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Earth retaining structure in Tirana

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ABSTRACT

A large cinematographic and shopping centre is designed to be built in Tirana. It will be a special structure, partially underground, situated in an excavation of depth 22 m, with a minimum distance of 10 m to a large existing shopping centre. For the first phase of the project, the main engineering challenge was to design a safe and economic structure to ensure the stability of the neighbouring existing shopping centre and the ground itself. This paper is focused on the engineering challenges of the design and construction of the earth retaining structure, which was decided to be a combination of a piled wall and reinforced concrete frames forming a rather complicated structure but a very economical solution. The solution described in this paper made the construction costs drop to 35% of the cost of the initial design. The construction of the earth retaining structure began in 2011 and was successfully completed in 2012. The rest of the project, the commercial centre itself, is still under construction.

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Introduction

The main project consists of the design of the new commercial centre in eastern suburbs of the capital of Albania, Tirana. The architectural three dimensional view of the commercial centre is shown in Fig. 1, where it can be observed that it lies in a slope, with the back part underground.

The structural engineering team was given the duty to design an earth retaining structure for the first phase of the project. The total length of the excavation that needed protection was 190 m. Based on the architectural design and the topographic survey, it resulted that the depth of excavation would be approximately 22 m.

Besides the large depth of excavation, the problem was complicated due to the presence of an existing large shopping centre at a distance of 10 m, as illustrated in Fig. 2. The existing structure had two underground stories, which induce pressure to the new structure because of the larger depth of the new one.

Another important requirement from the Client was to ensure passage of vehicles at the top of the excavation. This means that the new retaining structure had to be designed for lateral pressure arising from moving loads too.

The new commercial centre is designed to offer lateral support for the earth retaining structure at the bottom part of excavation. However, until the construction of the underground stories of the new commercial centre, the earth retaining structure must be able to support on itself.

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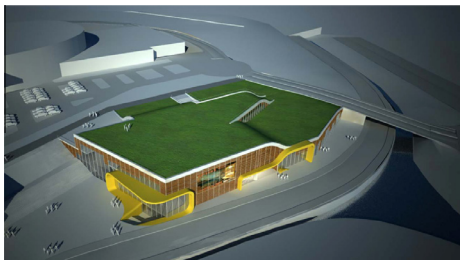

Fig. 1. Architectural three dimensional view of the proposed shopping centre.

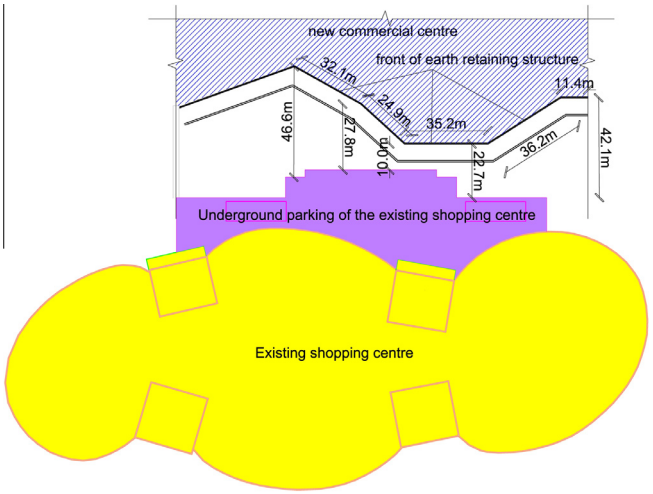

Fig. 2. General layout of new and existing structure.

Design proposals

There was a structural design already prepared for the earth retaining structure, prepared by another design team prior to engagement of the new team. It consisted of a contiguous piled wall, whose cost was found to be unsuitable for the investor. The two main design proposals are described in the following paragraphs.

Contiguous piled wall

The standard construction practice in Albania is to build contiguous piled walls for earth retaining purposes. Also, the shopping centre on top of the excavation was nearly completed and its investors required a quick solution to ensure the stability of the slope and the shopping centre areas nearby. As a result, the first proposal consisted of a "traditional" contiguous piled wall.

The piles of the piled wall had a total length of 37 m, with 15 m length below excavation and 22 m above the bottom of excavation. Due to the large height, the stability of a cantilevered wall could not be ensured, so anchoring was required. The designed anchors had a total length of 15 m and a large number of them were required. The piles themselves had a diameter of 1 m and axial distance between piles smaller than their diameter.

