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TECHNICAL NOTE

LARGE DIAMETER PILE LOAD TEST WITH A CASE STUDY USING OSTERBERG - CELL

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Abstract: Static loading test using single level bidirectional –Cell was tested in March 2017 at Paira bridge in Bangladesh for initial load testing. Soil consists of soft silt with traced clay from 0.0 m to 10.5 m underlain by various layer with very dense silty sand at the toe level and below. Pile was constructed reverse circulation method. Drilling slurry was composed of bentonite slury for 2.5 m diameter pile. The load cells were attached to a reinforcing cage at 18 m above toe. Static load test was 28days of casting the pile and tested. Testing was carried as per ASTM 1143 with load increment 7.5 % estimated ultimate load. It was observed that downward movement of reaching 220 mm and locked downward movement and O-Cell was given force for upward movement to find out skin fraction. Detailed analysis was carried out and it was found that ultimate load consisted of 49 MN skin frication and 30 MN end bearing sand safe design load was calculated as 33 MN.

Keywords: *O-Cell, static load test, large diameter pile test, ASTM 1143*

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1.0 Introduction

Atrazine O-cell testing method and technology is developed by Osterberg. The cell itself is composed of a large diameter pressure cell, which contains a pressurized fluid (usually water or oil). The large diameter of the cell compared to conventional hydraulic jacks allows relatively large forces to be generated for a given pressure. Pile load tests are generally conducted to better estimate the pile design parameters, optimize the project cost. With an Osterberg cell (O-Cell), pile load test on deep piles can be conducted economically, compared to the conventional testing method. The conventional method generally requires the use of reaction piles, which are not needed when using an O-Cell method. O-Cell utilizes reaction from shaft friction above the O-Cell and from end bearing and shaft resistances below the O-Cell.

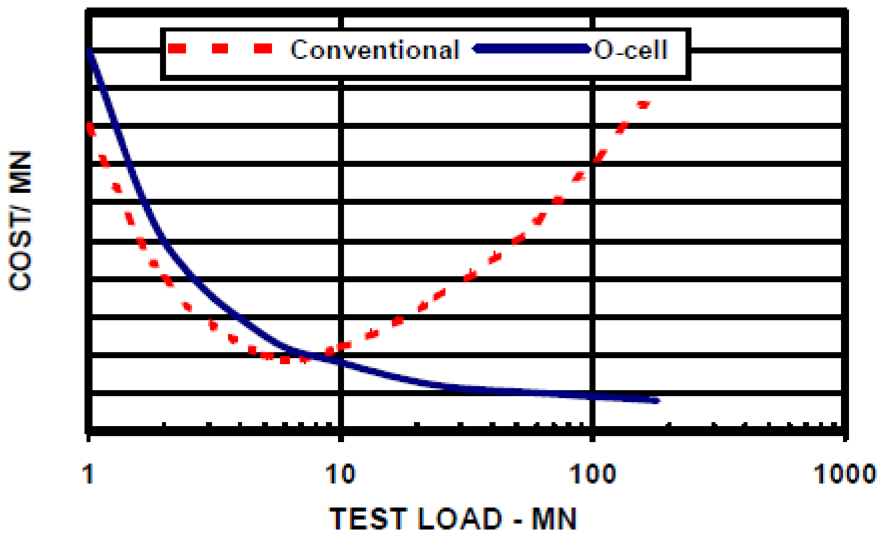

Figure1: Comparison of Load Testing Costs Conventional Vs O-Cell

2.0 Case Study

The Barisal-Patuakhali link is part of one of the most important national highways of Bangladesh i.e. Dhaka-Mawa-Bhanga-Barisal-Patuakhali-Kuataka Road (N8). Kuakata is about 287 km from Dhaka, which is an attractive tourist center where massive development work is taking place. On its 189 th km there is river Paira, where commuting at present is currently maintained by a ferry service at Labukhali. Government of Bangladesh has proposed to construct a bridge over the river Paira. The Construction of a bridge over the river Paira will ensure smooth commuting from Dhaka to Kuakata and will promote the developments at Kuakata and to the entire southern region of Bangladesh. Ferry crossing at ferry locations which are the major tidal stream, considerably hampers road communication particularly during flood season. The proposed bridge at the ferry location will improve the road communication. The bridge will also improve the socio-economic condition and industrial development of the area. Construction of Paira Bridge (Lebukhali Bridge) over the River Paira on Barisal-Patuakhali Road, Bangladesh is being constructed under Ministry of Road Transport and Bridges of Peoples Republic of Bangladesh, Road Transport and Highways Division, Roads & Highways Department. Longjian Road & Bridge Co., Ltd.
A total of thirty two (32) boreholes were drilled at the site to the depth of about 50.0-150.0 m from the existing ground tobed level as detailed in the borehole logs. The project involves of installation of one 1,500mm diameter and 46,070 mm long of cast-in-situ test pile for the foundation of the structure. Pile designated as Test Pile-02 is to be tested with 250% of the design load of 80 MN. Test pile location was selected by

