

**EXTRAORDINARY PROJECT – RAILWAY TUNNEL SH16
BIRTOUTA – SIDI ABDALLAH – ZERALDA
KM 10+700 – 10+880, ALGERIA¹**

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In November 2015 SH16 Tunnel in Birtouta – Sidi Abdallah – Zeralda Railway project in Algeria was designed. As a superstructure of the tunnel a soil-steel structure with deep corrugation 380 x 140 mm was chosen. The tunnel is 180 m long, has a diameter of 12 m and three bends. The maximum cover depth above the structure is around 7 m. To increase bolted connection capacity, due to extremely large axial force, unique 4-row bolts connections were used with class 10.9 bolts. Main reasons to choose corrugated steel plates technology were savings and short installation time. As a fully watertight tunnel was required, a double sealing system was designed. The first element of the system is a permanently flexible sealant applied along overlaps and in plastic caps on the bolted connections. As the second element of the watertightening system an EPDM membrane was proposed (for the first time ever) to entirely cover the round shape of the tunnel. Connections between pieces of EPDM were made according to the manufacturer's specific instructions. The installation of the structure began in December 2015 and was executed by teams of the main contractor supervised by a technical assistant from ViaCon Construction sp. z o.o. and one of the designers. The SH16 tunnel is the first ViaCon structure supplied to Maghreb countries.

Key words: tunnel, flexible soil-steel structure, backfilling, water tightness

1. INTRODUCTION

The railway tunnel SH16 presented in the paper is located between km 10+700 – 10+880 of Birtouta – Sidi Abdallah – Zeralda railway line near Alger in the north of Algeria. The tunnel superstructure is a large SuperCor SC-94R hot deep galvanized steel structure with a circular profile, internal span $S = 12.02$ m and beveled slopes at both ends, forming a tunnel for two railway tracks.

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Investor: People's Democratic Republic of Algeria represented by ANESRIF

Supervision: ViaCon Sp. z o.o. Poland

Design: ViaCon Sp. z o.o. Poland

Product: Corrugated steel structure type SuperCor SC-94R.

Contractor: Yapı Merkezi / Infrarail SPA

Assembly: Yapı Merkezi / ViaCon Sp. z o.o. Poland

Design Requirements and Assumptions:

- Geometry suitable for electrified double track railway of normal gauge 1435 mm with the distance between axes equal to 4.0 m,
- Live load acc. to: EN 1991,
- Cover depth: 6.71 m under the road and 6,00 m in the remaining area,
- Backfilling: aggregate compacted to 98% standard Proctor density
- ($\gamma = 24.10 \text{ kN/m}^3$ up to 2 m over the crown and $\gamma < 20.30 \text{ kN/m}^3$ above 2 m)
- Seismic effect taken into account as horizontal acceleration ($A_H = 0.4$),
- Durability: 100 years,
- Corrosion protection layers:
 - zinc coating of thickness conforming to EN ISO 1461 standard,
 - internal surface painted with polyurethane paint of thickness 100 μm .

SuperCor SC-94R structure parameters:

- Diameter 12.02 m
- Bottom length 180.08 m
- Top length 138.62 m
- Steel S315MC
- Bolted connections 4 rows of class 10. 9 bolts

The free edges of the steel structure were finished with reinforced concrete collar constructed with such elements as steel face and two rows of anchor bolts. The 4-row bolted connection was an innovation which had to be designed because of the huge value of normal forces induced by high cover of the structure.