The main advantage of this proposal was the existing expertise of Albanian contractors in execution of similar works (although, with smaller depth). Given the time limitation induced by the construction of the shopping centre on top of the excavation, the construction of a contiguous piled wall was considered a good solution regarding construction time.

The BoQ of this proposal amounted to 2 million Euros, i.e. approximately 10,500 Euros per one metre length of the earth retaining structure.

Piled wall combined with reinforced concrete frames

The new proposal consisted of a combined earth retaining structure, with a piled wall and a reinforced concrete frame as shown in Fig. 3. The basic idea that led to this design proposal was the drastic reduction of earth pressure in the upper 12 m of the structure. This was achieved by replacing the piled wall with a reinforced concrete frame at the top 12 m.

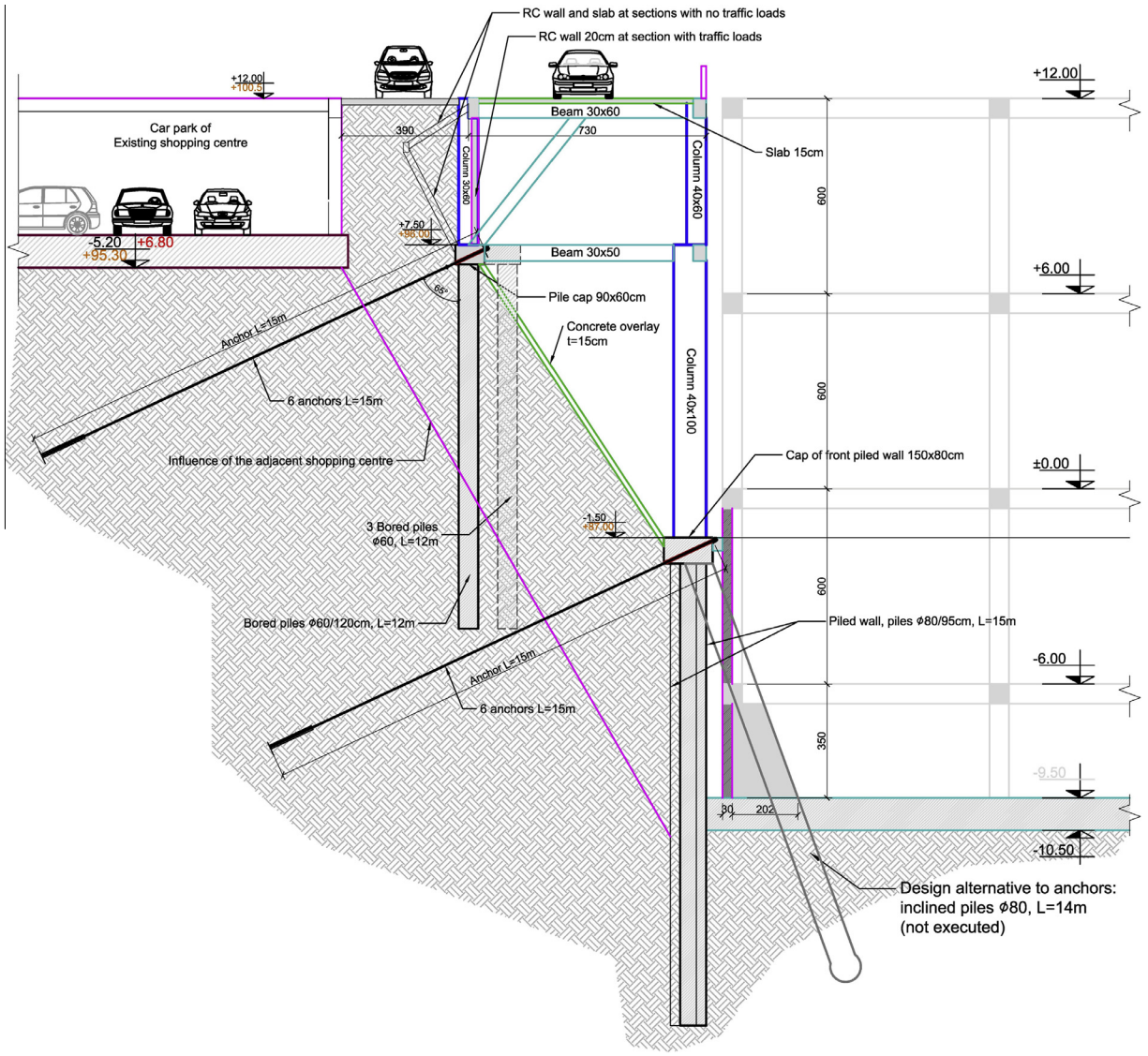

Fig. 3. Cross section of the earth retaining structure, second proposal.