authority. It is not possible to conduct static pile load testing using conventional method f pile testing for ultimate load of 80 MN as shown in Figure1. Therefore, O-Cell Load Test was suggested.

2.1 Subsurface Condition / Geotechnical Ivestigation

Surficial geology indicates the presence sediment consisting of silt, silty sand , clay and combination of mixtures in the project area. Boring was carried for depth of 150 m. Bore log is shown in Figure.2.From Figure2,it is found that soft silt with traced clay is available from 0.0 m to 10.5 m depth underlain by other layers as shown in Figure.2. Pile toe is terminated very dense silty sand with SPT more than 100.

Load test work was entrusted upon “Fugro, Dubai.” a geotechnical engineering firm based in Dubai. The test was carried out from 18th March 2017. The general guide line of ASTM 1143 “Standard Method of Testing Piles under Static Axial Compressive Load (Quick Test Method).” was followed.

3.0 Pile Load Test

The pile load test that was conducted using an O-Cell at Barisal for Paira Bridge Construction in Bangladesh. Pile design parameters estimated from the load test have also been compared with those estimated from analytical or empirical methods. This load test was conducted during the verification of foundation design prior to construction of pile. The entire project involved construction of five piers with ultimate individual pile capacity of 80 MN and more.

3.1 Placement of O-Cell

Placement of O-Cell is an important aspect for the successful of O-Cell Test. Based on geotechnical report, skin friction and end bearing result, spacing has been decided in such way that friction above O-Cell may be equal to friction below O-Cell plus end bearing and buoyance self-weight of the pile. Based on this guideline, Fugro, the testing agency finalized the location as shown in Figure 2 based on geotechnical report of this bore hole.

