# DESIGN OF ZAM 1 TUNNEL CONCEPTUAL, TECHNOLOGICAL AND STRUCTURAL ELEMENTS

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**Abstract:** *The paper presents Zam 1 tunnel located on local variant of Curtici - Simeria railway executed for the rehabilitation of the line for trains with a maximum circulation for passenger trains speed of 160 km/h and 120 km/h for freight trains. The tunnel is designed for double track line and has a length of 610m. The tunnel crosses rock layers on entire length (altered basalt and altered limestone) so the NATM technology has been adopted. The paper presents the types of sections considered, execution technology and the method for structural calculation and validating and the verification of these.*

**Key words:** *tunnel, portal, shotcrete, anchors*

## 1. Main characteristics of the project and construction

Tunnel 1 (Zam 1) is located between km 523+ 757 and km 524+ 367 (L = 610 m), on a section where Curtici - Simeria railway alignment has been modified, between the stations Campuri Surduc and Ilteu. This modification has been done in order to increase the circulation speed of the passenger trains to160 km/h for trains and the circulation speed for freight trains to 120 km/h.

In the same variant are located three tunnels (Tunnel 0 having the length of L = 340 m, Zam 2 having the length of L = 227m and tunnel 3 with a length of 603m).

Tunnel Zam 1 is located on the left bank of the Mures river, in an area with both forested (the first part of the route) and deforested slopes (the latest part), with a difference between the rail level and riverbed of approx. 30m-40m.

In plan, the tunnel has a curve with a radius of 1500 m. In longitudinal profile, slope of tunnel is 3 $^0/_{00}$ over the entire length. Maximum coverage of the tunnel is of approx. 46 m.

For safety, there have been placed 24 niches at min 25m interval symmetrically located on both sides.

Longitudinally, were placed 24 niches were placed at min. 25m symmetrically on both sides.

### *1.1. Geological, geotechnical and geomechanical conditions*

From the geomorphologic pont of view the studied area is located in Mureş river corridor, passageway that separates the Metaliferi Mountains from Poiana Rusca Mountains, both being parts of the Western Carpathians.

Mureş corridor is formed during the Neogene by dipping formations older along fracture systems and is characterized by low-lying, relatively uniform slopes and the topography is less rugged and has a character of terraced hills towards north and terraced towards south.

Based on data from geotechnical and geophysical investigations, one can appreciate that tunnel Zam 1 crosses the following formations:

- Layer I: represents the topsoil and deluvial layer and it is characterized by a thickness of 0.3 to 0.9 m (average thickness = 0.53 m);
- Layer II consisting of deluvial rock fragments and heavily damaged and heavily cracked (clay material clogged), characterized by a thickness of the 1,2 - 6,7 m;
- Layer III is represented by the basaltic rock core with alternating black shale clays, cracked and damaged, characterized by a thickness of 8.3 to 44.9m;
- Layer IV bedrock: compact (basalt), slightly cracked and weathered, extends to an average depth of 21.47 m.

### *1.2. Tunnel cross sections, lining systems, the construction method*

Inner section of the tunnel is established to ensure the clearing for both the rolling material and pantograph and catenary according to documents UIC, STAS 4392-84 Railway clearance and TSI

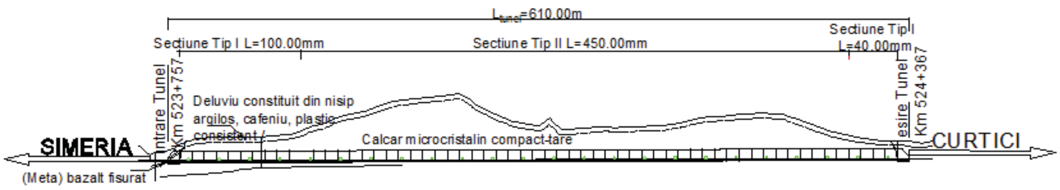


**Fig. 1.** *Profil longitudinal tunel Zam 1*

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2008/163 - Safety in Railway Tunnels. The inner section is circular with a radius of 5.8m, for double railway with lines spacing of 4.2m, with a height from NST of 7.87m, the distance between the railway axis and the banchine is of 2.2m and the banchine has 1.2m.

