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The Designing of a Three-level Excavation Pit in Soft and Sensitive Clays in Oslo, Norway

Design d'un trou d'excavation à trois niveaux dans des argiles à faible résistance mécanique à Oslo, Norvège.

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ABSTRACT: The aim of this paper is to present the solutions and construction of an excavation pit in Oslo city. However, the soil conditions are difficult since a thick layer of soft and sensitive clay is found quite shallow under the terrain. The excavation pit, the depth of which is between 3 and 8 meters, has three different base levels making the excavation and the deformation control even more challenging. A sheet pile wall around the whole construction site and in between the different base levels was designed. Potential large deformation of the sheet pile wall and the infrastructure behind was one of the main concerns during the design and the construction phase. In order to improve the stability of the excavation pit, the soil in front of the wall was reinforced by means of lime-cement piles. Furthermore, the wall was supported by struts connected to a reinforced concrete slab for the deepest part of the excavation. A comprehensive discussion of the result is made. The technical solution proved to be cost-effective and can be used in similar projects.

RÉSUMÉ: Le but de cette contribution est de présenter les solutions et l'exécution d'un trou d'excavation dans la ville d'Oslo (Norvège). Les conditions de ce projet sont particulièrement difficiles du fait de la présence d'argiles faibles, proches de la surface. Le trou d'excavation, dont la profondeur s'étend de 3 à 8 mètres, comprend trois niveaux de base distincts, rendant l'excavation elle-même ainsi que le contrôle de la déformation délicats. Un mur de palplanches fut conçu autour de l'ensemble du site de construction ainsi qu'entre chaque niveau basal. Le risque de déformation, potentiellement importante au niveau des murs de soutènement et des ouvrages périphériques, fut le sujet de considérations particulières. Par exemple, la stabilité du trou d'excavation a été améliorée à l'aide de colonnes de sol traité à la chaux-ciment installées dans le sol. De plus, le mur de soutènement dans sa partie la plus profonde fut renforcé par des étais fixés à un panneau en béton renforcé. Les résultats sont discutés en détail dans notre contribution. La solution technique s'est révélée rentable et peut être utilisée dans d'autres projets.

Keywords: sensitive clay; excavation pit; displacements; monitoring

1 INTRODUCTION

A major current focus in the construction industry is to ensure a safe and at the same time cost-effective excavation process. This project is located at Skøyen in Oslo city and involves the construction of 12 residential buildings, 8 floors

each, and one administrative building of 11 floors with a common basement on total area of 20.000 square meters (Figure 1). Sweco Norge AS has been responsible for the geotechnical design of the three-level excavation pit and the foundations; moreover we have been involved as the controller of the excavation work. The soil conditions are demanding considering the thick layer of soft and sensitive clay together with groundwater level quite shallow under the terrain. The present paper presents the construction solutions and procedures used in the excavation of the pit as well as the monitoring program with the pore pressure measurements and the displacement of targets installed on the retaining structures and the neighborhood infrastructure.

Figure 1. Model of a planned construction.

2 CONDITIONS

Geotechnical investigation was conducted including execution of rotary-pressure-sounding, CPTU, gathering undisturbed samples, laboratory tests and installing of piezometers. Previous geotechnical investigations were also obtained in order to collect additional information.

2.1 Soil conditions

A top layer of compacted and dry clay and landfill was identified at the surface with thickness of about 1-2 m. Underneath a medium to hard clay down to about 4 m below the surface is found. Further down very soft silty clay over the bedrock is presented. Bedrock lays from 6 to 40 m beneath the surface. Undrained shear strength c_u^{DSS} is lowest about 4-10 m below the surface and varies from 14 to 20 kPa. Undrained shear strength is however increasing with depth. The silty-clay is lightly overconsolidated and is little to medium sensitive with S_t about 3-13. Main design parameters for different clay layers in the western part of excavation pit are presented in Table 1 and in Table 2. At the eastern part of the excavation pit the soil conditions are slightly better.

Table 1. Basic soil parameters used in design.

Layer	w [%]	γ [kN//m^3]	IP [%]	OCR [-]	St [-]
M-H Clay	30-40	19	20	2-3	3-11
Silty clay	35-50	19	8-20	1,4-2,3	4-13

Table 2. Strength and deformation parameters used i design.

