Analysis of O-cell loading piling test at construction site of Expo 2017, Astana, Kazakhstan

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ABSTRACT

International Exposition will take place in 2017 in Astana, Kazakhstan as an Expo 2017 on Future Energy. Astana will have Center of the Arts, Energy Hall and even a city with an indoor shopping and entertainment pavilions. EXPO complex occupies 173.4 hectares. The leading construction companies will build the "city of the future". Nowadays, foundation of Expo 2017 Project is constructing by modern geotechnologies in Astana, Kazakhstan. For instance, 1000 mm diameter bored pile was tested by O-Cell loading Test from 14th April to 15th April, 2014. Length of pile is 31.50 m. Working load is 14500 kN and planning test load of the pile is 29000 kN. The hydraulic jack assembly comprising of three 5000 kN capacity bi-directional hydraulic jacks, was installed at 16.80 m below the cut off level. There were pair of tell-tale rod installed at the top and the bottom of the hydraulic cell assembly. Ten levels of vibrating wire-type strain gauges comprising four units at each level were installed in the test pile to measure strain at nominated locations. Adjustment for additional elastic compression is calculated as PL/EA where P is the applied load, L is the length, E is the elastic modulus and A is the cross-sectional area. The results of O-cell load test show that in the equivalent pile load-head settlement curve test pile would have a rigid pile settlement is 4.2 mm at 29000 kN. And also the test pile would have an elastic settlement of 9.66 mm at 29000 kN.

Keywords: O-cell loading test, hydraulic jack, strain gauge

1 INTRODUCTION

Expo complex consist of vertical farm (wind), Expo park, Congress Hall, International Pavilions, Thematic Pavilions, Performing Arts Center, National Pavilion of Kazakhstan. Overall building area of the Expo complex is equal to 173.4 hectare. Overall view of Expo 2017 Future Energy is shown in Fig. 1.

Exhibition buildings will have solar panels installed on their roofs. Wind turbines will be built around some constructions, and cool or arm air will be circulated through buildings using geothermal heat pumps. Will be constructed the largest spherical building in the world, the embodiment of the planet and the symbol of Expo. It will be unique and beautiful; shining construction, covered with semi-spherical glass. View of National Pavilion is shown in Fig. 2.

Fig. 1. Expo 2017 Future Energy, Astana, Kazakhstan

Fig. 2. National Pavilion of Kazakhstan at Expo 2017
Two pile load tests, O-cell load test and conventional static load test, were conducted at the early stages of Expo 2017 Future Energy. The O-cell load test and conventional static load test were performed by “Strainstall Middle East” LLC and “ZETAŞ” company respectively.

2. GOETECHNICAL CONDITION AND DETAILS OF PILES

Typical geotechnical conditions of the Expo 2017 construction site which mentioned before are represented by the following soils:

Soil 1 – loam with detritus is covered by top soil and fill-up soil in the depth of 0.20-0.40 m. the thickness of layer varies from 3.6 to 8.1 m. On the field description loam is brown, carbonated, and with middle coarse sand band which is thickness equal to 5 cm and with 5-10 cm thickness loamy sand layer.

Soil 2 – middle coarse sand is brown, with loamy soil which is thickness equal to 5-10 cm and water-saturated. The middle coarse sand thickness is 0.60-4.50 m.

Soil 3 – Coarse sand thickness is 1.0-3.9 m. Coarse sand is described by semi-gravel, color is brown, and with middle coarse sand band which is thickness equal to 5-10 cm, water-saturated and include 10 per cent gravel fragment.

Soil 4 – loam is deep-brown and mahogany color. And include debris and detritus up to 10 per cent.

Geotechnical condition of construction site and details of piles are shown in Fig. 3.

Two tested piles are situated in the same area and details of tested piles are same. Diameter of piles equals 1000 mm and depth of pile equals 31.5 m. Placement of tested piles is shown in Fig. 4 according to the pile draft of Expo 2017.

2. O-CELL LOAD TEST

The Osterberg load cell test is another form of static load test [Briaud, 2013]. For a large diameter pile, the capacity can be investigated with the O-cell test developed by Dr. Jorge Osterberg. The O-cell test has been used since 1984 for drilled shaft and driven piles [Lee, Park, 2008].

O-cell load test for a bored pile was carried out from 3rd August to 4th August, 2014. The hydraulic jack assembly comprising of three 500-tonne capacity bi-directional hydraulic jacks, was installed at 16.80m (330.60 m RL) below the Cut off Level.

