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NONTRADITIONAL SUPPORT OF THE WESTERN PORTAL OF THE TUNNEL POVAŽSKÝ CHLMEC

Jan Faltýnek

Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7, Prague 6, Czech Republic
correspondence: jan.faltynek@hochtief.cz

Abstract. The paper is focused on general description of support elements used on the Western Portal of the tunnel Považský Chlmec in Slovakia, near the City of Žilina. It presents basic aspects of the method of the shell structure. In this case the shell structure in combination with pile walls was used. You can also find here detailed description of geotechnical behaviour together with the setting up of the numerical model constructed in PLAXIS. Conclusions of important points from the entire paper including results evaluation you can find at the end of the paper.

Keywords: Tunnel, Finite element method (FEM), PLAXIS, shell structure, pile wall, anchor.

1. Introduction

Two-tube tunnel Považský Chlmec with length of about 2.2 km forms the major part of technically very challenging section Žilina (Strážov) - Žilina (Brodno) of future highway D3 in the Slovak Republic. The route forms the western bypass of the city of Žilina.

The excavation in the area with flysh evolution represents for the designer and also the contractor of the tunnel solving many difficult geotechnical problems. One of them is the technical solution of the construction pit of the western tunnel portal, which was key for compliance with the construction schedule because of the planned construction process.

The competition for the contract was launched and construction is still in progress in Design and Build mode (DB) - specifying the conditions according to FIDIC Yellow Book. It allows the designer and contractor to optimize technical solutions, under the conditions specified in the tender documentation. Limited areas of permanent works, tight deadlines of contractual milestones of construction and complicacy of geotechnical conditions in the area led the designer and contractor of the company HOCHTIEF CZ a. s. [1] to change the concept of securing the stability of the construction pit of the western portal and following excavation beside the original draft from the previous step of project documentation. After considering all options, it was decided to use a method of the shell structure.

2. Method of the shell structure

Method of the shell structure could be classified to the hybrid Cover & Cut methods that combine various aspects of the Excavated and Cut & Cover underground structures.

First part of a construction process is a cutting of a ground down to the level of the lower surface of the shell structure (Figure 2 STAGE 2). That is concreted (Figure 2 STAGE 3) and generally backfilled after curing. The material under the shell structure could be excavated at the same time with the landscaping of the backfilled surface (Figure 2 STAGE 4). This is very positive in terms of time of construction process. There is a big difference from the classic Milan method in the shape of the supporting structure, which is in this case vaulted.

The vault behaviour of the structure is very positive from the structural point of view. The option to keep the cross section the same like in the excavated part of the tunnel is also advantageous. You can use the same formwork car. Method of the shell structure is particularly used for tunnels that are carried shallowly, where can be problem during excavation with breaking the cover of a tunnel, or in landslide areas where the landslide could be in a portal construction pit activated. Economically, this method leads to savings earthworks and difficult enumerable reduction of the risk of construction.

3. History of this method and its modifications

Method of the shell structure is in Czech called literally “turtle method”. The term ‘turtle’ was created during the construction of the eastern portal of Branisko tunnel (1996), in the Slovak Republic and its author is Ing. Ermín Stehlik. In this case the shell structure was on one tunnel tube monolithic and on the other tube prefabricated. It is another point of interest of this tunnel. Method of the shell structure is quite widespread abroad, for construction in and outside of the urban areas. In the Czech Republic, this method was first used on the railway section Zábřeh - Krasíkov, tunnels Malá Huba and Hněvkovský I.

