DESIGN OF ANCHORED DIAPHRAGM WALL FOR DEEP EXCAVATION

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ABSTRACT: High-rise buildings pose new challenges for engineers, especially in the field of calculations and design of above-ground structures, bases and foundations. Some consideration the anticipated responses to adjacent buildings during construction are presented. This will require the design professional to survey the condition of the adjacent properties to understand their present condition and fragility, establish acceptable limits, conduct soil-structure analyses of various support systems and develop limits on their respective movements, and develop a monitoring strategy. This paper shows the technology for support excavation structures as shoring system for 1000 mm thick diaphragm wall, which is supported with four layers of pre-stressed anchorages. The shoring system calculations had been designed by PLAXIS 2D, which can assess in very detail the deformations and settlements in the soil. The basement walls are a formed with reinforced concrete diaphragm wall panels, which are supported with ground anchors. The basement slab is to be a pile-supported raft, which is a made up of discrete sections to accommodate thermal and lateral movements. These numerical methods were a carried out within the investigation of the interaction of anchored diaphragm wall of high-rise buildings with soils in the problematic ground conditions of Astana. Recent advances in monitoring by using 3D laser-scanning technologies and acquiring quality information about built environments using embedded and other advanced sensors give to engineers a real picture of soil-structure interaction. This information is combined with the design model to create an integrated model, which is a dynamically updated during the construction period.

Keywords: CPT, Diaphragm wall, Plaxis 2D, the CAD system

1. INTRODUCTION

High-rise buildings give new challenges for engineers; therefore, designers of both above-ground and underground parts of the building are forced to resort to more complex methods of calculation and design. Especially this applies to technicians, who are involved in the design of foundations for high-rise buildings.

The completed project will have five towers with different heights, the tallest construction will be 310 m with 75 floors and it will be the tallest building in Central Asia. The design of the project provides a four-level basement and tower buildings, which intend to use for offices and residential buildings. The structure includes five towers, from them: 14 story Hotels apartments, 75 stories Residential, 30 story Offices, and a 17 storey Residential, 31 storey Office. The internal dimensions of the sub-structure itself are approximately 220m x 195m on plan and they are typically 17.4m deep.

By complexity, problematic design, erection, operation, impact on the environment and people, high-rises can be attributed to the structures of increased danger and complexity. Buildings above 75 m require completely different approaches to design. After the construction, ADP will become the tallest building in Kazakhstan and Central Asia, the height of one of the blocks of the complex will be 320 m (Figure 1). Before starting the laying of the foundation, need to decide on its technology and depth. It depends on the expected load on it and the features of the natural conditions, namely the type of soil and the depth of the groundwater.

Fig. 1   Abu Dhabi Plaza building in Astana

The Features of high-rise buildings present high requirements for the results of the EGS (engineering and geotechnical survey) and should solve the following main tasks in their implementation:

-study of the geological structure of the soil massif with large volume (up to 60 m in depth and at least 2 foundation widths beyond its contour)

-reliable assessment of the hydrogeological and hydrochemical conditions of both the compressible soil massif and in the excavation zone and adjacent territory with the establishment of their corrosive aggressiveness, in time;

-Determination of deformation and strength properties of dispersed and rocky soils at large ranges of voltage changes;

-Instrumental observation and monitoring of deformations of the soil massif of the basement foundation and the adjacent territory under static effects.

2. CHARACTERISTICS OF THE CONSTRUCTION CONDITIONS

It is well known that central Kazakhstan was dominated by "schist's, slates, mafic igneous rocks, and granites", since interpreted to reflect the dominance of large former subduction accretion complexes. The monotony of their basalt/ chert/ turbidite-dominated lithology's and the nearly chaotic aspect of their penetrative internal structure make it extremely difficult to find markers in large subduction-accretion complexes by which to outline their large-scale structures. The oldest rock in this area is Precambrian granites and gneisses overlain by Neoproterozoic to Cambrian carbonates and carbonate-rich slate, which in turn are unconformably covered by Ordovician volcanic and sedimentary rocks. These rocks were deformed and intruded by granite at the end of the Ordovician. After the early Devonian, southeast Kazakhstan continued to be the area of active volcanism with some interruptions, until the Late Permian and locally Early Triassic. Continental sedimentary deposits of Jurassic and younger age overlie the Paleozoic volcanic with a major angular unconformity. In our study area Early Carboniferous, volcanic rocks rest with a weak angular unconformity on Devonian rocks and with a major unconformity on older complexes.

