Decision Process for Selection of Retaining Structure for an Excavation in Soft Clay

Turan Durgunoglu\textsuperscript{1}, Fatih Kulac\textsuperscript{2}, Selim Ikiz\textsuperscript{3},

Ali Gunay\textsuperscript{4}, Onder Akcakal\textsuperscript{5}

\textsuperscript{1}Zetaş Zemin Teknolojisi A.S., Reşadiye Cad. No: 69/A 34794 Çekmeköy Tel: +90 (216)4844170 Fax: +90(216)484474, İstanbul Turkey, durgunoglut@zetas.com.tr
\textsuperscript{2}Zetaş Zemin Teknolojisi A.S., Reşadiye Cad. No: 69/A 34794 Çekmeköy Tel: +90 (216)4844170 Fax: +90(216)484474, İstanbul Turkey, kulacfatih@zetas.com.tr
\textsuperscript{3}Zetaş Zemin Teknolojisi A.S., Reşadiye Cad. No: 69/A 34794 Çekmeköy Tel: +90 (216)4844170 Fax: +90(216)484474, İstanbul Turkey, selim.ikiz@zetas.com.tr
\textsuperscript{4}Zetaş Zemin Teknolojisi A.S., Reşadiye Cad. No: 69/A 34794 Çekmeköy Tel: +90 (216)4844170 Fax: +90(216)484474, İstanbul Turkey, aligunay@zetas.com.tr
\textsuperscript{5}Zetaş Zemin Teknolojisi A.S., Reşadiye Cad. No: 69/A 34794 Çekmeköy Tel: +90 (216)4844170 Fax: +90(216)484474, İstanbul Turkey, onder.akcakal@zetas.com.tr

ABSTRACT

In recent years the number of shopping malls has increased rapidly parallel to development of the cities within Turkey. Due to the need for large and flat areas, many of these structures have been constructed in areas with poor subsoil conditions. The need for large underground car parks added more to the difficulty of geotechnical problems. Kagıthane Mall Project described in this paper is a particular case having difficult geotechnical problems to be solved. The structure is planned to have four basement levels to excavation depth of approximately 17 m. According to the soil investigations, soil profile consists of very soft Golden Horn Clay at the top overlaying bedrock sandstone which is located at a depth ranging from 10 m to 28 m below ground surface. The site is very close to Kagithane River therefore groundwater level is high. The shoring system was decided to be formed as tie back system having multilevel prestressed anchors at the original design. Pre-bidding studies have shown that, high displacements are likely at the sections which have soft clay dominated soil profile because of the low anchorage capacities and low modulus of elasticity of soft clay. Therefore, an alternative shoring system has been studied and proposed to be implemented during the bidding stage. In the proposed system the following construction steps have been implemented. Construction of the diaphragm walls, 5 m deep excavation in front of the diaphragm wall with one row of prestressed anchor, improvement of the soil with jet grouting at this level underneath the foundation and also within the temporary berm against the diaphragm wall, excavation to form a 5 m wide berm in front of the diaphragm wall and then a 1/1 slope to reach the foundation level at -17 m, construction of core part of the superstructure to zero level, level by level excavation to take out the temporary berm replacing it with steel tube struts to support the diaphragm wall from the slabs at the previously constructed core structure, construction of the remaining part of the building by integrating it to the diaphragm walls in slab levels while disassembling the steel struts from bottom to top in parallel with the rise of the building. This
alternative system has shown to limit the expected displacements therefore to make a safe construction possible, to shorten the construction period and to bring cost reduction in overall project.

INTRODUCTION

The vicinity of the Kagithane River at Golden Horn has become very popular recently with the increase of the population of Istanbul in the European Side. Numerous projects have been started almost simultaneously near the river shoreline on very soft Golden Horn Clay. Combination of poor subsoil conditions and deep excavation demand formed difficult geotechnical problems to be resolved. Low modulus value of soft clay restricts designers and limits the depth of the excavations even in prestressed anchored systems. For deep excavations it was necessary to implement a more rigid support system than prestressed anchors in order to limit the resting horizontal displacement upon excavation. An alternative solution has been developed for the Kagithane Mall Project. In the design methodology and the resulting displacements are presented within the paper.

