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# Different aspects of design and monitoring of deep excavations – a case study

## Differents aspects de la conception et du suivi des excavations profondes – une etude de cas

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**ABSTRACT:** 23 m deep basement excavation was required to be retained in a shopping mall and hotel project namely “İstinyePark İzmir” with a perimeter of 850 m. Soil profile consists of clay and sand layers overlying on the inclined bedrock where water level was approximately 3 m below the ground level. Prior to the tender phase, shoring was planned to be applied with secant piles supported with pre-stressed anchors and jet grouting on the toe part. Due to the drawbacks of this preliminary design contractor company proposed an alternative system to fulfill the Employers requirements. Diaphragm wall was proposed instead of secant piles to reduce the number of joints which have risk of high amount of groundwater seepage. Instead of extending the diaphragm wall in rock stratum, an alternative system was proposed to shorten the construction period. Preliminary anchor tests were conducted and quantities were optimized. Tension micropiles were proposed instead of bored piles to ease the water-proofing works. Design, construction and monitoring phases of this challenging project are described and evaluated within the paper.

**RÉSUMÉ:** Une excavation avec 23 m de profondeur et un périmètre de 850 m devait être réalisée pour un projet de complexe hôtelier et de centre commercial, le “IstiniyePark Izmir”. Le profil géotechnique était constitué de couches d’argile et de sable recouvrant le substratum rocheux incliné, et le niveau d’eau était à environ 3 m de la surface. Avant la phase d’appel d’offres, il était prévu d’exécuter un soutènement en rideau de pieux sécants, stabilisé par des ancrages précontraints et avec des colonnes de jet grouting en partie inférieure. En raison des inconvénients de cette solution, l’entreprise contractante a proposé un système alternatif pour répondre aux exigences des employeurs. Un soutènement en paroi moulée a été proposé à la place des pieux sécants afin de réduire le nombre de joints, qui présentaient un risque élevé d'infiltration des eaux souterraines. Au lieu de prolonger la paroi moulée dans le substratum, une solution de reprise un système alternatif a été proposée de façon à réduire la durée de construction. Des essais préliminaires des tirants d'ancrage ont été effectués et les quantités de tirants optimisées. Des micropieux en traction ont été proposés à la place des pieux forés pour faciliter les travaux d'étanchéité. Les phases de conception, de construction et de suivi de ce projet complexe sont décrites et évaluées dans le présent document.

**Keywords:** Deep excavation, diaphragm wall, micropile, monitoring

# 1 INTRODUCTION

Within a prestigious shopping mall and hotel project namely "İstinyePark İzmir", 21-23 m deep excavation was required for the construction of five basements. Foundation area of the structure was approximately 41.000 m² and the perimeter of the basements was 850 m. First basement level was designed as shopping floor where remaining basements were planned as carpark. Structure consisted of 1-4 floors on the podium side and 25 floors for the hotel tower part.

*Figure 1. General View of the Project*

Construction site was located 500 m far from the Izmir Bay and high ground water level was expected. The site is close to sea, however fresh water was encountered due to the underground aquifers in this region. To provide the stability during the excavation a water-tight shoring system was required around the proposed basement levels.

Soil investigation studies are performed in different durations prior to the tender stage and soil/rock profile is determined. Soil profile was given as fill and alluvium soil layers laying over the inclined bedrock.

Bedrock is approximately 33 m below the ground level on the north side (tower part) of the site and reachs nearly surface level on the south side (podium part). Under the fill layer there are alluvium layers which consist of clay (CI, CL), sand (SC) and gravel (GP-GM) soils. Baserock consists of mainly flysch which is a sequence of sedimentary rock layers shale and sandstone. Shale, sandstone and limestone layers are also encountered during the soil investigations.

# 2 PRELIMINARY (TENDER) DESIGN

Prior to the tender stage, Employer shared a preliminary design prepared by a design company with the bidders and bidders are requested to submit their alternative solutions for shoring and also piling works.

