Temporary support of excavation walls-case study

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ABSTRACT: Various methods of temporary stabilization of soil excavations are used to support the excavations wall. Soldier pile system and bored concrete piles are very versatile excavation retaining system for deep excavations in urban areas surrounded by major structures and infrastructures provided that limiting lateral displacements are not exceeded. In this study we have surveyed performance of various support systems that applied in excavations walls of entrance ramp of the Niayesh road tunnel project. These walls were supported by soldier pile system reinforced by soil nails and Bored Pile system reinforced by anchors and struts elements. The lateral deformations of walls were monitored parallel to the excavation progress from several target point on the surface of the wall. Some Finite Element models were developed to analyze performance of the walls. The analyses results were compared with monitored lateral deformations and performance and stability of each system were compared with other systems.

1 INTRODUCTION

The Niayesh road tunnel project’s site is located at Tehran, Iran. Entrances of the tunnel are supplied by some access ramps. According to the adjacent building, streets, underground urban installations and project specifications, the walls of these ramps are stabilized by different systems during and after excavations.

The main scope of this study is to analyze the performance and stability of the initial support systems for the walls of the four main entrance ramps of the tunnel, North East (NE), South East (SE), West (W) and Kurdistan (K). Figure 1 presents plan of entrance ramps of the tunnel.

2 PROJECT SPECIFICATIONS

For NE and SE ramps, the soldier pile system has been purposed as initial support for excavation walls.

Regarding project specifications height of soldier pile walls varies from 4 to 19.5 meters in NE and 4 to 10 meters in SE and the wall shorter than 4 meters will support by the soil nailing system.

Analyses of soldier pile system were carried out for 5 different heights i.e.; 19.5, 14, 10, 8, and 6 meter walls. For all the types, IPB400 steel sections used as soldier piles with 4.5 m spans which is covered with shotcrete facing.

For W ramp the bored piles restrained by prestressed anchor or soil nails, have purposed to initial support of excavation walls. The height of the pile walls varies from 4 to 10.5 meters and the wall shorter than 4 meters will support by the soil nailing system.

Analyses of pile system were carried out for four different with heights of 10.5, 8.7, 7.5 and 6.2 meter walls. For all the types, reinforced concrete piles are used with 3 [m] spans which is covered with shotcrete facing. Diameter of the piles for 8.7 to 10.5 meter heights were 1 [m] and for shorter walls were 0.8 [m].

For 8.7 to 10.5 meter walls, the piles have a 5 meter shaft pile beneath final excavation level and for 6.2 to 8.7 the depth of the shaft piles are 4 meters and for shorter piles, the depth of the shaft piles is 3 meters. For 7.5 to 10.5 meter walls, a pre-stressed mono bar anchor are used to restrain each pile and the shorter piles are restrained by soil nails.

For K ramp, the bored piles restrained by struts have purposed to initial support of excavation walls. Regarding project specifications height of the walls
varies from 4 to 14.5 meters and the wall shorter than 4 meters will support by the soil nailing system.

Analyses of pile system were carried out for four different heights i.e.; 14.5, 10, 8, 7.5 and 6 meter walls. For all the types, 1 [m] diameter reinforced concrete piles are used with 3 [m] to 4 [m] spans that is covered with shotcrete facing. The spans between the piles for 10 to 14.5 meter wall are 4 [m] and for shorter walls are 3 [m].

For 8 to 14.5 meter walls, the piles have a 5 meter shaft pile beneath final excavation level and for 6 to 8 the depth of the shaft piles are 4 meters and for 4 to 6 meter walls, the depth of the piles is 3 meters.

For 7.5 to 14.5 meter walls, a steel pipe with 4046 [mm] diameter and 11 [mm] thickness were used as a strut to restrain each pile to the pile located in the opposite side of the ramp. The shorter piles were not restrained.

Table 6. Geotechnical parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal friction angle</td>
<td>29</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Cohesion (kg/cm²)</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Natural density (gr/cm³)</td>
<td>1.8</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Reference E (kg/cm²)</td>
<td>400</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Unload-Reload E (kg/cm²)</td>
<td>1200</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.32</td>
<td>0.3</td>
<td>0.3_</td>
</tr>
</tbody>
</table>

3 SUBSURFACE CONDITIONS

Geotechnical studies have been performed to recognize subsurface layer conditions and to assess the geotechnical parameters. The geotechnical parameters were explored by in-situ observations and laboratory test on soil samples (POR, 2008). Based on the field and the laboratory test results, subsurface conditions were obtained (shown in tables 6).

4 FINITE ELEMENT MODELING

4.1 Software

Plaxis (Plaxis, 2002) is a finite element package specifically intended for the analysis of deformation and stability in geotechnical engineering projects. Construction stages are simulated in analyses and geometry of slope and material parameters were considered similar to analysis conditions described below.

The 15 node triangular element type was selected for the mesh used in the FE model. The Hardening-Soil model (Schanz et al. 1999) was used for modeling the soil. All the parameters were applied in modeling according to the results of geotechnical investigations.

In the simulation, soil nails were modeled by Geogrid elements. Geogrids are with normal stiffness but no bending stiffness. They can only sustain tensile force and no compression. Soil anchors include two parts, the bonded length that is grouted and modeled by Geogrid elements and the unbounded length that is not grouted and it is modeled by “node to node” anchor elements. The node to node anchor elements are springs used to model ties between two points. For W ramp walls, the unbounded and bond lengths for anchors were selected equal 9 and 6 [m], respectively.

The struts were modeled by “fix end anchor” elements which are fix-end spring. Finally, the Piles were modeled by “Plate” elements. Plates are structural elements with bending and axial stiffness.

