DEVELOPMENT OF T-Z CURVES FOR BORED PILES EMBEDDED IN CEMENTED SAND FROM DYNAMIC LOAD TEST

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Abstract— Soil response due to axial compression loading is represented by a relationship curve between pile shaft resistance (τ) and pile movement (z) or “T-Z Curve”. The curve can be obtained by several methods, such as analytics formula, Direct Shear Test, and Instrumented Static Load Test. Instrumented Static Load Test give the best result because the resistance and the movement are measured in site. However, the test is very expensive. Hence, another method which can establish T-Z Curve is still needed. In Indonesia, PDA Test is the most common dynamic load test. The t-z curve has not been established from the test yet. This paper presents the findings that the t-z curve can be developed by PDA test by carried it out in different energy. The curve from dynamic load test will be compared with instrumented static load test to verify the reliability of the result. The test is carried out in bored piles embedded in cemented sand. This research presents that PDA Test can establish T-Z Curve as good as the instrumented static load test.

Index Terms— T-Z Curve, Instrumented Static Loading Test, Dynamic Loading Test.

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1 INTRODUCTION

PILE foundation is a type of foundation which can receive loads from its upper structure to soils. The axial loading is transferred to the soil through pile shaft and pile tip. Besides, pile movement occurs along the loads is distributed to the soils. The movement is directly proportional to the loads. The movement is higher as long as the loads heavier. Hence, the understanding of pile behavior is important to evaluate the bearing capacity of soils to ensure that the piles of a building or another infrastructure are strong enough to receive the loads.

Coyle and Reese (1966) proposed a theory of load transfer curve and subsequently developed by Kraft et. al. (1981) becomes the t-z curve. The t-z curve represents the response of soil and pile under axial loading. The t-z curve is a relationship curve between shaft resistance (τ) and pile movement (z). Shaft friction is an ability of soil to receive load through pile shaft. There are some methods to obtained t-z curve, such as analytic formula, Direct Shear Test, and Instrumented Static Load Test. The analytic formula is introduced by Kraft and Kagawa (1981). The formula is limited to single soil layer. The direct shear test is a laboratory test. This method establishes t-z curve by test concrete and soil in particular rate of shear.

An instrumented static load test will determine whether the piles comply with the design or need longer or more depending on the results of tests, not depending on the method of calculation. Static load test of piles is the most accurate method of determining the bearing capacity of the soil. Load tests are performed to confirm the sustainability of the pile-soil system to support the pile design load with an appropriate factor of safety. In this research, the maximum load applied is 250% workload. After the load has been applied and the all movements are measured, a load movement curve is plotted. VWSG (Vibrating Wire Strain Gauges) as an instrument can monitor strain when the loads are applied. An instrumented static load test is the best method to establish t-z curve. However, this method is not too economical to get pile behavior. Therefore, another method is needed to obtain pile behavior by the t-z curves.

Another method that common be used to test the pile is dynamic load test. In the past, dynamic load test only can be applied for driven piles, nowadays it can be applied for bored piles. One of the tests that become popular in Indonesia is PDA (Pile Driving Analyzer) Test which was developed by Goerge Goble, Frank Rausche, and Garland Likins (GRL) in Case Institute of Technology, Ohio. Dynamic load test is common to be used as a pile test in addition to static load test because the test is more economical. Strain gauge and accelerometer is set near to pile head. The instruments will response the ram stroke as a wave propagation along the pile which are measured at the pile top. Using the principle of wave mechanics theory and signal matching, the wave can be interpreted to give information on bearing capacity, friction distribution along the pile, structural behavior, and pile integrity. T-z curves are primary important to predict pile behavior. However, the t-z curve has not been established from the test yet. This research presents the findings that the t-z curve can be developed by the test. The pile was tested with different hammer drop height, and it will produce different energy. The higher energy will mobilize larger pile-soil resistance until it reaches a condition where with greater energy there is no increase in soil resistance. The result from dynamic load test will be compared with instrumented static load test to verify the reliability of the result.

2 Test Procedure

2.1 Dynamic Load Test

Pile Driving Analyzer (PDA) is a complete full-system computer with special strain transducer and accelerometer to determine the force and velocity graphic form when pile struck by a hammer. Results of PDA consist of pile capacity, displacement, hammer energy, etc. PDA testing is done after pile has enough strength to resist impact from the hammer, another anticipation can be done using a cushion or lower the hammer stroke and use a heavier hammer.

