Geotechnical and Topographical Investigations for Tunnel Bătuţa IV Pan-European Corridor Rehabilitation

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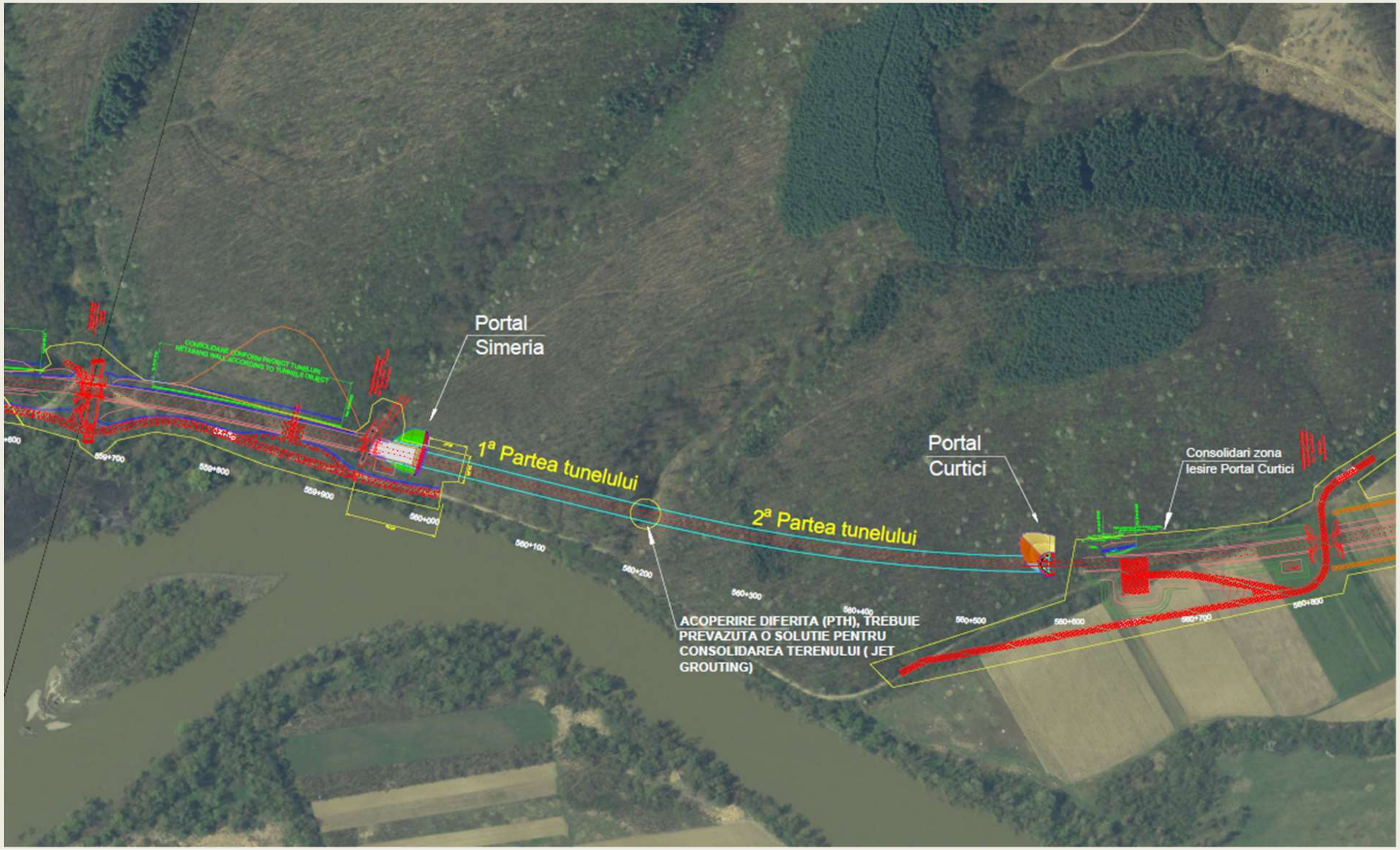
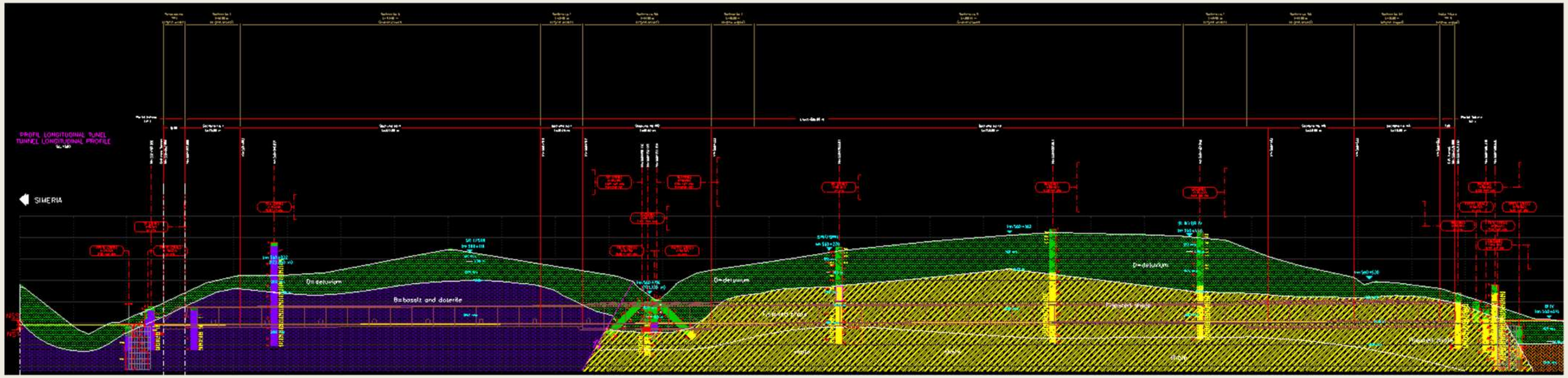
Tunnel characteristics