The contractor company which is awarded for the shoring and piling works offered an alternative system to eliminate the disadvantages of the preliminary design and provide economy with great advantages in construction schedule.

Two of the critical shoring sections are highlighted in this project, one on the podium (South) side (Figure 2 left) and the second is on the tower (North) side (Figure 2 right).

Preliminary tender design was submitted with secant piles, pre-stressed anchors and bored piles under the foundation. Secant piles were given as 1000 mm in diameter and with 0.8 m horizontal spacing. Pre-stressed anchors were designed as 9 levels. Reinforced concrete shear wall was proposed in front of the secant piles to provide a continuous beam for anchors.

Podium side section where rock elevations raises over -2.00 m elevation secant piles were designed with 3 m socket below the excavation level. Anchorages with 400-600 kN loads were given with lengths vary between 12 and 32 m. Podium do not have many floors and tension piles with 800 mm diameter were designed against uplift. Tower part was located on the north corner where the rock inclines down to -31.0 m and secant piles were socketed into bedrock. Anchorages with 400-450 kN loads were given to support the secant piles with lengths vary between 18 and 36 m. Toe grouting was considered in the design in front of the secant piles and 1000 mm diameter bored piles were given under the tower structure.

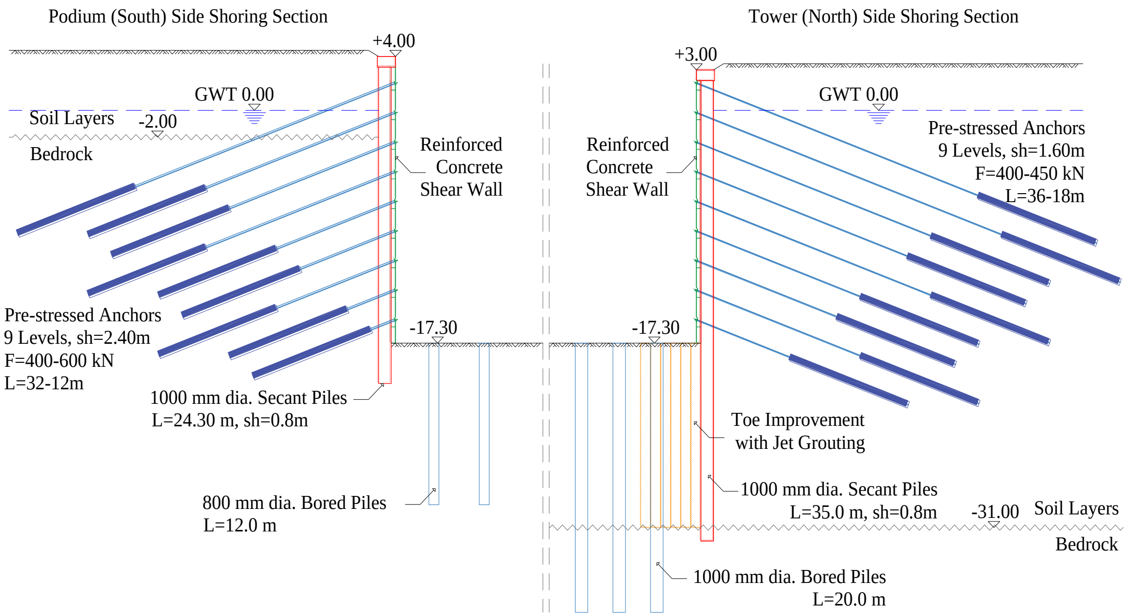


*Figure 2. Preliminary (Tender) Design Sections*

## 3 DRAWBACKS OF THE PRELIMINARY DESIGN AND PROPOSED FINAL DESIGN

Preliminary design was prepared by a design company and bidders were requested to submit their alternative solutions. One of the main drawbacks of this preliminary design was the risk of failure in providing a water tight cut-off wall with secant piles which has approximately 20.50 m height over the excavation level. Secant piles had to be constructed with joints in each 0.8 m which means approximately thousand numbers of joints with potential of excessive ground water seepage failure.