Layer	c_u^{DSS} [kPa]	c_u^{DSS}/s_u^E [-]	c_u^{DSS}/s_u^C [-]	G_{50} [kPa]
M-H Clay	50-20	0,37	0,66	16700-9300[1)]
Silty clay	16-24,5[2)]	0,37	0,66	2500-6500[3)]

[1)] Linearly decreasing from 2 to 4 m
[2)] 16 kPa from 4 to 9,5 m, then linearly increasing according to equation c_u^{DSS} = 16+1,54×(z-9,5 m)
[3)] 2500 kPa from 4 to 9,5 m, then linearly increasing

Laboratory tests including cone, uniaxial and triaxial test, have been the basis for the interpretation of the design parameters. Samples were obtained by the standard 54 mm piston and disturbances were however extensive. Hence, low peak strength values and higher axial failure strains were obtained from the laboratory tests. However, the local correlations for CPTU has been considered as the most reliable data to obtain strength values from.

2.2 Groundwater conditions

Groundwater data has been assembled concerning several building projects in the last 60 years. The groundwater level lies historically at the

depth of about 1-2,5 m beneath the terrain and it lies highest in the northwestern part and lowest in the southeastern part of the area. Before starting the building activity hydraulic piezometers was installed around the excavation pit.

2.3 Neighborhood conditions

The construction site is located in the urban area with mostly residential and office buildings (Figure 2).

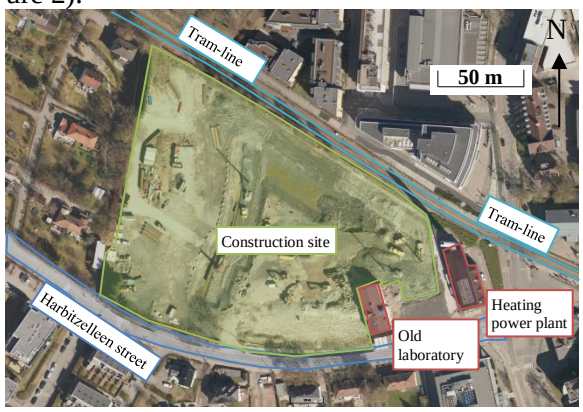

Figure 2. Site satellite view (Norgeskart, Kartverket).

Most of the buildings lie more than 20 m from the construction pit. There are however 2 buildings which lies adjacent to the excavation pit. The heating power-plant is founded directly on stripe foundations and lies between 6-10 m from the construction pit. The old laboratory is also founded directly on stripe foundations approximately 2 meters below the terrain and lies just 0,5 m from the excavation pit. Displacement targets are installed on most of the neighbour-buildings. Additionally, displacement targets are installed on the 2-track tram-line, on a distance 5-10 m from the excavation pit in the north. The registration of the displacements was on the regular basis registered manually every month or as required.

3 DESIGN PRINCIPLES

3.1 Calculation

Excavation method mainly depends on excavation depth, soil conditions and accepted deformations. Due to the soft soil conditions, earth pressures are quite large on the supporting structures. Failure may cause large economic consequences or even consequences in terms of risk to life. Thus, the level of safety must be high. Static calculations for critical profiles were done using Geosuite Excavation software. For the excavation in front of section B-1 the calculation in Plaxis 2D was conducted. In this paper sections C-1 and B-1/B-3 are in focus (Figure 3). The results of the calculations have shown that the expected horizontal displacements are 60 mm and 40 mm, respectively.

3.2 Excavation

The conditions at this project are challenging. Soils are very soft and easily remolded at the excavation base and groundwater level is close to the terrain. Additionally, the construction pit is planned to have 3 different base levels and must be stable in all excavation states. The designing is done in close collaboration with the general contractor in order to obtain an optimal solution. Furthermore, the excavation pit is drawn in 3D in Autocad Civil 3D. Hence the excavation contours and other objects were exported in digital form and sent to the responsible subcontractors for direct use in construction excavators.

The construction sequence depends on geotechnical conditions and construction progress schedule. However, conclusions on general excavations sequence have been made: Level C, Level A and Level B (Figure 3).

