Offshore Jet Grouting - A Case Study

Turan DURGUNOGLU (ZETAS), Fatih KULAC (ZETAS), Selim IKIZ (ZETAS),
Ogan SEVIM (ZETAS), Onder AKCAKAL (ZETAS)

ABSTRACT

Having high budgets and construction difficulties, offshore structures serve sensible and attractive solutions with an expanding application area all over the world. Because of the marine sediment layers, generally offshore structures subject to be constructed on unfavorable soil conditions. A similar problem was encountered in the scope of an offshore plaza structure in Doha Port, Qatar. Since marine sediments exist with a thickness varying between 3 m to 12 m on the Simsima Limestone bedrock, soil improvement was recommended prior to plaza construction. Some locations of the site were filled and as a result dredging of the made ground was required before soil improvement works. Sea bed was dredged at a depth of -6.00 m and a flat platform was formed prior to soil improvement works. For soil improvement, offshore jet grouting technique is designed and implemented in accordance with the soil conditions and structural surface loadings. Ø80 cm diameter jet grout columns are constructed to a depth of bedrock. System is modeled in Plaxis 3D Foundation and checked in order to fulfill the settlement criteria considering embankment and superstructural loadings. For jet grouting applications a spud barge and a cantilever platform which is carried with a crane are mobilized to the site. Jet grouting is operated on this barge and cantilever platform simultaneously, in order to meet the tight construction schedule. After the soil improvement works, the seabed is dredged and plaza blocks are placed on a granular capping layer which is placed on the jet grout columns. In the scope of the quality control works core samples are taken from the jet grout columns and uniaxial pressure tests are performed to determine the modulus and strength of soilcrete. Since application difficulties and tight schedule of the constructions as in Doha Port, selection of a proper soil improvement method has provided important benefit to the project. It is again proved that, jet grouting is a convenient method because of versatile equipment, high production rate and a reliable output with a sufficient quality control for offshore soil improvement works.

1. INTRODUCTION

Off-shore structures are frequently demanded in shorelines of cities to serve various missions. The unfavorable soil conditions are one of the biggest challenging difficulties encountered during off-shore constructions. Beside bearing capacity problems, in some projects strict settlement constraints come forward in accordance with the importance of the structure. An off-shore sculpture plaza was planned to be constructed at the Museum of Islamic Art, Doha. Due to strict settlement criteria of the sculpture plaza, soil improvement works are designed and implemented carefully and presented in this interesting case study.

2. PROJECT DESCRIPTION

The Museum of Islamic Art is located on the south side of Doha’s Corniche on a man-made island sixty meters from the shore. A C-shaped peninsula provides protection from the Persian Gulf on the north and from unsightly industrial buildings on the east. (http://www.arcspace.com, 2009) In the scope of the Museum of Islamic Arts Project an
offshore sculpture plaza is planned to be constructed by Qatar Museums Authority. Sculpture which is approximately 24.5 m high is designed by the well known artist Mr. Richard Serra. Sculpture is planned to be placed on an off-shore plaza which is on the edge of the C-shaped peninsula (Photos 1 and 2).

Plaza is designed as standing on a rectangular area having dimensions approximately 60 m and 38 m. (Figure 3) Plaza is constructed by means of the precasted concrete blocks as given in section view below. (Figure 2)

Precasted concrete blocks and sculpture plaza were designed by engineering group, COWI and the loads under the sculpture plaza were submitted as given Figure 3. Under
core part of the plaza block type soil improvement was requested to bear maximum 300 kPa load and under remaining parts wall type soil improvement was requested to bear maximum 150 kPa load.

To minimize the settlements under the sculpture four bored piles with 100 cm dia. are implemented. Piles are embedded to base rock minimum 3.5 m. Sculpture is designed as standing on a separate foundation.

3. SOIL PROPERTIES

As stated in the soil investigation report prepared by Fugro Peninsular in 2010, two boreholes were performed on the plaza construction area. Boreholes were operated on the made ground which will be excavated and replaced with concrete blocks and back-fill.

Soil profile is given in the soil investigation report as; (Fugro Peninsular, 2010)

- **For the top 12.00-13.50 m**, made ground represented mostly by boulders, cobbles and gravel in a medium dense state.
- **For the layer which has a variable thickness between from 3.40m thick in BH-01 to 10.7m thick in BH-02**, marine sediments represented by a coarse grain sequence at the top and a fine grain unit at the bottom.
- **And the base rock** which represented by the geological formation Simsima Limestone, represented by a moderately strong and strong fine grained limestone, with numerous pockets of greenish-grey attapulgite clay.

Soil profile is also illustrated as given in Figure 4;

4. SETTLEMENT LIMITS

It is stated in the specification issued by the Client Qatar Petroleum that ground improvement shall minimize the settlements of the block walls and ensure that the long term total settlements are kept within 25 mm. And special care shall be taken to ensure that the differential settlements shall be less than 15 mm over a length of 10 m.
5. JET GROUTING DESIGN

Because of the existence of made fill and marine sediments, soil improvement is planned to be implemented under the sculpture plaza. Made fill and marine sediments under the seabed will be improved with a suitable method which will be operated on a platform in the sea.

Jet grouting is selected as a convenient method because of the less weight of its equipment, high production rate and a reliable output with a sufficient quality control.

Jet grout columns are designed based on the section capacity of the columns.

