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DESIGN AND EXECUTION OF TURDAS TUNNEL

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Abstract

The paper presents aspects of the design and execution of the Turdas tunnel located on the local variant (route), on the Coşlariu - Simeria section, from the rehabilitation project of Brasov – Simeria railway line, component part of Pan European Railway Corridor IV, for train circulation with maximum speed of 160km/h. The tunnel crosses through alluvial deposits with silt and clay with locally sand layers at the upper part, sand and gravel with water in the middle part and marly silty clay and neogenic marl, with swelling phenomena, at the lower part. The overburden is between 2.00m and 13.00m. The initial project provided execution in underground, on 510.00m in the central area and from surface at both ends, 225.00m at the entrance and 45.00m at the exit. The new optimized project, based on new geological and geotechnical studies, proposed an execution from surface for the entire length of the tunnel. To establish the optimal solution two methods of surface execution and structural solutions were analyzed comparatively: ”Cut and Cover” and ”Cover and Cut”. The adopted method was “Cut and Cover”, with a structural solution composed of a temporary retaining structure – diaphragm walls with a special internal lining. This has been divided in six sections with different behavioral types, taking into account the ground configuration in longitudinal profile and the geological and geotechnical data. The technological execution phases are presented in detail. To investigate the behavior of this type of structure under soil and swelling actions, three-dimensional finite element analyses were carried out, taking into account the execution phases for each cross section. A monitoring system was provided to verify the stresses in the temporary retaining structure and the internal lining and also to calibrate future calculations.

Keywords: tunnel, surface execution, design, Cut and Cover

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1. INTRODUCTION

In Romania, tunnels built from surface are present in all existing ways of communications: subway, railway and road.

Concerning the subway, the majority of stations, from lane I, along Dambovita River to those of the Vth lane - section of 800m between Raul Doamnei and Valea Ialomitei station – were built from the surface.

Using surface execution methods, before 1990 were built the tunnels against rocks falling on DN7C – Transfagarasan and the passages in Bucharest, while the Sacel tunnel and ecoducts on Highway A1 were completed after 1990. [1]

When it comes to the railway network, before 1990 were built the tunnel under crossing the Coal Road, on railway line Albeni - Alunu and the majority of the constructions against rocks falling on railway lines on Valea Jiului and Valea Oltului. The tunnels built after 1990 include Sighisoara and Danes, both containg parts with surface execution and the Turdas tunnel, which is the first tunnel entirely built by Cut and Cover method. The present paper presents the Turdas tunnel. [1]

The Turdas tunnel is located on the railway section between Coslariu and Simeria, which is part of the Brasov – Simeria railway line and part of the Pan European Railway Corridor IV.

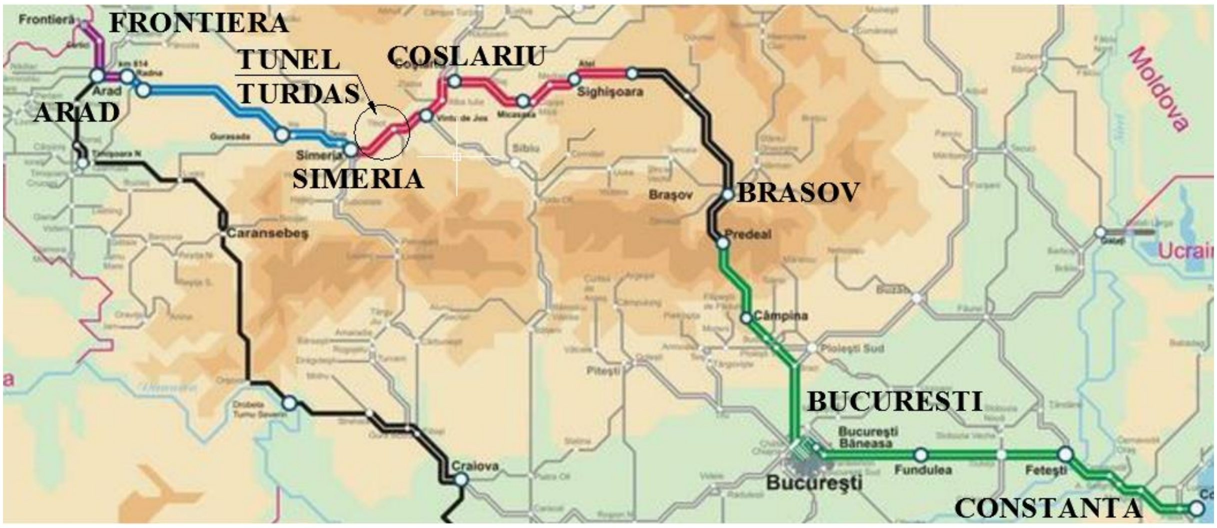

Figure 1. Pan European Railway Corridor IV – Turdas tunnel [2]

