International Conference on Case Histories in Geotechnical Engineering

(2013) - Seventh International Conference on Case Histories in Geotechnical Engineering

02 May 2013, 4:00 pm - 6:00 pm

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Seventh International Conference on
Case Histories in Geotechnical Engineering
and Symposium in Honor of Clyde Baker
April 29 - May 4, 2013 CHICAGO

DEEP EXCAVATION ON 3 SIDES OF A 21 STORY BUILDING: ACCOUNTS OF A SUCCESSFUL DEEP EXCAVATION PROJECT

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ABSTRACT

TOOBA deep excavation project was conducted in a densely developed area in the North West of Tehran, capital of Iran, to provide space for 4 basement levels for multiple buildings around the already functional TOOBA tower. TOOBA tower is located in the northern leg of the excavation boundary in a way that the northern side of the building abuts the excavation edge. Hence, this project involved excavation on 3 sides of the roughly rectangular plan of TOOBA tower to the depth of 16.5 meters below its foundation level. The necessity for constraining the deformations of the tower commended the construction of contiguous bored concrete piles around the building supported at 4 different levels with tieback and wailing system. A monitoring program for measuring the deformations of the tower and supporting system was also enforced during and after excavation.
The three-dimensional nature of the retaining structure required careful design and construction procedure to avoid problems such as the intersection of the anchors. Each tieback was given a unique direction which was defined by 3 angles relative to the local x, y and z axes. Therefore, complicated forces were exerted on the wailing system and piles. The excavation procedure was ensued with no excessive deformations occurring in the building during or after the excavation. This paper considers some of the design and construction aspects of this successfully completed project.

INTRODUCTION

The deep excavation project for TOOBA commercial complex is located in 35° 45’ 58.41” N, 51° 22’ 12.58” E in a densely developed urban environment in North West of Tehran, capital of Iran. This deep excavation project was aimed at providing space for 4 basement levels for hypermarket and parking spaces of multiple buildings around the already functioning TOOBA tower. The office building block, referred to as TOOBA tower in this paper, is located in the northern leg of the excavation boundary in a way that the northern side of the building abuts the excavation edge. Hence, this project involved excavation on 3 sides of the roughly rectangular plan of TOOBA tower to the depth of 16.5 meters below its foundation level. Other sides of the excavation boundary, on the other hand, were excavated to the depths varying from 9 to 28 meters depending on the sloping ground condition. Fig. 1 shows the plan of the site and the location of the adjacent structures. A 5 story school building and a 2 story residential building adjoin the excavation boundary from south and west, respectively.

The geometry of the excavation site and the need for space for the movement of heavy equipment in the excavation pit ruled out the possibility of using a strutting system as retaining wall. The necessity for constraining the deformations of the tower commended the construction of contiguous bored concrete piles around the building supported at 4 different levels with tiebacks and wailing. A monitoring program for measuring the deformations of the tower and supporting system was also enforced during and after excavation.
The three-dimensional nature of the retaining structure required careful design and construction procedure to avoid problems such as the intersection of the anchors, excessive deformation of the tower, and the possibility of the tower being lifted by the grouting pressures exerted to its foundation during the installation of the ground anchors. Converging tiebacks under the foundation of the tower create a zone of closely spaced tiebacks which might cause a considerable localized grouting pressure on the foundation. In order to avoid the intersection of the tiebacks each tieback was given a

unique direction which was defined by 3 angles relative to the local x, y and z axes. Therefore, complicated forces were exerted on the wailing system and piles.

Fig. 1. Arial photo of the site (Source: "Tehran." 35° 45' 58.41" N and 51° 22' 12.58" E. ***Google Earth.*** *June 30, 2009. September 30, 2012.*

Fig. 2. 3D view of the building and the location of the tilt meters

The Building itself is quit irregular both in plan and in vertical cross section. Fig. 2 shows the 3D view of the building. As it can be seen the building is about 64 meters tall on the east side and about 42 meters tall on the west side. The vertical load exerted by the building is estimated to be 200 kN/m^2 on the taller side and 150 kN/m^2 on the other side.

The excavation procedure was ensued with no excessive deformations occurring in the building during or after the excavation. This paper considers some of the design and construction aspects of this successfully completed project.

GROUND CONDITIONS

4 years before commencing of the excavation 10 exploratory borings to the depth of 75 meters were performed to provide SPT N-values, obtain soil samples and observe groundwater table. In addition to that 3 observation wells to the depth of 11 meters were used to carry out PLT tests on the soil. Borings were conducted using rotatory augers with wash-boring method and continuous core sampling.

