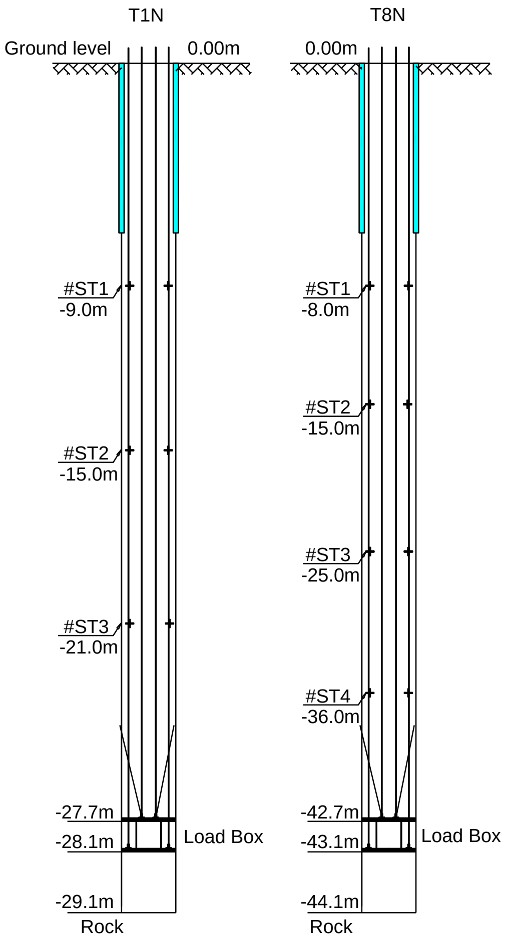

Fig. 4 - Test pile instrumentation

a. Test piles installation

b. Testing process

Fig. 5 - The site of the test

Test program: The load test by a standard ASTM D (2013) was conducted after 28 days. The maximum load was 7.173 *kN*, which was divided into 15 load increments of 478.2 *kN*. For each interval, the load increment was maintained for 10 minutes, and the displacements and strain were recorded at 0, 5 and 10 minutes. The upward and downward displacements of the pile at the load box, the upward displacement of the pile head and the data from strain gages were measured and recorded.

4 Analysis of vertical bearing capacity of bored piles

Load – displacement measurement: Figures 6 and 7 show the results of the relationship between upward and downward displacements at the load box and the head displacement of two test piles at each load increment. The downward displacements of the tip of pile T1N and T8N are 6.47 *mm* and 14.9 *mm*, respectively. The upward displacement at the load box of the pile T1N is 9.00 *mm*, higher than the value of 7.28 *mm* of the pile T8N. The reason could be that the pile T1N is shorter than the pile T8N causing lower side resistance value. The highest pile head displacements of the piles T1N and T8N are 3.58 *mm* and 4.03 *mm*, respectively.

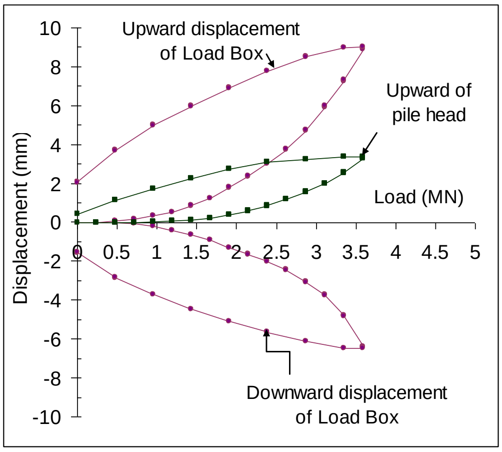

Fig. 6 - The load-displacement curve of the test pile T1N

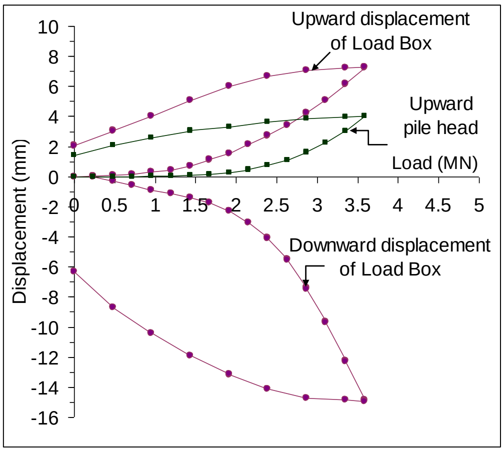

Fig. 7 - The load-displacement curve of the test pile T8N

Figure 8 shows the comparison of the upward and downward displacements of the pile at the load box. It illustrates the difference in the displacement of the pile tests.