3.1. Shell structure found on plain ground

A shallow tunnel, where the rock strength increases very quickly with the depth, is a typical example of

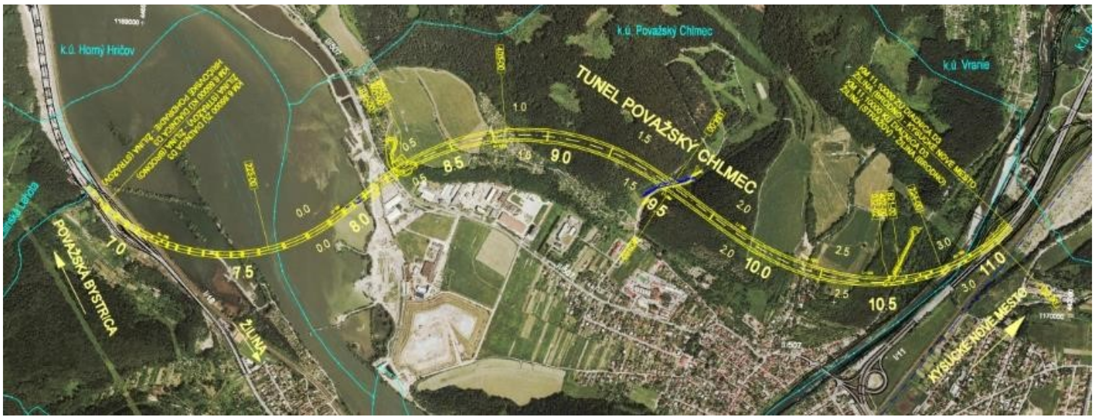

Figure 1. Section situation of the D3 motorway Žilina (Strážov) - Žilina (Brodno).

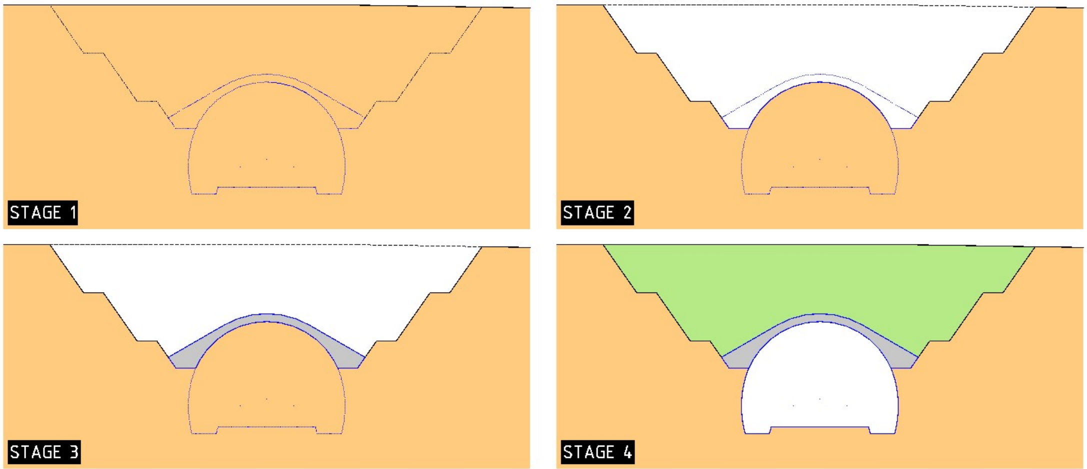

Figure 2. The construction process of the basic method of the shell structure shell structure found on plain ground

Figure 3. The eastern portal of the tunnel Branisko, left - monolithic, right - prefabricated shell structure (photo by Ing. Libor Mařík [2])

Figure 4. The shell structure on the Schellenberg tunnel (photo by Ing. Jiří Zmítko)

this type of construction. This leads to the use of better quality rock mass as a support for the shell structure. It means that a shell structure rests only on the plain ground. This solution was used for example in tunnels Hněvkovský I and Schellenberg in Germany.

3.2. Shell structure additionally supported

In worse geological conditions the base part of shell structure is additionally supported due to uneven deformation by columns of jet grouting, micropiles or by using SN rock bolts. This solution was used for example in Sudoměřice tunnel and in bypass around the town of Jihlava (I / 38), where the shell structure was concreted on low-formwork. Another example is the use of this type of structure in the central construction pit of the tunnel Povážský Chlmec. There was the shell structure supported by micropile walls as well as in the case of the western portal of Žilina tunnel.

