Flexible steel structures used for ski tunnels in the Parang Mountains, Romania

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Abstract. The main idea of this project was to create an access road for tourists and also to improve winter sports conditions, especially for skiing, in the beautiful Parag Mountains. Because the road rises to 1600 m at alpine elevation, it was a challenging project. One of the structures was delivered and assembled in November 2019, in three weeks of hard weather conditions, using a 5-person work team.

1. Introduction

A tunnel can be defined as a closed or roofed structure carrying a road through, or under, an obstacle. This obstacle may be anything in the path of a preferred road alignment, such as a mountain, a body of water, a building, or a complete development [1].

As a short history, tunnels have been known since ancient times. The first tunnels were natural, formed in different caves. They had variable sections and were found in limestone rocks.

The first tunnel was made by the Egyptians and the Babylonians, 4000 years ago. This tunnel served the purpose of connecting two buildings – the royal palace to the temple – in Babylon. The length of this brick-lined tunnel was 910 m. In Europe, the first tunnel was built by Roman Emperor Claudius in A.D. 54 for carrying spring water through the Apennine Mountains. Its length was 5.8 km. It was completed in 12 years by 30,000 laborers.

The development of first railway tunnel in the world was constructed between 1895-1922 to connect Switzerland and Italy. The shape of the cross-section was a horseshoe, its length was 19.82 km. The first highway tunnel was constructed in Hungary between 1851-1853 and its length was about 350 m. The first underground tunnel was constructed in 1843 by Sir Marc Brunel. The first navigation tunnel was constructed in France in 1679. Its length was about 160 m. America’s first vehicular tunnel was built in 1866 and is known as Washington S.T. Tunnel constructed under the Chicago River.

During the second half of the twentieth century, the development and progress of explosives and sophisticated equipment flourished, which made the tunneling process more feasible.

Tunneling helps to make work easier for different approaches under different circumstances. It is dependent on the experience and the knowledge of the engineer. Tunneling works are carried out primarily by civil engineers.[2]

Nowadays, tunnels can be grouped into categories according to their purpose and the place where they are built:

Railway tunnels - railway tunnels (single or double track) and subways

Road tunnels - tunnels for public roads and car traffic

Hydrotechnical tunnels (galleries) with free-flow or pressurized pipes
Tunnels for navigation and floating
Tunnels – aqueduct
Protection tunnels
Tunnels for the mining industry

Also, according to the geographical area where the tunnels are built, they are divided into mountain tunnels, tunnels in cities, and underwater tunnels.

We can also classify the tunnels based on surrounding material: tunnels in mud-stone rocks, tunnels in sandy soil, tunnels in hard stone rocks, undersea or riverbed tunnels, and open-cut tunnels [2].

Tunnels have improved connections between regions and have been used as a catalyst for the economic development of previously isolated regions. Conventional tunnel construction has always been a significant engineering challenge. Success depends not only on careful planning and execution but also on ensuring that there is an optimal interaction between processing technology and specialized chemistry of support systems. Depending on the rock and the soil encountered, problems can occur during excavation, even with the best possible planning, high-performance technologies, and optimal construction execution [3].

In the selection of the best and most efficient solution for any tunnel, there are key points to consider: The cross-section with length, waterproofing type, nature of rocks, equipment, time, energy, and cost estimation.

The design concept and construction of tunnels must follow the steps from the logic scheme (figure 1).