Based on the field description of the soils confirmed by the results of static sounding and laboratory tests, a division of the soils composing the site of prospecting for engineering-geological elements in the stratigraphic sequence of their occurrence was a carried out [1]-[10].

All experiments were a performed with CPT surface (Figure 2). Soil test at each point of penetration came to the ends under the limit forces on the probe in accordance with GOST 19912-2001.

According to below map, Astana is located in the region, which has very low risk in terms of seismic hazard. According to seismic risk distribution map, peak ground acceleration a_{max} should be taken a value between 0 m/s^2 to 0.2 m/s^2 which is equal to 0.02 g, therefore, could be ignored in structural design.
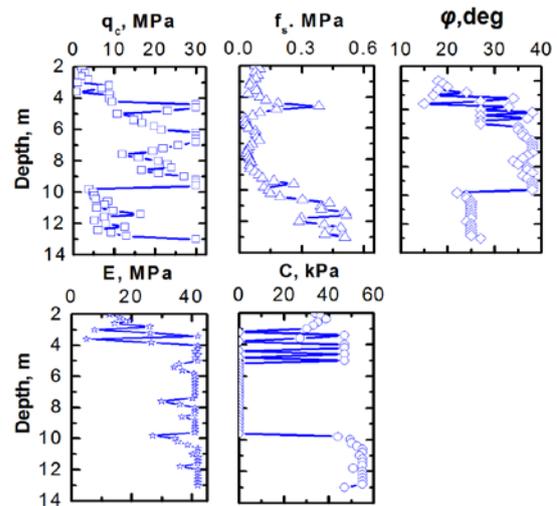

Fig. 2   Results of CPT-1 in construction site ADP, Astana, Kazakhstan

3. SOIL CONDITIONS AND DESIGN PARAMETERS THE DIAPHRAGM WALL

The design of anchored retaining structures providing lateral support for deep temporary excavations in urban areas was traditionally based on simple numerical models.

Joining for the diaphragm wall panel – Diaphragm wall cannot be constructed continually for a very long section due to limitation and size of the mechanical plant. The wall is usually constructed in alternative section. Two stop end tubes will be placed at the ends of the excavated trench before concreting. The tubes are withdrawn at the same time of concreting so that a semi-circular end section is formed. Wall sections are a formed alternatively leaving an intermediate section in between. The in-between sections are built similarly afterward but without the end tube. At the end a continual diaphragm wall is constructed with the panel sections tightly joined by the semi-circular groove. Soil profile at southern section related to new diaphragm wall location is adopted from actual site observations during diaphragm wall construction at the south side for Phase‐1 works. Elevations of soil layers are taken from average levels recorded in as-built

elevation drawings related to south side of phase‐1 works.

The groundwater level is taken at a depth approximately 4.0 m to below the ground level. Recommended soil parameters are given in table 1.

Table 1 Geotechnical parameters for the design of the shoring system

EGE	Depth (m)	γ, kN/m3	φ', deg	c',kN/m^2	E, MPa
1	4.0	18.5	25	1	15
2	4.5	19	35	1	25
3	5.5	18.5	26	30	30
4	1.5	20.5	35	1	50
5	2.0	23.5	38	40	65
6	Below	24.0	38	50	100

Note: EGE-1 Clay/Loam, EGE-2 Sand & Gravel, EGE-3 Loam & Clay, EGE-4 Rock Debris, EGE-5 Sandstone, EGE-6 Hard Sandstone.

3.1 Anchor Design Calculations

Pre‐stressing loads (tension: T forces) of ground anchors are shown on the shoring section drawing as determined ′Pre‐tensioning force in Plaxis inputs dividing to the tension forces by spacing (distance) between adjacent anchors on the same level for the anchored section (Figure 3). After these pre‐stressing stages, the tension forces on the ground anchors generally increase up to the capacity of the anchor tendons with a safety factor.

The finite element method is a based on a model in which the behavior of soil and structure is integrated. The properties of soil are introduced by means of stress-deformation relations. With this method, fundamental calculations of stresses and deformations of soil and structural members can be made.
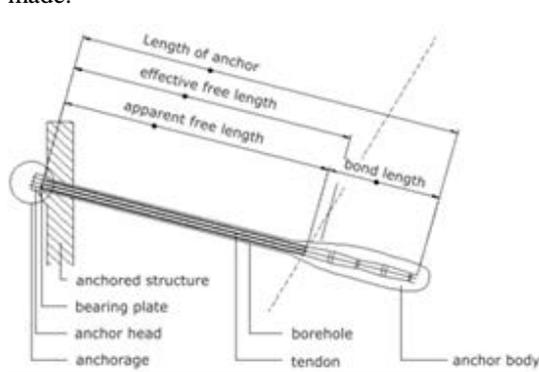