Figure 5. The shell structure supported by micropiles in the central pit of the tunnel Považský Chlmec (photo by Ing. Libor Mařík [2])

3.3. Shell structure with foundations fixed to sheeting construction

In the case of very unpleasant geotechnical conditions it is necessary to secure the lateral sides of the tunnel over the entire height in another way - Milan or pile wall. The shell structure in this case is fixed into sheeting structure and form the support (strut) level of the vertical sheeting elements to ensure the safety of the construction pit. This complex and unique solution has been used in Euerwang tunnel on high-speed line Nuremberg-Ingolstadt in Germany and Považský Chlmec tunnel in the Slovak Republic on the western portal which technical solution is the main topic of this paper.

Figure 6. The fixed shell structure on the Euerwang tunnel (photo by Ing. Jiří Zmítko)

4. Original way of securing the western portal and start of excavation

The original way of securing the western portal by tender documentation (which was not obligatory) consisted of the slope stabilization of construction pit by layer of shotcrete with two concrete reinforcing meshes. Layers of surface soil were secured by nailing. SN rock bolts were used in the lower parts where occurrence of disintegrated rock was supposed. Prestressed stranded anchors passing through reinforced concrete walers were among the other elements ensuring the stability of the construction pit. In this way arranged construction pit the classic Cut & Cover tunnel should be constructed.

Initiation of the excavation was assumed under the protection of micropile roof piping.

5. New way of securing the western portal

The contractor HOCHTIEF CZ a. s. decided to change the concept of securing the construction pit after the thorough consultation with the designer at the stage of processing of tender documentation. The method of the shell structure combined with anchored large-diameter pile walls was used for securing the portal area. Pile walls work as a construction pit sheeting and also as a protection of the sides of the tunnel during the subsequent excavation under the shell structure roofing. This change reduced volume of earthworks and activities with the necessary technological pauses, e.g. concreting of the reinforced walers, implementing multilevel anchors etc. The size of the territory affected by construction and the number of anchoring elements were reduced too. The length of Cut & Cover tunnel was shortened to one concreting block. The risk of losing stability of a high slope decreased. The important point was also the possibility of an earlier commencement of the excavation on the western portal.

The faces of the excavation pit are stabilized by anchored steal sheet pile walls.

(1.) excavation of shallow sloped construction pit at a gradient of 1:1.5 at the level of drilling of the large-diameter pilot walls;

(2.) drilling and subsequent concreting of the reinforced concrete piles 0,8 m in diameter length of 16 m, 18 m and 19 m with an axial distance of 1 m;

(3.) excavation on the first anchor level;

(4.) aking concreate walers with dimensions of 0.7 x 0.8 m, making and activation of prestressed stranded anchors length of 16 m and 18 m drilled with axial distance of 2 m;

(5.) excavation of the construction pit at the level of the bottom shape of the shell structure;

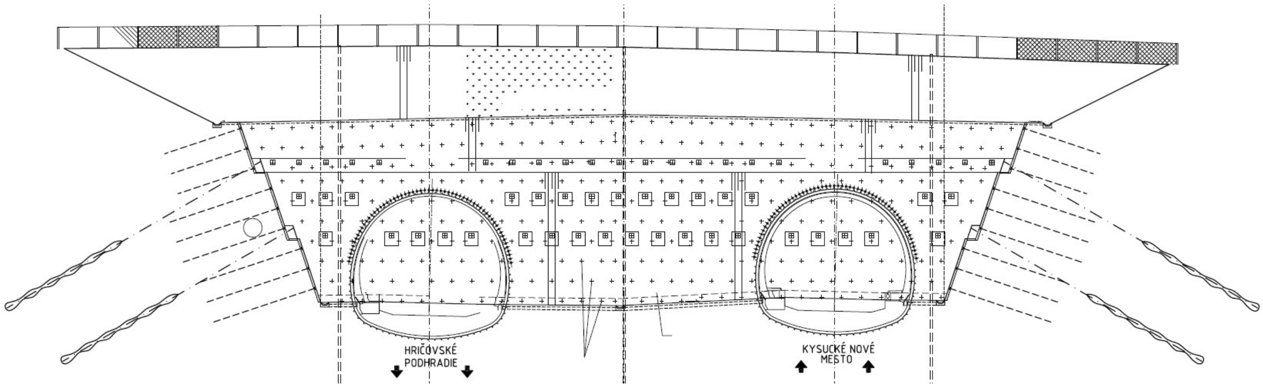

Figure 7. Original way of securing the western portal

(6.) creating a niche in every individual pile, which is used for connection of the reinforcement of the shell structure with the reinforcement of piles (in each pile was added additionally glued anchor);

