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Bored pile wall as retaining structure, Tuchmacherstrasse – Zurich, Greencity

Paroi de pieux forés comme structure de soutènement, Tuchmacherstrasse – Zurich, Greencity

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ABSTRACT: An access road to the underground parking spaces for a multi-purpose development with appartments, offices and shopping facilities in a new area of Zurich, had to be built directly along the property boundary. This required a 6 m deep slope cut in the existing motorway embankment, which had to be secured by a permanent retaining structure. A possible future lane extension running parallel to the motorway also had to be taken into consideration. The chosen retaining structure could not restrict the construction of any future lane extension. As a result an anchoring of the retaining structure was not allowed. The subsoil consists of a sequence of slope loam as well as weathered and compact rock.
Due to the construction restrictions as well as the subsoil conditions, a cantilever piling wall with 12 m long bored piles was designed and executed. A head-bar was incorporated into the design in order to reduce deformation in areas of weaker soil conditions. Deformation calculations were carried out using the finite-element program Plaxis 2D.
A second excavation was required for a further construction project directly below the new pile wall. Due to the weathered and fractured nature of the rock encountered, the stability of the existing bored pile wall could not be guarenteed without the construction of a second retaining structure. As a result, a second bored pile wall has been executed below the first one in order to keep deformations to an absolute minimum.

RÉSUMÉ: La route d'accès au parking souterrain d'un nouveau quartier écologique à Zurich comprenant logements, bureaux et magasins devait être construite directement le long de la limite de la parcelle. Pour cela, un terrassement d'une hauteur de 6 m était nécessaire dans le talus sous l'autoroute existante. Cette incision nécessitait une structure de soutènement permanente. La possibilité d'une extension future de l'autoroute devait aussi être considérée: Le soutènement choisi ne devait en aucun cas restreindre la construction d'une éventuelle voie supplémentaire. L'utilisation d'ancrages était donc prohibée. Le sous-sol consiste d'une suite de limons de pente, de roche molassique altérée et de roche molassique saine.
Pour répondre aux exigences imposées ainsi qu'aux conditions géologiques, une paroi de pieux forés encastrée dans la roche saine a été projetée et exécutée, avec une longueur des pieux de 12 m. Une poutre de liaison en tête de paroi a été conçue afin de limiter les déformations en des endroits avec des conditions géotechniques localement moins favorables. Des calculs de déformation ont été conduits à l'aide du logiciel de modélisation aux éléments finis Plaxis 2D.
Un projet de construction consécutif nécessitait l'excavation d'une fouille directement à l'aval de la nouvelle paroi de soutènement. A cause de l'altération et de la fracturation de la roche en place, l'encastrement du pied

de cette dernière ne pouvait être garanti qu'avec une deuxième paroi de soutènement. Par conséquent et pour limiter autant que possible les déformations, l'enceinte de fouille a été réalisée avec une deuxième paroi de pieux.

Keywords: Molasse rock; bored pile wall; retaining structure; finite element analysis

1 INTRODUCTION

In the southwest of Zurich, Switzerland's biggest city, a new multi-purpose development is currently under construction. It lies between the river Sihl in the west and the Motorway A3 in the east, as shown on Figure 1, an replaces an old industrial area. Running under the name “Greencity” and comprising apartments, offices and shopping facilities, this project aims to install the first district of the city that is fully complying with the sustainability standards of the so-called 2000-watt society.

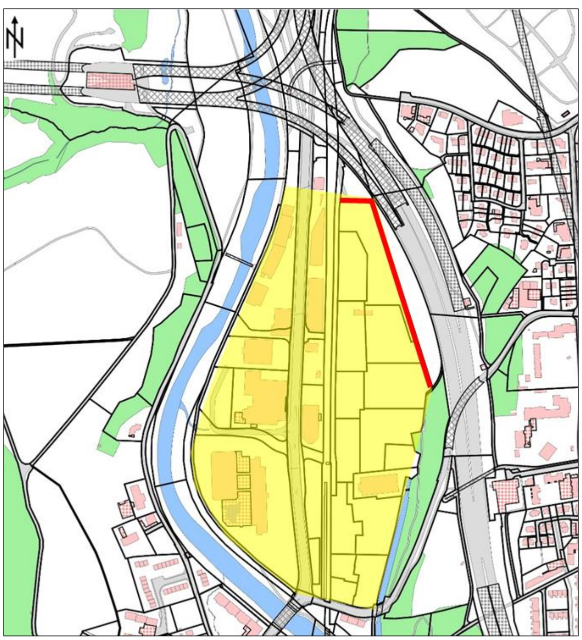

Figure 1. Situation of Greencity projet (yellow) and permanent retaining structure (red line)