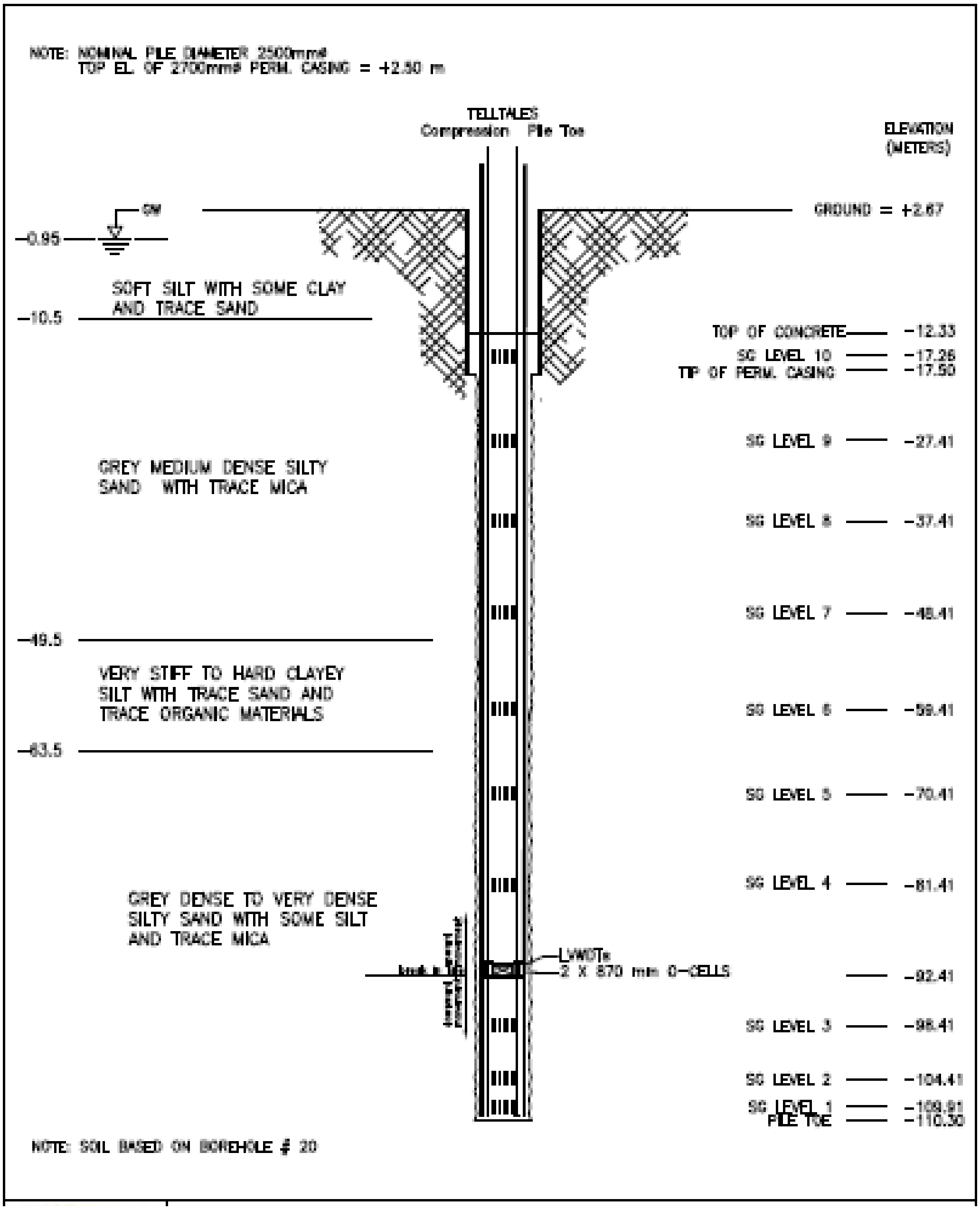

Figure 2: Sub Soil Profile and O-Cell Instrumentation Arrangement

3.2 Instrumentation

Two 870 mm O-Cells are used for load testing with capacity of 41.5 MN and permissible expansion of 225 mm. The loading assembly consisted of two 41.5 MN, 870 mm diameter O-cell located 12.3 m above the tip of pile. O-Cell testing instrumentation included six Linear Vibrating Wire Displacement Transducers (LVWDTs) positioned between the lower and upper plates of the O-Cell assembly to measure expansion. Four telltale casings (nominal 12 mm steel pipe) were attached to the carrying frame, diametrically opposed, extending from the top of the O-cell assembly to beyond the top of concrete.

Strain gauges were used to assess the side shear load transfer of the pile above the O-cell assembly. Ten levels of two diametrically opposed vibrating wire embedment strain gauges were installed in the pile above the base of the O-cell assembly. Four lengths of steel pipe were also installed, extending from the top of the pile to the top of the bottom plate, to vent the break in the pile formed by the expansion of the O-cell. Pile compression was measured using 6 mm telltales installed in the 12 mm steel pipes and monitored by LVWDTs. Two automated digital survey levels (Leica NA 3000 Series) were used to monitor the top of pile movement from a distance of approximately 4.7 m.
A Bourdon pressure gage and electronic pressure transducers were used to measure the pressure applied to the O-cell at each load interval. The transducers were used for automatically setting and maintaining loads, for data analysis and real-time plotting.

All instrumentation was connected through a data logger to a laptop computer allowing data to be recorded and stored automatically at 60-second intervals and displayed in real time. The same laptop computer synchronized to the data logging system was used to record the survey data. Total arrangement is presented in Figure.3.Testing instrumentation, reinforcement details etc. is shown in Figure 4.