Overcut between the piles was considered as 20 cm however this length can be easily disappeared when two adjacent piles are constructed with a verticality ratio over 1/200 towards different directions. Boring speed and production rate of the secant piles should be decreased dramatically to provide smaller verticality ratio but this time construction expenses and work period becomes far from to satisfy the expectations of the Employer. To prevent the risk of failure with excessive ground water seepage, Diaphragm Wall application was proposed. Alternative design was prepared with 800 mm thick diaphragm walls which socketed into bedrock (Fig. 3).

Due to the high NSPT values of the gravelly sand layers on the toe part of the shoring, jet grouting could be very costly and it was unnecessary due to the very dense gravelly sand layers.

NSPT values of the gravelly sand layers were over 45. Deformation modulus, $E_M$ was calculated between 10-17 MPa in pressuremeter tests and 12.5 MPa was considered in design. Elasticity modulus of the gravelly sand layers in the toe part of the shoring is calculated as 50 MPa considering Briauds Method as below.

$$E_{oed}=M=E_M/\alpha_M\,,\quad \alpha_M=0.25 \text{ (Briaud, 1992)} \qquad (1)$$

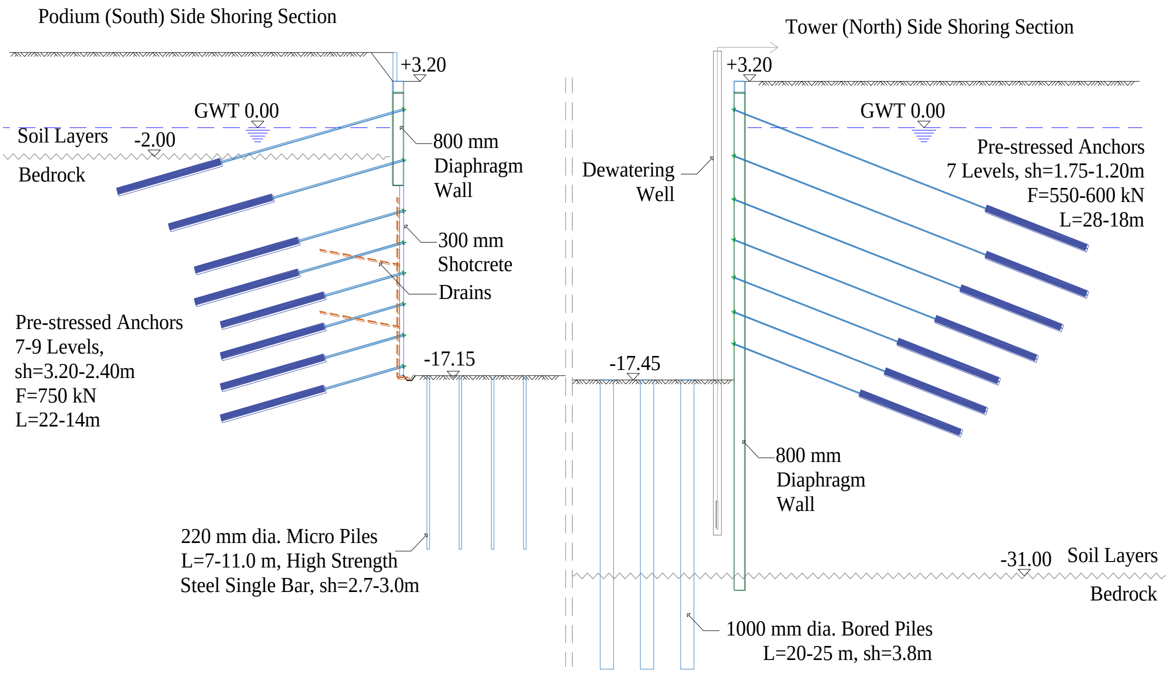


*Figure 3. Proposed Final Design*

*Figure. 4 Diaphragm Wall Construction*

Another drawback of the preliminary design was the expected low production rate in the rock layers on the podium side. It is proposed to apply diaphragm walls down to rock level and support with shotcrete and pre-stressed anchors underneath. Diaphragm walls were proposed to be constructed with grabs (Fig. 4).