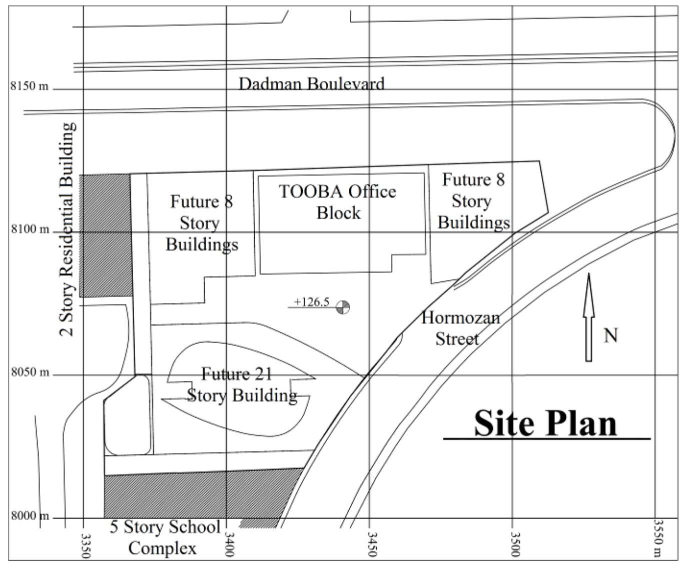


Fig. 3. Plan view of the location of the site, the adjacent and future buildings, and the neighboring streets

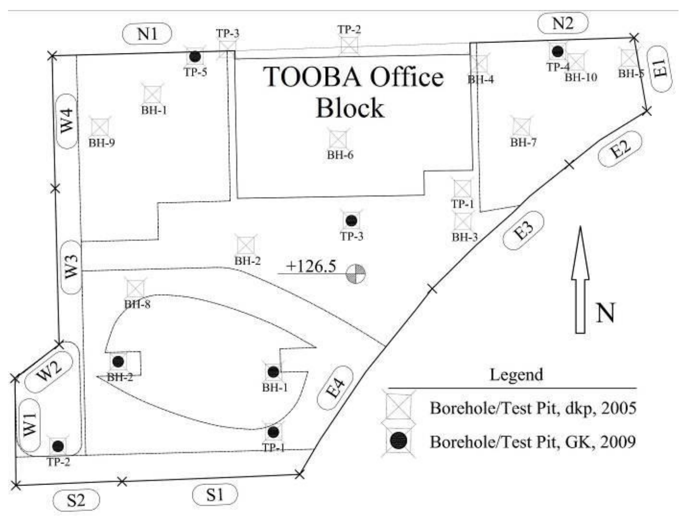


Fig. 4. Location of test pits, bore holes,

For more careful geotechnical explorations 2 more borings to the depths of 80 meters and 5 more observation wells to the depth of 25 meters were made to complete the available geotechnical information on the site. In-situ density test were performed in addition to PLT tests in the observation wells. The later borings were more resent (after the decision for a deep excavation project for the site was taken). Therefore, these tests were conducted with the deep excavation in mind. Soil samples in the later borings were obtained using core barrel method.

The samples from the borings of both series of explorations were used for laboratory tests including Atterberg limits, sieve test, density, and direct shear tests. Fig. 3 and Fig. 4 show the location of test pits and bore holes in addition to the location of the adjacent and future buildings.

Geotechnical explorations indicate that the site consists of altering layers of silty and clayey sand and gravel (SC, SM, SW, GC, GM, and GP) along with boulders and cementation. Soil to the East of the site is generally sandy, whereas the west of the site tends to contain more gravel. Soil is generally brown or light brown and rarely light green or grey.

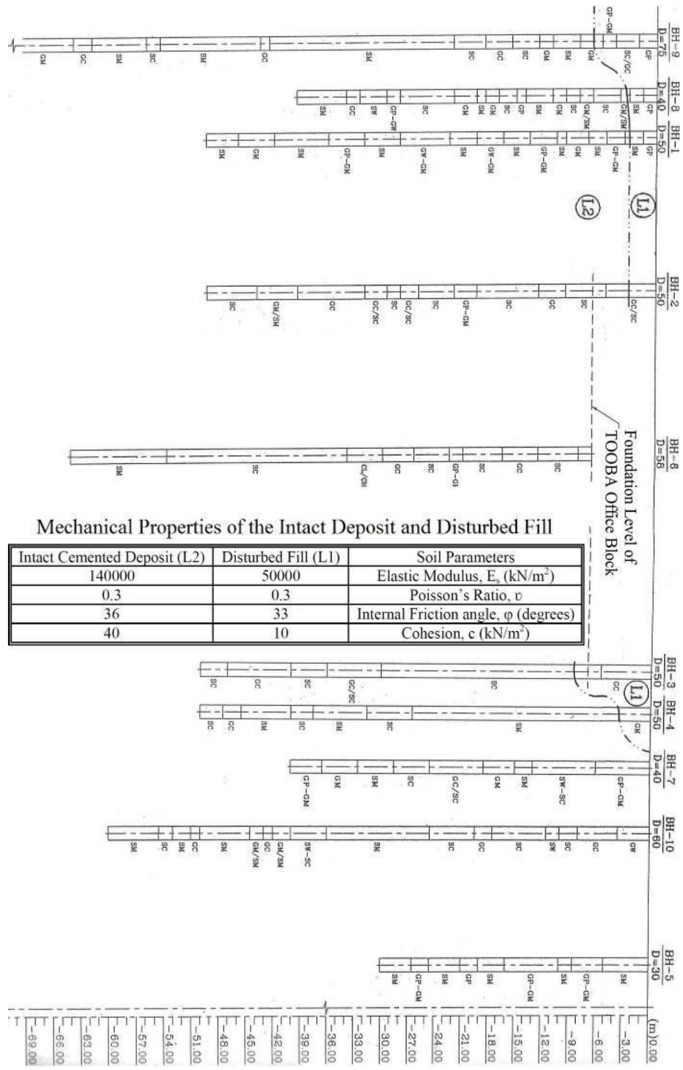
Past experience of the site shows that the soil is cemented and that its mechanical behavior is heavily affected by the cementation bonds between soil particles. Considerably lower shear strength parameters of remolded and disturbed specimens in direct shear test at laboratory is an indicator of cementation in the soil. As a result, soil parameters were estimated by interpreting the in-situ test results. Detailed information on the characteristics of the cemented soil of Tehran has been published by a number of researchers (Haeri and Hamidi [2009], Hamidi and Haeri [2008, 2005], Haeri et. al. [2006, 2005a, 2005b, 2004, 2003], Asghari et. al. [2004, 2003])