There were a pair of tell-tale rod installed at the top and the bottom of the hydraulic cell assembly.

Ten levels of vibrating wire-type strain gauges (Geokon- 4911 Sister bar type) comprising four units at each level were installed in the test pile to measure strain at nominated locations. The strain gauges were mounted at designated Level 1 to Level 10 as shown below. Placement of hydraulic jack and strain gauges is shown thoroughly in Fig. 5.

Fig. 3. Geotechnical condition of construction site and details of piles

Fig. 5. Placement of the instrumentation

Details of testing pile are shown in Table 1.
The hydraulic jack assembly and steel cages were jointed and lowered into the bored hole.

Load testing commenced by applying hydraulic pressure to the hydraulic jacks using an air-driven hydraulic pump. A high-pressure Bourdon gauge as well as a calibrated pressure transducer was used to measure the pressure. The displacement transducers, which were supported from the reference frame, were used to measure relative movements at the designated points of measurement.

It is to be noted that the loads applied by the bi-directional hydraulic jacks act in two opposite directions, resisted by upper side shear above the jack assembly and by the combined end bearing and lower side shear below the jack assembly.

A millimeter scale was fixed to the reference frame and direct readings from a dumpy level to this scale were observed to check that there were no errors in the displacement transducer readings.

The displacement, load and strain data were automatically recorded at 1-minute intervals.

The top and bottom of hydraulic jack assembly movements were measured using displacement transducers that were connected to telltale rods against the reference beam and the top of pile were measured using displacement transducers installed at the pile platform level. Instrumentations which are used for O-cell load test are shown in Fig. 6.

Fig. 6. Instrumentation details

Fig. 7 shows the load movement curves of loading and unloading of the test. The specifications for this project settlement criteria as follows: 4.2 mm at 14900 kN in case of pile top, 3.9 mm at 14900 kN in case of cell bottom and also 7.4 mm at 14900 kN in case of cell top. The results of the O-cell load test satisfy the specification.

The equivalent pile load-head settlement curve shows that rigid pile settlement is 4.2 mm at 29000 kN. Adjustment for additional elastic compression is calculated as \( PL/EA \) where \( P \) is the applied load, \( L \) is the length, \( E \) is the elastic modulus and \( A \) is the cross-sectional area. The results show that the test pile would have an elastic settlement of 9.66 mm at 29000 kN.

The equivalent top loaded load movement curves are derived and shown in Fig. 8.

Fig. 7 Preliminary Load-Movement Plot

Fig. 8. Diagram of Load-Settlement for boring testing pile

3. CONVENTIONAL STATIC LOAD TEST

Working pile static load test has been started on 19th July, 2014 and finished on 20th July, 2014. Static Load to bored pile created by two hydraulic jacks, which bears on anchor stand. Reaction strain was received by four anchoring bored piles.

Pile was tested by static and step-by-step increased load, enhanced to 12000 kN.

Details of conventional static load test and tested pile are shown in Table 1.

<table>
<thead>
<tr>
<th>Type</th>
<th>Diameter (mm)</th>
<th>Length (m)</th>
<th>Cut-off Level (m)</th>
<th>Toe Level (m)</th>
<th>Testing Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bored pile</td>
<td>1000</td>
<td>31.5</td>
<td>347.40</td>
<td>315.90</td>
<td>347.40</td>
</tr>
</tbody>
</table>
Below pile construction details and design parameters of static load test are shown in Fig. 9.

3. COMPARISON OF O-CELL LOAD TEST AND CONVENTIONAL STATIC LOAD TEST

Two pile load tests, the static load test and O-cell load test, were conducted at the early stages of Expo 2017 Future Energy project in Astana.

Two tested piles are situated in the same area and details of tested piles are same.

The static load test and O-cell load test were carried out by “ZETAŞ” company and “Strainstall Middle East” LLC respectively.

Settlement is often a governing factor for determining pile length or the number of the piles. The specifications for this project set settlement criteria as follows: 2.09 mm at working load, 10.51 mm at 2 times the working load. The results of the static pile load test satisfy the specification.

The pile construction procedures for the O-cell test are similar to those adopted for the static pile load test except O-cell was installed at 16.80 m below as shown in Fig. 5.

The results of O-cell load test show that the test pile would have rigid pile settlement of 4.20 mm at 29000 kN.

Comparison of equivalent pile head-settlement curves of O-cell load test and conventional static load test is shown in Fig. 11.