The lining has two layers, one exterior of 30cm thickness and one interior of 40cm thickness, with intermediate waterproofing from PVC and geotextile, mounted on the entire section.

Based on geological and geotechnical information, resulting from drillings and from geophysical investigations (geotechnical and seismic), the tunnel crosses two soil types.

In accordance with the two types of predicted soil types, two outer lining sections are being proposed:

**Section I** consists of a primary support (outer lining), which consists of: metal form support of GI 100, concreted anchors with the length of 3m placed at 2m in longitudinal section and 2.6m in transverse section and incline anchors (anchors with an inclination of 14˚, having 3.5m in length, at 50 cm in cross section and 2m in longitudinal section) 20cm thick shot concrete, intermediate waterproofing on the vault and straight legs. The final inner lining made of concrete has a thickness of 40cm, and the lower raft foundation is made of a concrete slab of 70cm.

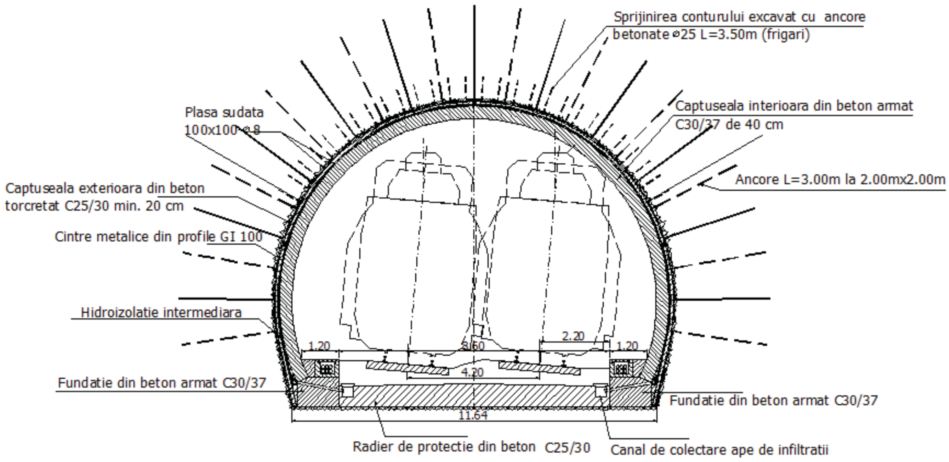

**Fig. 2.** *Type 1 Cross-section*

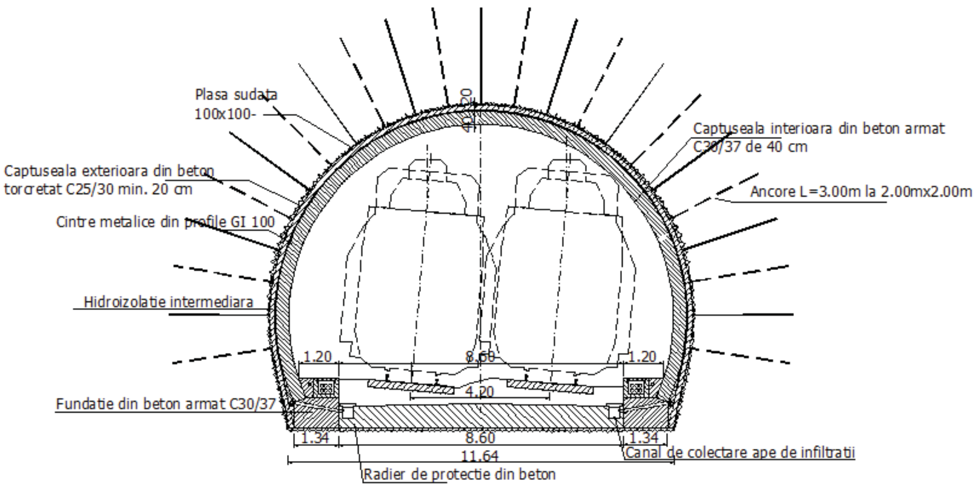

**Fig. 3.** *Type 2 Cross-section*

**Section II** consists of a outer primary support made by concreted anchors with the length of 3m placed at 2m in transverse section and at 3.4m in longitudinal section and 10cm thick shot concrete; intermediate waterproofing on the vault and straight legs; the final inner lining made by reinforced concrete 40cm thick, with the raft foundation made of a concrete slab of 70cm.

The entrance and the exit portal have the same configuration.

Portals are made of a special ring, cut at a 45° at the upper part and have a thickness of 40 cm; the lower part has a length of 9.70m and the upper part has a length of 5.85m; the portal exceeds the initial excavations.

The ring is similar to the inner lining in terms of thickness and composition, with waterproofing at the upper side and protection of reinforced concrete with a wire mesh.