(7.) profiling of the base of foundation pit by plane concrete into its final form, laying separating foil and geotextile;

(8.) reinforcing and concreting the shell structure block by block (thickness of the structure in the crown is 0.6 m, the arch span is 10.78 m with the rise of 3.53 m, final length on southern (right on the picture) tunnel tube 37.5 m and on northern (left on the picture) tube 50 m);

(9.) excavation of top heading and bench of the tunnel (excavation with horizontal sequence, unlimited length advance thanks to good workability by tunnel bagger);

(10.) additional supporting of the foundation of the shell structure and shaping the sides of the tunnel by shotcrete lateral beams;

(11.) making of the backfill (the shell structure was filled up after the tunnel excavation because of the need to meet a milestone for the beginning of the excavation, another reason was structural, because of the shell structure which had to be filled after making the supporting lateral shotcrete beams).

6. Geological conditions at the western portal

The excavation is in the upper part realized in fine-grained deluvial soil with the occurrence of fragments and rubble. They passed with increasing depth into the gravel-clay soil of fluvial terraced steps. The lower part of the construction pit was excavated in the zone variously weathered flysch formation (sandstones, mudstones, siltstones, conglomerates).

7. Numerical model of securing the western portal

The complexity of static calculations was based mainly on uncertainty about the actual behaviour of the structural elements (prestressed stranded anchors, large diameter pile walls, shell structure) and consideration of these ideas in the mathematical model. The most important thing for the creation of a numerical model is in this case the reliable and accurate interaction between the shell structure, sheeting wall and cooperating rock mass considering all phases of construction and the relevant load cases. The connection between the shell structure and the pile wall is capable of transmitting a certain inner forces. Its real stiffness but depends primarily on the quality of the execution.

During the processing of the project there were a large amount of computations, whose aim was to determine the effect of input variables. Secondary lining under the shell structure was examined in detail in the last phase stage simulating end of life of the construction pit supporting system where backfill weight rests directly on the secondary lining.

Calculations were performed by finite element method in program PLAXIS. The dimensions of the solved area were chosen so that the results were not affected by the boundary conditions. The finite element mesh in areas of interest was refined.

All rock and soil layers were considered as plane elements with the Mohr-Coulomb plasticity condition. The shell structure, pile wall, shotcrete supports and secondary lining were modelled as linear plane element. To the centreline of these structural plane elements was inserted so called "reference beam", which has a considerably smaller bending and axial stiffness. It deforms simultaneously with the structure. Thanks to it, there is no need to integrate internal forces from the stress in the individual sections. The interaction between structural elements and the rock mass as well as between the individual elements together was modelled using a specially tested contact interface element.

The reached ground water level and ground water flow due to the excavation of the bench was also considered in the calculation.

It was very important in the numerical model to take into account all necessary load cases. The weather load (mainly temperature) and shrinkage was modelled as prescribed volume strain of finite elements.