The project also includes the construction of a new access road to the underground parking spaces. This road is called Tuchmacherstrasse and needed to be built directly along the eastern property boundary at the foot of the motorway embankment (see Figure 1). This required a 6 m deep slope cut in the embankment, which had to be secured by a permanent retaining structure. The present article covers the different boundary conditions of this retaining structure project as well as the different design approaches used.

At a later stage, another excavation was required for the construction of one of the buildings directly below the new retaining structures. The implications of this excavation pit for the stability of the retaining pile wall are also going to be discussed.

2 PROJECT AND CONDITIONS

The slope cutting to be stabilised lies, for the largest part, at the foot of a rather steep embankment, with the motorway running directly above. At the northern end however, the motorway enters a bridge. Original structural plans showed that the bridge abutment and piers are founded on shallow foundations inside the weathered molassic rock, which, at the top of the slope, lies at a depth of about 2-4 m below the surface of the terrain.

Due to the close vicinity of the national motorway, the Federal Roads Office (FEDRO) imposed that:

a) a permanent retaining structure must be designed such that the occuring settlements or displacements do not endanger road security,

b) a future lane extension running parallel to the existing motorway must remain possible, and thus

c) no ground anchors should transgress the property boundary so as to not enter in conflict with any future geotechnical structures on federal property

d) a design double check must be done by an independent engineer.

To comply with the spatial constraints and the requirements of the FEDRO, a vertical cantilever wall with bored piles seated inside the intact bedrock was chosen as the best solution.

3 GEOLOGY

As already mentioned, the bedrock was encountered at relatively shallow depth beneath a 2-3 m thick layer of slope loam. The molassic rock, which is further described in chapter 3.2, possesses a weathering zone at its surface. Figure 2 shows the geological profile. No groundwater was present in the area of the retaining structure. However, rainwater infiltrates the ground and circulates on the rock surface as well as in the joints of the weathered rock.

3.1 Geotechnical parameters

To give an impression of the subsoil conditions, Table 1 shows the basic geotechnical parameters issued from the geotechnical investigation:

Table 1. Basic geotechnical parameters

Soil type	**γ (kN/m³)**	**φ' (°)**	**c' (kN/m²)**
Slope loam / backfill	19 (18-20)	23 (20-32)	0 (0-4)
Weathered Molasse	22 (21-23)	25 (23-27)	10 (5-15)
Intact Molasse	24 (23-25)	37 (35-40)	50 (40-60)