Fig. 3 Typical section of anchored diaphragm wall

The method can be used to calculate sectional

forces of the structural members, verify the global stability of the structure and to calculate and verify deformations (Figure 4).
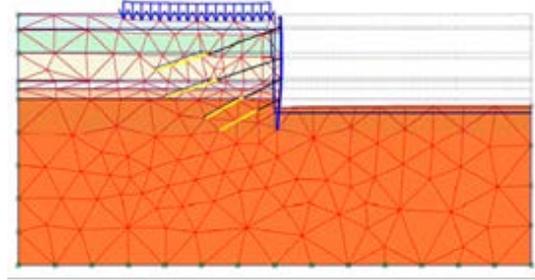

Fig. 4 Deformed mesh in Plaxis 2D, Section 1

When a load is an applied to soil, the water in the pores, as well as the solid grains, carry it. The increase in pressure within the pore water causes drainage (flow out of the soil), and the load is transferred to the solid grains. The rate of drainage depends on the permeability of the soil. The strength and compressibility of the soil depend on the stresses within the solid grains called effective stresses (Figure 5).
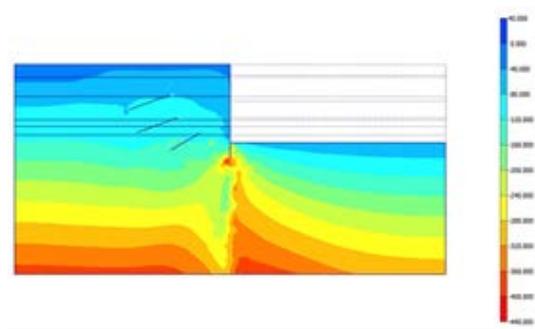

Fig. 5   Plot of effective stresses

The effective stresses are a measure for the forces in the contact points of the grains. Thus, the total stress is a summation of the effective stress and the pore water pressure.

After these pre-stressed stages, the tension forces on the ground anchors generally increase up to the capacity of the anchor tendons with a safety factor (see Table 2 and Figure 6).
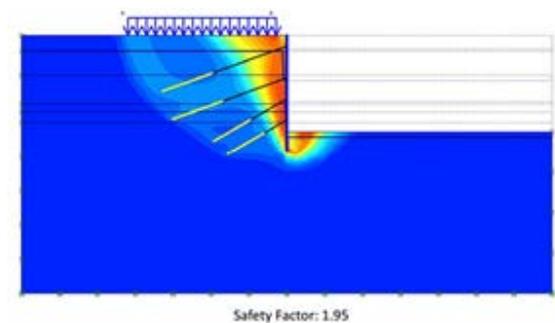

Safety Factor: 1.95

Fig. 6 Calculation scheme of unground construction

Table 2 Results of calculation by Plaxis for Section 1

Anchorage summary	Number anchors			
	1	2	3	4
Level (-)	3.0	9.0	13.0	17.0
Spacing, m	2.20	1.65	1.65	1.65
Free length, m	15	13	8	5
Grout length, m	10	10	8	8
Angle, degree	20	20	30	30
Total length, m	25	23	16	13
Prestressing load, kN	460	530	570	640
Calculated anchorage load, kN (:Cal=Tw)	607	672	670	675
Test load, kN (=Cal*1.25) (=Tw*1.25)	759	840	838	844
Locking load, kN (=Cal*1.10) (=Tw*1.10)	668	739	737	743

3.2 Method to Form aGround Anchor

A hole is predrilled on soil or rock in position carefully calculated. For rock anchor, an anchor bar with expanded sleeves at the end is an inserted into the hole. A dense high strength grout is an injected over a required length to develop sufficient resistance to hold the bar when it is stressed. Stressing is by hydraulic mean and when the stress is developed, the head of the bar is held by an end plate and nut. For injection anchor, a hole should be bored usually with an expanded end to increase anchorage ability. The pre-stressing bar is placed into the borehole and pressure grouted over the anchorage length. Gravel placement ground anchor can also be used in clay soils for lighter loading. In this method, irregular gravel is injected into the borehole over the anchorage length to form an end plug. The gravel p1ug is then forced into the soil using percussion method through the casing, forming an enlarged end. A stressing bar is an inserted into the casing and pressure grouted over the anchorage length as the casing is removed. It should be noted that certain protection measure against corrosion or rusting is required for the stressing bar. Usually, the bar may be coated with bitumen, wrapped by greased tape or filled with non-pressurized grout after stressing is completed.

