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Development of t-z and q-z Curves in Axially Loaded Bored Pile using Continuous Measurement of Strains

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Abstract— The bored pile foundation is a very appropriate type of foundation for highrise buildings and urban areas because the installation does not cause noise and vibration that endanger the surrounding buildings, but with its implementation carried out in the ground makes it difficult in monitoring the quality that can affect the bearing capacity. The instrumentation that is commonly used to obtain the load received by pile foundations through strain readings is Vibrating Wire Strain Gauge (VWSG), but has limitations due to local installation at a certain depth so it requires large amounts to obtain accurate load transfers. Recent advances in strain measurement using fiber optic provide new opportunities to monitor the performance of pile foundations. One of the unique technologies of optical fiber is Brillouin Optical Time-Domain Analysis (BOTDA) which is an innovative technique that allows continuous measurement. With continuous strain reading, it can be calculated the load transfer along the pile as well as the anomaly in the bored pile. This study uses data from the 41-storey Building Project in BSD City, Tangerang. In this project, an axial loading test is performed on the bored pile foundation which is instrumented with fiber optic. Based on loading test data and strain measurement can be obtained; (1)Load transfer along the pile based on real data on continuous strain reading; (2)t-z and q-z curves analysis.

Index Terms— Bored Pile, Axial Load, BOTDA, Strain, Load Transfer, t-z and q-z Curves.

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1 Introduction

CURRENTLY the instrumentation that is commonly used for strain measurement on a bored pile is a Vibrating Wire Strain Gauge (VWSG) which is mounted on a reinforcement before casting. However, VWSG has limitations including installation locally at a certain depth so it requires a large amount to obtain accurate load transfers and indirectly requires a large cost. Recent advances in strain measurement using fiber optic provide new opportunities to monitor the performance of pile foundations. One of the unique technologies of fiber optic is Brillouin optical time-domain analysis (BOTDA) which is an innovative technique that allows continuous measurement. In other words, continuous strain reading can be seen by the transfer of loads along the pile as well as the anomaly in the bored pile. By knowing the strain on the bored pile, can be obtained the load transfer and also constructing the t-z and q-z curves. This paper will discuss the stages of analysis to create t-z and q-z curves using data from the 41-storey Building Project located in BSD City, Tangerang. The type of foundation used in this project is the bored pile foundation with a diameter of 1000 mm, a total length of 36.3 m with an effective length of 30 m. In this project, an axial loading test will be carried out on the bored pile foundation instrumented with fiber optic instrumentation.

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2 Project Data

2.1 Soil Investigation Data

Based on soil investigation data, general soil conditions can be divided into 4 soil layers. The first layer is soft consistency silt soil with a thickness of about 6.5 m (NSPT = 2-4). The second layer is the silt of medium consistency of about 3 m (NSPT = 19-24). The third layer is cemented sand (NSPT> 50) which is located at a depth of about 9.5 m to 23 m. The fourth layer is the clay soil layer (NSPT = 14-28) located at a depth of 24.5 to the end of the drilling. Figure 1 shows the condition of the soil at the project site.

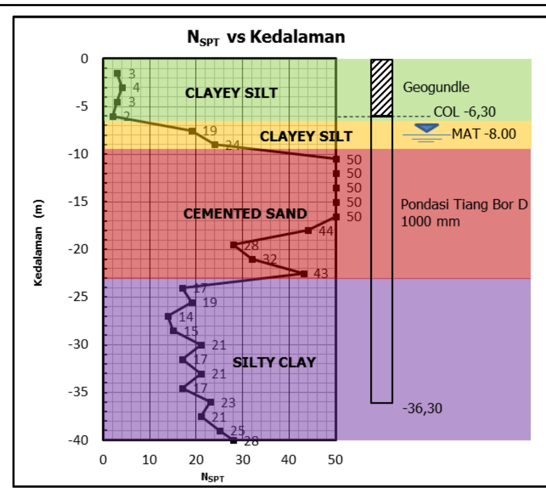

Fig. 1. Test pile and geotechnical investigation layout.