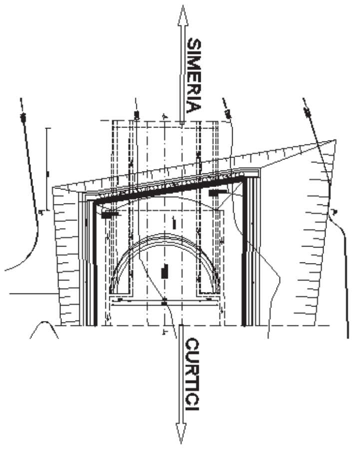


**Fig. 4.** *Exit portal -View plan*

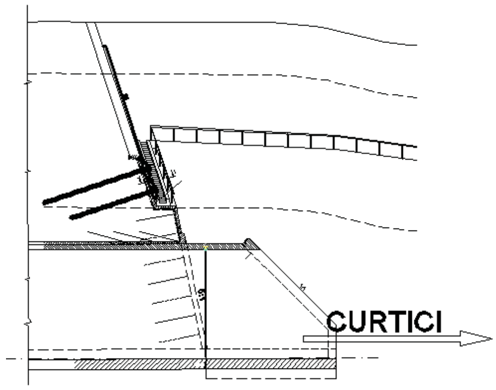


**Fig. 5.** *Exit portal - Longitudinal section*

The initial excavation is 5:1 on the rock zone and 3:1 on the deluvial zone, with a horizontal step between them, where a ditch is placed to collect and evacuate the water. The excavated rock surface is protected with shot concrete of 25cm thickness and the rock is strengthened with concrete anchors with diameter of 25 cm and length of 3.0m and the deluvial area is supported by anchors with variable lengths, from 2.00m up to 8.00m, and reinforced concrete elements.

## 2. Execution technology

The New Austrian Method (NATM) for hard rocks and The New Austrian Method adapted for weak rock with umbrella pipes are the chosen methods for the execution of these tunnel. The main idea of this method is that the rock around the excavated hole, can be turned into a supporting element (ring bearing rock), with the help a supporting system constructed in due time.

NATM concept provides a composed support, consisting of:

- The primary support is made of the rock mass (main component), eventually strengthened with anchors and the actual support applied on the exposed surface of the rock mass (secondary component) made by shot concreted lining, eventually, strengthened with metal form or arches;
- Secondary support consists of the inner lining, made of reinforced concrete.

The method has several important advantages, namely:

- the possibility of adapting technology and the type of section, during the execution, depending on the nature of the soil encountered;
- the possibility of excavating the whole section or two-stage excavation, the cap and the central core of the tunnel, depending on the nature of the ground encountered, thus leading to a higher productivity and creating an easy opportunity to transport materials;
- the possibility of mechanizing all operations and hence achievement of a high execution speed.