PROJECT DESCRIPTION

Kagithane Shopping Mall Project is located between Cendere and Sanayi Streets at the shore of Golden Horn as given in the figures below. There was an old carpet factory on the site which is demolished prior to construction.

![Figure 1a. General View of the Site.](image1a.png)  ![Figure 1b. Location of the Site in Istanbul.](image1b.png)

Shopping Mall is planned to be constructed with four basements and four stories. Maximum excavation depth is given as approximately 17 m from the existing ground surface and perimeter of the sites about 462 meters. Typical cross-section of the structure is given in the Figure 2.
Within the design studies at the bidding stage to provide economy to the project it is decided to use the shoring system as permanent basement walls for the structure. This decision brought up new details to be solved such as ground water isolation and continuity of the structural elements.

SOIL PROPERTIES

In the content of the soil investigations six bore holes are implemented with a maximum depth of 31.50 m in 2008. In 2011 second stage boreholes are implemented with a maximum depth of 27.80 m. Soil profile can be defined as fill layer with a thickness between 1.2-2.2 m at the top, alluvial layer consist of sandy clay with a thickness of 9 m to 27 m and fractured sandstone bedrock. Since site is located at the edge of the clayey zone and very near to the hillside, an inclined bedrock boundary is observed.

Soil layers are modeled with hardening soil model in Plaxis. Considered mechanical parameters are given in the Table 1. It is considered that alluvium deposit which encountered above the bedrock consists of mainly clayey soil locally known as Golden Horn Clay. Sandy clay layers are also encountered within the soil investigations. The laboratory test results are given in Table 2.
Table 1. Soil Properties.

<table>
<thead>
<tr>
<th>Layer</th>
<th>γ (kN/m³)</th>
<th>Ø’ (°)</th>
<th>c’ (kN/m²)</th>
<th>E50-ref (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayey Alluvium</td>
<td>18</td>
<td>26</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Sandstone</td>
<td>23</td>
<td>38</td>
<td>40</td>
<td>150</td>
</tr>
<tr>
<td>Improved Soil (with Jet Grouting)</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 2. Atterberg Limit Values of Alluvial Clay Layer.

<table>
<thead>
<tr>
<th>Bore Hole</th>
<th>Depth</th>
<th>LL</th>
<th>PL</th>
<th>PI</th>
<th>USCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>6.00-6.50</td>
<td>40</td>
<td>21.8</td>
<td>18.2</td>
<td>CL</td>
</tr>
<tr>
<td>S1</td>
<td>19.50-20.00</td>
<td>47.7</td>
<td>23.4</td>
<td>24.3</td>
<td>CL</td>
</tr>
<tr>
<td>S2</td>
<td>7.50-8.00</td>
<td>40.3</td>
<td>21.5</td>
<td>18.8</td>
<td>CL</td>
</tr>
<tr>
<td>S2</td>
<td>18.00-18.50</td>
<td>46</td>
<td>22.7</td>
<td>23.3</td>
<td>CL</td>
</tr>
<tr>
<td>S2</td>
<td>22.50-22.95</td>
<td>56.6</td>
<td>24.7</td>
<td>31.9</td>
<td>CH</td>
</tr>
<tr>
<td>S3</td>
<td>4.50-4.95</td>
<td>27</td>
<td>20.4</td>
<td>6.6</td>
<td>CL-ML</td>
</tr>
<tr>
<td>S3</td>
<td>15.00-15.50</td>
<td>31.7</td>
<td>20.1</td>
<td>11.6</td>
<td>CL</td>
</tr>
</tbody>
</table>

Since site is near to the Kagithane River, high groundwater is observed being about 3.0m below the existing ground surface.

PRELIMINARY (TENDER) DESIGN AND DISPLACEMENT PROBLEMS

The retaining system has been designed by a geotechnical consulting group which consists of bored piles and intersecting jet grout columns and pre-stressed anchorages. Bored piles are designed as Ø80 cm diameter with 90 cm spacing and two rows of jet grout columns are placed behind the bored piles to provide groundwater cut-off. A sample plan view of the pretender design is given in Figure 4.