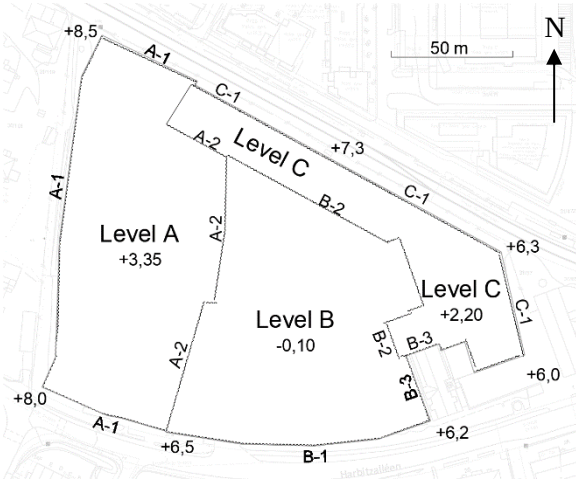

Figure 3. Overview base levels and sections sheet pile wall. Altitudes for the terrain behind sheet pile wall are presented.

The performed excavation work is presented in three phases.

3.2.1 Phase 1

Sheet pile wall and lime-cement piles were established around the area and also inside the area in order to divide different excavation levels (Figure 4).

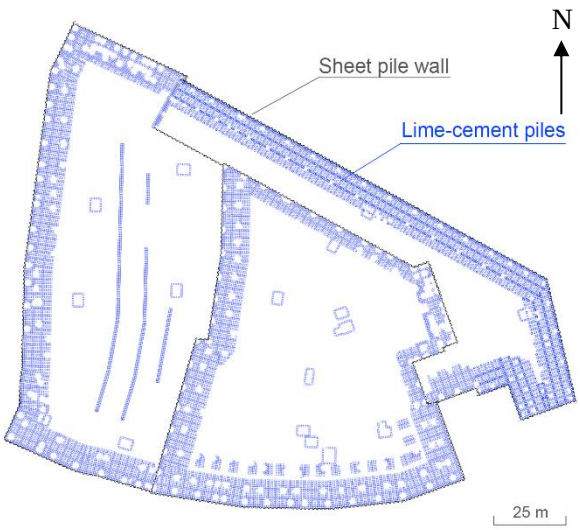

Figure 4. Phase 1; driving sheet pile walls in black colour and installation of lime-cement piles in blue colour.

3.2.2 Phase 2

The excavation started in the central area approximately 10-12 meters out from the sheet pile wall. After the excavation of the whole area, the concrete slab was established. Afterwards, concrete slab was established in the area. Section excavation to the sheet pile wall was done in 3-6 meters width and afterwards the concrete slab was immediately established. (Figure 5).

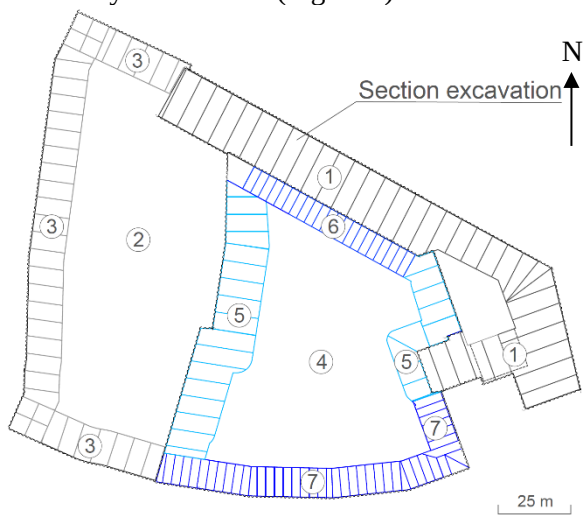

Figure 5. Phase 2; the sequence of section excavations. Note different size of sections.

3.2.3 Phase 3

A part of the south wall has excavation depth of 7 meters, and we used bracing of CHS steel-tubes. The bracings were prestressed with 400 kN. Section excavation to the sheet pile walls was done in 3 meters width and afterwards the concrete slab was immediately established. (Figure 6 and 7).