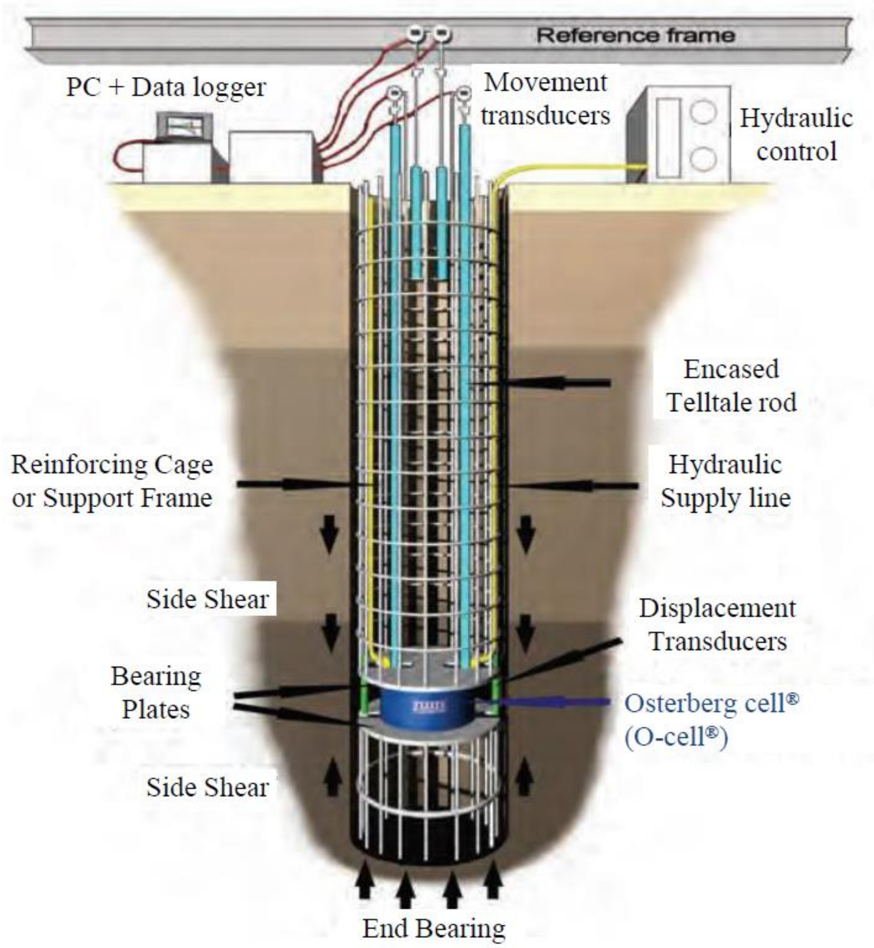

Figure 3: O-Cell Testing Schematic Diagram (Adopted from Loadtest, Inc)