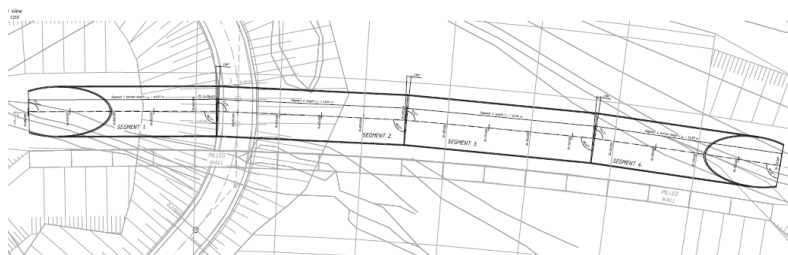


Fig. 1. Top view of the tunnel

The tunnel SH16 is located at a curve of the newbuilt railway and therefore had to be divided in four straight segments connected with welded bends.

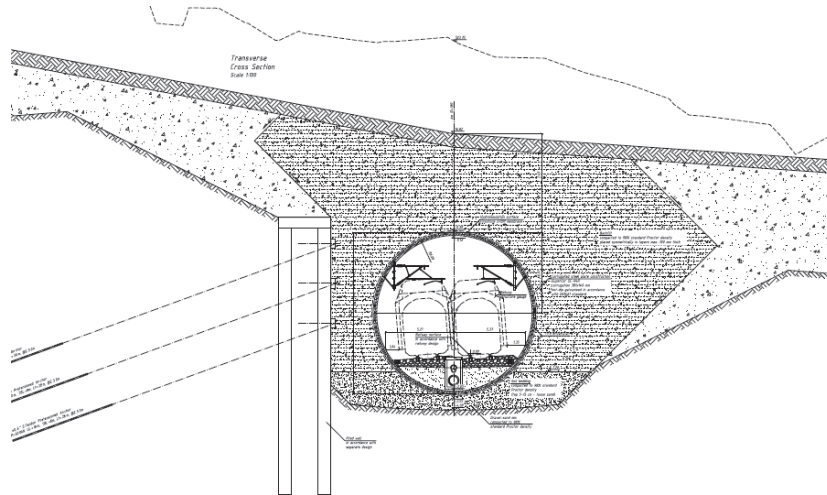


Fig. 2. Cross-section of the tunnel

2. BEARING CAPACITY CALCULATION

The main structural calculations of the corrugated steel plates construction were performed using the Canadian Highway Bridge Design Code (CHBDC). The loads were applied to the structure in accordance with Eurocode 1. Other structural calculations (concrete collar, overhead hangers support system, etc.) were calculated in accordance with adequate Eurocodes.

Structural calculations, performed in accordance with CHBDC, included:

- Ultimate Limit State – destruction by yielding caused by axial compression,
- Ultimate Limit State – formation of plastic hinge at the assembly stage,
- Ultimate Limit State – formation of plastic hinge at the operation stage,
- Ultimate Limit State – destruction of bolted connection.

The main load of the structure is constituted by backfilling weight. In the zone under the access road the structure is loaded with Eurocode LM1 traffic load. Soil and water conditions have been qualified as favorable for direct foundation. For the foundation, an aggregate layer was designed.

The foundation was constructed of water permeable soil – sand-gravel mix of fraction 0-45 with uniformity coefficient $C_u > 4$, curvature coefficient $1 < C_c < 3$ and permeability coefficient higher than 6 m/24 h.

The aggregate was free of organic and frozen parts. The sand-gravel was compacted to the minimum required compaction index as follows:

- $I_s \geq 0.95$ – in distance up to 20 cm from structure;
- $I_s \geq 0.98$ – in the remaining area.

3. OVERHEAD LINE HANGERS CONNECTED TO STEEL STRUCTURE

The structural design included the solution of connection the overhead line hangers to the object's superstructure. The connection was designed in accordance with acquired input data, i.e. hangers' location plan and hangers' general drawings, and is presented in Figure 3 below.