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2.2 Pile Configuration

The specifications of the bored pile tested is 1000 mm diameter, total length of 36.3 m with an effective length of 30 m with the quality of the concrete pile foundation using K-350. To remove skin friction, Geo-gundles are used from the top end of the pole to a depth of 6.3 m. The allowable bearing capacity for this bored pile foundation is 600 tons. In this project, the pile was given the name BP-47.

Two pairs of fiber optic sensor cables (A, B, C and D) will be installed on the main reinforcement from the top to the bottom end of the mast (see Figure 3). Sensor cables will be installed on each axis of the bored cross section (x-x and y-y).

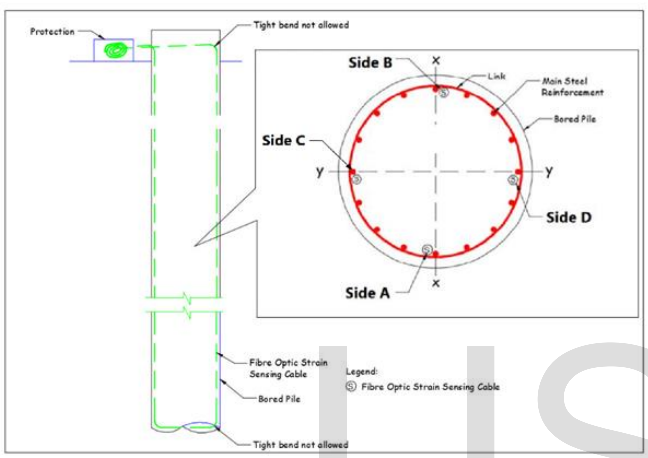

Fig. 3. Fiber Optic Cable Configuration in a Bored Pile.

2.3 Pile Test Data

In this project a static loading test was carried out on a BP-47 bored pile foundation based on ASTM D1143-07 with a kentledge system, a hydraulic jack with a capacity of 2000 tons was used and the load was controlled with pressure gauges. The Designed Load of 600 tons, will be cyclicly tested up to 200% Designed Load 1200 tons. From the test results, the maximum axial settlement at the pile head is 11.28 mm at 200% loading and gives the residual pile settlement at 1.34 mm. A summary of the results of the kentledge test for BP-47 can be seen in Ta-

TABLE 1
RESULT OF PILE CAPACITY USING PDA TEST

Cyclic	Load % (ton)	Maximum Settlement (mm)	Residual Settlement (mm)
1	50% (300)	2.65	0.05
2	100% (600)	5.57	0.22
3	150% (900)	8.59	0.39
4	200% (1200)	11.28	1.34

ble 1

3 FIBER OPTIC INSTRUMENTATION READING RESULTS

From the 4 fiber optic sensor cables (A, B, C and D), the strain reading results show that the strain reading results on sensor cables A and D that show Geo-gundles from the top of the pile to a depth of 6.3 m have the function of removing skin friction resistance. Therefore in this paper, strain measurments on sensor cables A and D was used in the analysis.