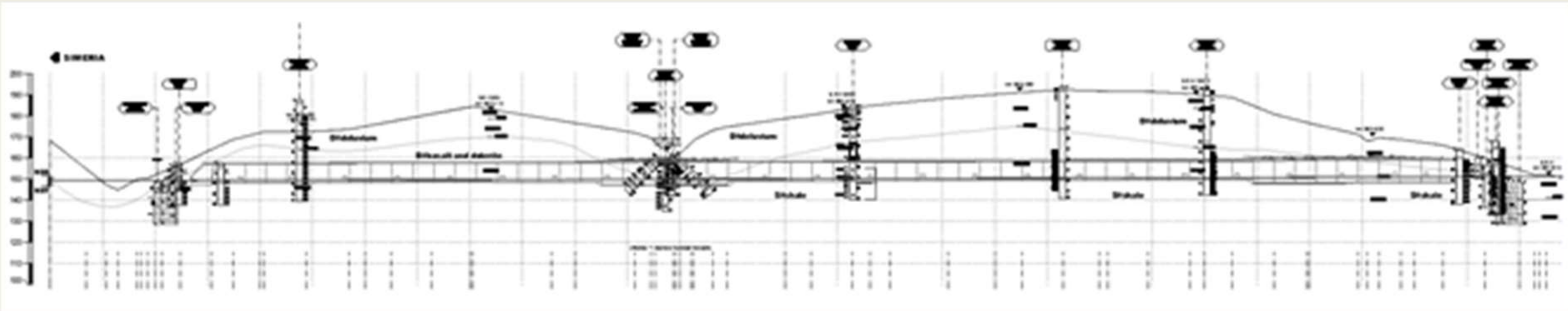
- 603 m in length;
- double electrified railway;
- the left bank of the Mures river, in the area with wooded slope.