PDA test will be carried out in accordance with ASTM D4945-12. Preparation should be done before testing is conducted. Make sure that pile head in straight, edge and flat surface. Attach strain transducer and accelerometer to the side section of the pile with 1.5 x diameter distance from pile head. Make sure the location of the transducers is approximately 180° and place in a straight surface perpendicular to pile body. Install hammer and cushion to pile head. After preparation, testing will be conducted on the pile by struck the pile head using proper hammer until sufficient energy and maximum pile stresses reached without breaking the pile. During the driving, some variable related to the test pile is monitored, such as bearing capacity, elastic settlement, integrity, etc. After the test output conducted, analyzing done by CAPWAP program or similar to simulate the load transfer in pile and soil behavior, friction and end-bearing capacity, elastic and net settlement.

This study was conducted to generate the t-z curve of the dynamic load test with the PDA Test. The higher energy will mobilize larger pile-soil resistance until it reaches a condition where with greater energy there is no increase in soil resistance. The basic concept is used to produce unit skin friction (τ) for each high value falling to reach maximum unit skin friction (τ_{max}). The τ and z values for all hammer drop heights are plotted and each segment will form the t-z curve.

2.2 Instrumented Static Load Test

The test methods described in this standard measure the axial deflection of a vertical or inclined deep foundation when loaded in static axial compression.

After the pile has been constructed, the pile are then awaited for 14 up to 30 days before testing to allow soil set up and dissipate excess pore pressures generated during driving. The pile head should be made as uniformly as possible so that the load applied to the test pile can work properly. In this research, the load applied directly using known weights (or also known as “kentledge system”): Center on the test pile or pile cap a test beam of known weight and of sufficient size and strength to avoid excessive deflection. Use loading materials such as steel or concrete so that the weight of incremental loads can be determined. All axial compressive load tests shall include apparatus for measuring the axial movement of the test pile top.

To create a t-z curve, unit skin friction and pile movement data are needed. Instruments (VWSG) are installed along the pile to measure strain (in microstrain) along pile testing. The data is processed to obtain skin friction and pile movement. The following steps are used to obtain t-z curve from instrumented static load test.

- The large difference in strain between the readable strain of a VWSG and the VWSG on it is calculated. For VWSG at the top is taken zero.
- The strain difference data at each depth and each load are taken of the average value.
- The axial load at the VWSG location is taken by multiplying the test load by the proportion of the average value of the strain change at the VWSG location to the average value of the maximum strain change.
- The magnitude of pile friction between the two VWSG is calculated by the axial load difference between the VWSG elevations divided by the cross-sectional area.
- The pile end resistance is calculated from the axial load below the pile divided by the cross-sectional area.
- The magnitude of the average strain changes on each pile segment multiplied by the length of the pile segment, so the amount of compression occurring in the segment is obtained.
- The magnitude of the movement in the middle of the segment is derived from the movement value of the above segment reduced by the compression of the segment.

3 Data and Analysis

The pile test was conducted on a bridge project located in Jakarta, Indonesia. The pile tests are performed as 2 piles, consists of PTP-1 and PTP-4. The type of foundation used is a bored pile. The pile is designed with 1000 mm diameter and 29 m depth. Both piles have similar ground conditions. The top layer is a firm clay soil and the underlying layer is a cemented sand.

Cemented sand has a different characteristic compared to general soils. It has a very high shear strength and it is very strong in carrying the load. The magnitude of friction of pile friction embedded in the cemented sand is very high.

Instrumented static load test and dynamic load test is carried out to test the capability of the bored pile in carrying the load. Both of them are carried out on the same pile where the instrumented static load test is performed first and then continued with the dynamic load test.