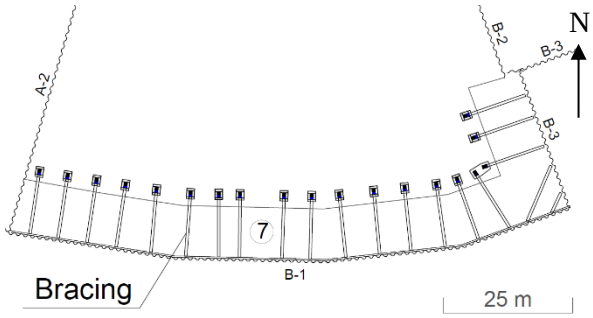

Figure 6. Phase 3; bracing with CHS steel-tubes on section B-1 and partially on section B-3.

Figure 7. Bracing of sheet pile wall in section B-1. The concrete slab to the sheet pile wall is established on the right side. There is however sheet pile wall still supported by soil on a part of the section B-1 on the left side.

4 MONITORING

4.1 Survey plan

Considering the complexity of the excavation and the sensitivity of the surrounding structures and infrastructure, the need for monitoring of displacements and groundwater level was mandatory. The survey plan was established in the early phase of the project and the displacement targets on the neighborhood infrastructure and piezometers were planned to be installed before the piling and excavation start in January 2017. The targets on the sheet pile wall were established in period from Mai 2017 to August 2017 depending on the actual excavation plan. Nevertheless, some of the targets were not installed punctually and some of the measurements were missing due to demanding construction plan.

4.2 Displacements

The displacement targets were established on the following infrastructures (Figure 8):

- top and bottom of the sheet pile wall,
- corners of the neighborhood buildings
- tram line track

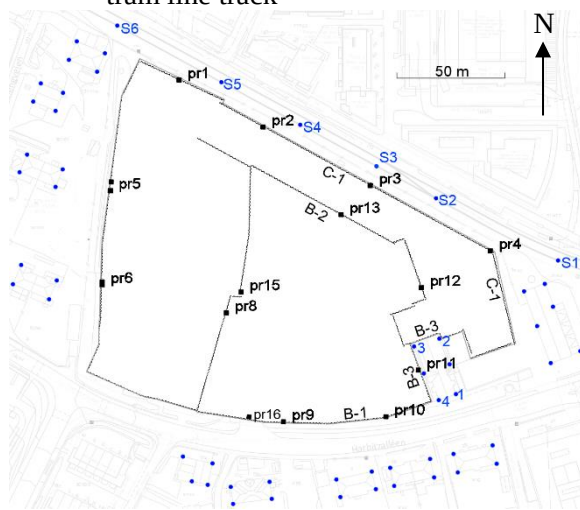

Figure 8. Locations of displacement targets on the sheet pile wall are presented by black squares and displacement targets on the structures are presented by blue circles.

This paper focuses on the monitoring of the displacements in excavation sections C-1, B-1 and B-3. The results of the horizontal displacements on targets installed on the top of the sheet pile wall are presented in Figure 9.

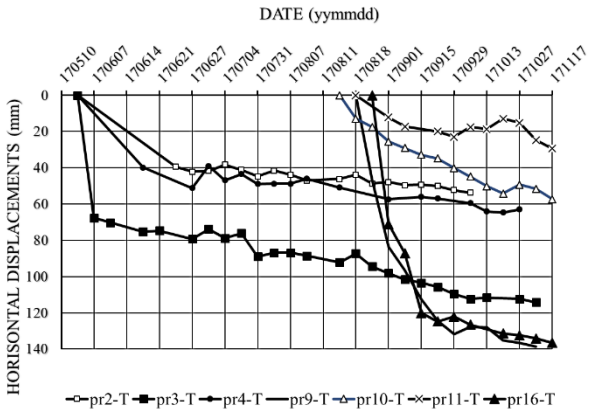

Figure 9. Horizontal displacements for targets installed on the top sheet pile wall for section C-1 (pr2-T, pr3-T, pr4-T), section B-1 (pr9-T, pr10-T, pr16-T) and B-3 (pr11-T).