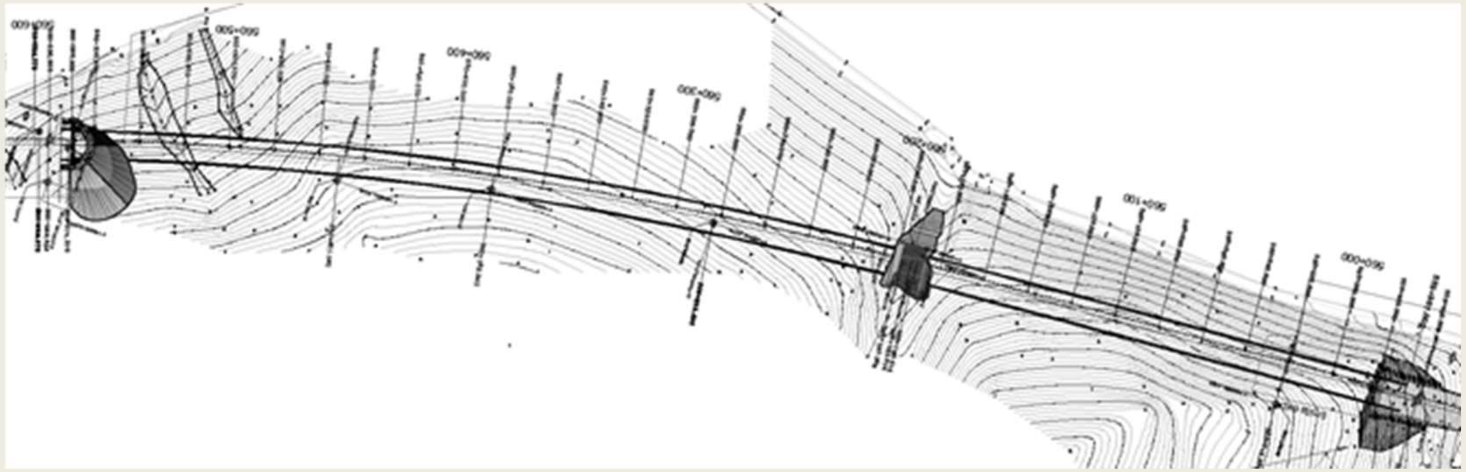
Geotechical investigation

The aim of this report is to show the geotechnical and topographical investigations fo tunnel BATUTA which have been carried out from the JV Astaldi-FCC in addition to the existing data. The new investigation confirmed part of the tunnel design (from Simeria portal to the central part of the tunnel itself) and lead to some needed modification in the rest of tunnel, i.e. from the central part to Curtici portal.





Geotechical investigation



In the following picture it is clear the location of the above mentioned boreholes and the subsequend geotechnical interpretation.

Geotechical investigation

All boreholes show a typical geotechnical sequence:

- A first level of deluvium form of plastic consistent-plastic stiff silty sand, mixed with small rock fragments and gravel, with size of rock fragments increasing with depth
- A second level of rock, which nature differs according to the location along the tunnel:
  - ❖ BASALT in FP1T2 and F9TT3 (Simeria Portal), fissured in the first meters and then compact from (-10.5) m to (-11.0) m;
  - ❖ BASALT in F10TT3 (Central part of tunnel), fissured in the first meters and then compact from (-13.0) m;
  - ❖ DOLERIT in F10T2 (Central part of tunnel), fissured in the first meters and then compact from (-9.2) m;
  - ❖ Altered SANDSTONE in F8T2 (Curtici portal);
  - ❖ Altered SANDSTONE in FP2T2 (Curtici portal), compact from (-15.30) m.