The frame consisted of front columns in line with the piled wall, bored piles 7 m behind the front line of excavation, bracing reinforced concrete elements, a slab on top of the structure and a few other complementary elements. The frames were placed at a distance of approximately 6 m apart from each other. The inclined bracing reinforced concrete elements have three main functions. First, they offer increased stability and stiffness to the structure. Secondly, they reduce the span of the horizontal beams under traffic actions, transforming them into two span continuous beams. Finally, the horizontal component of these elements' axial forces acts as a stabilising force for the back piles. Any negative effects of this structural scheme (such as axial loads in beams) were addressed carefully during design and the necessary measures were taken.

The slab on top ensured that the area above the excavation could continue to be used as a passage for vehicles, while reducing the lateral pressure to the structure. The slab transfers only vertical loads and bending moments to the front columns and the back piles.

The stability of the top 4.5 m was ensured by a simple scarification of the slope during construction. So, excavation of the top 4–5 m could be done without special measures for the stability of the slope. However, to ensure that no land is lost on top of excavation, the top 4.5 m needed to be backfilled. The stability of backfill was ensured by a vertical reinforced concrete wall at areas near the existing shopping centre and by a rotated V-shape assembly of a reinforced concrete wall and slab. The reason for using such a complicated structure is the reduction of lateral pressure transmitted to the main structure. The reduction is significant, and anchors are not required at section where this assembly is applied. The reinforced concrete wall has very low earth pressure, because of its angle of inclination being comparable to the angle of internal friction of the soil.

Fig. 4. Photo during the construction of the frames.

Fig. 5. Photo of completed frames (left) and present state of the structure (right).

As a result, the wall supports predominately axial loads arising from the surcharge. The wall is designed also for bending moments caused by its fixity with the slab. The slab supports low axial loads and relatively high bending moments (because of the surcharge). At areas with traffic on top of the excavation, this solution was found to be unsuitable. In this case, a reinforced concrete wall and anchors for the back piles were used (see Fig. 3).

The relatively favourable soil properties in the upper 12 m made it possible to ensure the stability of this part of excavation through bored piles of 60 cm diameter at a distance 3 m apart, situated at level −4.5 m. The stability of the soil in between the piles was ensured by giving the cross section a slope and by overlaying a reinforced concrete slab with thickness 15 cm. The drainage ducts were provided in the reinforced concrete overlaying slab to ensure drainage of water. The horizontal earth pressure that these piles carry is transmitted to the main piled wall at the bottom 9 m of the excavation, thus making the piles much more comfortable compared to the initial 22 m of earth pressure. Anchoring of the bored piles at cap level was found necessary at certain segments of the earth retaining structure. The anchorage made it possible to reduce the length of the back piles to the final length of 12 m.

The main piles of the piled wall in the front line of excavation (under the columns) were designed with diameter 80 cm and they were placed at a centre to centre distance of 95 cm with a staggered alignment of 30 cm from the straight line. This way, the clear distance between piles was up to 20 cm, which was allowed by the soil conditions. Piled walls for excavations up to 9 m are wide spread in Albania, so the main piled wall may be considered in normal conditions now, compared to the "extreme" initial conditions. Furthermore, the lower 9 m of excavation are only temporarily required to be protected by the earth retaining structure, until the new commercial centre offering lateral support for the main piles is built.

The obvious advantage of this structural scheme is the considerable reduction of design internal forces in main structural elements, resulting in economical cross section dimensions and low reinforcement ratios. However, there are lots of challenges. First, the proposed structural scheme has relatively difficult detailing requirements, mainly due to the presence of inclined structural elements. Considering the fact that the terrain is not favourable, there might be difficulties in the execution of reinforcement details. Another challenge (or disadvantage) is the number of structural elements to be designed. This proposal has front piles, back piles, columns, walls, horizontal elements, anchors, bracing elements and the slab, which require high design effort compared to the number of structural elements of the first proposal.