*PHASE 1*. The excavation

The excavation is executed with explosives in hard and very hard rocks.

This technology requires execution of a number of blast holes in the front surface of a certain length and loaded with a certain amount of explosive, which constitute a shooting scheme.

*PHASE 2*. Mounting the anchorages

The holes are drilled for anchors with the punching machine with multiple arms of Jumbo type.

The anchors are inserted and concreted. The nets and placed and mounted on small plates

The rock layers tightened with the help of the anchors forms a block that can resist in good conditions to the pressures of the massive.

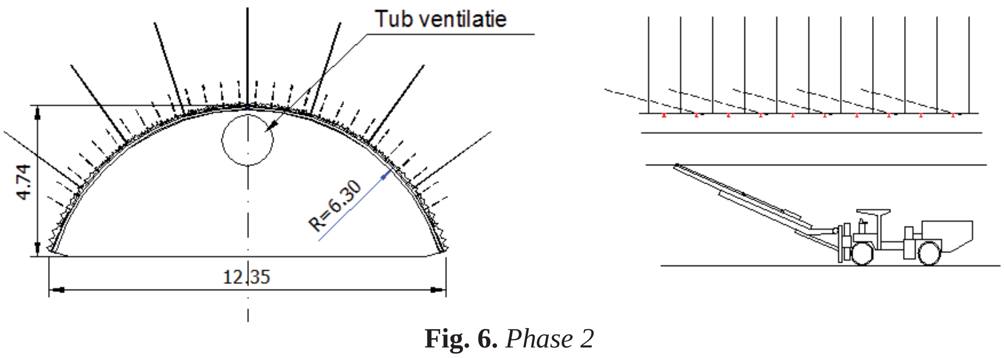


**Fig. 6.** *Phase 2*

*PHASE 3*. Constructing the outer lining made from shot concrete.

Shot concrete has a constant thickness of 20 cm along the whole length of the section.

The outer lining is made of shot concrete C25/30 class. On them, there are mounted wire Buzau type nets with a diameter of 6 mm, 80-100 mm mesh following the covering layers of 5 cm.

The shot concrete is applied in successive layers, of 3 cm thickness.

*PHASE 4*. Excavation of central core

Excavation of the central core is made with pick-hammer or explosives and the dumpers are loaded by using the excavator.

*PHASE 5*. Mounting anchors on the straight leg zone.

The mounting of anchors on the straight leg zone is done similarly as in Phase 2, with the same machine with multiple arms of Jumbo type.