Geotechical investigation

According to the Bieniawski classification based on Rock Mass Rating System, rock mass was defined in the investigated area as follows:

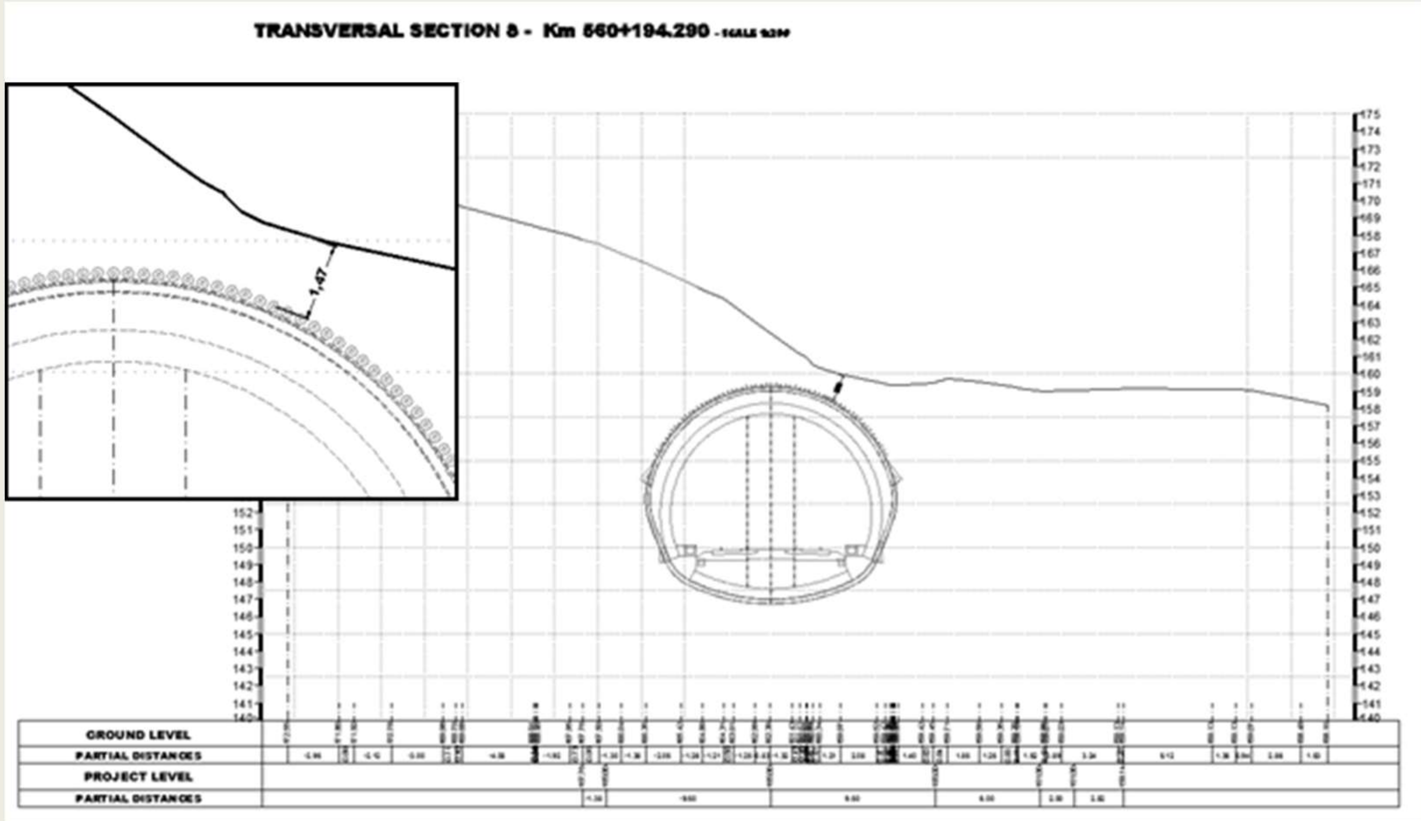
Investigated Area	Boreholes	Rock Quality	Class
Simeria Portal	FP1T2 – F9TT3	Fair Rock	III
Central part of tunnel	F10TT3 – F10T2	Fair Rock	III
Curtici portal	F8T2 – FP2T2	Poor/very poor rock	IV-V

It is clear that a new investigation was needed to define properly the use of different tunnel sections in the design: indeed no boreholes were already realized along the tunnel between the portals and the central part.
Another borehole was made (F11TT3) but it is short and does not reach the rock in deep, so it was not considered for tunnel design.