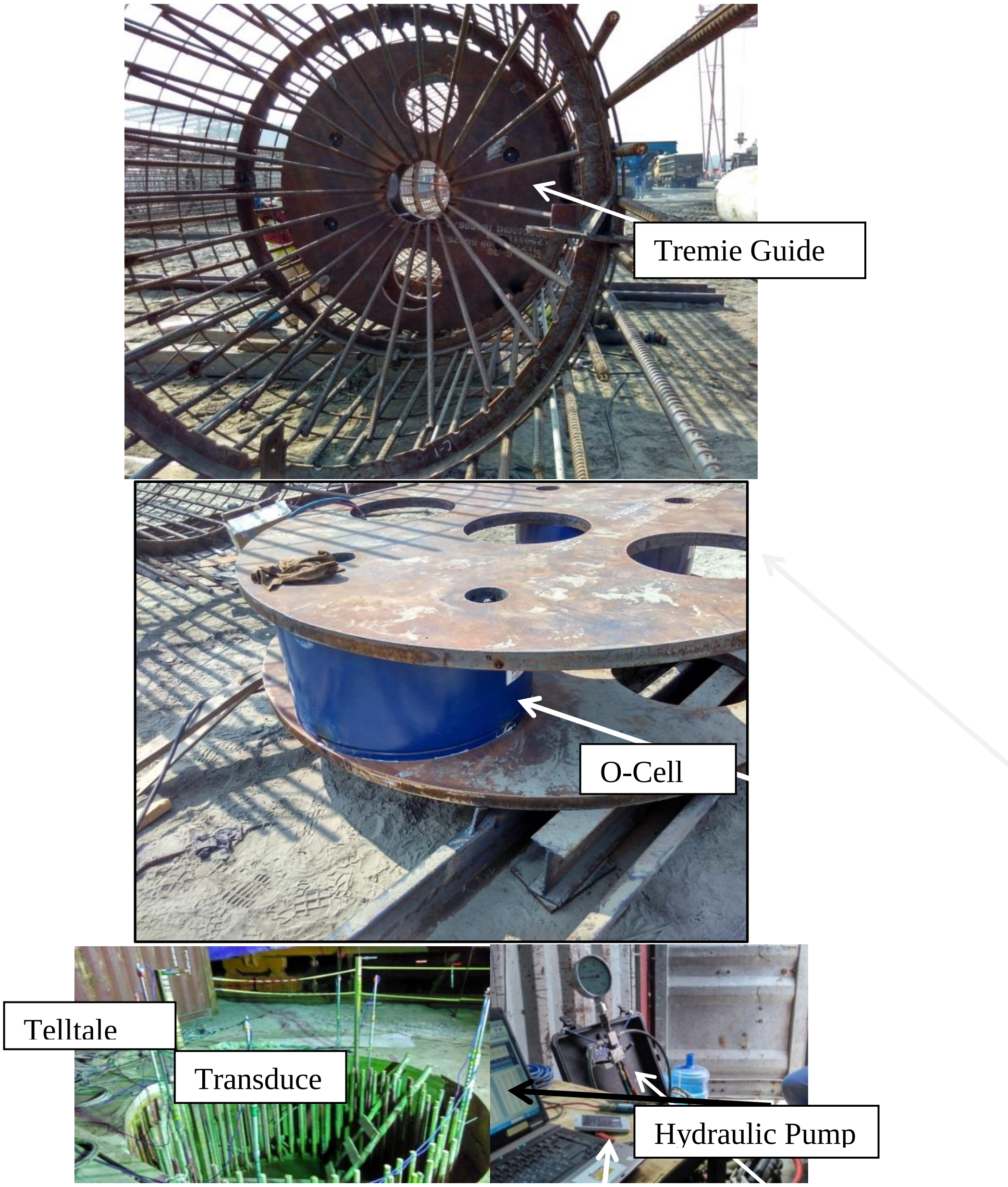

Figure 4: Typical Photographs of O-Cell

3.3 Load Test Procedures

Load increments were applied using the Quick Load Test method for the Pile, in accordance with ASTM D1143, holding each load increment for 8 minutes. Each load increment was approximately 5% of the estimated ultimate pile capacity. The data logger automatically recorded the instrument readings every 60 seconds. Typical photographs are shown in Figure 4. The loading of the O-cell was approaching its maximum stroke and locked. The pile was then given upward load to mobilize full skin fiction. The test pile was loaded in 20 increments to a bi-directional gross load of 80 MN. The pile was partially unloaded.

3.4 Load Test Results and Analysis

The load-displacement behavior recorded during the test was analyzed both in its individual components and in its recombined state to assess the pile performance as an integrated whole. The loads applied by the O-cell act in two opposing directions, resisted by the capacity of the pile above and below. Theoretically, the O-cell does not impose an additional upward load until its expansion force exceeds the buoyant weight of the pile above the O-cell. Therefore, net load, which is defined as gross O-cell load minus the buoyant weight of the pile above, is used to determine side shear resistance above the O-cell and to construct the equivalent top-loaded load-settlement curve.
In order to assess the side shear resistance of the test pile, loads are calculated based on the strain gauge data and estimates of composite pile modulus. Calculating load from the strain measurements proved to be complicated as applying a constant pile modulus to the strain measurements produced an unreasonable load distribution. Therefore, an approach to determine a strain-dependent pile modulus recommended by Fellenius (2001) was adopted to convert strain to load. Results of the load displacement curve for side shear and end bearing resistance are presented on Figure 5.