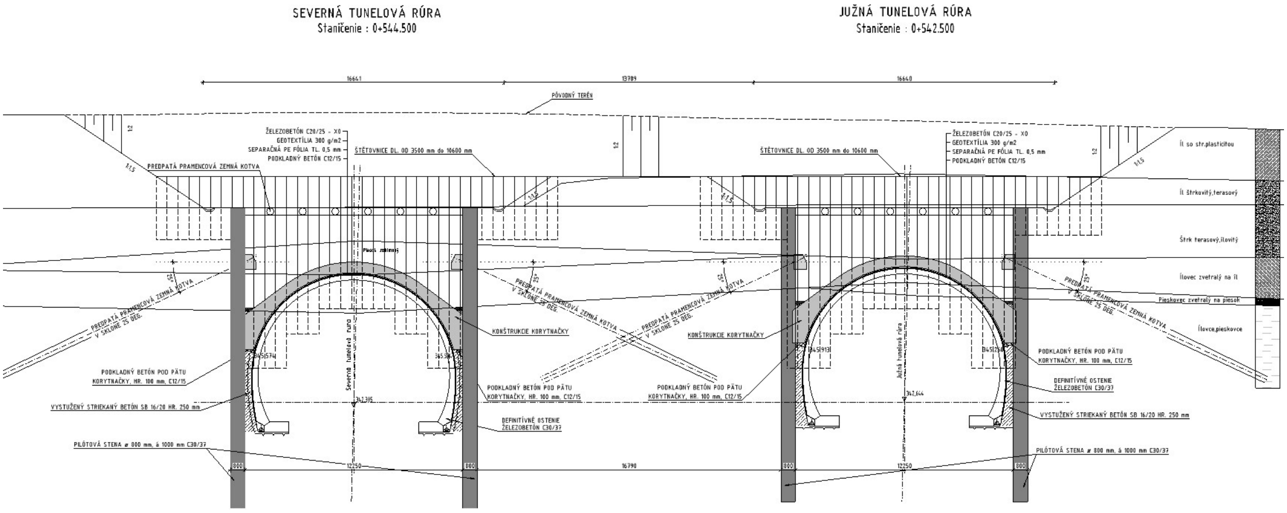

Figure 8. New way of securing the western portal

Surroundings of Žilina is located in a seismic zone. This effect was taken into consideration into the model using quasi-static calculation.

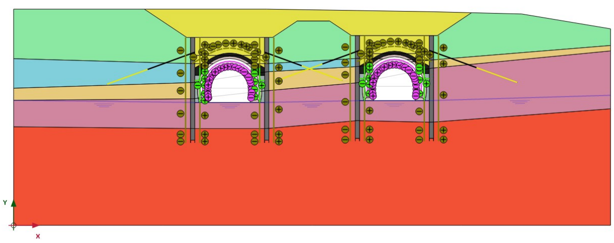

Figure 9. Scheme of a basic numerical model

8. Results of numerical modelling

The mathematical model confirmed the smooth feasibility of designed construction system. First the slope stability of the construction pit excavated at the level of pile walls was determined by the phi-c reduction method.

With "reference beam" internal forces acting on the pile wall were obtained.

The bearing capacity of stranded anchors was also evaluated.

As mentioned above, the greatest influence on the interaction of the whole system has a connection between the shell structure and pile walls. Connection height is about 1.5 m. It is very difficult to predict how a given node will behave. Therefore, it is necessary to monitor and evaluate stress at this point in principal stresses. From the structural point of view, the decisive stage is the construction phase after the completion of the excavation under the shell structure. The positive impact of the backfill on the distribution of stresses on the shell structure and pile walls was also confirmed.

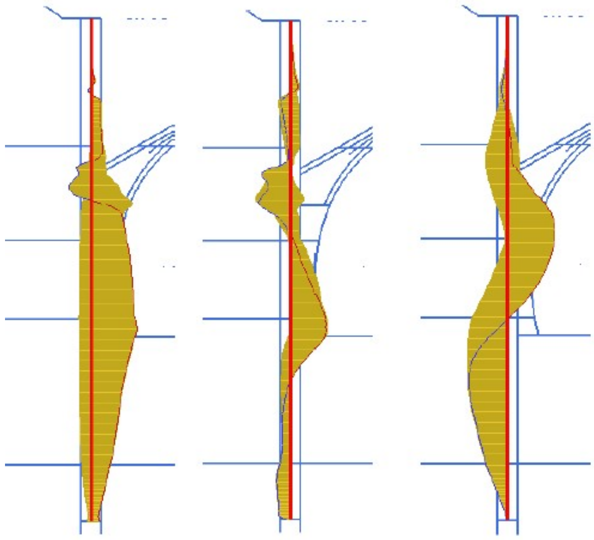

Figure 10. Envelopes of internal forces on the pile wall - from left to right (N_{max} = -695 kN, V_{max} = 550 kN, M_{max} = 900 kNm)

9. Conclusion

If predicted and actual geological conditions should be compared, it could be said, that sufficient consensus has been reached.