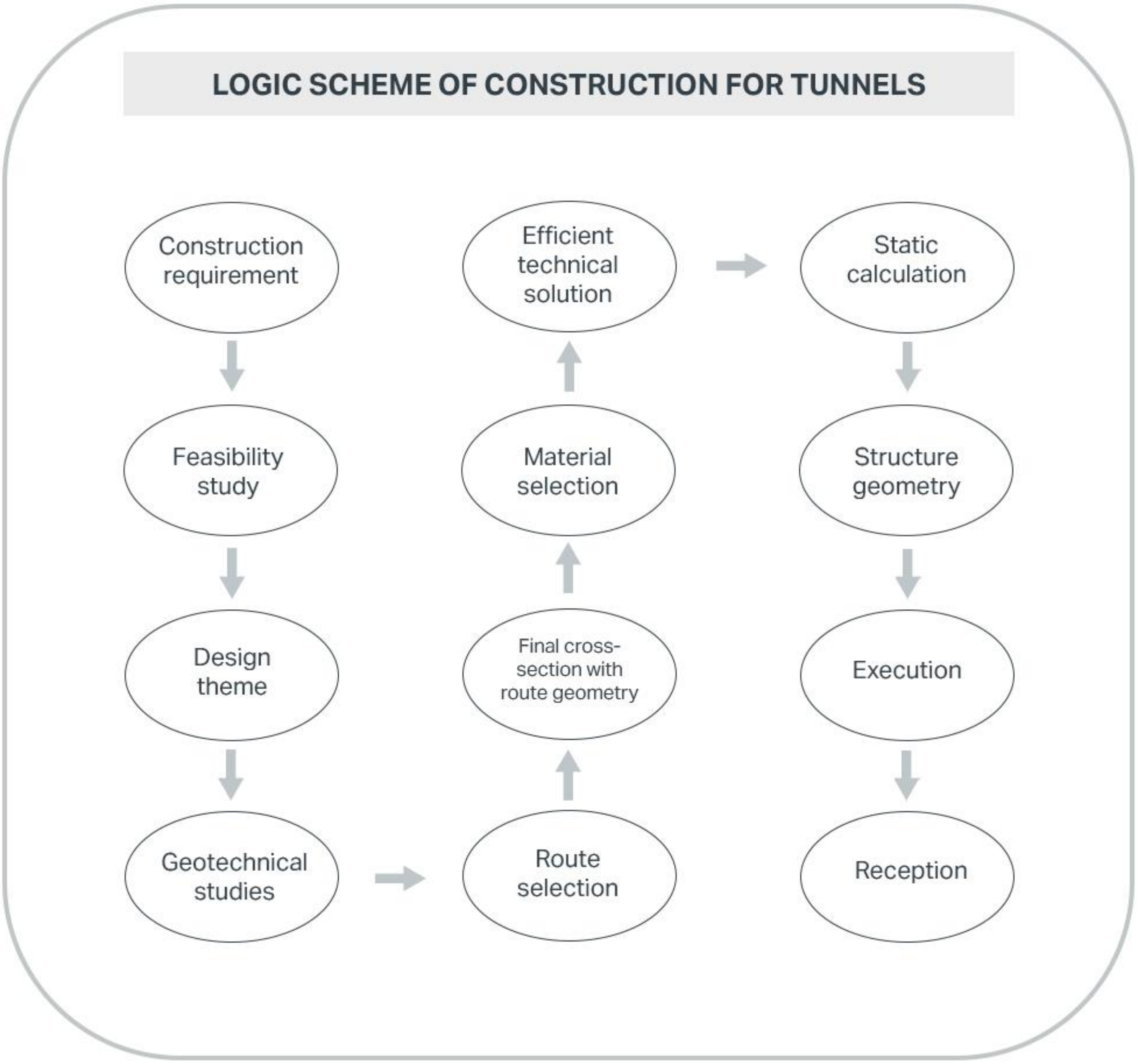

Figure 1. Logic scheme of construction for tunnels

The Parang Mountains are located in the Southern Carpathians, in the Petrosani region, between Jiu, Strei, and Olt rivers, in the southwest of the Parang Sureanu Lotrului mountain chain. Their length is over 50 kilometers and width approximately 25 kilometers. Parang Mare peak has a maximum altitude of 2519 meters. This mountain is crossed by the highest tourist route in Romania, the Transalpina, with spectacular serpentines of 150 kilometers and a beautiful view. The most known tourist resort is Ranca, where visitors can have a dream vacation in the middle of nature.[4]

Figure 2. Parang Mountains.[4]

For the project from Parang Mountain, it was necessary to find an unconventional technical solution, to provide both functions: road access for vehicles and ski slope. The ski tunnel can be classified into two types: indoor and outdoor. The tunnel built for this project is considered an outdoor tunnel, serving more than one purpose: Access for vehicles inside the tunnel and a ski slope on the top of the tunnel, which makes this tunnel more productive and unconventional.