Recent investigations

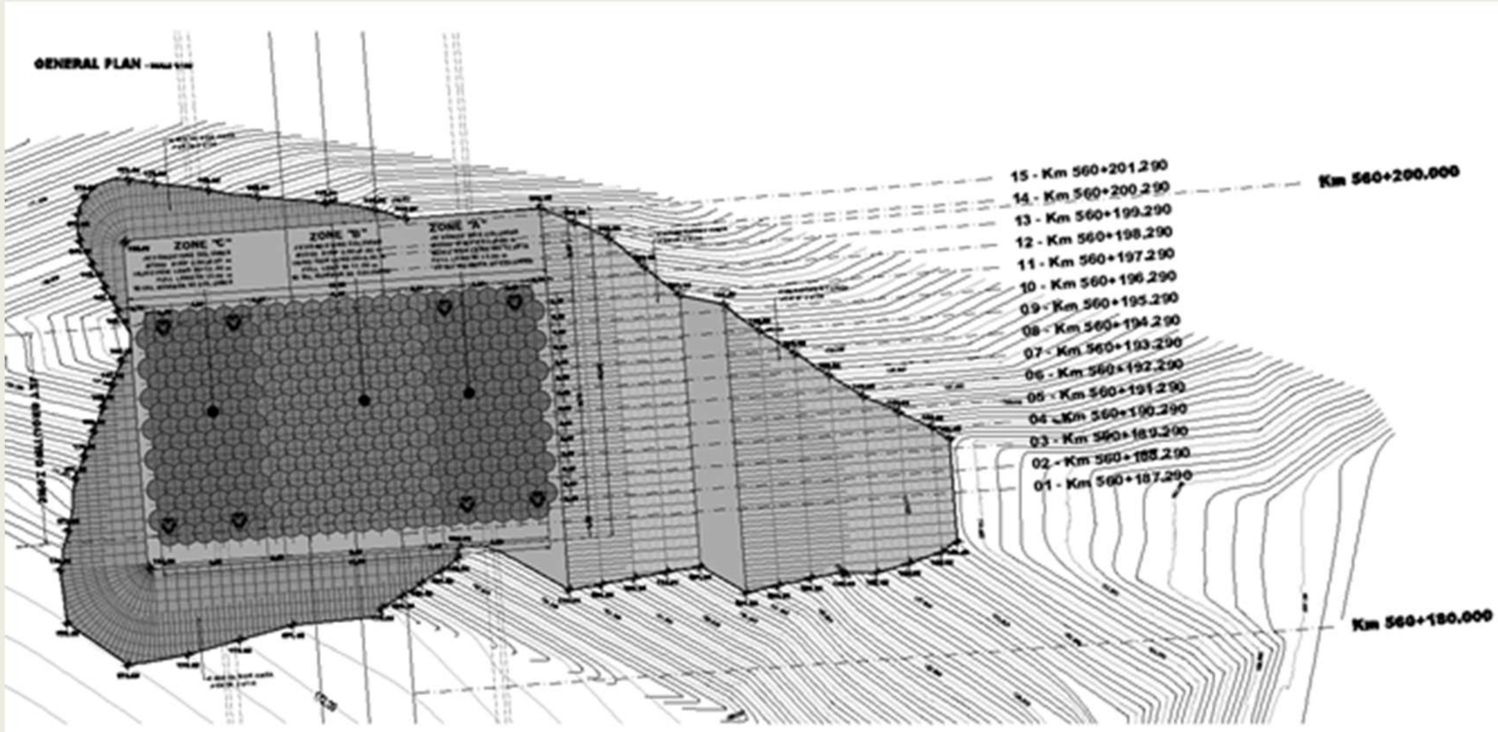
1. Topographical survey

The topographical survey confirmed the soil covering along a large part of tunnel but highlighted that in the central part, approx at km (560+195), the soil cover was less than 1.5 m: not feasible for the excavation of tunnel in safe conditions.