300 mm thick shotcrete and pre-stressed anchors were proposed to support the rock layers under diaphragm wall panels where bedrock rises over excavation level (Fig. 5). Vertical and horizontal drains were placed behind the shotcrete to collect the limited seepage water from the bedrock to eliminate excessive water pressures behind the slender shotcrete facing.

*Figure 5. Shotcrete & Anchors under the Diaphragm Wall on the Podium Side*


*Figure 6. Preliminary Anchorage Tests*

Besides, to shorten the construction period contractor company proposed 7 levels of anchors instead of 9 levels. Preliminary anchor tests were performed prior to design and anchor loads are increased considering the test results.

Design loads of the pre-stressed anchors were determined according to the preliminary tests. Anchor loads increased in soil layers from 40t to 55t and in rock layers from 60t to 75t.

Critical sections of the shoring were calculated with Plaxis software. Diaphragm walls were designed considering calculated bending moments and shear forces. Anchorage loads were calculated and lateral spacing of them were determined. Lateral displacements were calculated between 20 and 70 mm.

To prevent the uplift of the podium structure 800 mm diameter tension piles were given in the preliminary design however due to the difficulties in water-proofing works high capacity single-bar micro piles were preferred to provide convenience during construction (Figure 8). Design capacity of the tension piles were confirmed with 6 numbers of tension tests performed prior and during the construction.

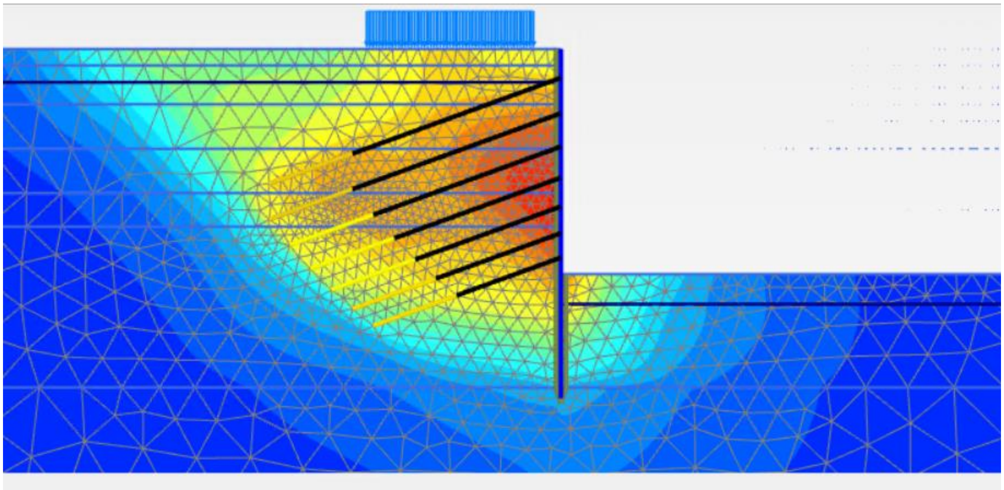

*Figure 7. Shoring Wall Calculation in Plaxis*

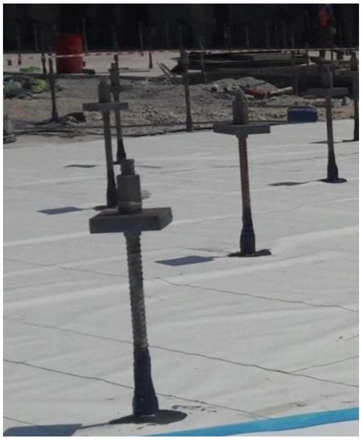

*Figure 8. Micro Pile Water Proofing Detail*

Micro piles were designed as double corrosion protection with HDPE sheathing and inner cement injection. (Figure 9)