3.3 Diaphragm Walling Technology

This method needs to construct an R.C. retaining wall along the area of work. Because the wall is designed to reach very great depth, a mechanical excavating method is an employed. A typical sequence of work includes:
1) Construct a guide wall; 2) Excavation for the diaphragm wall; 3) Excavation support using betonies slurry; 4) Inert reinforcement and concrete.

Guide wall – guide wall is two parallel concrete beams constructed along the side of the wall as a guide to the clamshell, which is a used for the excavation of the diaphragm wall, trenches (Figure 7).

Fig. 7 The guide wall for diaphragm wall

Excavation for the diaphragm wall – In normal soil conditions excavation is done using a clamshell or grab suspended by cables to a crane. Excavation support – excavation for the diaphragm wall produces a vertical strip in the soil which can collapse easily. Betonies slurry is used to protect the sides of soi1. Betonies is a naturally occurring clay which, when added to water, forms an impervious cake-like slurry with very large viscosity. The slurry will produce a great lateral pressure sufficient enough to retain the vertical soil. Reinforcement – reinforcement is inserted in form of a steel cage but may require to lap and extend to the required length. Concreting – concreting is done using termite. As Concrete being poured down, betonies will be displaced due to its density is lower than concrete. Betony is then collected and reused. Usually, compaction for concrete is not required for the weight of the betonies will drive most of the air voids in the concrete.

4. MONITORING DIAPHRAGM WALL IN CONSTRUCTION SITE ADP, ASTANA

One of the most important challenges at this

stage is to review the work, which has been done by the previous contractor. The inspection of the existing construction helps the engineers to decide whether to carry on or to modify it [11].

The objective was the structural inspection of the diaphragm wall in comparison to the theoretical position. In this case, the level of tolerance of the deviation from the theoretical position must be minimal since the design involves the construction of the inner wall (or parking wall) along the diaphragm wall, within a distance of 15 cm. More specifically, the distance between the inner sides of the diaphragm wall to the outer side of the parking wall must be 15cm, according to the design [11].

The high level of detail, which is required, made it necessary to utilize a method, which allows us to get the as-built situation as it is and to analyze into an advanced CAD system [11].

Recent advances in generating 3D environments using laser-scanning technologies, and acquiring quality information about built environments using embedded and other advanced sensors provide the capability to the frequently gather an integrated and accurate three-dimensional and material quality related as-built data. This information is combined with the design model with an objective to create an integrated model, which is a dynamically updated during the construction period [11].

The resulting model constitutes a color-based deviation model, as is indicated in Figure 8.
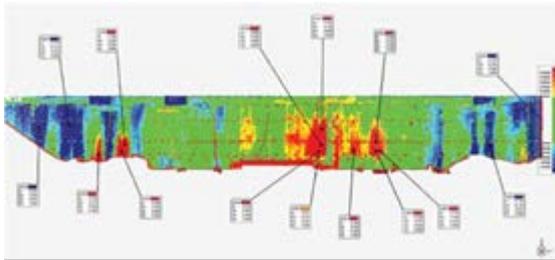

Fig. 8 Model of the west wall section

The site scanning, with the usage of the laser scanner technology, was the completed in four days with 400 scans in total. Advanced computer software gives us the ability to generate vertical and horizontal cross-sections, along with the diaphragm wall, allowing the user to define the interval between the consecutive cross-sections. The decision was based on the length of the panels, which constitute the diaphragm wall. Therefore, an interval of five meters between two consecutive cross sections allows us to check the as-built condition of every panel [11].

5. CONCLUSION

There is a need to consider the anticipated responses of the adjacent buildings during construction. This will require the design professional to survey the condition of the adjacent properties to understand their present condition and fragility, establish acceptable limits, conduct soil-structure analyses of various support systems and develop limits on their respective movements, and develop a monitoring strategy.

The color is an assigned according to the value of the deviation between the as-built measured data and the design model. In Figure 8, the areas, which are colored red, represent the highest deviation with values, which exceed 150 mm, in contrast to the green colored areas, which present the lowest deviation with the values, which fluctuate between 0 mm and 150 mm. The positive pattern of deviation is illustrated in red while the negative deviation is in blue. The red colored areas indicate the areas where the wall penetrates the parking wall and therefore must be a trimmed. The green areas indicate the parts of the wall where the deviation fluctuates within acceptable limits while the blue color indicates the areas where the wall deviates into the opposite direction.

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