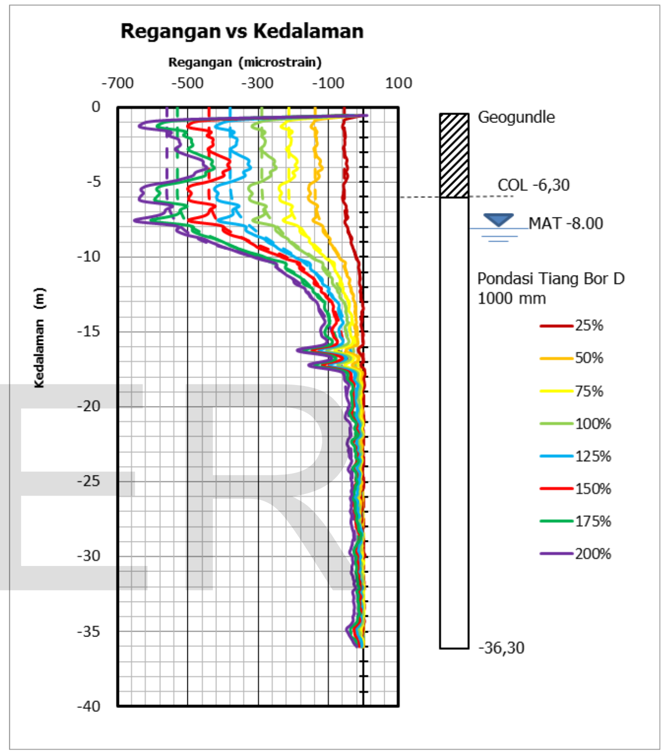

Fig. 3. Curve of Average Strain (A and D) vs. Depth

4 DETERMINATION OF CONCRETE BORED PILE ELASTICITY MODULUS

Concrete bored pile elasticity modulus can be calculated using strain data from optical fiber in the area using Geo-gundle (0 - 6 m), because the load that occurs in that area is only the load received from the pile head without any influence from the skin friction. Then for the determination of the stress from 0 - 6 m, it is obtained from the assumption that the cross-sectional area at the elevation is the same so that the stress value is the same to a depth of 6.3 m, so that the modulus of elasticity and strain correlation are obtained as follows:

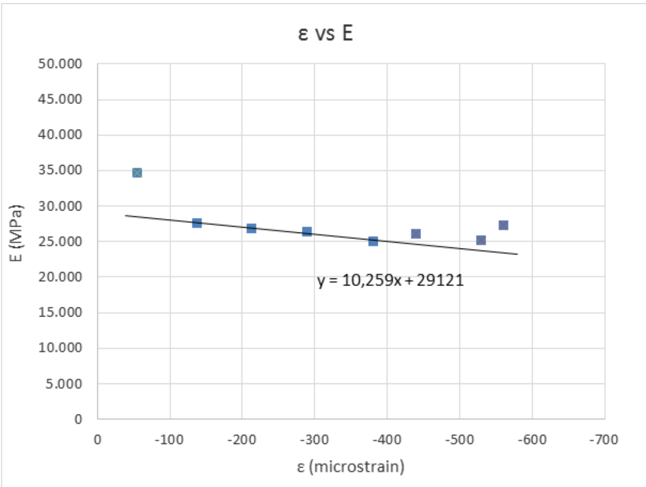

Fig. 4. Curve of Elasticity Modulus vs. Strain (0 - 6 m depth)

From the curve of modulus elasticity of the concrete vs strain above, the relationship is obtained in the line equation y = 10.26x + 29121. This line equation will be used to determine the elasticity modulus along the pile based on the strain measurement from the fiber optic sensor readings.

5 Calculation Result and Discussion

After obtaining the concrete modulus parameters along the pile, the load transfer can be obtained along the pile (see Figure 5). From the results of load transfer, it can be seen that the load highly reduces at silty clay layer and cemented sand layer.

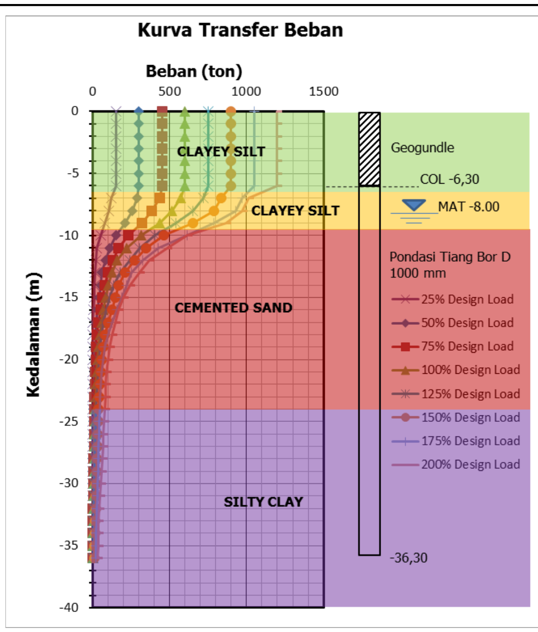

Fig. 5. Load Transfer Curve

Based on the Load Transfer Curve, the t-z curve can be obtained which is the skin friction of the pile (τ) and the displacement due to the movement of the pile (z) and also the q-z curve which is the relationship curve between the end of the pile (q) and the displacement at the pile bottom (z). Figure 9 and Figure 10 shows the t-z and q-z curves.