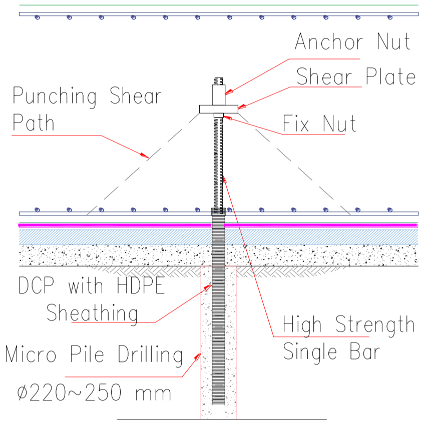


*Figure 9. DCP and Connection Details*

A dewatering system with deep wells, sump pits and lateral drains was proposed to lower the ground water level during the excavation. Also it is planned to run the system during the construction of the basement levels and eliminate the water pressures under the foundation until to construction of the basement levels.

1000 mm diameter bored piles were designed under the tower part of the structure to eliminate the excessive differential and total settlements. Piles were designed as socketed into the bedrock between 7 and 10 m in accordance with their service loads. Pile loading test was performed on one of the working pile for confirmation of the design.

## 4 CONSTRUCTION PHASE AND MONITORING

Diaphragm walls were socketed into the bedrock and ground water level was successfully lowered with dewatering system. An aerial vie of the constrcuton site is given in Figure 10. Site was excavated in dry conditions and anchorages applied in an efficient way with provided dry working platform in each levels. Anchorages drillings were implemented through steel reservation pipes located into the diaphragm wall reinforcement cage and cement slurry with chemical additions was injected where excessive ground water seepage was encountered after drilling.

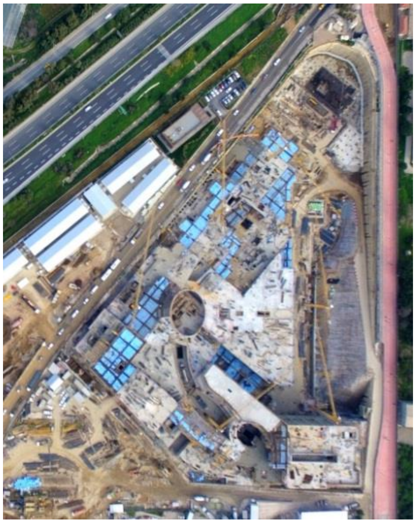

*Figure 10. Aerial View of the Construction Site*

Bored piles were implemented approximately 2 m above the final excavation level. Façade view of the shoring wall after the excavation for bored piling platform is given in Figure 11.

*Figure 11. Shoring Wall and Bored Piling*

Retaining system was monitored with inclinometers which were embedded into diaphragm wall panels during the construction. Lateral displacements were recorded and reported to Employer and Consultant. Inclinometer data showing lateral displacements of the sections which were illustrated in Figures 12 and 13 is given below.