In accordance with the experiences in similar projects, Ø80 cm diameter jet grout columns with 475 kg/m³ cement dosage will be suitable for this project with 1265 kPa estimated section capacity. Jet grout section capacity is calculated in Equation 1.

\[
F_{\text{JG}} = \frac{A_{\text{JG}} \cdot \sigma_{\text{JG}}}{FS}, \quad F_{\text{JG}} = \frac{0.5 m^2 \cdot 1265 kPa}{1.5 \times 1.1} = 383 kN \cong 380 kN
\]

A value of 1.1 partial factor of safety is considered for soilcrete section capacity calculations beside the general factor of safety which considered as 1.5.

Measured water soluble sulphate (SO4) values are 960mg/l for BH1 and 2280mg/l for BH2. As per BRE SD1-2005 the cement should be comply with CMIV/B in accordance with BS EN 197:2000.
Both design of wall and block type jet grout applications are given below;

Bearing capacity of Type 1 area (wall type) calculated in Equation 2.

\[
\frac{380KN}{1.25m \cdot 2.0m} = 152kPa
\]  

\[\text{(2)}\]

Jet grout settlement given in the Figure 4 will suffice to bear 150 kPa load under wall type (Type1) soil improvement area.

Bearing capacity of Type 2 area (block type) calculated in Equation 3.

\[
\frac{380KN}{1.25m \cdot 1.0m} = 304kPa
\]  

\[\text{(3)}\]

Jet grout settlement given in the Figure 3 will suffice to bear 300 kPa load under block type (Type2) soil improvement area.

Total jet grouting quantity to be implemented is calculated as 9,283 m.

6. SETTLEMENT CALCULATIONS

Since the loads will be transfered to the base rock with jet grout columns, preliminary calculation for expected settlements is considered as elastic settlement of the jet grout columns. Preliminary calculation for settlement is given in Equation 4.

\[
\delta_{\text{total}} = \frac{P \cdot L}{E \cdot A} = \frac{380kN \cdot 14m}{75000kN / m^2 \cdot 0.5m^2} = 0.014m = 14mm
\]  

\[\text{(4)}\]

To simulate the settlements under the plaza more accurately, system is modeled in Plaxis 3D Foundation. Model boundaries and 5 critical points are determined as given in the Figure 7.
First model is quarter part of the 150 kPa loading area which contains 300 kPa loaded part as an unfavorable situation. Second model is quarter part of the 300 kPa loading area. Described models are illustrated in the Figures 8 and 9.

In both two models bedrock depth is modeled at 15 m. 15 m jet grouts are modeled under the loaded areas. Calculated settlements for Model 1 are given in the Figures 10, 11 and 12.
Calculated settlements for Model 2 are given in the Figures 13, 14 and 15.

Superposed settlements under critical points are calculated as given in Table 1.
Table 1 : Superposed Settlements

<table>
<thead>
<tr>
<th>Critical Points</th>
<th>Settelsments, mm</th>
<th>Superposed Settelsments, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>δy1</td>
<td>16.3</td>
<td>20.3</td>
</tr>
<tr>
<td>δy2</td>
<td>9.0</td>
<td>17.0</td>
</tr>
<tr>
<td>δy3</td>
<td>14.1</td>
<td>17.1</td>
</tr>
<tr>
<td>δy4</td>
<td>16.7</td>
<td>20.7</td>
</tr>
<tr>
<td>δy5</td>
<td>11.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Settlement values calculated are under the limits of total settlement value 25 mm and differential settlement value 15 mm /10m as specified in the specification.

7. OFF-SHORE JET GROUTING APPLICATION

Prior to soil improvement works sea bed was dredged at the depth of -6.00 m and a flat platform was formed. Off-shore jet grout columns planned to be implemented with two different methods simultaneously within this project in order to meet the tight construction schedule. Total approximately 9,300 m Ø80cm dia. jet grouting have been implemented in 60 days reaching to a rate of 155 m/day. One is the jet grouting on the spud-barge mobilised to the application site (Photo 3), the other is the jet grouting on a cantilevered platform which is carried by a crane (Photo 4).

IPC 830B model drilling machine is used on the cantilevered platform because of its low weight and versatility. (Photo 5) The cantilevered platform is designed and fabricated specially for this project by Z Makine a sister company of Zetas. (Photo 6)

After the off-shore jet grouting works for leveling the sea bed clamshell grab is used before placing the fill and precasted concrete blocks.
8. **QUALITY CONTROL TEST**

Compression tests of the core samples taken from the jet grout columns are performed in the scope of the quality control applications. Assumptions on the material properties of the soil-crete columns such as section capacity and modulus were checked and approved.

9. **CONCLUSIONS**

Because of the unfavorable soil conditions and strict settlement criteria, soil improvement is implemented under the off-shore sculpture plaza in Doha Port. Regarding the soil conditions and structural surface loadings, off-shore jet grouting technique is considered as a proper solution for soil improvement. Variable base bedrock depth is encountered during the soil investigation and jet grout columns are implemented to the depth of rock stratum. System is modeled in Plaxis 3D Foundation and checked in order to fulfill the settlement criteria. Jet grouting is performed on spud barge and a cantilevered platform which is carried with a crane. In order to meet the tight construction schedule jet grouting is operated on this barge and cantilevered platform simultaneously. Core samples are taken from the jet grout columns and uniaxial compression tests are performed, in the scope of the quality control works.

With off-shore jet grouting, soil improvement works implemented successfully in a very tight schedule and provided important benefit to the project. In this case study it is again proved that, even working on an off-shore project, jet grouting provides a reliable and a quick solution because of versatile equipment, high production rate and a reliable output with a sufficient quality control.

**AKNOWLEDGEMENT**

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