Geotechnical monitoring of the shell structure consisted of determining the relative deformation by strain gauge sensors located in the major blocks in the top of the vault at both surfaces. It allowed to compare the results of a numerical model with reality. An interesting finding was that the shell structure on north and south tunnel tube behaves differently in reality. A comparison of the data after the excavation under the shell structure with the results of the monitoring are quite different. Both northern and southern structures in the case of a numerical model behave similarly (the upper fibres of a cross section are in tension, lower are compressed). Acceptable sim-

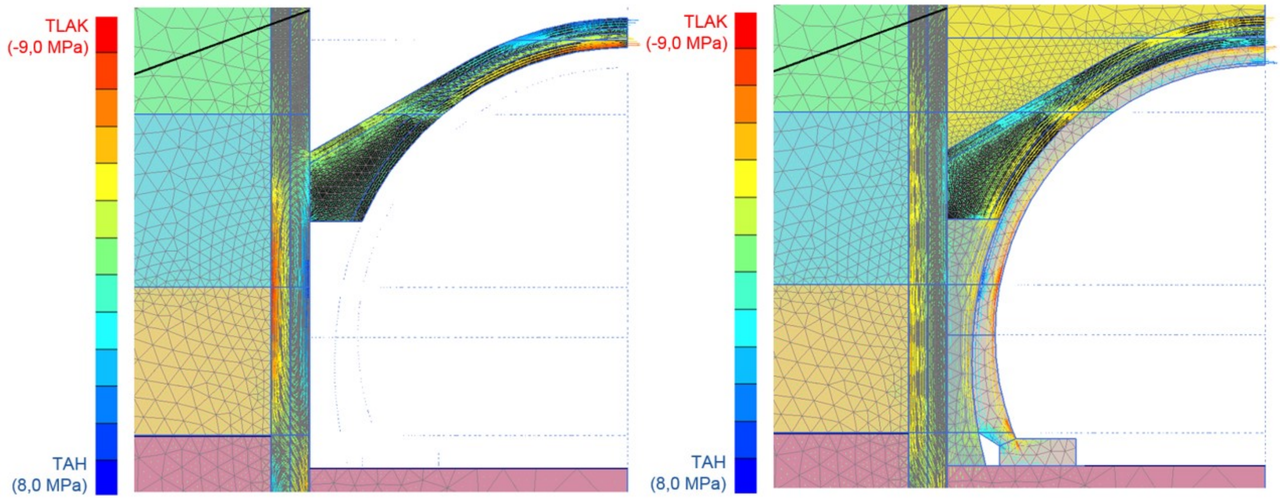

FIGURE 11. Distribution of principal stresses after the excavation stage (left) and after the final stage (right) (compression red and tension blue colour)

FIGURE 12. Shell structure on the western portal of the tunnel Považský Chlmec

ilarity is evident when comparing the southern shell structures. The results from the measurement on the north shell structure are not very close. That is also the same case for other construction stages. Simplifications of the numerical model (material model of construction elements and surrounding soil and rock, sub-horizontal layers etc.) and the real behaviour of the structural elements (the value of the prestressing in the anchors, the real execution of the connection between structures) may be a possible cause.

As you can see even the most complex mathematical model may not always accurately capture the geotechnical behaviour of the real structure.

The shell structure fixed into the sheeting structure belongs to the most unique and less conventional design solutions. The designer and contractor despite it managed to design and build a structure without significant problems during construction. Generally, it could be said, that the correct optimization of the solution of the western portal had contributed to reducing the risks during construction and speeded up the construction progress. At the time of writing this paper the construction is completed successfully, backfilled and supported by final lining of monolithic concrete. It allows the above mentioned recap.

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