![Figure 4a. Tender Design Typical Plan View.](image)

![Figure 4b. Tender Design Typical Section.](image)

During the tender process proposed support system is modeled in Plaxis and it was seen that very large horizontal displacements in the order of 287 mm, Figure 5.
would develop as a result of excavation. Therefore an alternative supporting system has been developed at the tender stage.

![Figure 5. Excessive Displacement with Preliminary Design.](image)

**ALTERNATIVE SYSTEM SOLUTION**

Since high horizontal displacements are expected in the original design according to the results of Plaxis models, an alternative shoring system is studied employing permanent diaphragm wall and struts. In accordance to the request of the client diaphragm wall is designed as permanent basement walls of the structure employing some additional details. Since excavation area is very large to install struts between bilateral sides, a sophisticated methodology is developed. Implementation phases of the alternative system are given as 5 m excavation in front of the diaphragm wall with one row prestressed anchor, improvement of the soil under the foundation and near the diaphragm wall with jet grouting, leaving 5 m berm and excavation to 17 m depth with a 1/1 inclined slope, construction of core part of the superstructure, excavation of remaining area to 17 m depth by means of supporting the diaphragm wall with steel pipes which hinge on constructed core structure at slab elevations. These phases are illustrated in Figure 6.
PERMANENT DIAPHRAGM WALL DETAILS

Diaphragm walls can be used as permanent basement walls of the structure by means of some modifications. Major problems are water isolation and continuity of the structural elements. Joints of the diaphragm wall sections are sensitive locations for water infiltration. To reduce the water infiltration between these joints special...
water-stops are placed between adjacent panels. Sample water-stop used is given in Figure 8.

**Figure 8a. Water Stop Section.**

**Figure 8b. Water Stop Rolls.**

Water-stops are installed between diaphragm wall panels by means of hydraulic jack developed for this purpose. These hydraulic jacks are placed at the edge of the panel excavation with water-stops. Hydraulic jack stop-end placement in the pit is given in Figure 9.

**Figure 9a. Stop-end Settlement in the Pit.**

**Figure 9b. Water-Stop Installation in Hydraulic Stop-End.**

After concreting stop-end splits up from the concrete by means of power pack and hydraulic jacks inside it and leaves the water-stop in the concrete. Installation process and the final view of the installed water-stop can be seen in the given Figure 10.

**Figure 10a. Stop-End Installation.**

**Figure 10b. Installed Water-Stop.**
Also to provide the continuity of the structural elements special connection reinforcements are attached in the diaphragm wall reinforcement cage. These reinforcements are placed at the elevations of slabs of each story and the foundation.

**CONSTRUCTION STAGE OF THE PROJECT**

At the date of the submission of this paper diaphragm walls has just been completed, site was excavated to the final elevation at the core zone and core part of the building was under construction. Although, large displacements were recorded in the similar projects which supported by anchorages near the Kagithane River, due to special support system and the methodology much smaller displacements are recorded by the inclinometers in this project. Although the predicted lateral displacements was 72 mm, precipitation during the construction caused erosion on the berm and total displacements were increased up to 100 mm. Displacements stopped after covering plastic sheet Figure 11 on the berm and final displacement before construction of building core was recorded as 100 mm.

![Figure 11. Inclinometer Readings.](image)

![Figure 12. General View of the Excavation Area](image)

![Figure 13. Covering the Berm to Protect Against Erosion](image)
CONCLUSION

Because of the low modulus of clay and high water level, it is determined that more rigid supporting systems are required for deep excavations in order to limit the resulting displacements upon excavation. A special methodology for the support system which is described in this paper is developed. Permanent diaphragm wall is applied with the water-stops by means of special hydraulic jacks. After the excavation of the core part of the pit very limited displacements are observed in comparison to the classical prestressed tie back system. Therefore the proposed system has provided the opportunity to limit the resulting lateral displacements.

AKNOWLEDGEMENT

The case study presented in this paper is developed by Suryapi in Istanbul, Turkey. We would like to extend our great appreciation to all the individuals involved in various stages during the realization of this challenging project. Special thanks are due to Mr. Altan Elmas General Manager of Suryapi, Mr. O. Ramiz Soylu Deputy General Manager of Suryapi and Mr. Ismail Turkeli Project Manager of Suryapi.