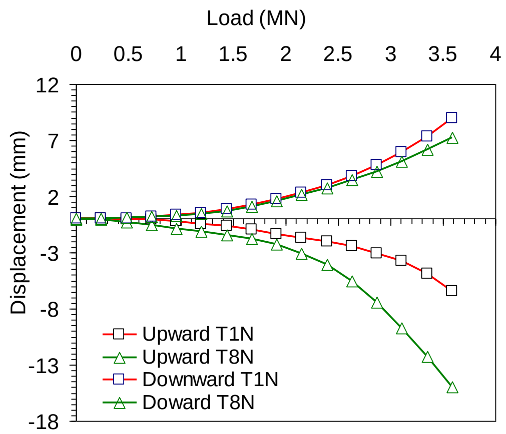

Fig. 8 - Displacement comparison

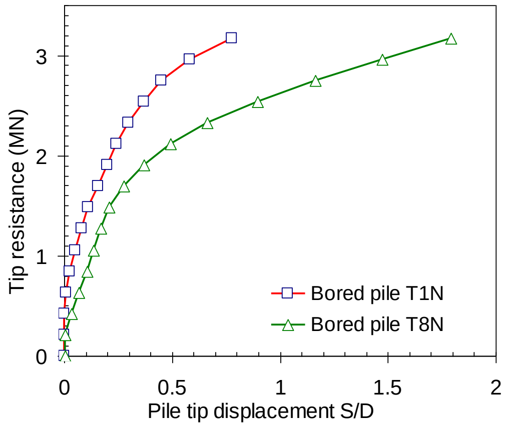

Fig. 9 - Tip resistance comparison

Figure 9 demonstrates the relationship between the pile's tip resistances and the relative pile's tip displacement (S/D). The pile tip resistances were determined by dividing the load at the pile's tip by the cross-sectional area of the pile (A = 1.13 m^2). The results show that the behaviour of the tip of pile T1N is better than that of the pile T8N. The displacement of the pile's tip in the rock layer could be affected by the existence of a layer of drilling humus in the pile's tip during drilling and cleaning processes. However, because the tip of the pile touches the rock layer, the load-bearing capacity of the tip could be more significant and there is no failure point in the displacement curve.

Load distribution:

The load at the i^{th} elevation $\left(P_i\right)$ along the pile is calculated by equation (1).

$$P_i = \Delta\varepsilon_i.E.A \tag{1}$$

where

$\Delta\varepsilon_i = \left(\varepsilon_0 - \varepsilon_i\right)$: the deformation value of the experimental pile when increasing the load from P_0 to $P_i\left(\mu m\right)$;

ε_i : the average deformation value of 02 strain gages at each elevation.

$$\varepsilon_i = \frac{(\varepsilon_{1j} - \varepsilon_{2j})}{2} \tag{2}$$

E : The equivalent Elastic Modulus of concrete and steel;

$$E = (E_c.A_c + E_s.A_s) \tag{3}$$

where E_c and E_s : the Elastic Modulus of concrete and steel, (MPa); A_c and A_s : the horizontal cross-section area of concrete and steel in the pile (m^2) and A is the horizontal cross-section area of the pile.

The equivalent concrete and steel reinforcement stiffness is 36.*1 GN*. For each load increment, the load distribution along the depth of piles was calculated. Figures 9 and 10 indicate that total skin resistance from the load box elevation to the pile head is 3500 *kN*. Both test piles show the decreasing slope toward depth as the SPT N30 increases with depth. Especially, the weathered rock absorbs approximately 50% of the total skin resistance.