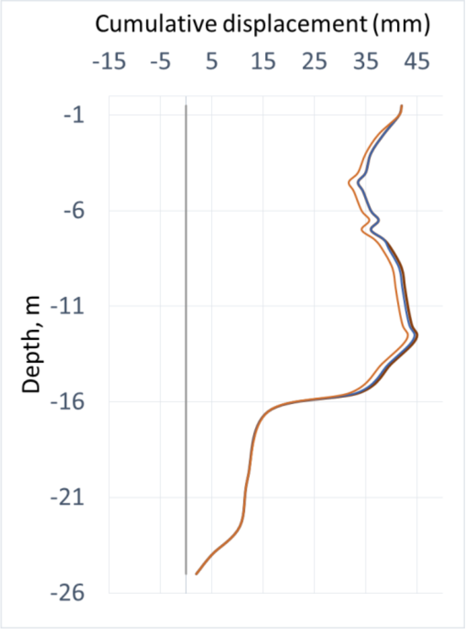


*Figure 12. Inclinometer Data of Podium Site-South Part of the Site*

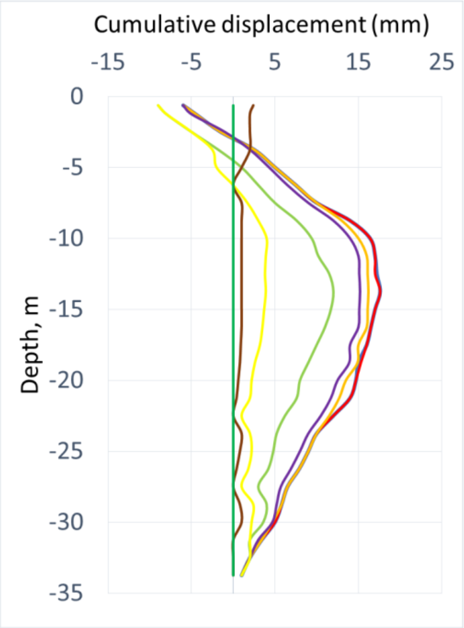


*Figure 13. Inclinometer Data, Tower Site -North Part of the Site*

As given in the inclinometer graphics lateral displacement increased up to 45 mm on the Podium-South side of the area where diaphragm walls were socketed into bedrock and shotcrete was applied underneath with pre-stressed anchors. Although structural continuity between the diaphragm wall and shotcrete was provided with dowel reinforcements, it can be seen in the inclinometer graphics that a smooth transition of rigidity couldn't be provided. Lateral displacement increased rapidly on this elevation however total displacement value was under the limit and estimation in the design.

Lateral displacement on the Tower- North side of the site increased up to only 20 mm which was under the limits and calculated values in the design stage. One of the reasons of this inconsistency can be the 3D arching effect of the diaphragm walls panel layout on the north side. Also soil parameters were determined considering unfavorable data collected in soil investigation works however encountered conditions were more favorable than estimations.

Anchor loads were monitored with load cells which installed on the anchor plates. No significant relaxation was observed in the pre-stressed anchors during the excavation period.

## 5 CONCLUSIONS

Due to the deep excavation of the shopping mall and hotel project "İstinyePark İzmir" retaining system was required to be constructed and to eliminate the uplift of podium part of the structure and to support the foundation under the tower part piling works were needed to be implemented. A preliminary design was prepared by a designer company prior to tender stage and alternative construction design was proposed by the awarded company to eliminate the drawbacks of the preliminary design which explained above. Diaphragm walls were preferred instead of secant piles to provide a sufficient cut-off against high ground water table. Since a dense gravelly sand layer exists under the excavation level, elasticity modulus of this layer re-calculated considering PMT results prior to final design and toe grouting was eliminated. Inclinometer readings showed very limited lateral deformation on this section which was also under the design phase estimation. Since higher capacities were reported in preliminary anchor tests, design load of the anchors was increased and an optimization was provided in total cost and time schedule with the decrease in anchorage quantity.

On the podium side of the project where bedrock rises over the excavation level, diaphragm wall panels were proposed to be constructed as socketing into bedrock but over excavation level where shotcrete and anchorages will be implemented for underpinning the diaphragm wall panels. This revision reduced the total construction costs and prevented time losses which could be encountered during excavation of the bedrock. Continuity of the vertical reinforcements was provided with dowels between diaphragm and shotcrete elements however an increase in the lateral deformations was encountered at the contact point of these elements. Although total displacement was under the design limits, it is noted that a more rigid transition can be implemented in the next projects to provide more uniform distribution of the lateral displacements.

Diaphragm walls were supported with pre-stressed anchors and shoring works were completed in a safe and timely manner. Dewatering was performed with deep wells and sump pits and site kept dry in each excavation step. Tension micro piles were proposed instead of bored piles against uplift and bored piles were constructed under tower part. Design of the piling was confirmed with tension and compression tests.

## 6 ACKNOWLEDGEMENT

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