The types of tunnels described earlier all belong to the conventional category (railway tunnels, road tunnels, hydro-technical tunnels, etc.). Considering all the characteristics of this project, this tunnel falls into the unconventional category, leaving no possibility to build it conventionally. This project is special because it was necessary to build a tunnel to the surface of the road, not to make a tunnel through the mountain (for example, to use the NATM method).

Since it was an unconventional tunnel, it was important to find the best solution for all the stages of the tunnel construction. The selection of a steel structure played a critical role in maintaining efficiencies in the quality of the structure as well as the project costs.

The route has been constructed to consider both comfort and optimum time savings. The idea is to make alpine areas more attractive as a habitat for people and wildlife. Also, underground traffic diversion conserves natural resources and prevents noise pollution. In developing urban areas, these underground tunnels guarantee eco-friendly nature and efficient mobility.

As a pioneer in the construction of bridges, tunnels, and the protection of the environment, the ViaCon Group recognized early on the potential of tunnel construction. By participating in important infrastructure projects, the company had the opportunity to leave its mark, becoming a top specialist in this field.

2. Case study

A similar railway tunnel project was realized in Algeria in 2015 with the function of a tunnel above the railway line. The structures had the following parameters: a Supercor structure with a span of 12.02 m, rise of 12.02 m, bottom length of 180.08 m, and top length of 138.62 m.

Figure 3. Railway tunnel Algeria (ViaCon Poland case study)

Figure 4. Railway tunnel Algeria (ViaCon Poland case study)

The expansion process of infrastructure in Romania is growing significantly under the government initiative known as the PNDL Program, which supports both the building of infrastructure as well as helping to solve the lack of roads and ski slopes.

PNDL is a multi-year financing program, coordinated by the Ministry of Regional Development and Public Administration, which has as its general objective the equipping of the administrative-territorial units with all the technical-urban endowments, of educational, health and environmental infrastructure, sports, social-cultural and touristic, administrative and access to the communication ways to ensure an attractive investment climate for the Localities of Romania.

The beneficiaries of the tunnel projects have applied under PNDL Program to transform the existing road into a multi-functional road that will provide access to vehicles as well as facilitating a ski slope.

2.1. Design

The present-day design includes the long-term environmental impact and also the lifecycle cost. Hence more importance is given in current design codes to the durability of structures [3].

The design stage of the project is one of the most important stages, requiring considerable attention.

2.1.2. Parameters of the Multiplate VM35 structures. The parameters for the steel structures were established after all the information from the site was collected. The major dimension of the structure consists of an 8.55 m span, a rise of 5.98 m, bottom and top lengths are 50.87 m and 35.35 m respectively, S355 steel with a total structural weight of 70 tons per each tunnel.

Due to the durability of corrugated steel sheet structures and its lower weight, it can be installed quickly and without difficulties using light equipment. The structures are designed flexibly in such a way as to distribute the external loads in the embankment around them and towards the foundations. This is why the installation must be carried out with special care to ensure their correct functioning.

A well-positioned corrugated steel structure, installed on a properly prepared foundation, properly assembled, and surrounded by a backfill made of carefully compacted stable material will work efficiently and correctly throughout the entire service life for which it was designed.

The flexibility of the structure allows a high tolerance in terms of dimensional or locational changes. More rigid structures often cause cracks.

Euro Codes and National Annex standards have been considered for all the design and parametrical aspects, and MATHCAD has been used for static calculation of the structure.[5]

2.2. Execution

The project execution started in autumn 2018. This project was designed to help develop the respective area, in the following ways:

- widening of the roadway by 4 m
- pouring asphalt level
- building culverts
- supporting walls

The principal idea of this project was to create an easy access road for the tourists and also to enhance conditions for winter sports, especially skiing, in Parang.