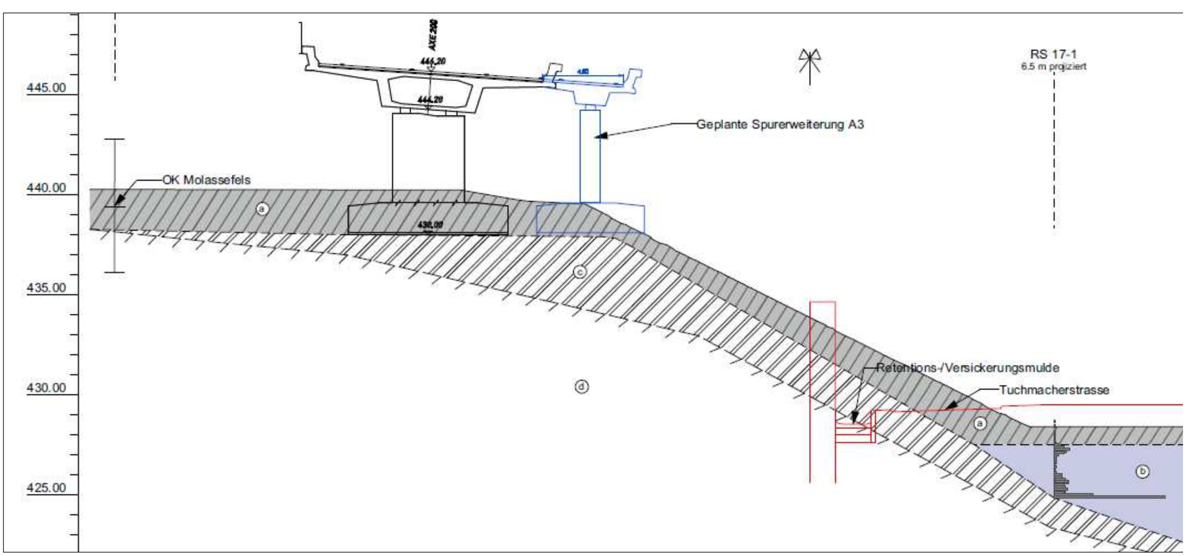

Figure 2. Geological profile: slope loam / backfill (dashed gray), gravel (blue), weathered Molasse (dashed white), intact Molasse (white). Position of the retaining structure in red

3.2 Molassic rock

Zurich lies in the great plain of Switzerland called Mittelland. The bedrock in this region consists of the so-called Molasse, a sedimentary rock which formed in the large basin between the Alps and the Jura Mountains of northwestern Switzerland and southern Germany. During the further alpine orogeny, the Molasse basin was horizontally compressed, resulting in a corresponding internal stress state (Hänni/ Ris 2017). In the project area, the molassic rock consists mainly of an alteration of marls, silt- and sandstones, sometimes in very thin layers, sometimes in important banks (see Figures 3 and 4). This subhorizontal layering gives the Molasse a strong anisotropic character.

A little bit further downhill from the retaining structure, the excavation pits for the buildings exposed the molassic rock over a height of several meters. In this area, the layers of the Molasse lie almost horizontally beneath the slope loam and gravels. Towards the east and the motorway, the rock surface gradually rises nearly parallel to the surface of the terrain, as shown on Figure 2.

Figure 3. Molassic rock in place

The rock surface is formed by a 0.6-1.0 m thick, hard and only slightly weathered bank of sandstone (see Figure 3). Below this sandstone bank follow several layers of marls, siltstones and sandstones presenting varying degrees of alteration.

Figure 4. Molassic rock with different layers and different degrees of alteration (indicated by red lines)

In the northeastern corner of the excavation pit, the molassic rock shows a clearly visible principal joint family, which is vertical and has a strike angle of 145°. With joint lengths of > 5 m and a joint spacing of 3-4 m (which is denser than in the rest of the pit, where the spacing is of about 5-10 m), these cross-strike joints cut across the whole stack of rock layers (see Figure 5).

Within the hard sandstone bank, the secondary joint family presents a spacing of about 0.2-1.0 m. Water infiltrates through these joints and circulates within the sandstone bank. The marly layer underneath weathers quickly and is transformed into a ductile to crumbly mixture of clay and silt. This weathered material forms a potential slip plane. Moreover, the vertical excavation surface intersects the principal joint family at a flat angle and thus weakens the stack of rock layers over the entire height of the cut (complete separation of the rock mass).

Over the weeks following the excavation, a progression of the opening of joints and fractures could clearly be observed. On one hand, this was due to the decompression of the rock through the excavation. On the other hand, water infiltrating the joints also led to swelling of the clayey marls.

Figure 5. Molassic rock with principal joint layers and joint surfaces

4 1ST RETAINING STRUCTURE

Due to the construction restrictions, the subsoil conditions, and the high loads from the motorway, a cantilever piling wall with 12 m long bored piles with a pile diameter of 1 m was designed and installed.

For the design of the permanent retaining wall, four different sections were analysed and the spacing of the piles was adapted to the different configurations. The most critical area in terms of tolerable deformations lies beneath the bridge piers. This is also the region where the retaining wall is closest to the motorway. For this portion of the wall, tangent piles were chosen. For the portion where the motorway runs on the embankment and is farther away from the wall, the pile-to-pile spacing could be increased up to 2.5 m, with a shotcrete infill. The variation of the pile spacing is a simple and very flexible solution to gradually adapt the wall to the respective conditions.

Since the piles are not secant, a head-bar connecting all the piles was incorporated into the design in order to reduce relative deformations between the piles in areas of weaker soil conditions.

With this very stiff structure, the displacements of the retaining wall itself as well as the motorway structures could be kept minimal. During the construction, the deformations were periodically monitored to detect any critical deviations sufficiently early. The stiff wall also helped to mitigate the risk of the activation of a potential slip plane inside the rock mass, as explained in chapter 3.3.