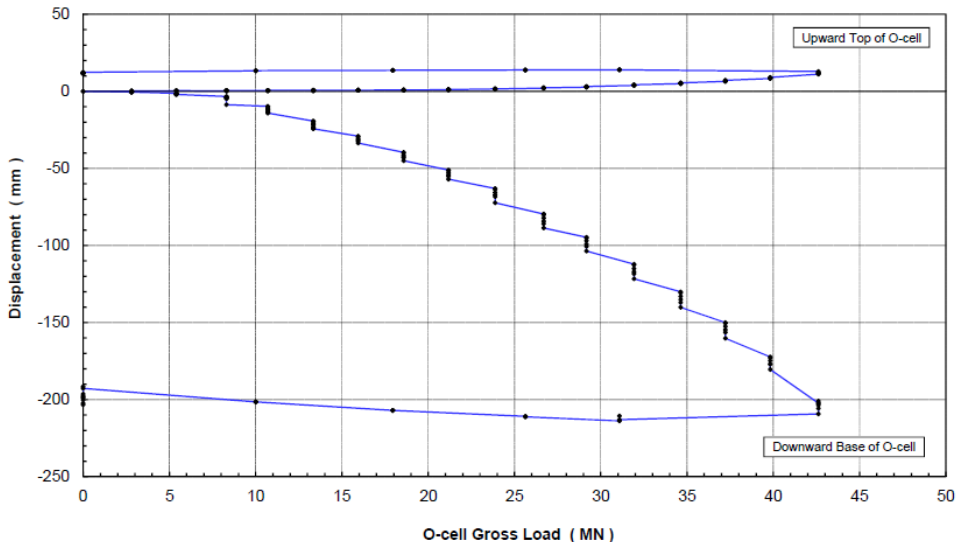

Figure: 5 Osterberg Cell Load-Displacement for Belled Pile

Net unit side shear curves developed from the strain gauges readings are presented on Figure 6 and mobilized side shear resistance values are presented on Table 1.

Table 1: Mobilized Side Shear Resistance

Load Transfer Zone	*Displacement(mm)*	*Direction*	*Net Unit Skin Friction(Kpa)*
Zero Shear to Strain Gauge Level 10	6.39	Up	51
Strain Gauge Level 10 to Strain Gauge Level 9	6.48	Up	23
Strain Gauge Level 9 to Strain Gauge Level 8	6.67	Up	20
Strain Gauge Level 8 to Strain Gauge Level 7	7.03	Up	100
Strain Gauge Level 7 to Strain Gauge Level 6	7.69	Up	100
Strain Gauge Level 6 to Strain Gauge Level 5	8.8	Up	54
Strain Gauge Level 5 to Strain Gauge Level 4	10.34	Up	50
4to Strain Gauge Level to O-Cell Level	12.05	Down	49
3 to Strain Gauge Level to O-Cell Level	206.33	Down	158
2 to Strain Gauge Level to O-Cell Level	201.34	Down	110

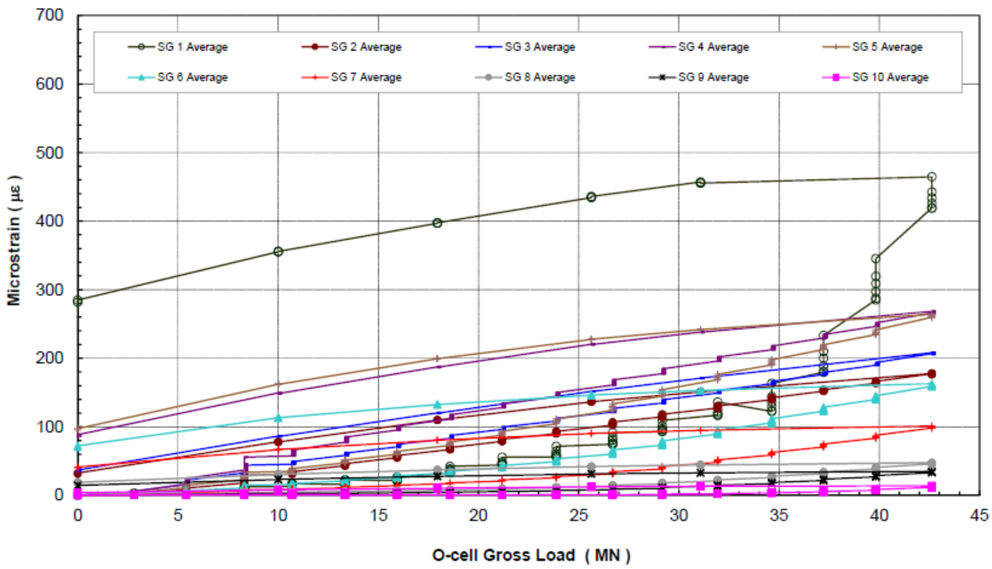

Figure 6: Mobilized Strains

The maximum O-cell load applied to the combined side shear and end bearing of the pile below the O-cell was 43 MN. At end of pile loading, the average downward movement of the O-cell base was 225 mm. Assuming the entire applied load was transferred to the base without any side shear resistance, the unit end bearing on the pile base was calculated to be 6020 KPa. The unit end bearing curve for the pile is illustrated on Figure 7.

