Deep excavation construction by top-down method in Zagreb

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Abstract

In the old central part of Zagreb, among a block of buildings, a business facility is being built. The underground structure consists of 5 belowground floors, with maximum excavation depth of around 19 m. For construction of belowground floors the so-called "top - down" method is used. This method is useful to avoid long-term work on the construction of geotechnical anchors and tampering of nearby parcels. Excavation support is ensured by a 24.5 m long reinforced concrete diaphragm wall held by floor slabs of the underground levels. The reinforced concrete diaphragm wall is designed as a permanent structure and presents a vertical cap wall of the underground part of the building. Floor slabs are retained with steel columns, which are founded on drilled shafts \( \varnothing 120 \) cm, 12 and 15 m of length.

Keywords: design principles, excavation, diaphragm wall, floor slab, steel column

1. INTRODUCTION

The city of Zagreb is the capital and the biggest city of the Republic of Croatia, a Central European city of rich history and cultural tradition. The city covers an area of 641 km\(^2\) with ca 800 000 residents.

A residential and commercial building called the Ban centre is located at the very heart of the city (see Figure 1), some 100 m from the Cathedral, the seat of the Zagreb Archdiocese on the Kaptol hill and near the city’s main square called – Trg bana Jelačića. The Ban centre should consist of five belowground floors, four of which are designed for garages, and eight aboveground floors for residential and commercial purposes.

Figure 1. Position of the Ban centre in Zagreb

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An underground part of the structure covers 3327 m² and the range of 290 m. The walls of aboveground floors are leaning on the diaphragm wall on the southern and western contour. The total excavation depth is 18.5 to 19.5 m under the surface of surrounding streets.

The residential and commercial Ban centre complex is close to surrounding buildings of various floor heights on the eastern, southern and western contour (maximal CL+BS+7). Some of the neighbouring buildings are of great significance, such as the Zagrebačka bank building, the Central Post Building and the Dental Clinic. On the northern side there is Cesarceva Street running up to Kaptol, i.e. to the Zagreb Archdiocese and to the Cathedral.

To minimize the impact on the existing buildings the construction pit should be set up using the top-down method, i.e. the construction from the top down. The Ban centre pit is one of the two pits being constructed by applying top-down method in Zagreb. Both pits were designed by the IGH Institute, and geotechnical works (reinforced concrete, diaphragm wall construction, bored piles construction and embedding of steel columns) are performed by the Geotehnika - Inzenjering Company.

2. LOCATION

The following contents and soil layers characteristics of the relevant area were determined on the basis of conducted investigations (significant soil parameters are shown in Table 1.)

Table 1. Design soil parameters

<table>
<thead>
<tr>
<th>Layer</th>
<th>Symbol</th>
<th>Model</th>
<th>$\gamma$ (kN/m³)</th>
<th>Material behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fill</td>
<td>MC</td>
<td>20</td>
<td>Drained</td>
</tr>
<tr>
<td>2</td>
<td>CL</td>
<td>HS</td>
<td>19</td>
<td>Undrained</td>
</tr>
<tr>
<td>3</td>
<td>GC</td>
<td>HS</td>
<td>20</td>
<td>Drained</td>
</tr>
<tr>
<td>4</td>
<td>CL/CH</td>
<td>HS</td>
<td>20</td>
<td>Undrained</td>
</tr>
</tbody>
</table>

2.1 Geotechnical characteristics of the location

The following characteristics and soil layers of the relevant area were determined by the conducted investigations (significant soil parameters are shown in Table 1.)

- Surface layer made of asphalt, then clay, rubble and concrete fill of varying thickness up to a maximum of about 3 m (layer 1).
- Under the surface layer there is a clay layer of low plasticity with or without sand (indicated by CL, CL/S) (layer 2).
- Under those layers there are heterogeneous layers of clay, silt, sand and gravel, from loose to medium compactness, and of varying layer thickness from depth of 12.9 m to 18.0 m (mainly layer 3.).
- The base is pre-consolidated clay of low to high plasticity (indicated by CL/CH) of half-firm to firm consistency up to the investigated depth of 30 m (layer 4).

The highest ground water level is 10 to 12 m under the terrain surface.