The Turdas tunnel is located between km 456+295 – km 457+075, having a length of 780 m, on the local variant (route) of the Coslariu – Simeria railway line, part of interval Vintu de Jos – Simeria, the local line being done during the line rehabilitation for maximum circulation speed of 160 km/h for passenger trains and 120km/h for freight trains.[3]

In plan the tunnel has a curved shape with a radius R=3000 m, on 605 m length between km 456+295 and km 456+900, followed by a connection curve, with a length of 80m and an alignment for a length of 95m. At the entrance and exit points of the tunnel are present two portal rings of 5.85 m each. In longitudinal profile the slope is i=5‰.[3]

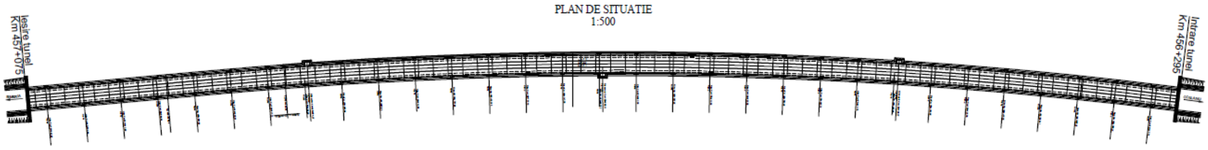

Figure 2. Plan view – Turdas tunnel [3]

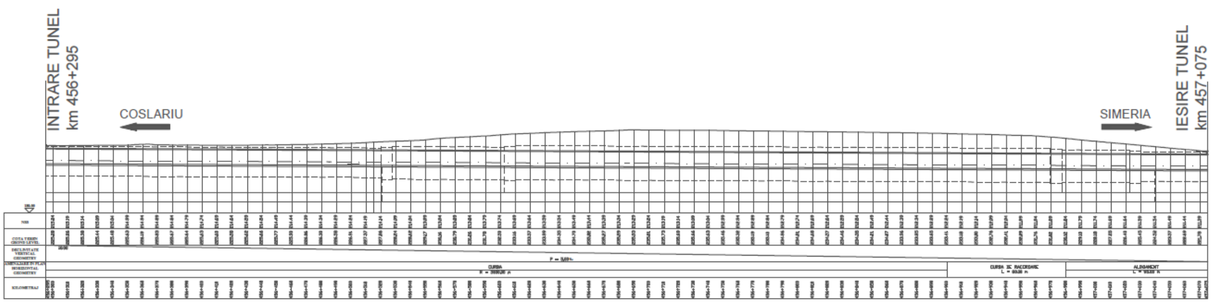

Figure 3. Longitudinal profile – Turdas tunnel [3]

2. GEOLOGICAL, GEOTECHNICAL AND GEOMECHANICAL CONDITIONS

The Turdas tunnel is located on the left side of the Mures River, in a hilly area with low slopes, whose slope rarely exceeds $4^0 – 5^0$.

The geological structure is characteristic for a river meadow and low terrace with alluvial Quaternary deposits represented by (from the top) clay and silts, continuing in the depth with coarse - medium sands passing gradually into gravel, having a quasi-horizontal setup and being slightly tilted towards the Mures riverbed. below these terrace formations, there are deposits from Neogene period represented by clayey and sandy marls, marly clays, sandstones, marly sands, clays and tuffs.

As a result of all the surveys made in the area the groundwater was intercepted as an unconfined aquifer. In the tunnel area, the free level of the groundwater ranges from -4.00 m to -11.00 m from the surface, following a normal, uniformly descending gradient to the Turdas stream, respectively to the Mures River. The four characteristic types of soil are presented Table 1.

Table 1. Typical soil types [3]

1.	Weathered layer, consisting mainly of dark brown silts and clays, very stiff
2.	Silts and clays within the cover unit with varying amounts of sand, stiff – very stiff consistency
3.	Sand and gravel layers within the cover unit.
4.	Marly clays (sandy) and neogene marl with sandy intercalactions, stiff – very stiff

Diffractometry analysis with X-ray was performed on various samples in order to determine the composition of fat clays and gypsum intercalations. This was determined on a multiple number of samples which presents a considerable content of swelling clay minerals. [3]

The ground has been characterized as active to very active according to the swelling pressure.