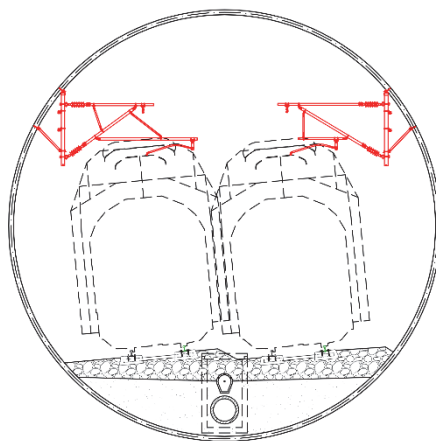


Fig. 3. Overhead line hangres

4. WATERTIGHTENING SYSTEM

The structure's watertightness was assured with use of a duplex sealing system. The first water penetration barrier in the upper part is elastic Firestone EPDM membrane tightly surrounding the steel tunnel structure connected with use of self-vulcanizing bands. The geomembrane is covered with non-woven geotextile on both sides. The second barrier is polyurethane adhesive sealant applied in structure slits and on the bolts in polyethylene caps whose size matches the shape of bolt heads and nuts.

Detail "A", Construction connections sealing
 Détail "A", l'étanchéité des connexions de construction
 Scale / échelle 1:5

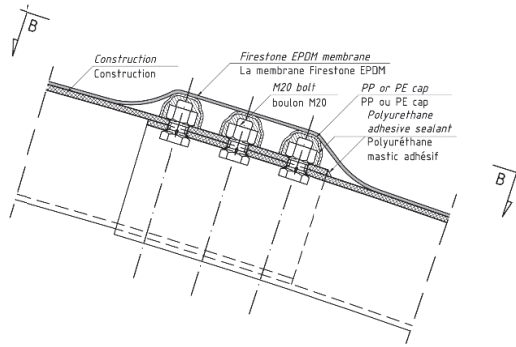


Fig. 4. Watertight solution of the tunnel

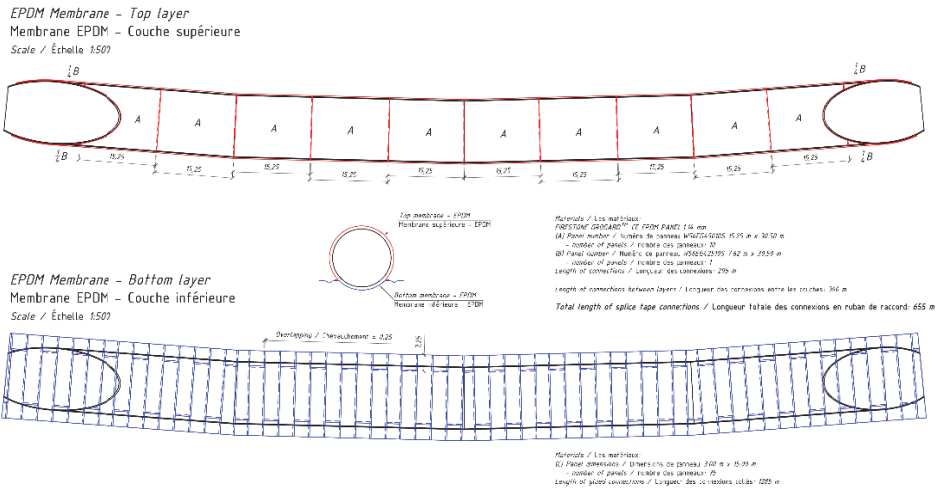


Fig. 5. EPDM membrane layout

Two draining pipes were designed along both sides of the structure to drain water infiltrating the backfill to the railway trenches. Bilayer PVC pipes of a diameter of 300 mm with perforation on upper 220° and nominal ring stiffness min. 8 kPa were chosen.

5. EARTHING

Due to the use of conductive materials, electric shock protection had to be designed. The designed protection is bonding of the structure to the rails with use

of aluminium rods of minimum cross-section area of 120 mm^2 . The connections were placed at distance a of 25 m from both ends of the structure. The layout of shock protection rods is presented in Figure 6 below.