For the dimensioning of the pile reinforcement, the shear force became determining and demanded a maximum amount of armature. As a consequence, the small pitch of the spiral reinforcement required an adapted grain size distribution for the concrete, so as to allow the concrete to spread evenly between the rebars.

For the design of this bored pile wall, the traditional limit equilibrium method (LEM, using active and passive earth pressure states) was combined with a finite element (FEM) analysis. The latter was required for the design calculation check for the FEDRO as it yields a realistic estimation of the absolute displacements of structures and soil.

4.1 Limit equilibrium method (LEM)

The piles were designed using the limit equilibrium approach implemented in the software DC-Baugrube. This is an easy-to-use and straightforward design software. However, with the present project, different limitations of this design tool were met.

First, the limit equilibrium method is made for calculating earth pressures and thus not really suited for modelling rock, especially if the rock is banked.

Second, in this software, the effect of inclined soil layers cannot be accounted for. In this specific case, this presented a difficulty for the correct representation of the load transfer from the bridge pier foundations onto the pile wall. By simply "folding over" the inclined soil layers into a horizontal position while applying the bridge load at its real foundation level, the load would then be transferred through the loam and not through the rock (see Figure 6).

According to Coulomb's earth pressure theory and German standard DIN 4085, the horizontal force E_{aVh} resulting from the additional active earth pressure caused by a vertical load V behind the wall can be calculated as follows:

$$E_{aVh} = \mathrm{V} \cdot \frac{\sin(\vartheta_{ag} - \varphi) \cdot \cos(\alpha + \delta_a)}{\cos(\vartheta_{ag} - \alpha - \delta_a - \varphi)} \qquad (1)$$

with
E_{aVh} = resulting earth pressure force (kN)
V = vertical load above wall head (kN)
ϑ_{ag} = inclination of Coulomb shear plane (°)
φ = friction angle of soil (°)
α = inclination of wall
δ_a = wall-soil friction angle (°)

Equation 1 shows that the additional earth pressure is a function of the soil friction angle φ. The friction angles of the slope loam and the molassic rock being very different, the aforementioned approach would lead to unrealistic earth pressures resulting from the bridge pier loads.

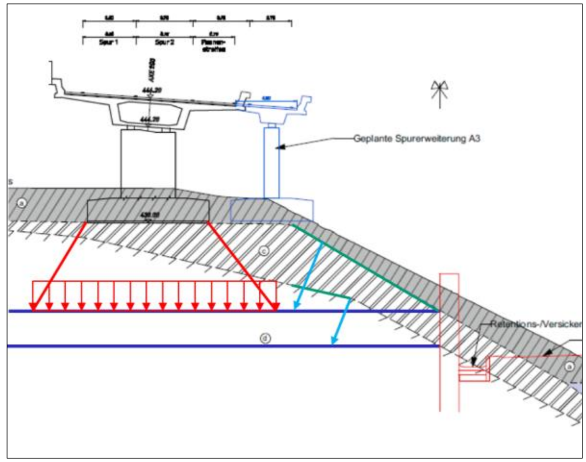

Figure 6. Folding-over of inclined soil layers into horizontal position (blue arrows) and downwards projection of bridge load (red arrows)

In DC-Baugrube, this problem was solved by projecting the loads of the bridge piers down on the virtual horizontal rock surface, as illustrated in Figure 6.

4.2 Finite element method (FEM)

To determine the displacements of the bored pile wall, the highway embankment and the bridge foundations, a finite element analysis was additionally conducted.

In the present case, the different constitutive models available in Plaxis 2D obviously allowed a more correct representation of the respective behaviours of soil and rock. For the rock, a linear-elastic constitutive model is sufficient, whereas the soil is more realistically modelled using a hardening-soil model accounting for small strain stiffness (HSS model).

Under the given conditions, a limit equilibrium analysis is not able to yield any reliable results for the deformation of the wall, and the calculation of the induced settlement of the bridge pier is generally not possible with the LEM.

As figure 7 shows, in the FE model, the real geometry could be represented without difficulty. Furthermore, the influence of potential slip planes could be studied in more detail using the FE method.