3. CHOICE OF EXECUTION METHOD AND CROSS SECTION

The initial project of the Turdas tunnel presumed two execution methods: natural tunnel on the central area on 510m length and at the ends, execution from the surface on the tunnel entrance on 225m length and at the end on 45 m. The typical cross section was provided for:

a. Zone with execution from the surface: pile walls on both sides of the tunnel entrance, at 17 m distance one from another, 1.20m in diameter thick disposed at 1.50 m inter – axis distance, with a capping beam of 1.50x1.00m; the finale structure is composed of an arch of 1.00m thickness, straight legs – 2.75m thickness, invert – 1.00m thickness (figure 4).
b. Zone with underground execution: shotcrete lining – 25 cm thick reinforced with fibers, steel ribs - IPE200, waterproofing, internal lining – 90cm average thickness reinforced concrete, invert – 1.00m thickness (figure 5).

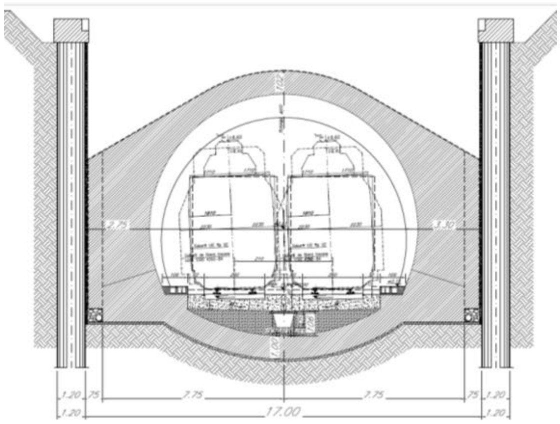

Figure 4. Initial cross section – surface execution[4]

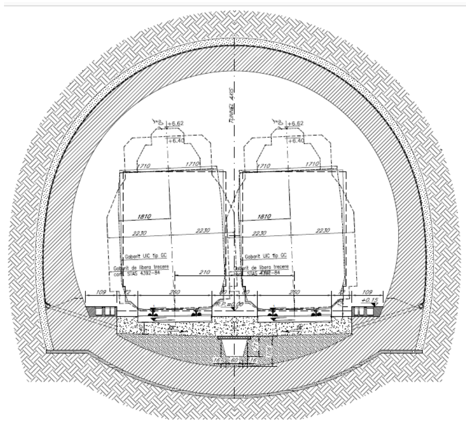

Figure 5. Initial cross section – underground execution[4]

Conventional method of execution is used for the central area, with a coverage between 4.00 – 13.00m. The proposed technology of execution consists of: [4]

- Consolidation of the sand-gravel layer, before excavation, using jet grouting from the ground level (figure 6);
- Ground and front consolidation on the excavation perimeter with fiber glass anchors: fiber glass anchors, 20cm of shotcrete with fibers, water drainage and single stage excavation (figure 7);
- Installation of the external lining composed from: steel ribs IPE200, 25 cm of shotcrete reinforced with fibers;
- Installation of the intermediary waterproofing, internal lining of reinforced concrete with average thickness of 90 cm and execution of the invert with thickness of 1.00m.

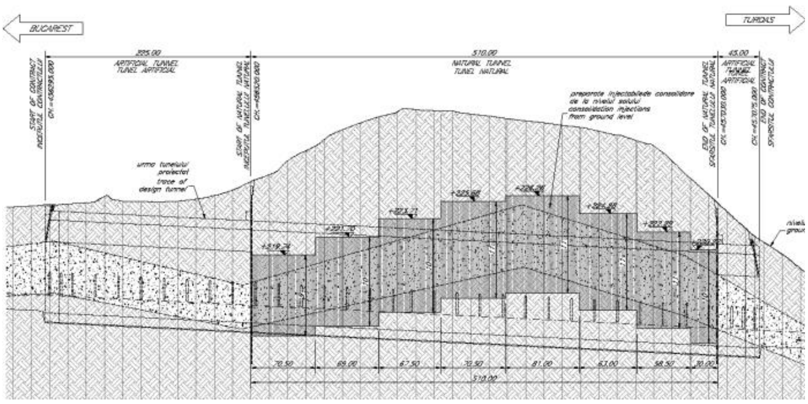

Figure 6. Initial longitudinal profile and consolidation of sand-gravel layer by jet grouting [4]