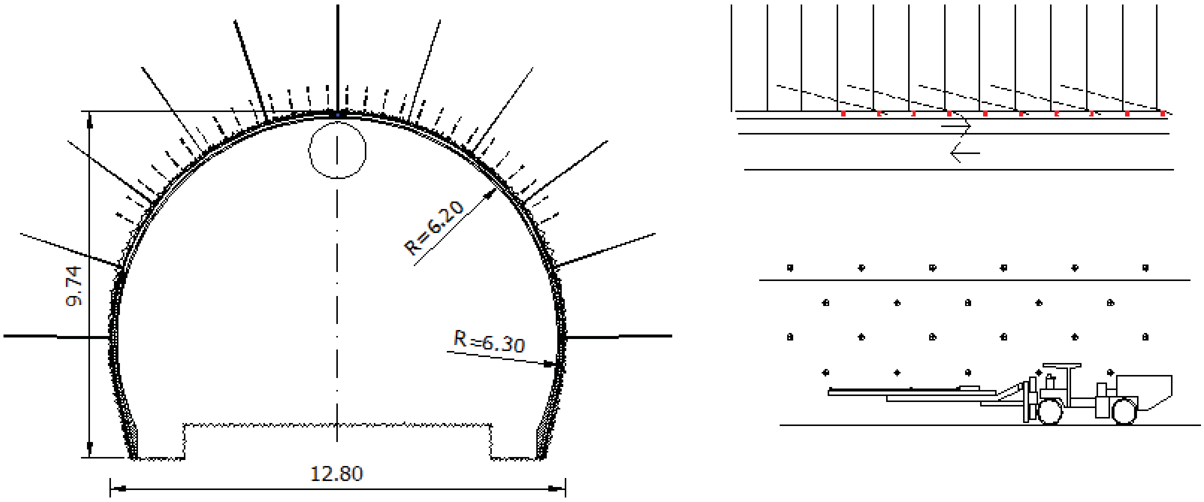


**Fig. 7.** *Phase 5*

*PHASE 6.* Shot concreting on the straight leg zone.

Operation is identical to that in Phase 3.

*PHASE 7.* Excavation of raft foundation with the pick- hammer on half-section.

To ensure the works flow, the raft foundation is half excavated, ensuring the works flow with a mobile bridge. The mobile bridge has wheels and joints so that in the next phase it can be placed under that excavated half.

The excavation is done with pick-hammer and it is made along sections of 8m length.

*PHASE 8.* Concreting of the raft foundation.

After the whole raft is excavated, it is going to be concreted. Concreting is done on sections of 8m length under a mobile bridge. Concrete is delivered with the concrete mixer and poured with a pump.

*PHASE 9.* Installing of waterproofing.

After making the first outside lining, the execution of the waterproofing layer follows. On the inner surface of the outer lining, a 2mm thick waterproofing plaster is made. The waterproofing consists of bituminous sheets which are fixed to the outer lining soffit. For lying the waterproofing, a mobile metal scaffolding is used.

*PHASE 10. Concreting of the inner lining.*

For this, the steel formwork is fixed, having also a vibrating device, the lining is executed as rings of 10 m length. At the joints, double asphalted sheets are fixed. The concrete is poured with powerful pumps. After the concrete is hardened, the steel formwork is relocated to another ring. Between the insulation and the inner lining of the tunnel at the top of the cap some holes are formed and they have to be filled by injection.

## 3. Structural design and dimensioning of the sections of the proposed

To validate and verify the proposed type of sections, numerical calculations are performed by using the finite element computation program, Plaxis 2D.

The model adopted for the type I is a computational model on the execution phases, two-dimensional, with an area of 55m high and 64m wide, with a coverage of 11.00m.

The model adopted for type II is a computational model on the execution phases, two-dimensional, with an area of 84m high and 64m wide, with coverage of 33.00m.

The soil is modelled with triangular elements, the outer lining and inner lining with slab –type elements and anchors with bar- type elements.

Ground characteristics considered tabulated below are affected with partial safety coefficients according to Eurocode.

**Table 1** *Ground characteristics Section Type I*

| Ground | γ (kN/m³) | c (kN/m²) | Φ (°) | E (kN/m²) | ν |
|---|---|---|---|---|---|
| Sand Clayey | 18 (20) | 51 (32) | 19 (15) | 1.31E+04 (1.19E+04) | 0.3 |
| Alterated Basalt | 27.5 (30) | 4000 (2500) | 25 (19) | 1.30E+06 (1.18E+06) | 0.2 |
| Basalt | 32 (35) | 16000 (10000) | 35 (27) | 1.87E+07 (1.70E+07) | 0.2 |

**Table 2** *Ground characteristics Section Type II*

| Ground | γ (kN/m³) | c (kN/m²) | Φ (°) | E (kN/m²) | ν |
|---|---|---|---|---|---|
| Silty clay | 20 (22) | 31 (19) | 19 (15) | 1.60E+04 (1.45E+04) | 0.3 |
| Cracked limestone | 23 (25) | 3000 (1875) | 25 (19) | 1.50E+06 (1.36E+06) | 0.25 |
| Limestone | 28 (31) | 10000 (6250) | 35 (27) | 1.87E+07 (1.70E+07) | 0.25 |