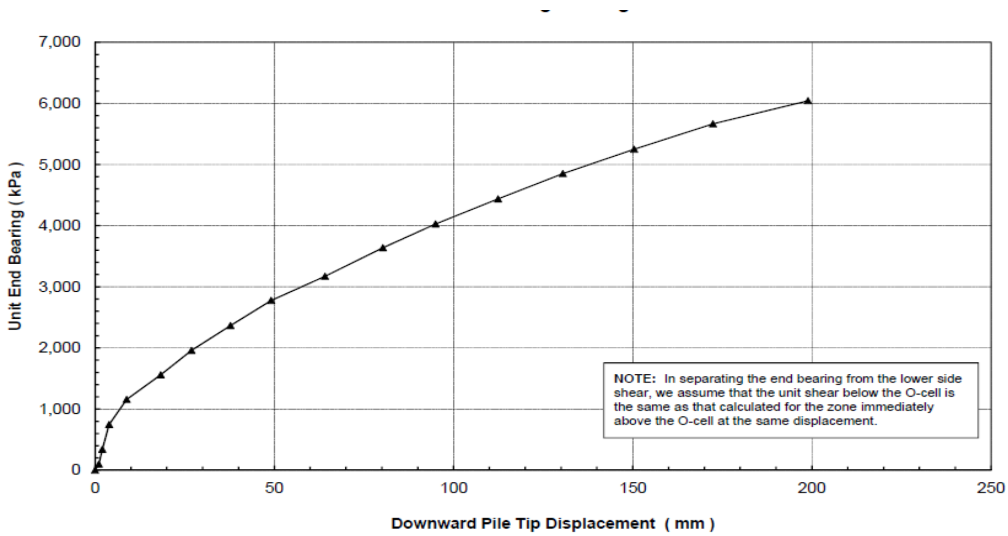

Figure 7: Mobilized Unit Bearing Resistance

4.0 Equivalent Top Down Load Settlement Curve

4.1 Assumption and Construction Methodology

It is assumed that for a known deflection, load applied to the upper cell shall be different than that of lower cell. For similar deflection top down load shall be sum of upward load and downward deflection. Therefore, the deflection x, upward skin friction and downward load are y and z, which equivalent top down load as y+z for downward settlement of x. Generally upward deflection is lower and this has been extrapolated for higher deflection and equivalent load is determined.

The results of the side shear resistance from above the O-cell and end bearing resistance from below the O-cell were combined to generate an equivalent top loaded load-displacement curve, which is presented in Figure 8. The total displacement curve has been adjusted for the additional elastic compression of the pile that would occur if the load applied below the O-cell were applied at the pile head. To demonstrate the ultimate pile top load capacity, the load-displacement data from the pile section above the O-cell has been extrapolated to the maximum measured end bearing displacement of 227 mm.

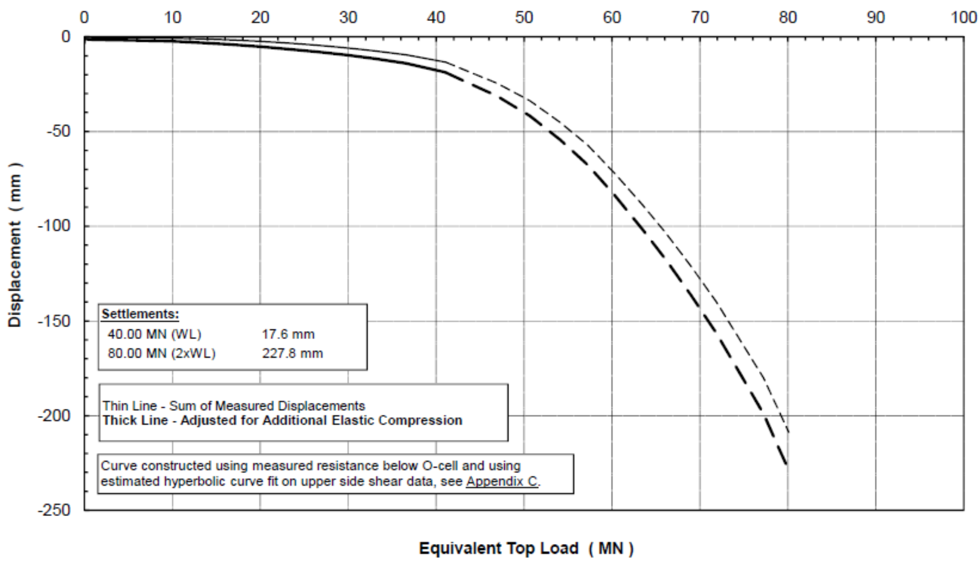

Figure 8: Equivalent Load Settlement Curve

5.0 Evaluation Capacity of Test Pile

5.1 Mobilization of Resistance

The interesting elements of the analysis of test results are centered on the development of pile component resistance with displacement. Reviewing Figure 5, it is noted that, while full side shear resistance is developed within 10-13 mm of pile displacement, significant pile displacement is required to fully develop end bearing resistance (Figure 6) ,while 225 mm of pile deformation was required to develop the same level of resistance in end bearing.