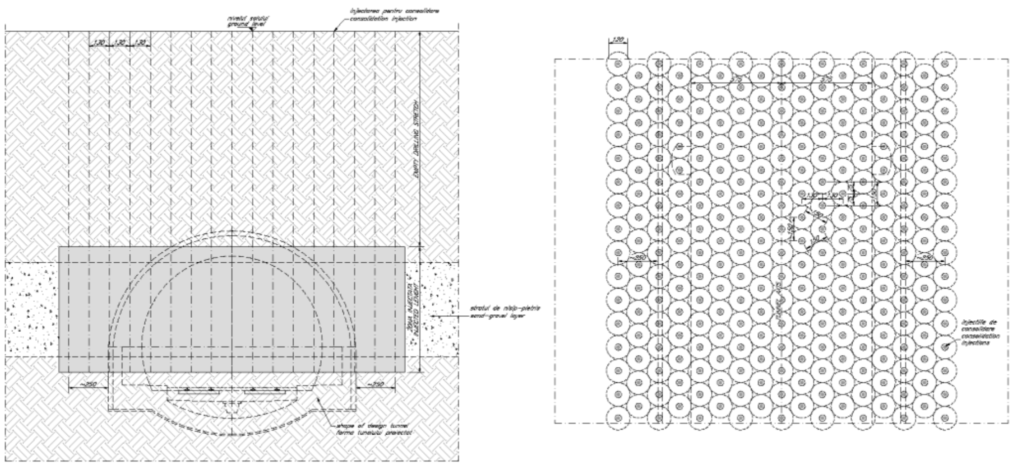

Figure 7. Initial cross section and plan view consolidation of sand-gravel layer by jet grouting [4]

After a new geotechnical study has been carried out, it resulted the need to adapt the initial project and therefore an execution from surface has been adopted for the entire tunnel, with the purpose of structural and economical optimization and reducing the execution time.[4]

The new solution of surface execution for the entire tunnel is supported by the following arguments: [4]

- low coverage and area subjected to temporary expropriation of about 70m wide;
- surface execution involves fewer hazards and risks than underground execution and it better suits the new geotechnical conditions.
- prevents water infiltration at the bottom of excavation and invert and reduces the swelling phenomenon

In order to determine the optimum cross section, two possibilities for surface execution were taken into account: cut-and-cover (fig. 8) and cover-and-cut methods (fig. 8). For the two solutions, two calculation models were developed using a finite element software.

Following the obtained results, the optimum solution was chosen taking into account the resulted stresses and this was the cut-and-cover method, which was later optimized.

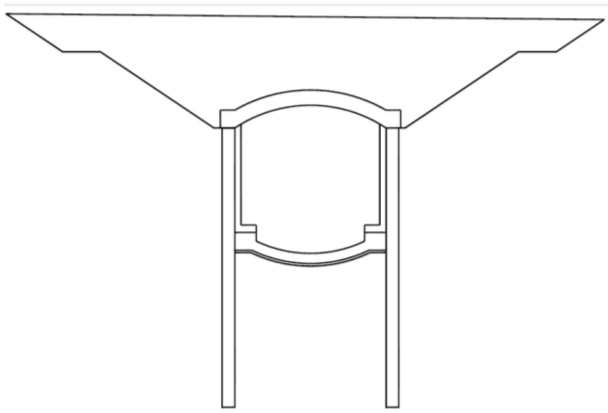

Figure 8. Cover-and-Cut cross section

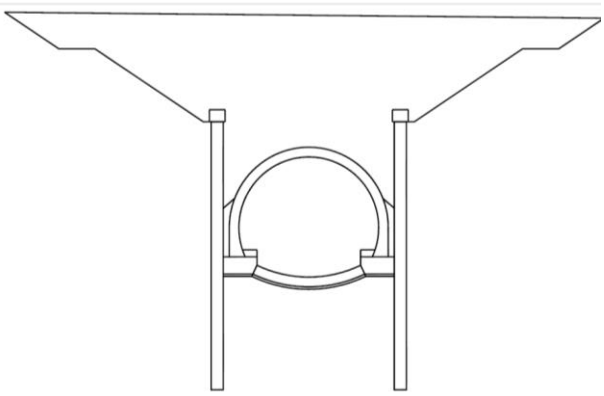

Figure 9. Cut-and-Cover cross section

The inner section was established based on gauges of rolling material, pantograph and catenary according to UIC standards, code 4392 – 84 - Railway gauges and TSI 2008/163 – Safety in railway tunnels. The adopted inner section has a round shape, with radius of 5.80m, for double track railway with the distance between lines of 4.20m and the height from the upper level of sleepers (NST) of 7.87m, the distance from the axis of the railway to the stay sill of 2.20m, and the stay sill of 1.20m.

The adopted designed execution method was cut-and-cover and the cross section is in accordance, being composed of (fig. 10):[3]

- primary outer support, composed of 80cm thick diaphragm walls on both sides on entrance, at 14.40m distance one from another and variable depths between 20.00m and 23.00m;
- final lining made of reinforced concrete C30/37 – 60cm thick, at the bottom an invert – 1.00m thick and foundations of 1.60m thickness.