Figure 5. First steel tunnel (author photo)

The second structure was delivered and assembled in May 2020, also within three weeks. It was necessary to use a crane of 40 tons and an arm of 25 m to realize the assembly.

Figure 6. Second tunnel assembly in May 2020 (author photo)

After the structures were assembled, the construction team made the overflow around and covered the structures with compacted ballast, following instruction from ViaCon Romania SRL.

2.2.1. Assembly of the steel structures. Plates are delivered to the construction site in bundles. Each bundle contains several plates with maximum numbers. The weight of a single bundle does not exceed four metric tons. The delivery includes a euro pallet - containing fasteners, anchor bolts, base channels, the assembly drawing (figure 7), and the assembly kit (figure 8).[6]

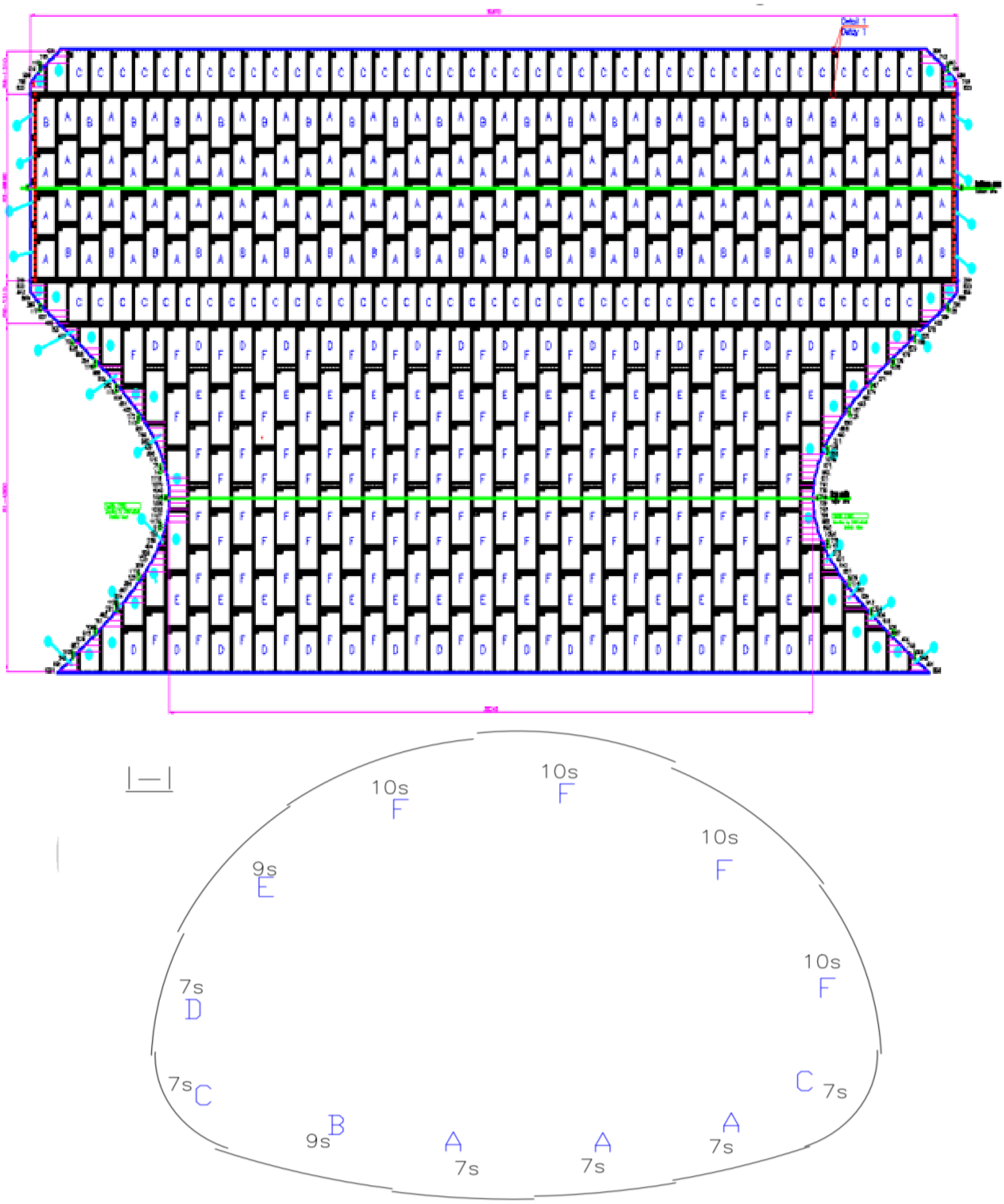

Figure 7. Assembly drawing of Multiplate VM35

In figure 5, all plate types are marked with a letter (A, B, C, etc.) or a number (1, 2, 3, etc.). All plates marked with the same letter are identical and can be put in any part of the structure where such a plate type is planned according to the drawing. All numbered plates have unique numbers and must be assembled exactly where they are marked on the drawing.[6]

Also, each drawing contains a table with types of plates and their heat numbers.

The total number of plates for one structure was 477 pieces.