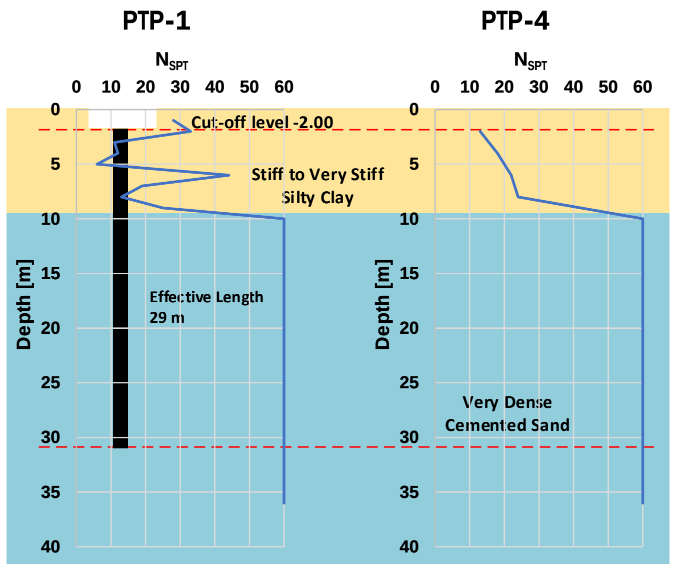

Fig. 1. Soil Condition from Drilling and Standard Penetration Test

3.1 Dynamic Load Test

The dynamic load test was carried using by PDA Test after the static load test on the same pile. The hammer capacity is 25 tons. For PTP-1, the pile is tested by 3 hammer energies, consists of 14.17 t.m, 24.30 t.m, and 26.50 t.m. For PTP-1, the pile is tested by 3 hammer energies too, consists of 18.12 t.m, 22.42 t.m, and 27.08 t.m. Thus, there are 3 data with different energies for each pile. Each of these energies produces different carrying capacity, unit skin friction distribution, and different pile movement. Based on the results of an analysis with CAPWAP Program, the value of the skin friction and the movement of the pile from each energy are plotted for each pile segment thus forming curves interpreted as t-z curves. Development of the t-z curve from dynamic test has a problem if the energy due to the impact loads is too low. If the energy is too low, the wave propagation does not reach the pile tip and there will be misinterpretation of the t values and the z values, so that the values are not make sense. In addition, the t-z curve at depths below 16 m has not entered the plastic condition because the energy is less large so that the t-z curve has not yet formed.

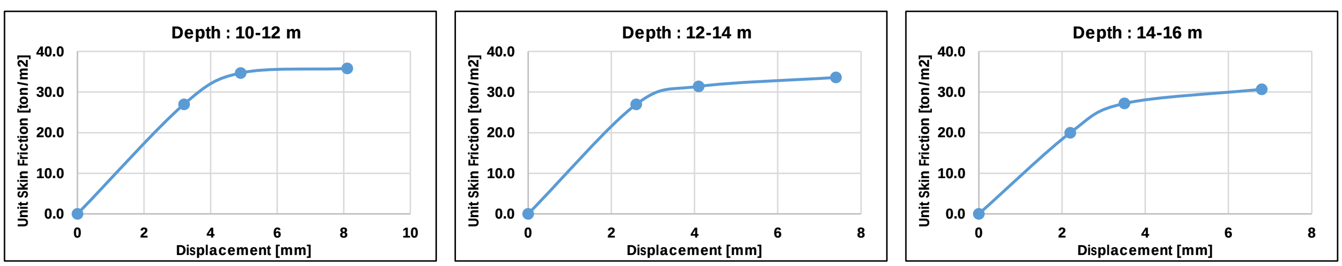

Fig. 2. T-Z Curve from Dynamic Load Test for PTP-1

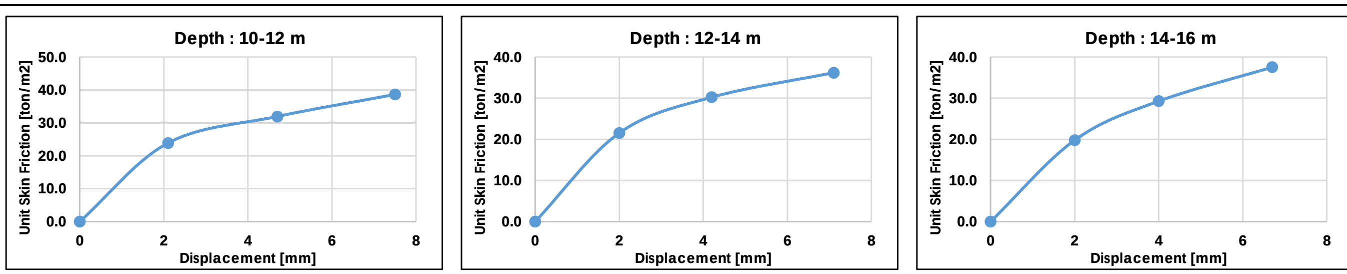

Fig. 3. T-Z Curve from Dynamic Load Test for PTP-4

3.2 Instrumented Static Load Test

The static loading test on this project is a cyclic loading test where loading - unloading occurs for each cycle loading. There are 5 cycles of loading, consists of 50% workload (296 ton), 100% workload (592 ton), 150% workload (888 ton), 200% workload (1184 ton), and 250% workload (1480 ton). Each loading and unloading stage is carried out by measuring the settlement through the dial gauge over the time, so it will be obtained the relationship between the load size, the pile top movement (or settlement), and the time. In this case, there are 11 elevation depth and 4 VWSGs are installed for each depth. Therefore there are 44 VWSGs are installed inside the pile.

Based on the measured strain data from VWSGs and the measured pile top movement from the dial gauges, the magnitude of the skin friction on the pile and the pile movement is illustrated by the T-Z curves. The T-Z curves are only formed up until 17 m depth because the existing workload has not been able to mobilize the unit skin friction in the lower depth until it reaches the ultimate condition.