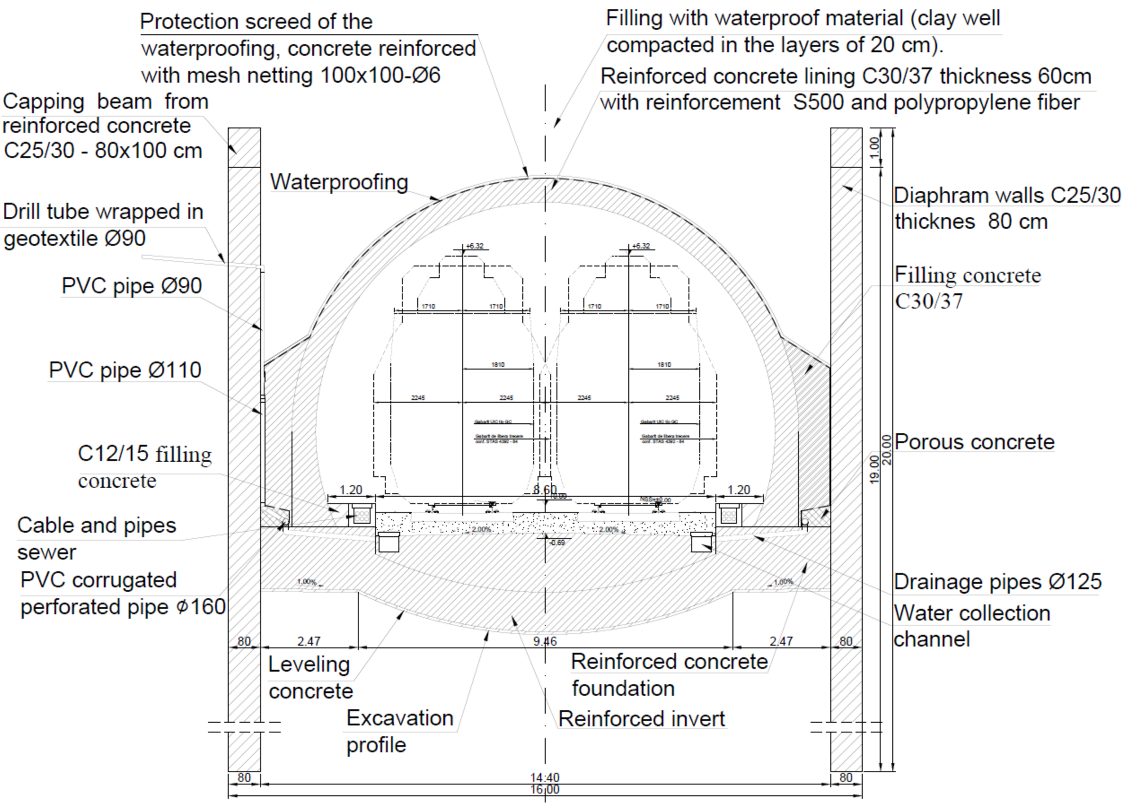

Figure 10. Adopted cross section [3]

The execution technology for the Turdas tunnel is cut-and-cover and the steps for this method are: [3]

- stepped execution of the temporary open excavation;
- execution of the working platform for diaphragm walls execution;
- execution of guide walls;
- panels excavation for diaphragm walls
- execution of the capping beam of the diaphragm wall;
- excavation between diaphragm walls until below the first row of struts;
- installation of the first row of struts;
- excavation until below the second row of struts;
- installation of the second row of struts;
- excavation until the final level (figure 11);
- pouring the blinding concrete 10 cm thick;
- execution of invert and foundations;
- removing inferior level of struts;
- execution of straight legs, arch and pouring concrete filling;
- restoration of natural ground at surface.

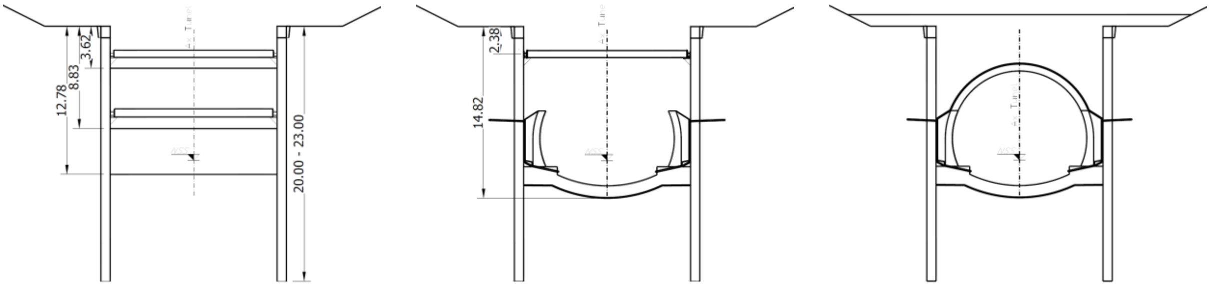

Figure 11. Phases of execution [3]