5.2 Design Implications

Data from test was utilized to define ultimate pile capacity and enable design optimization. From geotechnical investigation, design pile capacity was estimated as 32 MN and testing pile capacity was found to be 80 MN. Following contract specification has been considered as mentioned below:
Ultimate capacity is defined as load which causes maximum settlement of 10 % of diameter of the pile. For working pile, deflection is limited 20 mm. For large diameter pile, this deflection is too small, in which AASHTO LRFD 2012 recommendation has been considered keeping minimizing deflection of working pile.

The load test shall follow the procedures specified in ASTM D1143, and the loading procedure should follow the Quick Load Test Procedure. Unless specified otherwise by the Engineer, the nominal bearing resistance shall be determined from the test data as follows:

- For piles 600 mm or less in diameter (length of side for square piles), the Davisson Method (Figure 9);
- For piles larger than 900 mm in diameter (length of side for square piles), at a pile top movement, mm as determined from Eq. 3 as mentioned below; and
- For piles greater than 600 mm. but less than 900 mm diameter, criteria to determine the nominal bearing resistance that is linearly interpolated between the criteria determined at diameters of 600 mm and 900 mm.

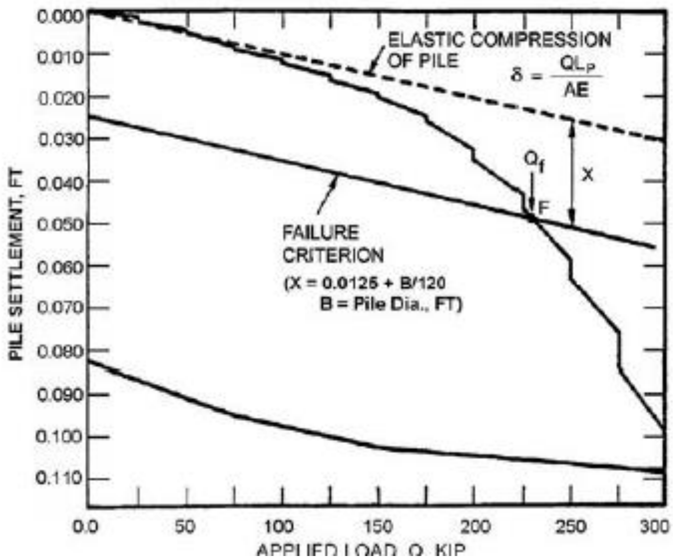

Figure 9: Alternate Method Load Test Interpretation (Modified by Cheney and Chassie, 2000 after Davisson 1972, Source:AASHTO LRFD 2012

$$S_f = (\frac{QL}{12AE} + \frac{D}{2.5}) \times 25 \qquad (1)$$

Where:
S_f= Allowable settlement in mm
Q = test load (kips)
L = pile length (ft)
A = pile cross-sectional area (ft^2)
E = pile modulus (ksi)
D = pile diameter (length of side for square piles) (ft)

Driving criteria should be established in consideration of the static load test results. Allowable settlement has been calculated as 123 mm and ultimate load capacity was found to be 66 MN. A factor of safety 2 is taken and design capacity is found to be 33 MN.

6.0 Conclusions

The behavior of bored piles tested using bi-directional static load test is different than conventional static test using kentledge system because the point of application is down below, where the pile tip is close to the point of load application. In conventional static load test, the friction is normally mobilized prior to the tip, but in the bi-directional test method, the pile tip may be mobilized prior to the friction.

It is important to note that the actual behavior of the pile under bi-directional load is different than the kentledge system. Hence, the calculation should be conducted to simulate the equivalent top-load curve of the bi-directional test results by considering pile elastic compression as well as the load transfer when the load is applied at the top, rather than from the bottom.

Test piles with targeted capacity of 32 MN and test result predicts capacity of 33 MN can be satisfied based on the results of bi-directional static load test. The maximum design bearing capacity proposed is 33 MN, which means that the allowable load is close to (more than by 1 MN) design load. Therefore, for practical purposes, no additional pile is added for construction stage.

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