Fig. 11. Comparison between of results of O-cell load test and static load test

Elastic method predicted curve does not exactly match the static load test results. As explained below this may be attributed to several factors which include the maintained time at each loading stage, overrun during concrete placement, construction effects and size of influence zone.

Maintained time: The maintained time for each loading stage is relatively short in the O-cell test (typically 4 minutes) compared with the static load test (typically 30 minutes). Table 3 summaries the maintained time effect on the settlement during the static load test. Pile settlement increases with holding time and these effects increase with loading level. Note that the equivalent pile load-head settlement curve is developed for 4 min holding time. Therefore, the settlement should be smaller for the O-cell test than for the static load test.

### Table 2. Details of testing pile

<table>
<thead>
<tr>
<th>Pile №</th>
<th>Diameter (mm)</th>
<th>Working Load (kN)</th>
<th>Test Load (kN)</th>
<th>Cut-off Level (mm)</th>
<th>Toe Level (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>166</td>
<td>1000</td>
<td>6000</td>
<td>12000</td>
<td>347.40</td>
<td>315.90</td>
</tr>
</tbody>
</table>

Following results are obtained from the mentioned static load test:
- the maximum settlement up to 6000 kN is 2.09 mm;
- the maximum settlement up to 12000 kN is 10.51 mm;
- the residual settlement after unloading to zero is 0.32 mm.

The working test pile is loaded up to 200% of the working load and settlements of the pile under various load steps are recorded. Recorded settlements of 2.09 mm (at 100% working load) and 10.51 mm (at 200% working load) are observed to be within acceptable limits which calculated as below:

\[ U_{2\max} = \left( \frac{PL}{AE} \right) + 0.01d = 25 \text{ mm} > 10.51 \text{ mm} \]  

The pile did not fail up to maximum test load and it is concluded by this full scale test that the pile performance is satisfactory.
Table 3 Settlement increments due to maintained time during the static load test

<table>
<thead>
<tr>
<th>Maintained time (h)</th>
<th>Loading step (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6000 kN (1.0 WL)</td>
</tr>
<tr>
<td></td>
<td>12000 kN (2.0 WL)</td>
</tr>
<tr>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
</tr>
</tbody>
</table>

Overrun: The concrete volume during construction was measured to obtain the overrun. Overrun is the ratio of the difference between theoretical and used concrete volume to the theoretical volume. Overrun of the pile for the static pile load test was 3.35% and overrun for the Ocell test was 4.56%. When the volume of the sacrificial hydraulic jacks installed is considered, the overrun of the two piles are almost the same. Therefore, differences due to overrun are considered to be negligible.

Influence zone: The pile head diameter is slightly larger than the pile toe diameter due to the bucket movement during the drilling process. The size of the influence zone of the O-cell test is smaller than that of the static load test due to load-transfer characteristics. Therefore, the settlement of the static load test may be smaller than that of the O-cell test. This effect is probably insignificant if the loading level is minor (less than 1.0 WL). Therefore, a larger settlement is expected during the O-cell test if the maintained time and pile length are the same.

4 CONCLUSIONS

1. Field O-cell load test was carried out and results of field test were analyzed first time in Astana, Kazakhstan. The method of O-cell has been studied and described advantages of using O-cell load test for large diameter pile foundations.

2. The O-cell testing method provides some important advantages. There is no structural loading system at the ground surface. Load can be applied at or very close to the base of a socket for measurement of base resistance. In conventional top load testing, most or all of the side resistance must be mobilized before there is significant load transfer to the base.

3. The O-cell test method offers a number of potential advantages versus the conventional testing of bored piles. These include: economy, high load capacity, shear/bearing components, improved safety, rock sockets and reduced work area.

4. Field conventional static load test was carried out at construction site of Expo 2017 Future Energy.

5. Also Comparison between of conventional static load test and O-cell load test was performed first time in soil condition of Astana.

6. The results of conventional static load test show that pile has settlement of 2.09 mm at working load 6000 kN, 10.51 mm at 2 times the working load 12000 kN.

7. Settlement of conventional static load test is larger than settlement of O-cell load test, so difference between of O-cell load test settlement and static load test settlement is equal to 1.08 times. But difference between of O-cell load and static load is equal to 2.5 times.

8. Differences between of O-cell load test and conventional static load test were attributed to several factors which include the maintained time at each loading stage, overrun during concrete placement, construction effects and size of influence zone.

REFERENCES