Taking into account the ground configuration in longitudinal profile and the geological and geotechnical data, the ground has been divided for calculation purposes into six characteristic sections: type I – around 165 m length, type II – around 60 m length, type III – around 80 m length, type IV – around 380 m length, type V – around 50 m length, type VI – around 45 m length.[3]

The clays present on site have swelling pressures between 50 kPa to 400 kPa, requiring preventive measure as: [3]

- using continuous diaphragm walls for preventing water ingress at the bottom of the invert;
- execution of a water collection and evacuation system;
- invert and foundations to be connected by chemical anchors to the diaphragm walls.
- calculations have been performed using Midas GTS NX software, which uses finite element analysis and can handle a full range of applications for geotechnical projects as deep foundations, excavations, complex tunneling systems, infiltrations analysis, ground consolidation and slope stability analysis.[3]

The software can simulate various execution phases, in our case 15 execution phases for each cross section were considered. The considered soil constitutive law was Mohr-Coulomb.[3]

The swelling pressure was taken into calculations by applying an uniformly distributed force of 200kPa on the invert, oriented towards the surface.[3]

The numerical model is shown figure 12 and a modeled execution phase it is shown in figure 13.

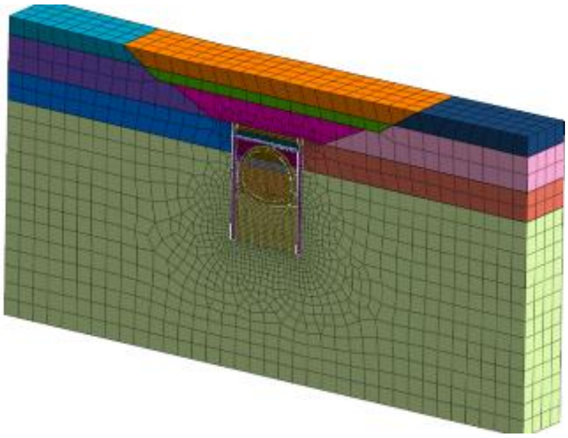

Figure 12. Structure geometry and mesh for the calculation model [3]

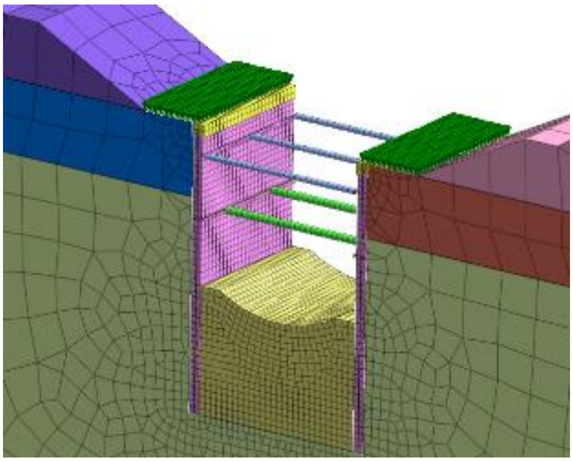

Figure 13. Excavation until final level[3]

The stress diagrams, bending moment - M [kNm], axial force - N [kN] and shear force - T [kN], obtained for the diaphragm walls are presented below for two execution stages: figure 14 - final excavation and figure 15 - removing inferior strut.