Type A plates were marked with black paint and number 126 pieces. Type B plates were marked with red paint and number 42 pieces. Type C plates were marked with yellow paint and number 78 pieces. Type D plates were marked with blue paint and number 34 pieces. Type E plates were marked with green paint and number 30 pieces. Type F plates were marked with orange paint and number 119 pieces.

The plates relate to high-resistance galvanized bolts and nuts M20 class 8.8.

The green lines from the assembly drawing are the axis of the structure (bottom axis and top axis).

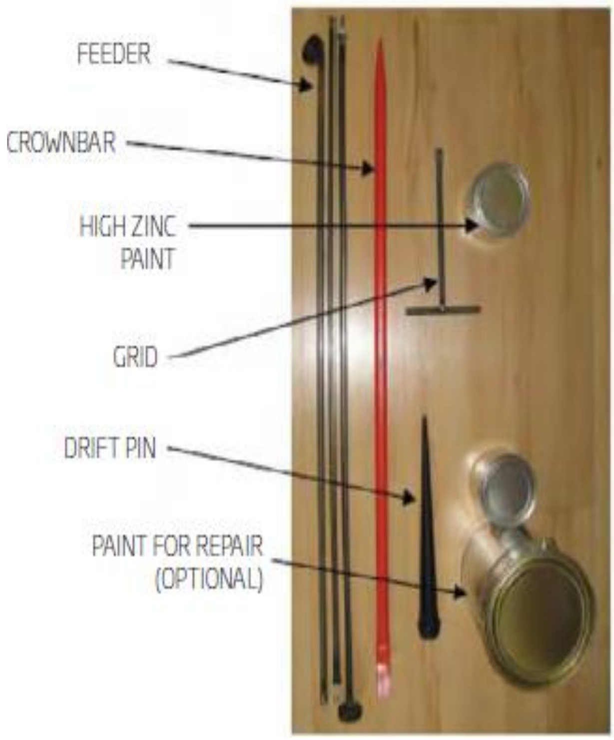

Figure 8. Assembly kit.[6]

The assembly kit is supplied with the structure (figure 8). It is necessary to have the required accessories, such as a feeder to match the holes of the plates, and high-zinc paint for repair if the zinc layer gets scratched.

The assembly crew should be equipped with the following additional equipment:

- crane with an adequate load capacity
- telescopic handler
- slings and belts for plate transport
- impact and hand wrenches
- ladders, scaffolding, basket lifts
- belts and tension chains
- hammers min. 3 kg (used to adjust holes, using the drift pins)

It is essential to know the size of the structure, the real situation from the construction site, and the purpose of the structure. The type of necessary equipment and tools should be agreed upon individually with ViaCon Technical Department.