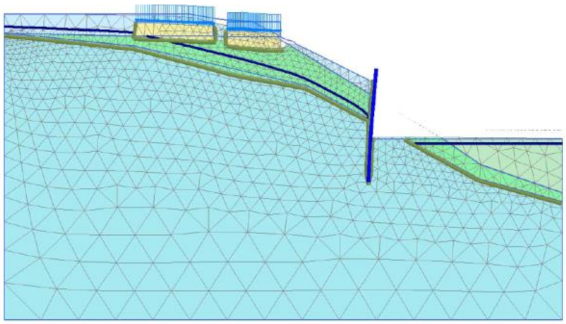

Figure 7. FE model showing the displacements of retaining wall and bridge foundations

With these calculations, it could be shown that the expected deformations of the pile wall would be sufficiently small und would not cause any serviceability problems for the motorway.

Basically, it would have been possible to design the retaining wall entirely based on the sectional forces given by the finite element calculations. However, to the present date, designing based on results from FE analyses is not yet broadly accepted in Switzerland. Due to the close vicinity to the motorway, the Federal Roads Office (FEDRO) required a design calculation check by an independent geotechnical engineer. This led to the decision to stick with well-known and proven design approaches for the design calculation check, so as to avoid any temporal delays for the project. The results of the finite element calculation were thus mainly used to demonstrate that the resulting deformations and displacements / settlements were acceptable and within the limits set by the FEDRO. In addition, they served as a control of the dimensioning with the simpler LEM.

5 2ND RETAINING STRUCTURE

From the beginning, a relatively shallow excavation pit for one of the buildings was planned directly below the new pile wall. As the project advanced, it was decided that this pit must be considerably deeper than initially planned. Although entirely inside the molassic rock, this deep excavation would at least weaken, if not endanger the horizontal support (passive earth pressure) at the foot of the first pile wall. Since the excavation should be deeper than the pile foot level of the first pile wall and due to the horizontal layering of the Molasse, there was a risk that blocks of rock could detach and slip horizontally on an underlying marly layer. The first retaining wall would then lose its stabilising passive earth pressure. The mechanism is illustrated in Figure 8.

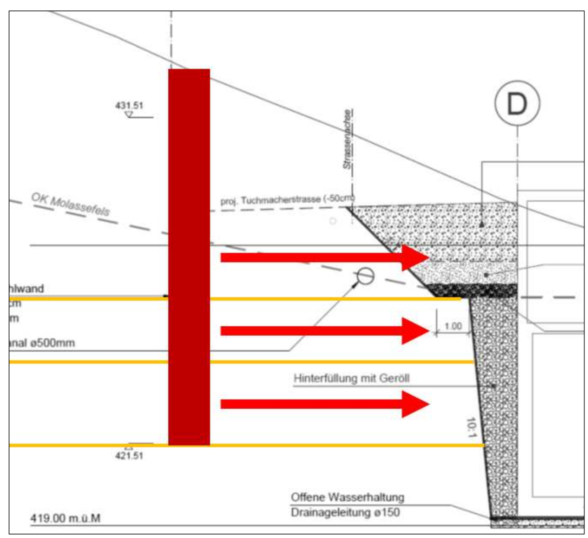

Figure 8. Potential loss of passive earth pressure support due to sliding blocks following the excavation for the pit

As a consequence, a second, dissolved bored pile wall was designed as a temporary support for the excavation pit. This second, lower wall takes on the pressure that is horizontally transferred from the foot of the permanent pile wall through the layered rock. With this measure, the stability of the upper pile wall could be guaranteed for the remaining duration of the construction work. The configuration of both pile walls in their finished state is visible on Figure 9, where the great length of the excavation becomes apparent as well.

Figure 9. Finished upper (permanent) and lower (temporary) pile wall beneath the motorway embankment

6 CONCLUSIONS

The Greencity project illustrates that excavations in rock – here the molassic rock typical for the area of Zurich – are not necessarily easy. Even though the rock material is of excellent quality for foundations, it can present considerable challenges for slope cuts and retaining walls. This is due to its anisotropic structure and the effects occuring when the rock is horizontally decompressed and exposed to the weather conditions.

As far as geotechnical calculations are concerned, the project shows how a simple and an elaborate design method can be linked together despite the differences in the underlying theories, and how external factors can influence the choice of the dimensioning method.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Hänni R., Ris H. 2017. *Geological and Geotechnical Rock Terminology of the Swiss Molasse formation*, research project VSS2010/504, FEDRO RBT.