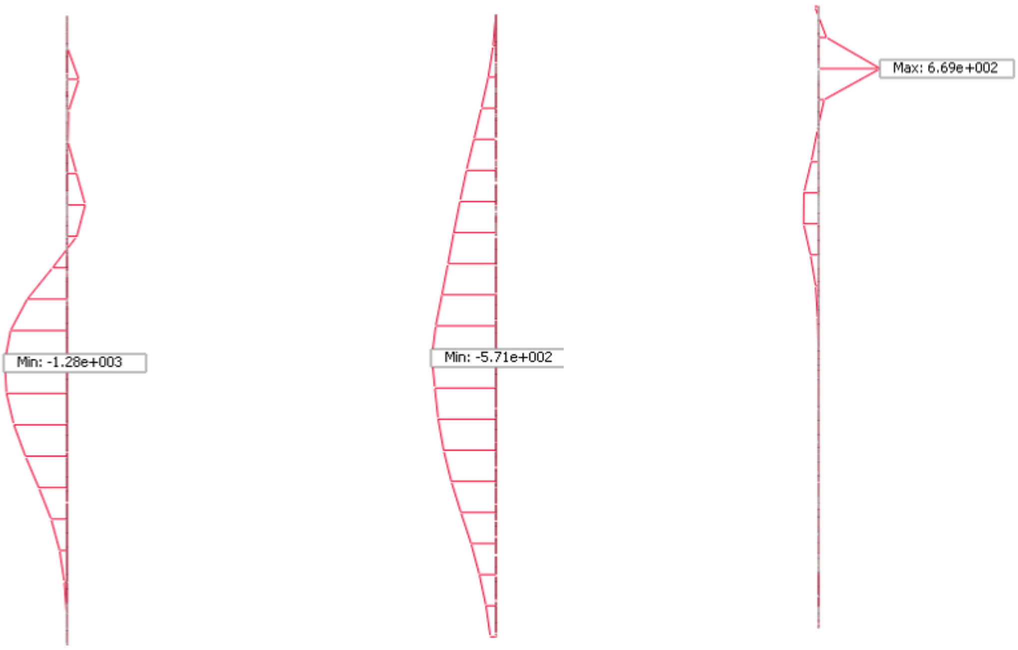

Figure 14. Stresses M, N, T for the diaphragm walls in final excavation stage[3]

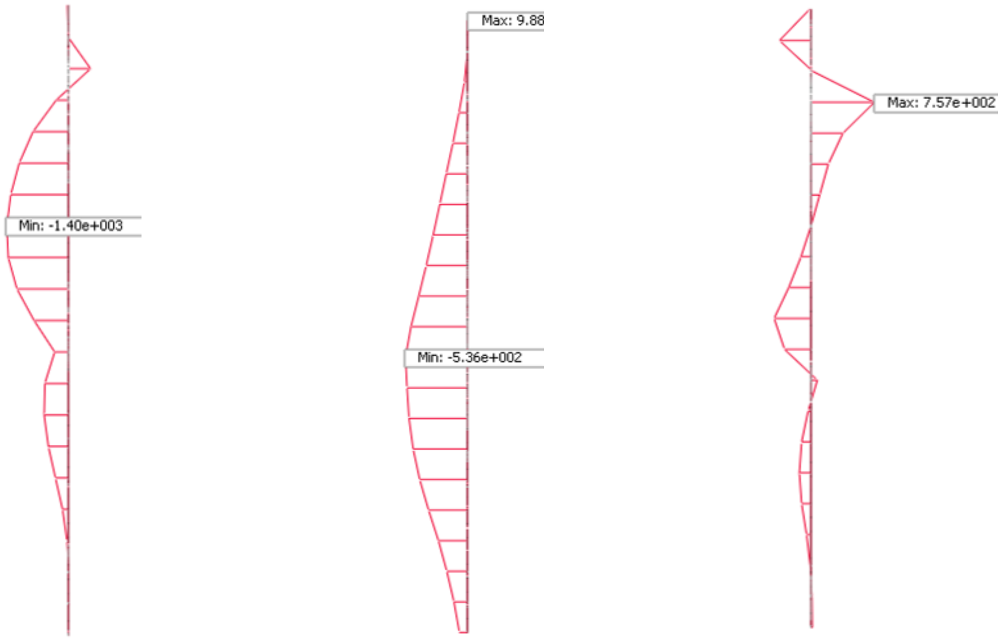

Figure 15. Stresses M, N, T for the diaphragm walls in removing inferior strut stage[3]

Next figures present the horizontal deformations for the ground for 2 execution stages: figure 16 - final excavation stage and figure 17 – after removing lower struts.

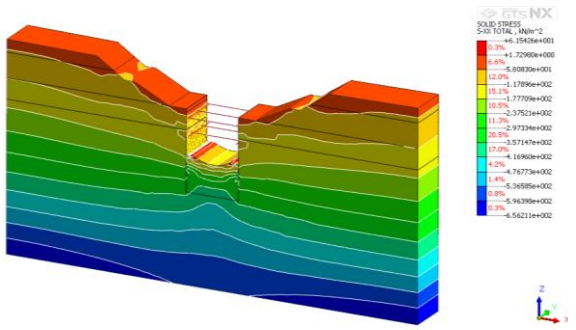

Figure 16. Horizontal ground deformations S-XX, for final excavation stage [3]