Displacements in the selected sections were the most extensive and have locally exceeded modeled values. As can be seen for section C-1, the initial horizontal displacement for pr3-T was particularly extensive in the beginning, which is associated with rather wide and imprecise opening of excavation sections towards sheet pile wall C-1. Apparently, measurements for pr2-t and pr4-T show that horizontal displacements have been significantly lower. Displacements for section C-1 in July 2017 are associated with the excavation of a central part of Level B and those in August 2017 are associated with section excavations toward the sheet pile wall section B-2. The horizontal displacements for pr9-T and pr16-T were however exceptionally high in the end of August 2017 and the beginning of September 2017, which is related to three extensive cases of leakage from the communal pipes along Harbitzalleen Street. Measurement results for pr10-T and pr11-T show that the displacements have been moderate even though the excavation depth is the same as by pr9-T and pr16-T. Evidently there is a lack of measurements for the section B-1 and B-3 between May and August 2017. This implies that the absolute displacements for targets installed on sheet pile sections B-1 and B-3 can be bigger. On the whole, the presented horizontal displacements measured on the top of the sheet pile walls, followed the upper limit of displacements modeled in those cases where no irregularities were presented. A lack of measurement data is however not within the scope of this paper.

The impact of the sheet pile wall displacements was observed on the displacement targets installed on the neighborhood buildings and infrastructure. Vertical settlement of the old laboratory is presented in Figure 10 and vertical settlement of the tram-line track is presented in Figure 11.

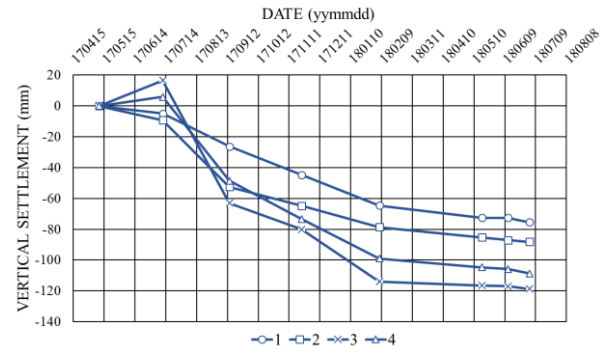

Figure 10. Vertical settlements for targets installed at the corners of the laboratory building. Look at the locations 1, 2, 3, 4 on Figure 8.

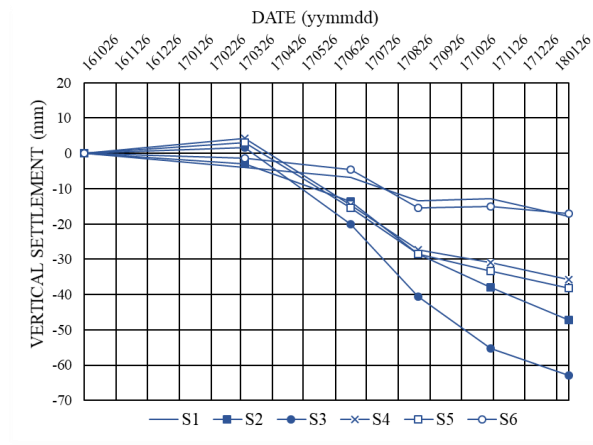

Figure 11. Vertical settlements for targets installed on the tram-line track. Look at the locations S1, S2, S3, S4, S5 and S6 on Figure 8.

The old laboratory has suffered the biggest settlements of all neighborhood buildings. The most significant settlements are observed in July and August 2017 when the Level B was excavated. However, settlements were being continued with significantly lower magnitude until February 2018. It may be assumed that the groundwater lowering has caused part of the settlements. The tram-line track has been monitored with 6 targets. The most settlements have undergone target S3 which was installed at the sheet pile wall C-1 beside the opening excavation section where some additional settlements were observed. It is apparent that the target measurements on the tram-line track are following the same pattern as for residual target measurements.

4.3 Groundwater

Totally seven piezometers have been monitored around the excavation before and during the excavation period (Figure 12).

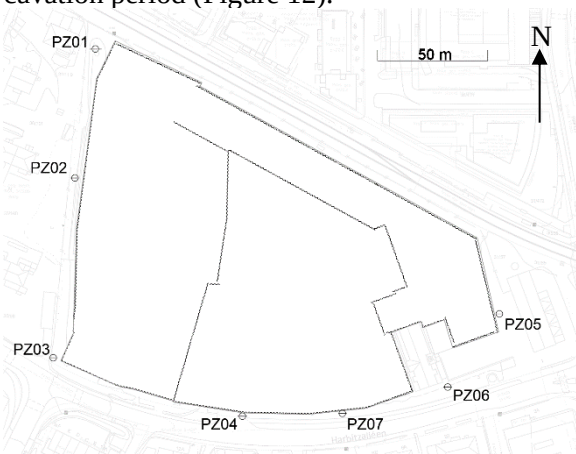

Figure 12. Locations of piezometers.