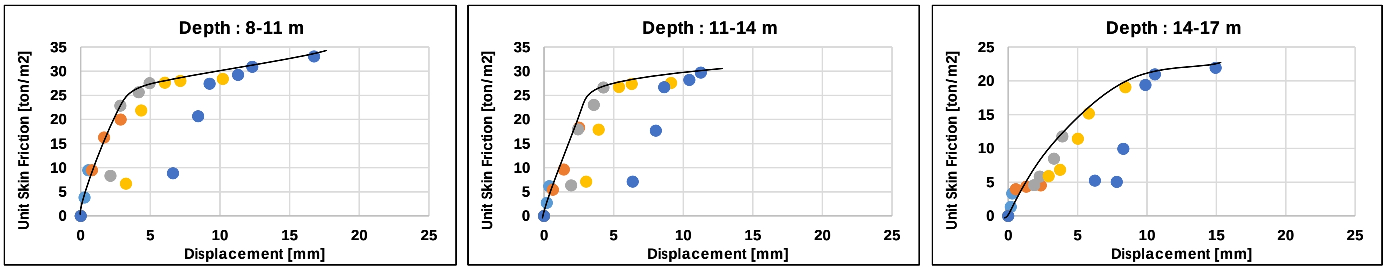

Fig. 4. T-Z Curve from Instrumented Static Load Test for PTP-1

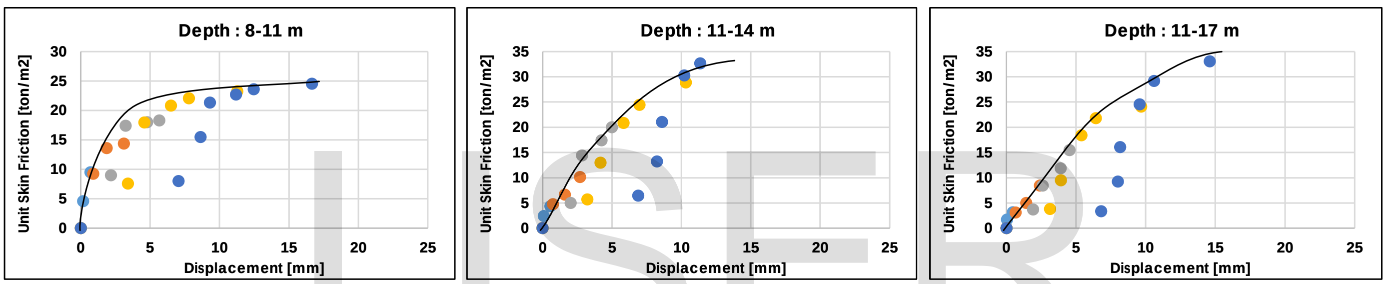

Fig. 5. T-Z Curve from Instrumented Static Load Test for PTP-4

3.4 Comparison Between Instrumented Static Load Test and Dynamic Load Test

The maximum unit skin friction of the pile under static loads and dynamic loads are shown in the following table.

The piles have been subjected to stress due to static load before the dynamic load is given. When the static load is released, the stress of the piles does not release at all. So there are residual stresses retained on the pile. When the dynamic test is performed, the stress of the piles consists of residual stresses and stresses due to the impact load. This phenomena causes the maximum unit skin friction from dynamic load tests is higher than instrumented static load tests as shown in Table 1. However, the difference of values between static and dynamic test can still be tolerated.

TABLE 1
MAXIMUM UNIT SKIN FRICTION

Pile	Depth [m]	Maximum Unit Skin Friction [ton/m^2]	
		Dynamic Load Test	Instrumented Static Load Test
PTP-1	10-12	35	33
	12-14	33	30
	14-16	30	21
PTP-4	10-12	38	25
	12-14	37	33
	14-16	36	33

Based on the t-z curves, it can be seen that the two tests (static and dynamic) have not yet mobilized all the pile capacity. Perfectly mobilized skin friction occur from the top until the middle of the pile. The existing static load or hammer energy needs to be enlarged so that the load transfer behavior on the pIle can be known until the bottom end of the pile.

4 Conclusion and Recommendations

Based on the research that has been done, the t-z curve that described the soil response to the load when the load is transferred through the pile skin friction can be developed from the dynamic load tests. The t-z curve was obtained by PDA test by carried it out in different energy and verified by a static test. The t-z curve for cemented sand from static and dynamic test has a very large unit skin friction, about 25-38 ton/m² from the test result. The unit skin friction from the dynamic load test is greater than the instrumented static load test because there was residual stress on the pile when the dynamic test is performed. The advantage that can be obtained from the dynamic load test is fast, economical, and

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the curve in accordance with actual conditions. The research shows that this curve cannot be developed if the given energy is too low because it will cause mis-interpretation, so to develop this curve required enough energy of impact load.

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