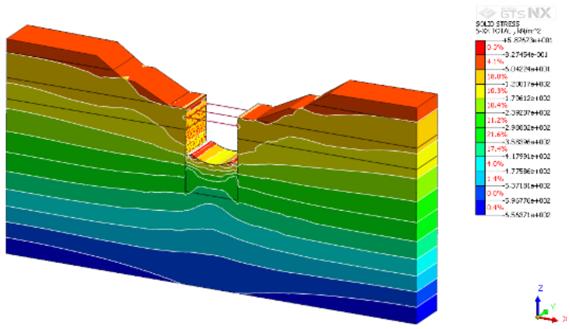

Figure 17. Horizontal ground deformations S-XX, after removing lower struts [3]

The considered soil constitutive law, Mohr-Coulomb, leads to higher displacements than in reality, as the scientific literature sustains and in future it is necessary to take into account a more realistic soil constitutive law, such as Hardening Soil or similar.[5][6][7] [8]

Stress diagrams, bending moment M [kNm] and axial force N [kN], respectively, obtained for the lining, foundations and invert are presented below figure 18.

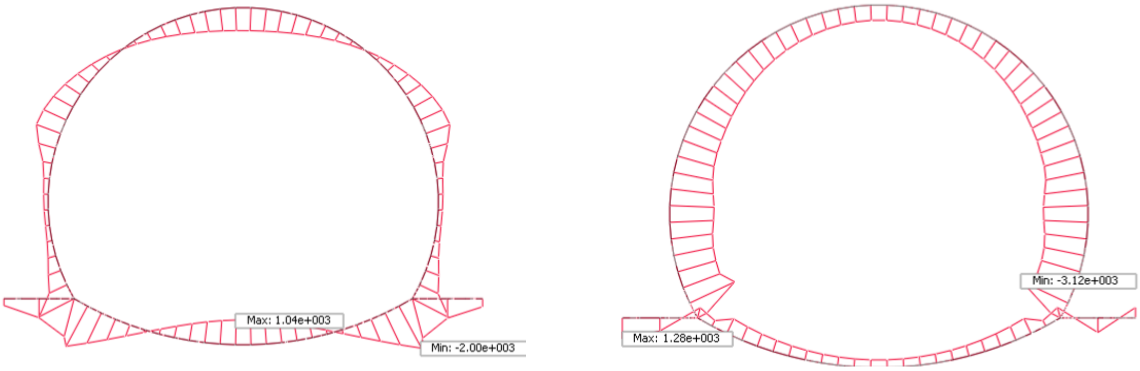

Figure 18. Bending moment (M) and axial force (N) for lining, foundations and invert[3]

4. MONITORING TURDAS TUNNEL [3]

Monitoring is the active observation of the phenomena that occur during the tunnel execution. Monitoring consists of collecting specific data that reflects the combined effect of all internal and external individual factors.

The main purpose of monitoring is to track and verify ground movements and structure response during tunnel construction and exploitation. In order to achieve this, the following equipment was provided:

- strain gauges in the diaphragm walls, invert, foundation and lining;
- inclinometers in the diaphragm walls;
- load cells for monitoring of the stresses in the struts.

The position of the instruments (figure 19) is using the position of the maximum stress in different stages of execution of the temporary and definitive structural elements of the tunnel.

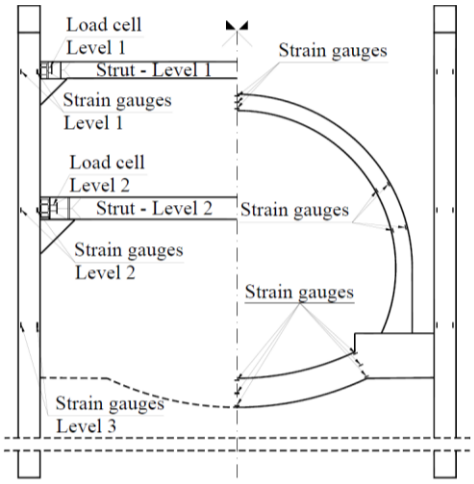

Figure 19. Positions and number of monitoring devices [9]

5. CONCLUSIONS

The Turdas tunnel is the first tunnel in Romania built using cut - and-cover method in swelling soils.

The cross section was designed to prevent and to overtake the negative effects of this swelling soil by:

- using continuous diaphragm walls for preventing water ingress;
- water collection and evacuation system;
- connection of invert and foundations to the diaphragm walls by chemical anchors.

The results obtained from monitoring during execution and service life will be used to calibrate the calculation model. Also, the results will provide a new perspective to tunnels executed from surface and in difficult ground.

The paper presents the efforts made for designing an optimum solution for the Turdas tunnel, in which the authors were members of the teams that made the technical expertise, design, execution and monitoring project.

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