Based on the SPT test results the soil to the west and south of the site is very dense and has corrected SPT value of higher than 50. However, a loose fill material was detected in the vicinity of the TOOBA tower to the depth of 8.5 meters below the ground surface. The foundation of the tower is located 8.5 meters below the ground surface on the dense soils. This could indicate that the pit for tower construction was excavated using slopes which were subsequently filled with the in-situ soil and BH8 and BH9 bore holes are probably located within this trench. Fill material was also present on the east side of the site to a depth of 7 meters.

To the authors' knowledge, this could be as the result leveling the geological folds in the area before development. It is well known that the site, which is located on a formation of geological folds consisting of shallow synclines and anticlines, has been leveled before the area turns into the heavily developed urban environment. In other words, the soil on the higher ground was cut and filled in the shallower areas without sufficient compaction effort.

Aerial photos of the site from 1969 corroborate our knowledge about the geological formation of the site. Aerial photos of the area in 1969 show the area before any construction development occur. Unfortunately, these pictures cannot be reproduced here for copyright issues. But, a syncline on the east of the site might explain why the bore hole BH9 indicate that disturbed fill is present at this part of the site to an approximate depth of 7 meters.

As discussed before, the site consists of alternating sub layers of sand and gravel with isolated patches of very hard clay encountered occasionally (for example a hard clay layer (CL/CH) was encountered at the depths of 23 to 27 meters below the TOOBA tower). Despite the fact that the site is very heterogeneous, but, from the mechanical point of view the site stratigraphy can be divided into two distinct layers, both consisting of sandy and gravelly sub layers.



Intact Cemented Deposit (L2)	Disturbed Fill (L1)	Soil Parameters
140000	50000	Elastic Modulus, E_s (kN/m^2)
0.3	0.3	Poisson's Ratio, υ
36	33	Internal Friction angle, φ (degrees)
40	10	Cohesion, c (kN/m^2)

Fig. 5. The disturbed layer (L1), the intact deposit (L2) and the alternating sand and gravel sub layers from the bore holes

The mechanical properties of these 2 layers are shown in Fig. 5 (the disturbed layer (L1) and the intact deposit (L2)). These two layers can be described as follows: A very dense cemented layer which is intact, and, a disturbed fill layer which has the same grain size distribution of the underlying soil but the broken cement bonds and lower compaction in this layer gives the soil lower elastic modulus, lower shear resistance and probably higher permeability. Therefore, it can be described as a medium dense soil.

The mechanical properties shown in Fig. 5 have been obtained based on the results of the field and laboratory tests and engineering judgment, and were used in some phases of the design. The presumed boundary of the disturbed layer has been sketched with a dash double-dot line based on the results of geotechnical explorations. Fig. 5 also shows the alternating sand and gravel sub layers discovered from the bore holes.

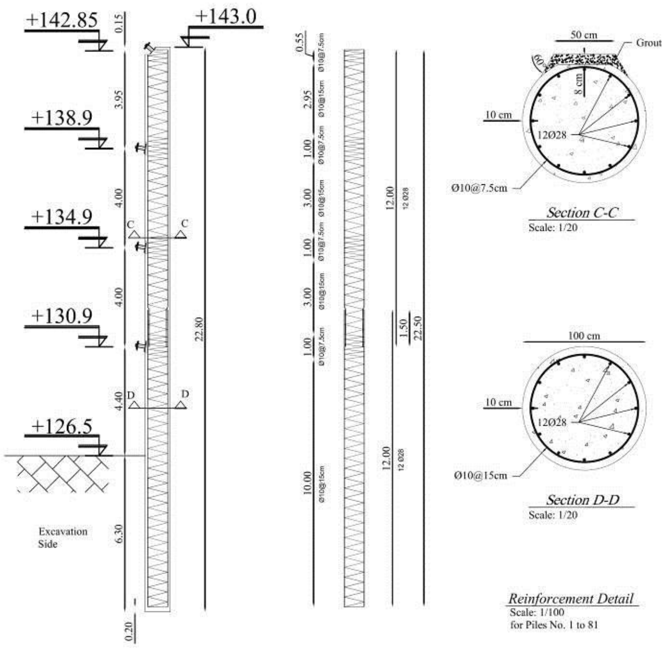


Fig. 6. Sample of reinforcement details for the piles on the west side of the TOOBA tower

GROUND WATERTABLE

During the geotechnical investigations a number of abandoned drainage wells (drains) were discovered to the north and east of the TOOBA tower. The water level in the borings and observation wells were extremely different in each boring and well. It is thought that the water level in borings is affected by penetration of water from abandoned drains and flumes. For example test pit TP4 (See Fig. 3) was engulfed by water when it reached a sand lens 9m from the ground surface. The rate of water entering the well was so high that efforts for pumping the water out for continuing the boring of the well were abandoned.