**Table 3** *Ribbs characteristics*

| Secţiune | Element | $E_{echiv.}$ (kN/m³) | EA (kN/m) | EI (kNm²/m) | ν |
|---|---|---|---|---|---|
| Tip I | Cintru HEB100 | $2.1x10^8$ | $5.460x10^5$ | $9.45x10^2$ | 0.2 |

**Table 4** *Anchors characteristics*

| Section | Anchors concreted | EA (kN/m) |
|---|---|---|
| Type I and II | Φ32 | $16.89x10^4$ |

**Table 5** *Characteristics of shot concrete for external lining*

| Section | Shot concrete | E (kN/m³) | EA (kN/m) | EI (kNm²/m) | ν |
|---|---|---|---|---|---|
| Type I | 20cm | $3.2x10^7$ | $6.4x10^6$ | $2.133x10^4$ | 0.2 |
| Type II | 10cm | $3.2x10^7$ | $3.2x10^6$ | $2.667x10^3$ | 0.2 |

**Tabel 6** *Characteristics of reinforced concrete for internal lining*

| Section | Reinforced concrete | E (kN/m³) | EA (kN/m) | EI (kNm²/m) | ν |
|---|---|---|---|---|---|
| Type I and II | 40cm | $3.2x10^7$ | $1.28x10^7$ | $1.707x10^5$ | 0.2 |

The model of soil behaviour is the Mohr-Coulomb model.

Design software allows the simulation advancing front so there are considered 5 phases of advancement, 1m each phase.

The phases considered are: - excavation of the crown, installing of anchors, fixing the metal form, shot concreting; - excavation on the straight legs zone and raft foundations - concreting of the raft foundations and inner lining.