At the end of the design, this structural scheme resulted in a much more economical design than the first solution, with a BoQ that amounted to 700 thousand Euros, i.e. approximately 3685 Euros per metre length of the structure.

Project implementation

The investor accepted the new proposal, due to its obvious benefits regarding construction costs.

The implementation of the first phase of the project (i.e. the earth retaining structure) started with the detailed topographic demarcation of the site and structure. The execution of works for construction of the earth retaining structure followed a rigorous sequence and time schedule, as recommended by the structural engineering team.

Excavation of topsoil down to depth 4.5 m on the entire length of the structure started immediately after the demarcations. The excavation face did not require special treatment to ensure the stability because of the good properties of the soil and good weather conditions at time of construction. The excavation face near the existing shopping centre was given a slope imitating the natural state of surrounding earth, while preparing it for the construction of the reinforced concrete overlaying slab.

After the excavation of topsoil, the site was prepared for the construction of back piles. A flat area with width 770 cm (enough to ensure safe passage of construction vehicles) was prepared at the end of excavations of topsoil. The back piles were constructed through drilling and concreting, without steel jacketing. A reinforced concrete cap connecting the concreted piles was built on top of them in accordance with the drawings and specifications given by the designers. Special attention was paid to the correct execution of reinforcement details of the cap. It was made clear to the contractor that these details have a great influence on the next construction stages. The reinforcement of bracing elements and other interconnecting elements had to be positioned correctly before concreting the cap. Also, ground anchors located at the top of the back piles were built during this phase. According to the design, anchors were necessary only in vicinity of the car park of the existing shopping centre, where lateral pressure is high. Careful execution of works ensured successful construction of the anchors underneath the existing foundations without causing any damage to the existing structures.

After the completion of the cap, the next stage consisted in construction of frame elements such as horizontal elements, columns above the already built bored piles and inclined elements. Next, the excavation of the slope began down to further 9 m in depth, reaching the level of front piled wall cap. A photograph taken at this stage is shown in Fig. 4, where the back piles and nearly half of the frame have been built.

For the execution of front piled wall, it was necessary to build a temporary site road for equipment and machinery. The front piles were drilled and concreted in the next stage, followed immediately by the construction of their cap. Reinforcement details of the front columns were carefully positioned into the piled wall cap prior to concreting.

Probably the most difficult stage was the next one, consisting of the construction of the final details of the earth retaining structure. The partially built structure had a few missing elements, such as the front columns and nearly half of the length of horizontal and bracing elements. Their reinforcement had to be carefully positioned in the intersection joints with the already built elements. Another challenge was the construction of columns with height 9 m while ensuring good vibration of concrete. To achieve this, the concreting was done in three levels of the column (at 3 m, 6 m and on top). The successfully completed frames and development of excavation down to the level of the front piled wall are shown in Fig. 5.

After the completion of all the structural elements, including the top slab and interconnecting horizontal elements, the structure could be considered complete in 2012 (Fig. 5, right). The only missing structural elements are the anchors at the front piled wall. They are intended to be built after the excavation of the top three metres below the level of the cap. The ducts for the anchors are already prepared, however few concrete drilling works might be necessary during construction. The construction of the new shopping centre has not yet begun, but the earth retaining structure is ready for the continuation of excavations.

Conclusion

The construction cost of the combined structure amounted to 35% of the total predicted construction cost of a "traditional" contiguous piled wall. The two proposals described in this paper were widely discussed by the design team prior to the presentation of the project to the Client. Especially for the second proposal, careful constructability options were discussed, in order to ensure that the execution effort would not top the BoQ prediction.

A careful construction sequence ensuring safe and reliable construction of the structure during all the phases of execution was clearly defined in the design. The design team recognised the importance of a clearly defined construction sequence which would influence the safety of the structure during execution and working life. The design team concluded that the second proposal, the one comprising of the combination of a piled wall with reinforced concrete frames, is the most technically acceptable solution and the most economical.

Acknowledgement

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