Hence, initial design considered the possibility of localized groundwater intrusion into the pit during excavation. Therefore, the design considered drains near the bottom of the excavation. Drains were also installed to conduct the waste water from TOOBA tower to the drainage network and avoid accumulation behind the retaining structure.

No permeability tests were conducted on the soil but the formation of the shallow sliding block as the result of raining, which will is discussed in a separate paper by the authors of this article (Haeri et al., 2012), shows that the crushed nature of this fill has given it higher permeability as well.

CONSTRUCTION PROCEDURE

Anchored walls are usually constructed using top-down excavation method. Anchored or tieback walls generally consist of a vertical element (such as discrete driven or cast in place soldier beams or continuous sheet-pile, continuously bored piles, etc.) with one or several levels of pre-tensioned anchors which are installed in the stable ground behind the retained soil and transmit the tensile load into the ground. The construction sequence and technique is well described in the literature (i.e. FHWA 1998, 1999).

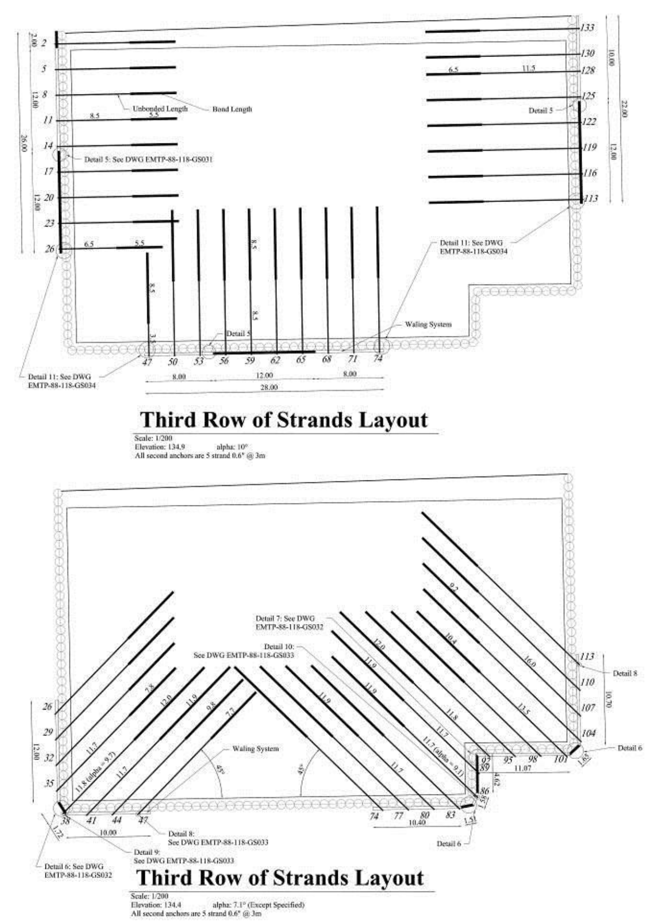


Fig. 7. the layout of anchors installed for the third level of wailing

Similarly, the sequence of construction at the site for anchored wall consisted of pile installation, excavation and support. All piles are installed prior to excavation. Fig. 6 shows a sample of the reinforcement details for the piles on the west side of the tower. Reinforcements were placed in the pre-born cavities around the tower before the concrete for the piles were placed. As it can be seen in Fig. 7, a total number of 134 piles were built. Excavation around the building was carried out in sections to ensure symmetric deformations of the wall. Fig. 7 also shows the layout of anchors installed for the third level of wailing.

Excavation of each lift of the soil around the tower proceeded in stages; Fig. 8 shows the sequence in which the soil blocks in each lift of excavation were removed. This figure shows blocks 1 through 14 in which blocks with similar hatching indicate the ones that were excavated simultaneously or at least successively to minimize the effect of excavation on the tower. For each lift of excavation soil is usually removed until 1 meter below the anchor level of that excavation lift. 2 cross sections of the retaining wall are shown in Fig. 9 and Fig. 10 (sections A-A and B-B are shown in plan view in Fig. 3).