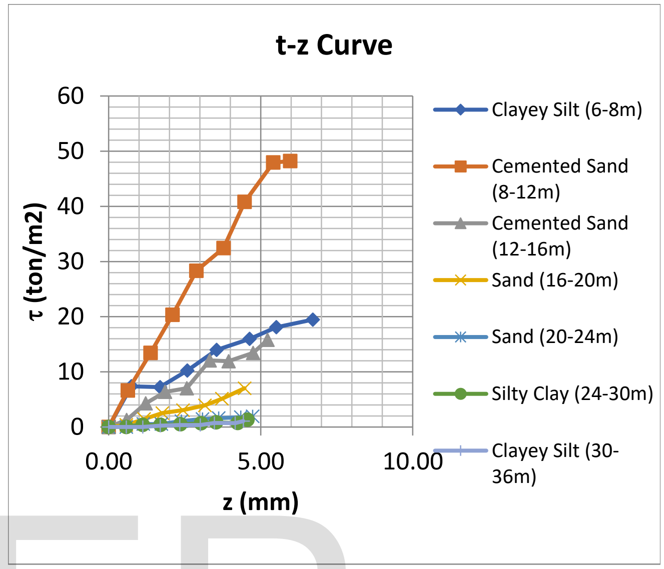

Fig. 6. t-z Curve

From the t-z curve it can be seen that the skin friction resistance that is mobilized is only up to a depth of 20 m, in other words at depth more than 20 are still in elastic condition. The friction resistance value in the cemented sand layer can reach 48 tons/m² meaning that most of the load is carried by the layer.

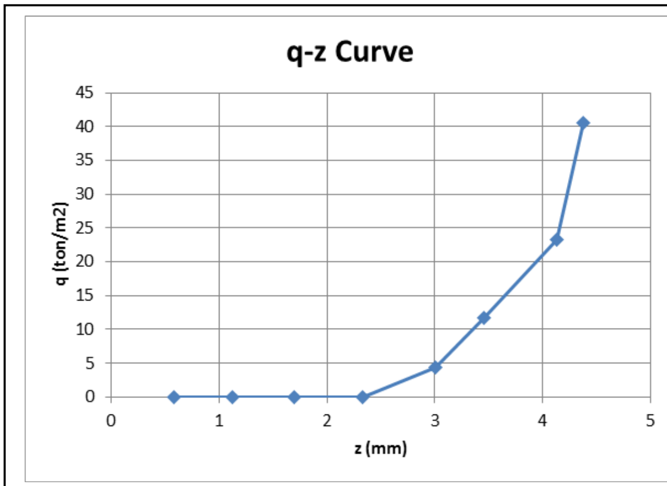

Fig. 7. q-z Curve

6 Conclusion

The case study was taken from the 41-storey Building Project located in BSD City, Tangerang regarding load transfer of the bored pile foundation with a diameter of 1000 mm with an axial loading test and instrumented with fiber optic, some conclusions are obtained as follows:

1. Based on the condition of the bored pile at a depth of 0 to 6 m from the pile head (having no skin friction resistance), it can be obtained Curves and equations for the elasticity modulus (E) of the bored pile and the strain. So that the load transfer curve along the pile and also the t-z and q-z curves can be determined.
2. From the t-z curve it can be seen that the skin friction resistance that is mobilized is only up to a depth of 20 m, in other words at depth more than 20 are still in elastic condition. From this condition, the pile length can be reducing to optimize project budget.
3. The friction resistance value in the cemented sand layer can reach 48 tons/m^2 meaning that most of the load is carried by the layer.
4. Fiber optic sensors is powerful tools to obtained continuous strain profile for a better understanding of pile behavior. Continuous strain profile should given more accurately load transfer. Not only load transfer the condition of bored pile also can be interpreted from the strain profile.

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