2.2 Description of retaining structure

Stability of the construction pit is diaphragm wall, which was designed as a permanent structure, it also forms the perimeter bearing wall.
of the belowground part of the building. The diaphragm wall excavation depth is 23.5 m, 5.7 m of which is under the excavation bottom. A layer of firm pre-consolidated high plasticity clay is present in the lower 6 to 7 m of the diaphragm excavation (layer 4 in Table 1.), which eliminates the seepage of ground water through the construction pit bottom. The retaining structure consists of (see Figure 3):
- 60 cm thick and 23.5 m long reinforced concrete diaphragm wall (see Figure 4).
- Ø60 cm jet grouted columns of 6 to 7 m long under the foundation of adjacent high buildings.
- Four 30 cm thick braced floor slabs and foundation slabs
- Ø120 cm reinforced concrete bored piles length of 12.0 and 15.0 m under the base of excavation (see Figure 5).
- Temporary steel columns of belowground floors – HEM 400.
- Concrete columns/piles of belowground floors.

Floor slabs are compressive elements of the support structure taking over soil and water pressures. They have large longitudinal stiffness and practically eliminate subsequent horizontal diaphragm displacements in the strutting levels. As floor slabs are being constructed prior to the excavation of each individual phase, the top-down construction with removal of excavated soil through temporary openings in the floor slabs is applied. Such a technology requires a high quality performance of diaphragm’s vertical element joints.

Steel columns, which have been previously directly driven into reinforced concrete bored piles through casing drilling, take over the load from the floor slabs of belowground levels in the construction phase. To reduce the buckling length of slender steel columns the area between the cased drilling for the piles and embedded steel profiles is filled with river gravel. In this phase the floor slabs’ load is taken over to the ground by the piles and diaphragm wall. Following the foundation slab construction the reinforced concrete columns and walls dimensioned on the building’s total load are going to be erected around steel columns (down-top construction).

The advantages of such construction type for the belowground structure are the following:
- Safety of design solution.
- Savings in construction time.
- Diaphragm wall represents a perimeter bearing wall of the underground part of the building.
- Savings in time and costs

Special requirements for protective structure and construction pit excavation:
- The need for the foundation operations for the load bearing structure’s columns on the reinforced concrete piles due to retaining of the floor slabs’ load up to the completion of piles’ and foundation plate becoming monolithic
- The need for a precise construction of diaphragm wall segments to eliminate seepage of ground water on the segments’ joints.
- Construction precision (horizontal positioning and verticality) of steel columns driven into piles.
- Complex technological solutions for the connections of the structure’s horizontal elements with temporary columns and RC diaphragm wall.
- Heavier digging of the construction pit and a more difficult removal of soil.
2.3 Description of the construction technology

Preparation works, excavation and diaphragm wall construction, piles and temporary steel columns driving, and diaphragm wall bracing are carried out through the following phases:

1. Preparation works and placement of the working platform for the diaphragm wall and piles driving.
2. The construction of the inlet channel for the diaphragm wall excavation.
3. Excavation work for the diaphragm wall in the segments of 23.5 m excavation depth with a special machine with bentonite slurry (see Figure 4).
4. Embedding of diaphragm’s rebar cages and concreting (see Figure 4).
5. The construction of diaphragm’s head beam.
6. The construction of the jet grouting column (diameter 60 cm, length 7-8 m, axial distance 40 cm) under the foundation of existing high buildings.
7. Construction of reinforced concrete bored piles ∅120 cm (see Figure 5).
8. Embedding of steel columns HEM 400 into the bored pile.
9. Filling the area between the casing and steel profile with river gravel.
10. Construction of floor slabs
11. Undertaking of the pit excavation
12. Construction of the foundation slab

2.3.1 Technology of the RC diaphragm wall construction

The excavation for the diaphragm wall (see Figure 4) has been performed in segments by means of 60 cm wide and 250 cm long special machine’s grab under a continuous protection with bentonite slurry. All the corner panels were carried out in one segment to avoid interruptions in concreting and ensure water tightness. The adopted allowable maximal excavation deviation from the vertical is 0.5%, which is a stricter condition than the one implied in the norm EN 1538: 2000.

The connection between several segments was executed by constructing specially prepared border elements (prefabricated reinforced concrete I profiles with embedded seals) in order to achieve water tightness.

Two rebar cages at the 25 to 35 cm distance were rammed into either segment, (to enable embedding and concreting under contractor procedure), into which the Comax elements for the connection with floor slabs were put in. The adopted deviation in the cage positioning according to height was ±1 cm.