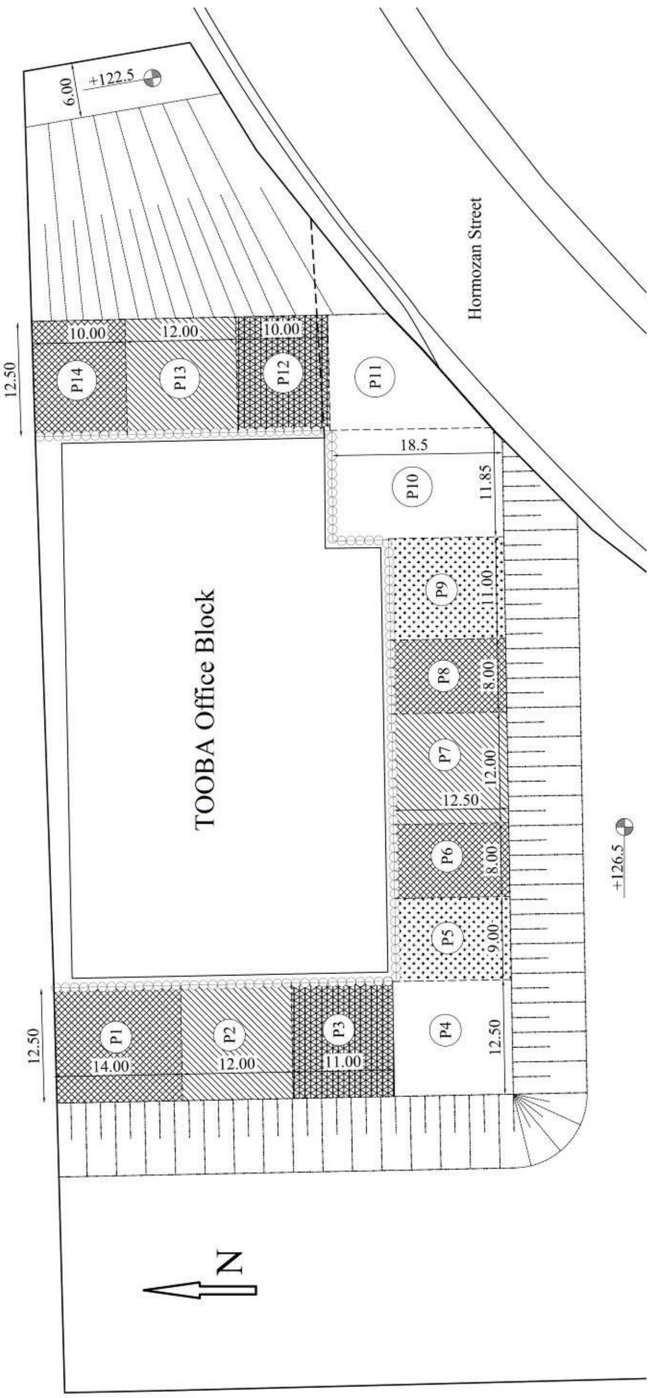


Fig. 8. Sequence of removing the soil around the tower in each lift of excavation

Fig. 11 shows the excavation of block 7 during the 2nd lift of excavation and subsequent anchor and wailing installation. Each excavation block was followed by a stage of anchor and wail installation. Once an entire lift was excavated and the wailing system was in place, preloading of anchors was also carried out in the same sequence as excavation. This ensured an approximately symmetrical deformation around the tower.

In addition to design specifications and construction plans, the exact angle at which each anchor should be installed was given to the contractor in charts and tables.

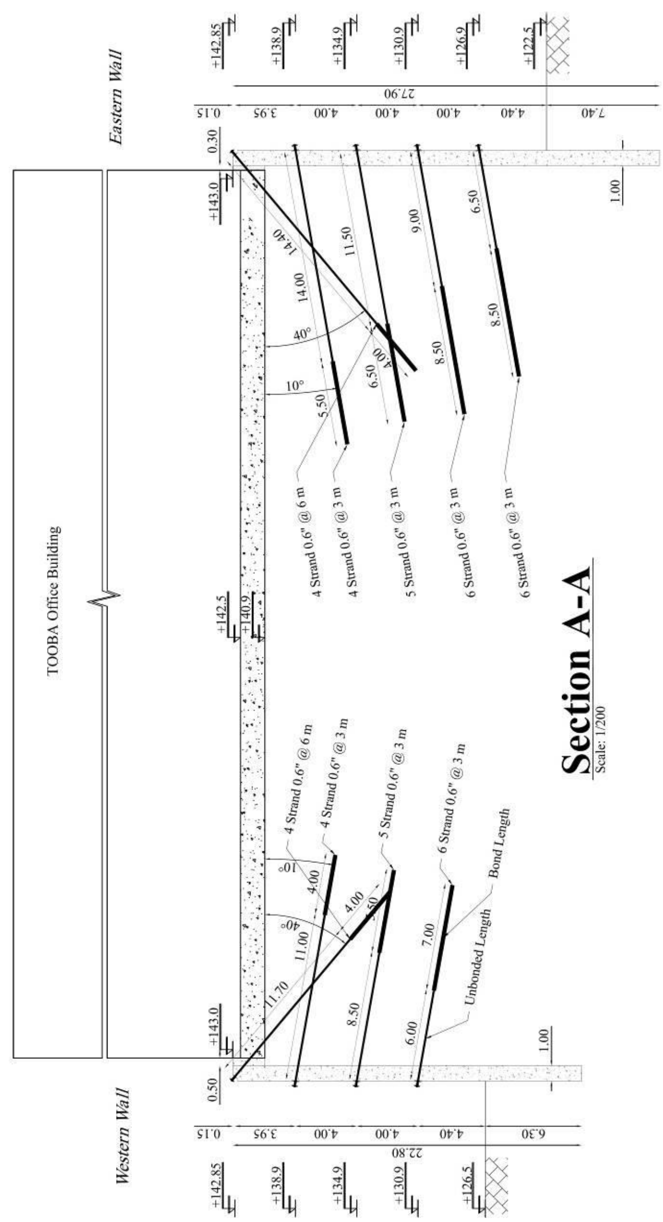


Fig. 9. Section A-A depicting details of the retaining structure on the east and west of the tower

Two samples of the details of anchor heads designed for this retaining structure have been provided in Fig. 12. Fig. 13, Fig. 14 and Fig. 15 provide some pictures taken by the second author of this paper from the construction site.