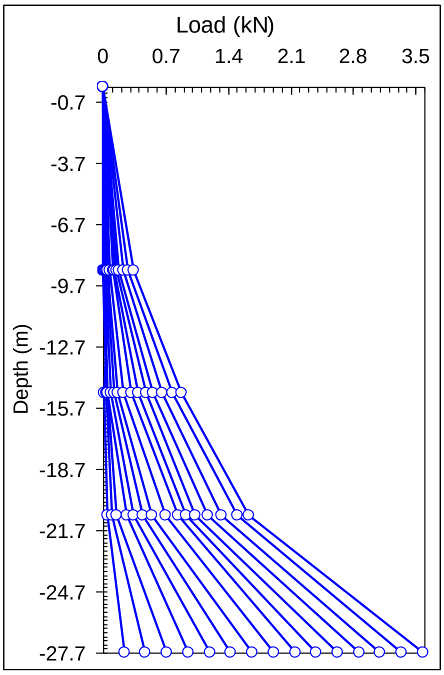

Fig. 10 - Load distribution along with the depth of test pile T1N

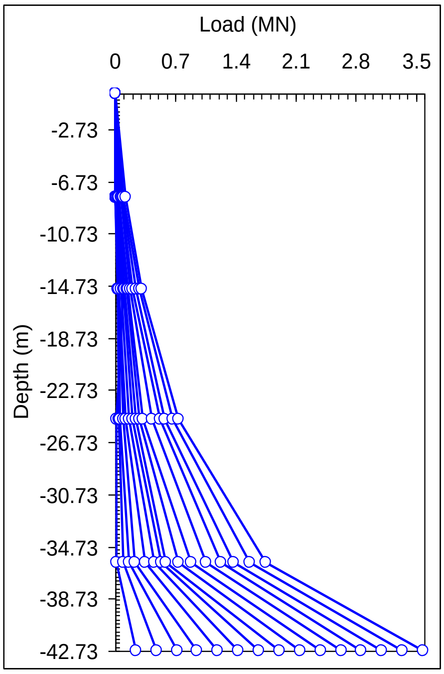

Fig. 11 - Load distribution along with the depth of test pile T8N

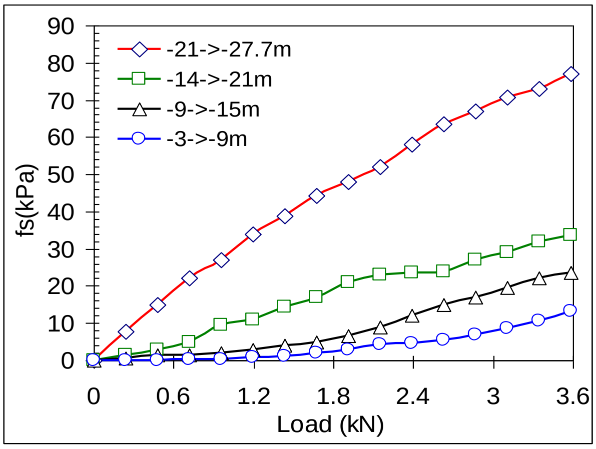

Fig. 12 - Side resistance of test pile T1N

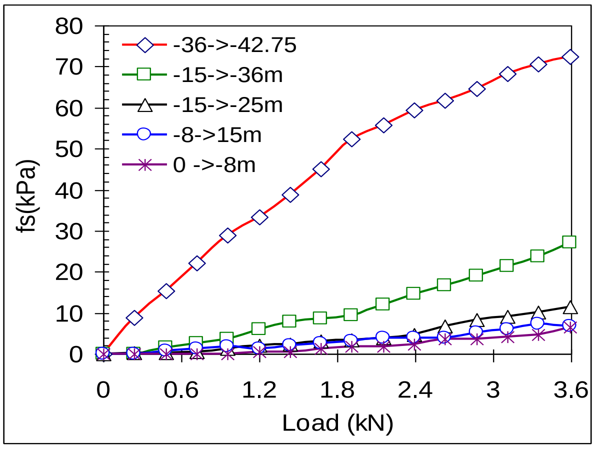

Fig. 13 - Side resistance of test pile T8N

Side resistance: Figures 12 and 13 present the side resistance between the strain gages levels. The average side resistance was determined by dividing the different load between strain gages by the surface area. According to AASHTO (2017), the ultimate side resistance in the weathered rock layer for the piles T1N and T8N are 130 *kPa* and 90 *kPa*. The maximum value of unit side resistance between the load box position and strain gage ST3 in the pile T1N is approximately 77 *kPa*, while that value in the pile T8N is 72 *kPa*. It means that the ultimate side resistance along the length above the load box level has not occurred.

5 Conclusion

The paper presented the result of the Bidirectional load test (O-Cell method) for bored piles in the Tra Khuc river. This method provides several advantages, such as no heavyweights, safety and faster than a traditional static load test.

Two D1200 *mm* bored piles were tested with the maximum load capacity of 7,173 *kN*. The highest downward and upward displacements at the load box position are 6.47 *mm* and 9.00 *mm* for the pile T1N, and 14.9 *mm* and 7.28 *mm* for the pile T8N.

The axial strain obtained from strain gages were used to analyze the axial load distribution along the depth of the pile. Both test piles show the decreasing slope toward depth as the SPT N30 increases with depth. The weathered rock absorbs approximately 50% of the total side resistance in both test piles.

The side resistance of the pile in the weathered rock mixed with gravel layer is 77.14 *kPa* for the pile T1N and 72.34 *kPa* for the pile T8N which are not the ultimate side resistance of the piles in this layer.

The experimental results on the side and tip resistances of bore piles with different rock types could help Vietnamese engineers to understand the behaviour of the deep foundation in different rock condition. Hence, the research results in this study could be applied in practice in designing and constructing bore piles.

Acknowledgements

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