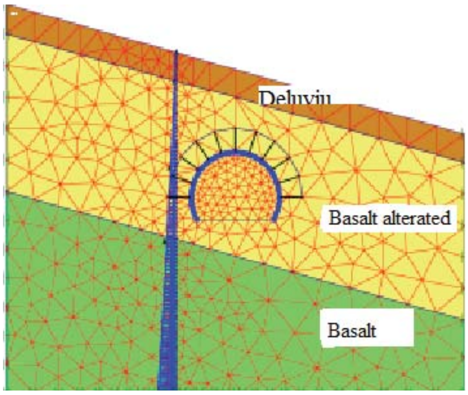


**Fig. 8** *The geometry of structure (Section type I)*

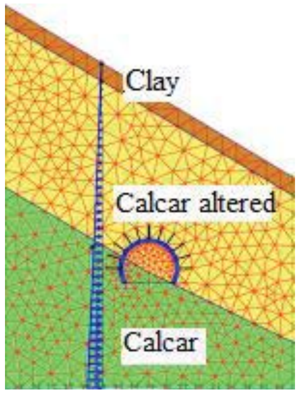


**Fig. 9** *The geometry of structure (Section type I)*

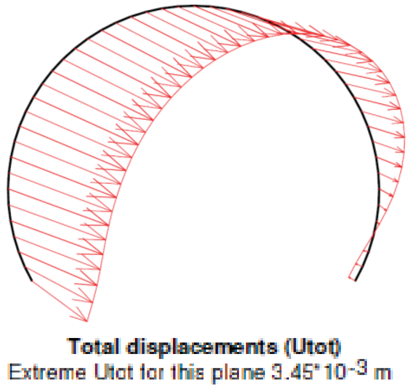


**Fig. 10** *Displacements diagram (type I)*

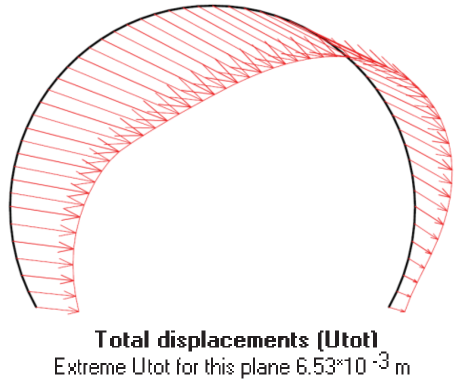


**Fig. 11** *Displacements diagram (type II)*

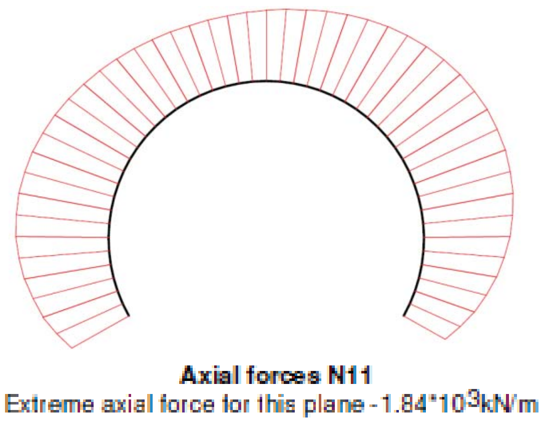


**Fig. 12** *Axial forces (type I)*

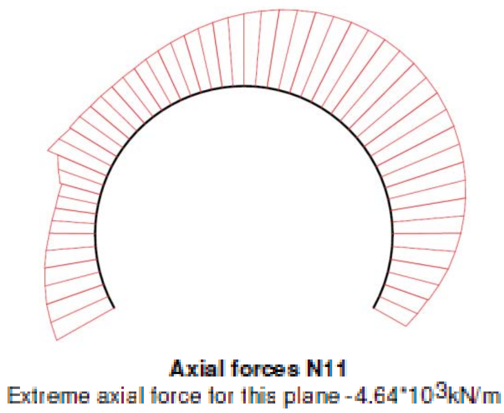


**Fig. 13** *Axial forces (type II)*

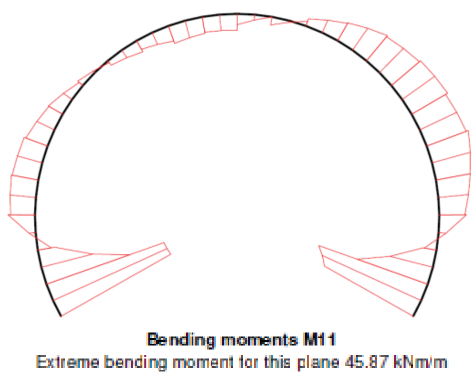


**Fig. 14** *Bending moments diagram (type I)*

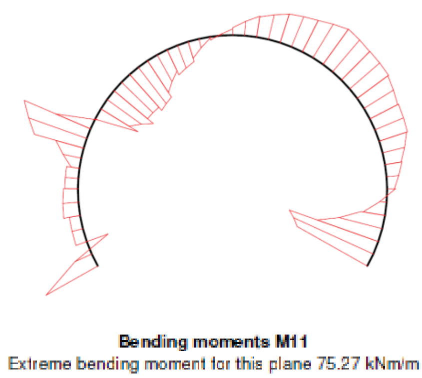


**Fig. 15** *Bending moments diagram (type II)*

Determination of the stresses required for the reinforcement dimensioning of the inner lining is designed considering that the initial support system is affected in time, while the inner lining becomes the main supporting element, overtaking the permanent loads and the earthquakes. The resulted sectional stresses have led to a constructive reinforcement.

In Figures 10 and 11 are diagrams for the displacements of the sections of type I or II.

Figures 12 and 13 show the diagrams for the axial forces of the two sections, and Figures 14 and 15 show the moment diagrams.

## 4. Conclusions

Zam 1 tunnel is the only one of the four existing tunnels on alternative route, which is realised entirety with NATM.

The type of rock which is traversed by the tunnel has imposed two types of sections: type I on 160m and type II on 430m.

To compensate the low initial geological investigations, there are provided geological charting of the rocks encountered at every step and trough evaluation of their class it is appreciated if it is necessary to adapt the initial supporting elements.

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