MONITORING & INSTRUMENTATION

A monitoring program for measuring the deformations of the tower and supporting system was enforced during and after excavation. Instrumentations on the tower included 17 prism targets (PT) and 4 tilt meters (TM). Also 6 load cells were installed on the anchor wall to monitor the changes in the anchor loads. The location of the tilt meters on the tower was shown in Fig. 2. EAN-90M tilt meters are used in 2 perpendicular directions to measure tilt in both north-south and east-west directions. ERT-20P-MT mini prism targets, on the other hand, were installed on all 4 sides of the tower. These targets can yield displacements in x, y and z directions. Fig. 16, for example shows the approximate location of the prism targets on the east side of the tower. A TS09 total station was used to record the displacements from the pillars installed outside the excavation pit. Fig. 17 show the tilt meter number 01 and a sample of prism targets used on the tower.

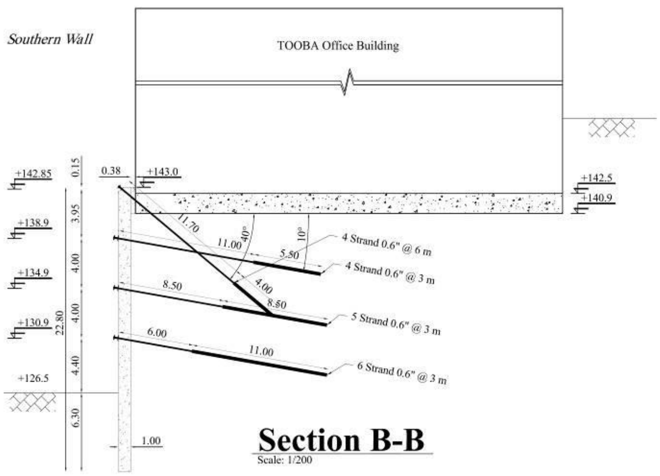


Fig. 10. Section B-B depicting details of the retaining structure on the south of the tower

Fig. 11. Excavation of block 7 during the 2nd lift of excavation

ELC-30S load cells were installed on the tieback wall in order to measure the changes in tieback pre stress loads. Normally a reduction in tieback load could signal relaxation in the tieback bond length; in a tieback wall designed to minimize deformations, on the other hand, an increase in tieback load normally indicates that the anchor lock-off load could not impede further deformations and that the wall deformations have occurred at the tieback location and have further stretched the tieback. Fig. 18 shows the load cell mounted anchor head and another anchor head without load cell for comparison.

RESULTS OF MONITORING

Prism Targets and Tilt Meters:

Prism targets and tilt meters were used to monitor the deformations of the tower. During the early stages of excavation deformations were very small and the data records from prism targets and tilt meters sometimes produced contradictory results. However, this was not a very unusual observation since the readings from the prism targets at this stage were very close to or within the reading tolerance of the optical reading instrument.

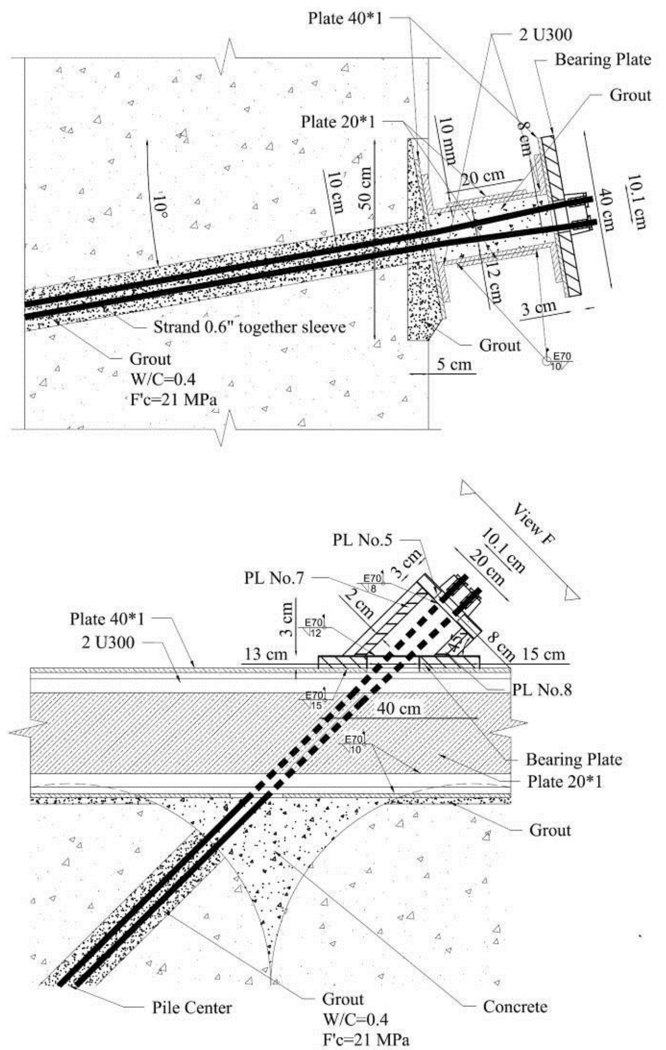


Fig. 12. Two samples of the details of anchor heads designed for the retaining structure