4.2 Analysis conditions

At the location of NE and SE ramps, the excavations walls, with maximum height of 19.5 meters in NE and 10 meters in SE, will be stabilized with Soldiers Pile system and walls shorter than 4 meters of height will be stabilized with Soil Nailing system.
Table 8. Safety factor-NE & SE.

<table>
<thead>
<tr>
<th>Wall height M</th>
<th>Factor of safety</th>
<th>Max lateral deformation mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.5</td>
<td>1.3</td>
<td>32</td>
</tr>
<tr>
<td>14</td>
<td>1.59</td>
<td>19</td>
</tr>
<tr>
<td>10</td>
<td>1.9</td>
<td>5.9</td>
</tr>
<tr>
<td>8</td>
<td>2.15</td>
<td>3.5</td>
</tr>
<tr>
<td>6</td>
<td>2.55</td>
<td>1.4</td>
</tr>
</tbody>
</table>

In Soldier Pile system, at first the IPB pile sections will be installed. In the next stage, the wall will be cut off vertically, from the top elevation to the bench of the current ramp. During the excavation process, the span between the piles will be covered by a shotcrete facing and the piles will be restrained in the soil by soil nails in several elevations.

At the location of W ramp, the excavations walls with maximum height of 10.5 meters will be stabilized with the Pile system. In this system, at first the shaft for casting of the concrete pile sections will be bored and the concrete will be cast. In the next stage, the wall will be cut off vertically, from the top elevation to the bench of the current ramp. During the excavation process, the span between the piles will be covered by a shotcrete facing and the piles will be restrained to the back soil by pre-tensioned anchors or by soil nails, in a specified elevations.

In K ramp, the excavations walls with maximum height of 14.5 will be stabilized with the Pile system and walls shorter than 4 meters of height will be stabilized with Soil Nailing system. In this system, as W ramp, the concrete pile sections will be casted. In the next stage, the wall will be cut off vertically with a shotcrete facing on the span. The piles will be restrained to the pile located on the opposite side of the ramp by struts, in specified elevations.

4.3 Results

For NE and SE ramps, the safety factors calculated from finite element analysis by Plaxis for all walls are summarized in Table 8.

For W ramp, the safety factors calculated from finite element analysis for all walls are summarized in Table 9.

For K ramp, the safety factors calculated from finite element analysis by Plaxis for all walls are summarized in Table 10.

5 MONITORING

The performance of the stabilizations systems of the ramps walls have monitored by Laser Total Station recordings at certain time intervals during and after the excavation process. Figure 11 presents the progress of lateral deformations during and after construction for 19.5 m wall in NE ramp.

Figure 8. The horizontal deformations of the 10 m wall.

Table 9. Safety factor-W.

<table>
<thead>
<tr>
<th>Wall height M</th>
<th>Factor of safety</th>
<th>Max lateral deformation mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.5</td>
<td>1.92</td>
<td>5</td>
</tr>
<tr>
<td>8.7</td>
<td>2.44</td>
<td>3</td>
</tr>
<tr>
<td>7.5</td>
<td>2.35</td>
<td>4</td>
</tr>
<tr>
<td>6.2</td>
<td>2.30</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 9. The horizontal deformations of the 10.5 m wall.

Table 10. Safety factor-K.

<table>
<thead>
<tr>
<th>Wall height M</th>
<th>Factor of safety</th>
<th>Max lateral deformation mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.5</td>
<td>1.83</td>
<td>13.5</td>
</tr>
<tr>
<td>10</td>
<td>2.08</td>
<td>5.8</td>
</tr>
<tr>
<td>8</td>
<td>2.42</td>
<td>4.4</td>
</tr>
<tr>
<td>7.5</td>
<td>167</td>
<td>27.2</td>
</tr>
<tr>
<td>6</td>
<td>1.70</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Recommendations of FHWA suggest horizontal deflections of 0.005H, as an upper limit of acceptable performance during construction. The modeling results ($\delta_1$) were analyzed and compared with the in-situ monitored data ($\delta_2$).

The maximum reported horizontal deformations are presented in Table 11.

As shown in Table 11 all the wall horizontal deformations were much lower than 0.005H that suggested by FHWA (FHWA, 2003) as an upper limit of acceptable performance. It must be noted that all of these
walls are for temporary support systems of excavation and all of them were fully stable in their service life.

Results display that for soldier pile system, steel section and soil nails, in higher walls monitoring results are lower than the model results. But this difference is less for the shorter walls. For the 19.5 m soldier pile wall it was about 52% of monitored values while for 8 m soldier pile wall it was about 14% of monitored values.

In the walls that restrained by anchors, results for deformation from monitoring and models are less than other walls with the same height that supported by other systems. It must be for pre-stressed nature of the anchoring system, whiles other systems need to some initial movement to get mobilized.

### 6 CONCLUSION

In this paper, the performance of the temporary support systems of the 4 major entrance ramps of the Niayesh road tunnel was surveyed. These systems constructed by steel or reinforced concrete pile sections that are restrained by soil nails, anchors or struts. Several finite elements models have been expanded to analyze stability and performance of the support systems.

The performance of the support systems was monitored and recorded during and after the excavation progress. The results of the models are compared with the in-situ monitored data. This comparison indicated that:

- All the systems were stables and their maximum lateral deformations satisfied the criteria and the project needs.
- In the soldier pile system, the monitored values from higher walls are lower than results of the model.
- Difference between in-situ and model results is less for the shorter walls.
- For the wall with the same height and different support systems the lateral deformations, from minimum to the maximum are; anchored piles, piles restrained by struts, soldier pile system and finally unrestrained piles.

### ACKNOWLEDGEMENT

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### REFERENCES

FHWA0-IF-03-017; Geotechnical Engineering Circular No. 7.