The registration of the groundwater level was on the regular basis registered manually every 2 weeks. The entire data has not been acquired due to difficult access to piezometers during building period. Furthermore, PZ04 was damaged and later replaced with PZ07. The results of the monitoring piezometers from December 2016 to June 2018 are presented in Figure 13.

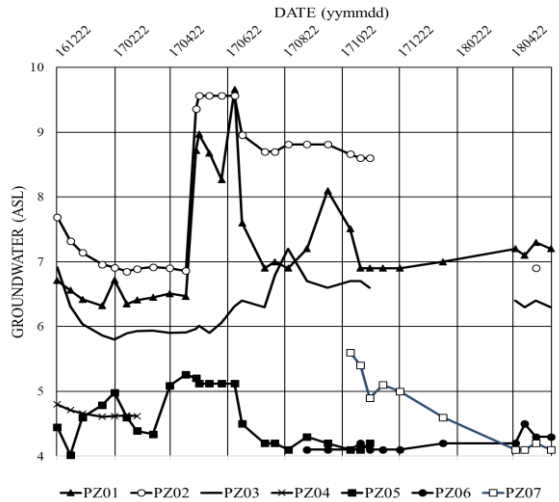

Figure 13. Observed groundwater level in meters above sea level (ASL) in a period from December 2016 to June 2018.

Recently installed piezometers showed matching groundwater level with historical data before the building period. Changes in pore pressure were observed in the building period. Moreover, the changes are to some extent associated with excavations and installation of lime-cement piles nearby piezometers. Selected observation program has some limitations on quick groundwater changes, though in the long term the results seem to be valuable. The piezometers PZ01 and PZ02 are located on the NW where the terrain and the groundwater levels are the highest. Measurements indicate that the groundwater has been preserved on approximately the same level. The measurements for piezometers PZ05 and PZ07 show a drop of about 0,5 – 1 m in pore pressure which can be associated with excavation along B-1 and B-3. Due to excavation depth up to 8 meters, the pore pressure drop is considered to be small.

5 DISCUSSION AND CONCLUSION

In this paper the construction solutions and procedures used in the excavation of the pit as well as the monitoring program with measurements of

the displacement targets installed on the retaining structures and the neighborhood infrastructure has been presented. The excavation in difficult soil and groundwater conditions involves three different levels on total area of 20.000 square meters.

We have demonstrated a three-phase excavation solution which was based on the geotechnical assessment and the construction progress schedule. The aim was to brace the excavation Level C and Level A with concrete slab prior to start the excavation of the Level B below. The section excavation is a well-proved method which was successfully integrated in our solution. We noted there were relatively small displacements of the sheet pile wall considering only the sequence excavation and immediately concrete slab construction. It seems very likely that the excavation of the entire Level B generated most of the displacements of the sheet pile wall and the neighborhood infrastructure since the major displacement development started just after the full depth excavation in the central part of Level B. The displacements of the structures behind the excavation pit may be in general explained by the combination of two different effects. Firstly, the unloading effect may generate the relocation of soil stresses and the uplift in the excavation level. Secondly, the sink of the groundwater level under the excavation pit may generate the groundwater flow hence sinking the groundwater level behind the sheet pile wall. Sinking of the groundwater outside the excavation pit is however possible to validate only with piezometers PZ05 and PZ07. Measurements from the other piezometers show that the groundwater level changed negligibly. It should be noted that this implies on the good tightening of the sheet pile wall. We have focused on monitoring of the displacements in the most exposed excavation sections: C-1, B-1 and B-3. The measured displacements were considerable and followed the expected rate unless the irregularities were presented.

The decision for appropriate excavation method and successively evaluating the monitoring data has been crucial in this project. Furthermore, the delivering of excavation contours in digital form to the responsible subcontractors has been decisive for a quick and precise excavation. Our experience indicates that the close communication with the general contractor and subcontractors is beneficial due to project agility and cost-efficiency.

6 ACKNOWLEDGEMENTS

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