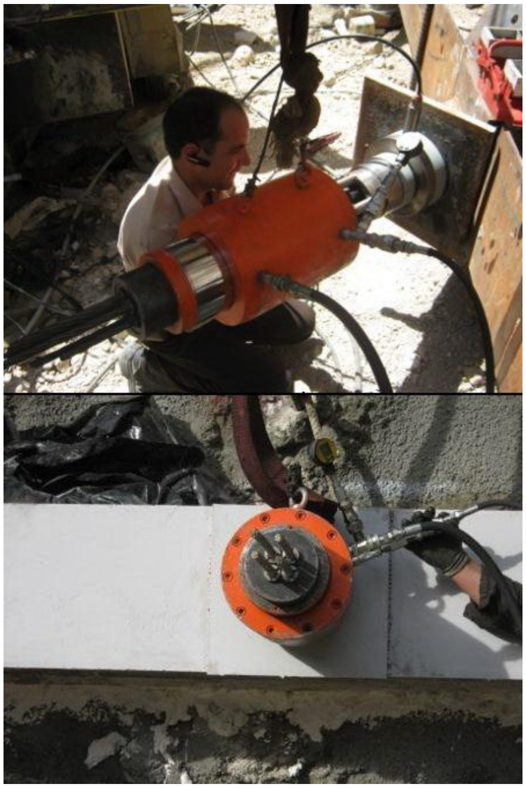


Fig. 13. Pre-stressing of the anchors with hydraulic device

Fig. 14. A view from eastern side of the tower; at this point, excavation is complete and the construction of the foundation of the intended building has begun

Contradictory readings from the prism targets which sometimes indicated that opposite sides of the tower was deforming in opposite directions continued during entire excavation process. These readings were regarded very seriously because the fact that the tower might lose its structural integrity was a serious concern. Therefore, visual inspection of the building was performed regularly for any signs such as cracks that may corroborate the readings from prism targets. Since no visual problems were observed, these differential deformations deemed to be as the result of error in reading the targets including operator and device error. Nevertheless, these differences in the deformations were not large enough to generate too much concern.

During the excavation of the first 3 lifts general pattern of the movement of tower indicated a rotation about 0.02 degrees toward North (outward the excavation) and 0.02 degrees toward east. Total deformations from the prism targets at this point rarely exceeded 10 mm. After this point (with installation and pre-stressing of the 4th level of anchors and continuation of the excavation), general pattern of tower deformation showed tilting about 0.02 degrees toward south (inward the excavation pit) and continued tilting toward east (about 0.05 degrees) at the end of excavation.

Fig. 15. A panorama view of the tower and the retaining system. In this image, all 4 levels of wailing have been installed.

The general pattern of movement suggested by the prism targets corroborates the rotational like deformation of the building towards south and east. During the first 3 lifts of excavation total deformations yielded from the prism target readings rarely exceed 5 mm and were always less than 10 mm. Readings at this stage, as stated before, yield contradictory results; after this point on, however, general pattern of displacements obtained from the prism targets corroborate the rotational like deformation of the building towards south and east.

Fig. 16. ERT-20P-MT prism targets on the east side of the TOOBA tower

Fig. 17. Tilt meter number 01 on the tower rooftop and a sample of the mini prism targets used in the project

The prism targets installed near the top of the building had maximum deformations; however, deformations of these targets were less than 20 mm towards south and less than 15 mm towards east during and after the excavation. Small rotation of the tower towards the north at the beginning of the excavation could be as the result of pre stressing of anchors and the grouting pressure exerted on the tower foundation.

Load Cells:

6 load cells were installed on almost random tiebacks of the retaining wall on the southern and eastern leg of the tower. The load cell on the second row of tiebacks and one of the 2 load cells on the 4th level showed consistent anchor load throughout the excavation process. Two of the load cells installed on the 3rd row of the tiebacks and one other load cell on the 4th row showed a very small increase (less than 1 percent of the pre-stress load). The only load cell on the eastern side of the building was installed on an anchor on the 3rd level of tiebacks which showed a reduction in the pre-stress load about 1 percent of the tieback lock off load.

Fig. 18. ELC-30S Loadcell mounted on the anchor below to monitor the changes in the anchor pre-stressing load. Another anchor without a load cell is shown (above) for comparison.

SUMMARY & CONCLUSION

This contribution documented a deep excavation work in north-west of Tehran which included excavating very close to 3 sides of a 21 story functioning office block and two other structures. A monitoring program for measuring the deformations of the tower and supporting system was also enforced during and after excavation. Since any significant damage to the office block could have irremediable results, and 3D nature of the excavation meant that actual factor of safety would be less than the factor of safety obtained from 2D analyses, using a higher factor of safety for the tieback retaining wall (compared to that of other retaining walls designed for displacement sensitive structures) is justified even though extensive instrumentation is normally a good reason for using lower safety factors.