2.2.2. Rules of assembly. Assembly of the structure should be started from the bottom plates (figure 9).[6]

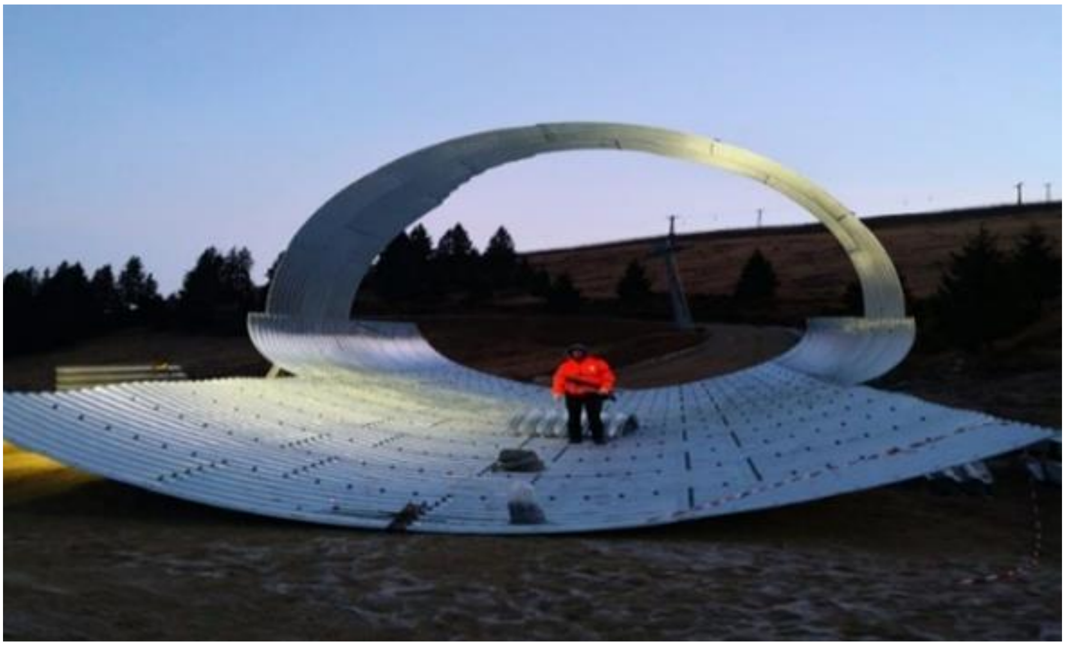

Figure 9. Assembly of bottom plates (author photo)

During assembly of the bottom part, it is necessary to provide the mounting space under the plates to put in the bolts. The bottom axis should be controlled all the times at the stage of assembly of the bottom. After assembling the bottom plates, we assemble the side plates (figure 10). [6]

Figure 10. Assembly of side plates (author photo)

After assembling the side plates, we proceed to assemble the top plates (figure 11). Top plates can also be pre-assembled in small sections to ease the assembly of side plates. During assembly it is not advisable to tighten the bolts to the maximum defined torque (they should be tightened firmly) - this will be helpful to avoid problems with mounting the next plates (rings). Tightening the bolts to the required torque shall be done after assembling the entire structure and before the backfilling. Nuts can be located inside or outside the structure. Their location does not affect the "work" and bearing capacity of the structure.[6]

For practical reasons, it is good to place all the nuts in the bottom part of the structure on the inside, while in the rest of the structure on the outside (from the backfill side). Access to the nut placed from outside at the area of the bottom plate is limited and does not allow for properly tightening the bolts.[6]

Figure 11. Assembly of top plates (author photo)

During assembly, the dimensions of the structure have been checked on an ongoing basis. Structures with larger cross-sections deformed under their weight, which makes assembly more difficult. For structures with a span of more than 4 m, like in our case, it is recommended that the assembly of all cross-sectional sheets is carried out by just a few meters. This applies to the side plates with the bottom and side panels with the upper ones. [6]

Additionally, the mounting belts should be used to maintain the nominal dimensions of the cross-section. After assembling the structure, it is necessary to repair the damage to the anti-corrosion coating that occurred during transport and assembly of the structure.[6]

2.2.3. Control of the bolt tightening torque and the structure shape. After the assembly, the bolt tightening torque should be checked. Required tightening torque: 360 Nm (minimum) for the structure with a span larger than 7m, in our article the span is 8.55 m [7].