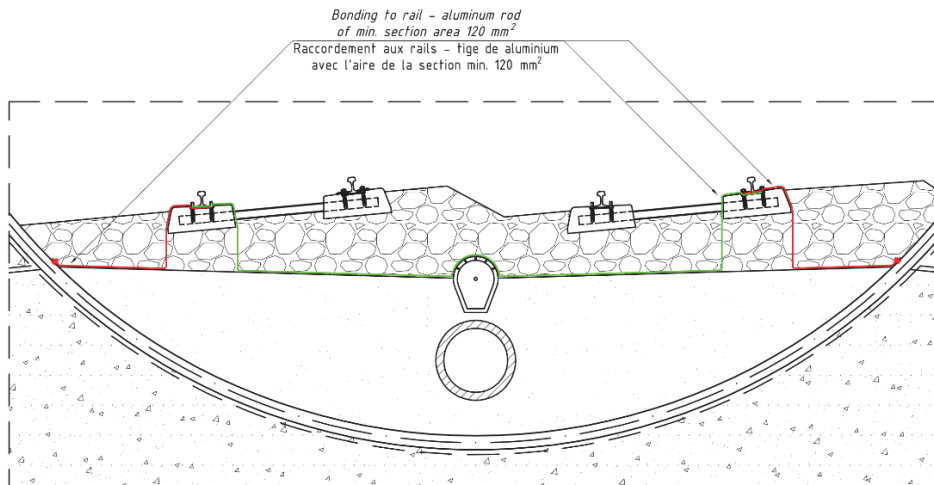


Fig. 6. Electric shock protection.

The other considered phenomenon was stray currents which may occur in the backfill material. After analyzing scientific literature in that matter it was concluded that for the AC transit system (which is in use in Algria) the stray current phenomenon does not exist, so there a is no need to provide cathodic protection.

6. ASSEMBLY AND BACKFILLING

The tunnel construction process consisted of the following phases:

- 1) Construction of a piled retaining wall with earth anchors performed in parallel to excavation works,
- 2) Excavation of the foundation trough,
- 3) Placing and compaction of the gravel foundation,
- 4) Placing a 9-centimeter layer of loose sand, which lets the corrugation sink into it,
- 5) Installation of the bottom layer of EPDM membrane protected with non-woven geotextile on both surfaces,
- 6) In parallel, prefabrication of bottom segments of the structure (joining every 8 plates into segments),
- 7) Placing the bottom plates in the designed position,

- 8) Continuous assembly of bottom plates, side plates and prefabricated top elements (every 5 top plates of rings),
- 9) Assembly of the beveled inlets,
- 10) Tightening of parallel bolts, application of polyurethane adhesive sealant in the structure slits and on the bolts in polyethylene caps,
- 11) Placing the draining pipes,
- 12) Installation of the top layer of EPDM and non-woven geotextile on the top surface,
- 13) Backfilling with compaction index verification,
- 14) Reinforcing and casting the concrete of the collars,
- 15) Installation of the structure's internal development elements.

The assembly process was performed by Turkish and Algerian contractors' workers with constant supervision of an experienced Polish fitter. Also, authorial supervision of the construction was carried out. The process was launched in December 2015 and finished in May 2016. Construction works were disturbed by a few weather breakdowns which caused excavation flooding on two occasions. Also, the speed of the assembly was not rewarding in the first phase of the process due to the lack of staff training and equipment shortages. The first half of the structure was finished after 4 months of works, whereas the assembly of the second half took only 2 months. The average speed of assembly in the end of the process was about 30 plates per day.