The purpose of the deep excavation is to accommodate enough space for 4 basement levels for a 21 story building in the south of the site and multiple 8 story buildings on the rest of the site. The excavation procedure was ensued with no excessive deformations occurring in the building during or after the excavation. This paper considers some of the design and construction aspects of this successfully completed project.

The project site consists of layers of silty and clayey sand and gravel with boulders. The difference between the in-situ and laboratory tests indicated that soil is highly cemented. As a result soil parameters were estimated by interpreting the in-situ test results.

From geological point of view, the site was located on a formation of geological folds consisting of shallow synclines and anticlines. Aerial photos from 1969 of the area which show the area before any construction development corroborate our knowledge about the geological formation of the site. More recent aerial photos of the site show that the site was leveled before the area turns into the heavily developed urban environment of today. In other words, the soil on the higher ground was cut and filled in the shallower areas without sufficient compaction effort. Therefore, a disturbed fill layer which has the same grain size distribution of the underlying soil but the broken cement bonds and lower compaction in this layer gives the soil lower elastic modulus, lower shear resistance and probably higher permeability was present in some locations of the site.

The retaining structure was supposed to be a short term one designed for a 4 month period. However, the construction hit unexpected delay due to legal problems between investors and construction was halted for a period of a year. However, the retaining structure for the tower performed well during the entire construction process.

Previous experience with soil nail walls and anchored retaining walls in the cemented soil of Tehran indicates the injected grout forms a very strong and very stiff interface between the installed tensile elements and the cemented soil. This well documented project is an example of performance based design in geotechnical engineering.

REFERENCES

Asghari, E., Toll, D.G., and Haeri, S.M. [2003], "*Triaxial Behavior of Cemented Gravely Sand, Tehran Alluvium*", International Journal of Geotechnical and Geological Engineering, Vo.21, No.1, pp. 1-29, Kluwer Academic Publisher, Netherland.

Asghari, E., Toll, D.G., Haeri, S.M. [2004], "*Effect of Cementation on the Shear Strength of Tehran Gravely Sand Using Triaxial Tests*", Journal of Sciences, Islamic Republic of Iran, pp. 65-71.

FHWA, [1998], "*Design Manual for Permanent Ground Anchor Walls.*", FHWA-RD-97-130, Federal Highways Administration, September.

FHWA, [1999], "*Ground Anchors and Anchored Systems.*" Geotechnical Engineering Circular No. 4, FHWA-IF-99-015, Federal Highways Administration, June.

Haeri, S.M. and Hamidi, A. [2009], "*Constitutive Modeling of Cemented Gravelly Sands*", Geomechanics and Geoengineering – An International Journal, Vol. 4. No.2. pp. 125-141.

Hamidi, A. and Haeri, S.M. [2008], "*Stiffness and Deformation Characteristics of a Cemented Gravely Sand*", International Journal of Civil Engineering, Vol. 6, No.3, pp. *159-173.*

Haeri, S.M., Hamidi, A., Hosseini, S.M., Asghari, E. and Toll, D.G. [2006], "*Effect of Cement Type on the Mechanical Behavior of Gravely Sands*", International Journal of Geotechnical and Geological Engineering, Springer, Vol. 24, No.2, pp. 335-360.

Hamidi, A., and Haeri, S.M. [2005], "*Critical State Concepts for a Cemented Gravely Sand*" Electronic Journal of Geotechnical Engineering, Vol. 10E, Pages 1-13.

Haeri, S.M., Hamidi, A. and Tabatabaee, N. [2005a], "*The Effect of Gypsum Cementation on the Mechanical Behavior of Gravely Sands*" ASTM Geotechnical Testing Journal, Vol. 28. No.4. pp. 380-390

Haeri, S.M., Hosseini, S.M. and Toll, D.G. [2005b], "*The Behavior of an Artificially Cemented Sandy Gravel*", International Journal of Geotechnical & Geological Engineering, Springer, Vol 23, pp. 537-560.

Haeri, S.M., Yasrebi, S.S., Orumiehi, & Asghari, E. [2004], "*Effect of Cementation on the Shear Strength of Granular Deposit of North Tehran*", Amir Kabir Journal of Science and Technology, Vol 15, No. 59-c, pp. 43-57 [in persian].

Haeri, S.M., Yasrebi, S.S, Oroumiehee, M.A. and Asgari, E. [2003], "*Engineering Geological Aspects of Cemented Alluvium of Tehran*", Scientific Quarterty Journal of Geoseiences, Bulletin of Geological Survey of Iran, Vol.11, No.47, pp. 2-15 [in persian].

Haeri, S.M., Sasar, M., Afshari, Q., [2012], "Accumulation of Rainfall in the Permeable Fill behind a Soil Nail Wall", 7^{th} International Conference on Case Histories in Geotechnical Engineering and Symposium in Honor of Clyde Baker, Wheeling, IL (Chicago, IL area), April 29-May 4, 2013

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