After the cages were positioned the concreting of the diaphragm wall was performed by means of contractor’s procedure with the concrete.

2.3.2 Technology of the bored piles construction and embedding of steel columns

Bored piles (see Figure 5) were constructed applying the excavation protection with steel casing of 1200 mm outer diameter up to the entrance into underlying clay, i.e. 0.5 – 1.5 m above the concreting level (layer 4 from Table 1A requested deviation from the ideal position
was ±5 cm, and from the vertical 0.5%, which is stricter than requests according to the EN 1536: 1999. The drilling depth was 29.80 and 32.80 m. The effective piles' lengths under the excavation were 12 and 15 m.

After the completion of the excavation the rebar cage was rammed into the bored pile followed by concreting by means of contractor procedure.

In the sequence a steel column was driven into the bored pile (steel profile HEM 400 with structural elements for the connection with floor slabs). The columns' positioning was performed using a specially prepared structure mounted on the casing drilling. Such structure enabled nearly ideal verticalization of the column with a deviation in relationship ±1 cm to the needed position. The concreting of the lower 3 m piles followed, which means making the structure with the steel column to act compositely.

Due to the buckling length reduction the area between casing drilling and steel column was filled with river gravel while extracting casing drilling after the completion of concreting works.

### 2.3.3 Technology of the slabs construction and the joint with piles and diaphragm wall

RC floor slabs of the cellar will be carried out on the levelled soil following the excavation. The layer of lean concrete and protective foil separating lean concrete from the concrete of the slab structure are going to be laid on the levelled soil. The procedure implies that it can be easily removed after resuming excavation under concreted floor slab.

Prior to laying reinforced floor slab the COMAX elements (see Figure 6) will be set on the diaphragm’s front, which will become accessible now after excavation. They are designed to take over the role of the linear support along the floor’s perimeter. All steel columns are being prepared forehead for the construction of the joint with floor slabs, in the manner shown in Figure 7. A 300/700/2.5mm steel plate will be set up, which will be used as a supporting surface of the RC floor slab on the steel column in the first phase. The Ø28mm holes for the passage of floor slabs’ rebar chords will be made.

The preparation for the construction of RC columns into the floor slab in the second phase includes setting up of the PVC precast pieces.

![Figure 6. Positioning of the COMAX elements on the diaphragm's rebar cage](image)

### 2.3.4 Excavation technology

The excavation of the structure is being carried out after the construction of reinforced concrete diaphragm wall and the bored piles.

At the beginning the digging reaches the lower dimension of the plate of the underground floor's first level where the reinforced -1 floor slab is being concreted on the beforehand prepared soil. Then follows the tunnelling excavation under -1 floor slab reaching down to -5 floor, where the reinforced concrete base gets constructed in the last phase.

Tunnel excavation is being carried out simultaneously through two phases from both sides. The first phase is the excavation (taking the material out), carried out by a big excavator, with a 20 m arm length, located close to the diaphragm wall, itself. The work involves leaving an opening in each reinforced slab of the underground garages large enough for the excavator’s work.

The tunnel excavation under reinforced concrete slabs is being carried out by means of tunnelling machines. The machines are going to push the material towards the excavator, so that it can take it out and load it into vehicles, which will take it away to the waste disposal.

The second excavation phase ensues over descending and ascending ramp used for loading
and taking away of the excavated material. The tunnel excavation in the second phase is being carried out in the same way as in the first, but this time the machines digging the material perform the loading into the lorries during the same process.

The building is being ensured from the uplift pressure during erection by constructing a drainage layer under the foundation plate, so that seepage water is being collected through sump shafts and transported by means of automatic pumps into the sewers.

Figure 7. Preparation of hanging plate_1 floor

3. CONCLUSIONS

Ban Centre is an important project for Zagreb city and engineers working on it due to its construction complexities, requiring maximum involvement of both, engineers and workers. As one of the most important things that requires special attention is that diaphragm wall, bored piles and HEM profiles must be performed on exactly precise way since their accuracy is the base of the design of floor slabs. It should be noted, that previous experience on the project "Cvjetni prolaz" was our great advantage, as we were able to avoid certain problems and perform work without major difficulties.

Now, the project is in progress according to the plan and is in the last phase of the excavation.

REFERENCES