7. DEFORMATION VERIFICATION

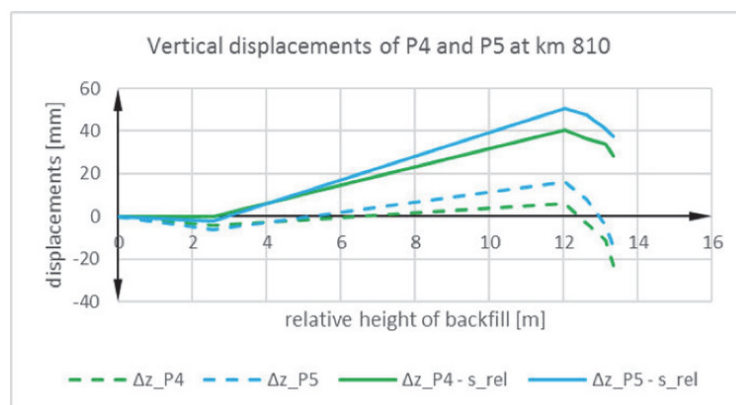


Fig. 7. Vertical displacement of the crown point in relation to the cover height (the dashed line presents settlement displacement with and the continuous lines present displacements in relation to the structure's bottom)

During the entire backfilling process precise geodetic measurements were performed. The structure's deformation was compared to the behavior of the structure predicted with use of FEM analysis and met the estimations sufficiently well.

The results of the surveys of the vertical displacement of the crown point for one of the controlled sections can be seen in the Figure 7. The picking effect at the level of the structure's height can easily be noticed. Also, the structure's settlement caused by sinking into the loose sand layer can be observed.



Fig. 8. Bedding preparation before steel structure assembly



Fig. 9. Assembly of the bottom part of tunnel



Fig. 10. The assembly with a ring by ring method



Fig. 11. Instalation of EPDM membrane and nonwoven layers



Fig. 12. View from concrete MSE wall side of the tunnel



Fig. 12. Inside view , ballast under the rails

8. SUMMARY

Construction of the SuperCor circular structure of SH16 tunnel of Birtouta – Sidi Abdallah – Zeralda Railway was finished with a delay but can be considered as a great success. It is the first soil-steel structure in the Maghreb countries, shipped from the central Europe. At the same time, it is one of the longest tunnels made of corrugated steel plates in the world and a promising foretaste of possibilities created by the Northern Africa's market.

ViaCon as a company and its staff gained a lot of experience both in designing and assembling in conditions differing significantly from the European reality.

The structure has been put into operation in September 2016 and has a noticeable share in the technological leap of Algeria and protecting the population of that area of the country against exclusion from the labor market.



Fig. 13. View from outlet of the completed tunnel

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STRESZCZENIE

W listopadzie 2015 roku zaprojektowany został tunel SH16 linii kolejowej Birtouta – Sidi Abdallah – Zeralda w Algierii. Ustrój nośny obiektu zaprojektowano jako stalowo-gruntową konstrukcję podatną z blach falistych o profilu fali 380 x 140 mm. Długość tunelu wynosi 180 m a średnica jego kołowego przekroju poprzecznego to 12 m. Tunel znajduje się na łuku poziomym, więc konstrukcja tunelu została wykonana w czterech prostych odcinkach, połączonych pod kątem za pomocą elementów spawanych, tak aby wpisać się w krzywiznę toru. Maksymalny naziem nad konstrukcją wynosi 7 m.

Ze względu na wyjątkowo dużą siłę osiową, wprowadzono dodatkowy, nigdy wcześniej nie stosowany, czwarty rząd śrub, dla zwiększenia nośności połączenia śrubowego. Wszystkie użyte śruby są klasy 10.9.

Ze względu na wymaganie szczelności został zaprojektowany i wbudowany podwójny system uszczelnienia tunelu. Jako pierwsze zabezpieczenie, zastosowano trwałe elastyczny uszczelniacz aplikowany w szczelinach połączeń blach nakładanych na siebie oraz na śrubach i nakrętkach przy użyciu plastikowych kapturków. Jako drugie zabezpieczenie, zastosowano gumową membranę EPDM, przy użyciu której szczelnie otoczono konstrukcję stalową tunelu.

Obiekt został oddany do użytku we wrześniu 2015 roku i jest jedną z najdłuższych konstrukcji powłokowo-gruntowych na świecie.