Tightening of the bolts has been checked using a torque wrench. Five percent of the total number of bolts should be checked. A minimum of 95% of the bolts tested must meet the requirements regarding the size of the torque. The inspection is carried out on randomly selected bolting connectors, located evenly around the structure.

During the backfilling of the structure, the tightening of the bolting connectors has been checked in a random pattern.

The site engineer is responsible for checking the dimensions of the structure during its construction. During the assembly of large span profiles, it is natural that the structure deflects under its weight, as a result of which the structure may reach a lower height and a greater span. During backfilling, the structure's crown point will be picked up [7].

When the backfill reaches the level of the crown point, the process of uplifting shall be finished. This process should be controlled by performing necessary measurements so that the tolerance of the cross-section is maintained [7].

The contractor was obliqued to present a report of the behaviors of the structure after assembly and during backfilling and the report of bolting connectors tightening.

2.2.4. Soil preparation. It is necessary to follow the instructions from the technical data sheet once the foundation under the construction is realized. It is indicated to use gravel-sand mixtures with fraction 0 - 45 mm, uniformity coefficient $Cu \geq 4.0$, curvature coefficient $1 < Cc < 3$, and water permeability $k > 6$ m/day [7].

The compaction index Is min.= 0.98, according to the standard Proctor test. For the structures with a span larger than 4.0 m, as in our case, the foundation was contoured in a way corresponding to the shape of the bottom plate and reached the level of side plates (a few centimeters below where the side plates connect with the bottom plates). In any case, particular attention shall be paid to the densification of the foundation aggregate where the side and bottom plates connect. The thickness of the aggregate foundation was 25 cm. Regardless of whether the aggregate foundation is flat or contoured, its upper layer (5-10 cm) must consist of uncompacted gravel and sand bedding so that it can freely adapt to the corrugation of the plates [8].

Aggregate located directly next to the structure shouldn't contain grains larger than 32 mm. Before assembly of the structure, the delineation of the structure axes, ordinates of foundation, shape, and density index need to be checked. The correctness of the substrate preparation should be verified and accepted by the responsible person before starting assembly works of the structure [9].

2.2.5. Final work. The project was finished in a timely manner and was fully functional as of September 2021. It was a challenge to finish this project within the timeline at the appropriate level of quality because of adverse weather conditions and access.

In the Parang Mountains, the weather was bad with stormy wind, resulting in many difficulties in handling the plates in these adverse conditions.

Figure 12. The final stage of the first tunnel (internet photo newspaper “Stirile Transilvaniei”)

Figure 13. Drone view of two tunnels and slope ski (internet photo newspaper “Stirile Transilvaniei”)

3. Conclusions

The design of the project for the construction of the two steel structures analyzed in this paper raised a significant series of difficulties in terms of consolidating and improving the existing road, joining the new extension functions: access for cars and also for the realizing of ski slopes, working with the team in an area with a high slope, difficult access for construction equipment due to the narrow area and on the slope.

Currently, the tunnel construction is completed, and will be inspected at intervals of one year to verify the behavior of the construction over time. If it is proven that the executed works do not show damages, the adopted solutions can be used for other similar constructions.

The steel structures have a series of advantages in comparison with the classic structures (concrete, precast):

- Simple design (few details regarding the execution)
- Easy and rapid assembly
- Reduced execution time
- Can be put into place without disrupting traffic, with very little equipment and few workers

Each structure was assembled in three weeks, with a team of five workers. It was necessary to use a crane of 40 tons and an arm of 25 m to realize the assembly.

Tunnels can be extended in length if future needs dictate. The juncture between old and new sections of the tunnel can be done using the same type of structure (type Multiplate, profile VM35). Care must be taken during any future modifications to keep loads and soil envelope support to keep the tunnels balanced and uniform. Any tap-ins or similar modifications must be done in a manner to keep the entire tunnel periphery symmetrically loaded and supported and to maintain the stability of the soil envelope [10].

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