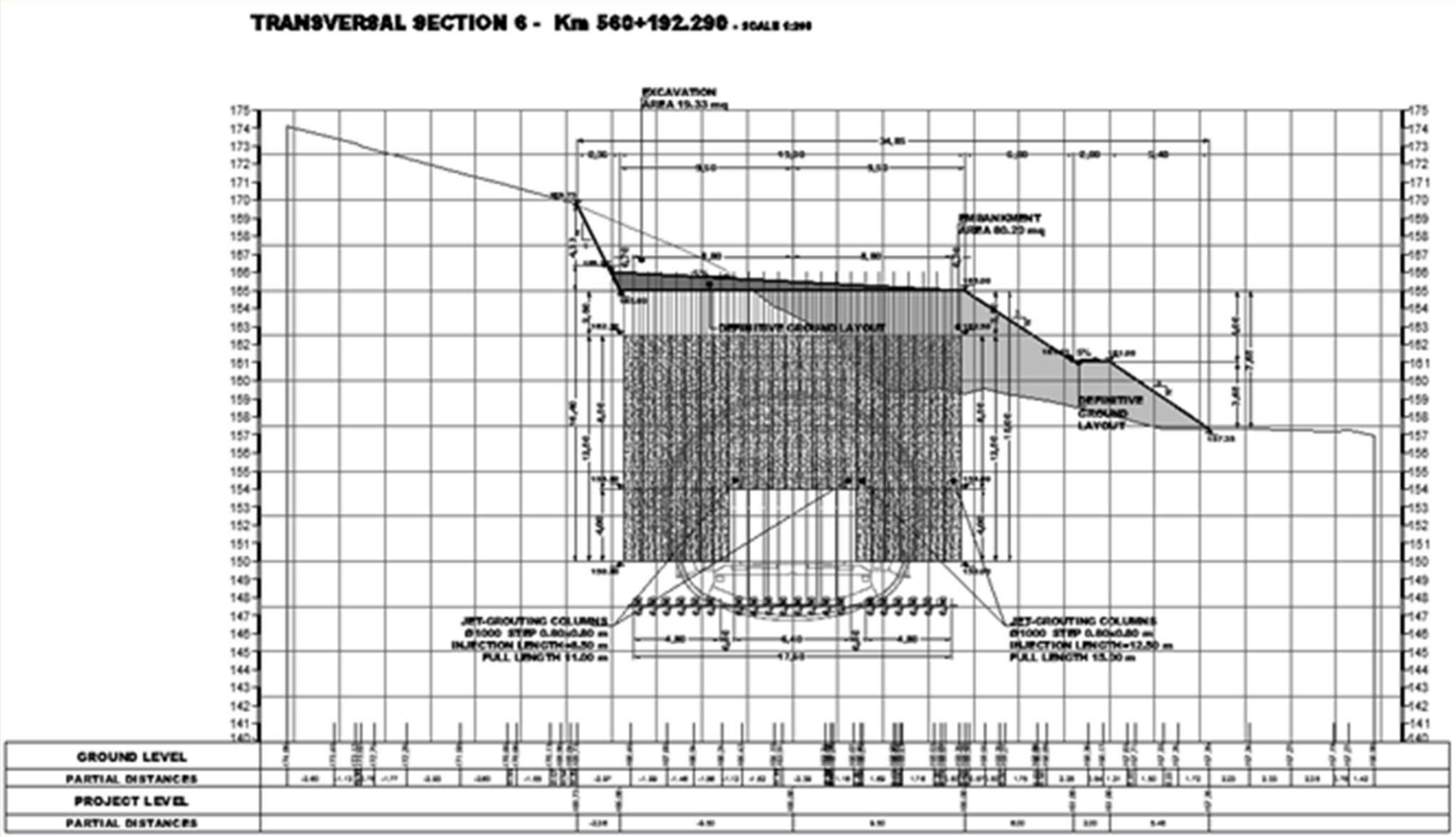


Recent investigations

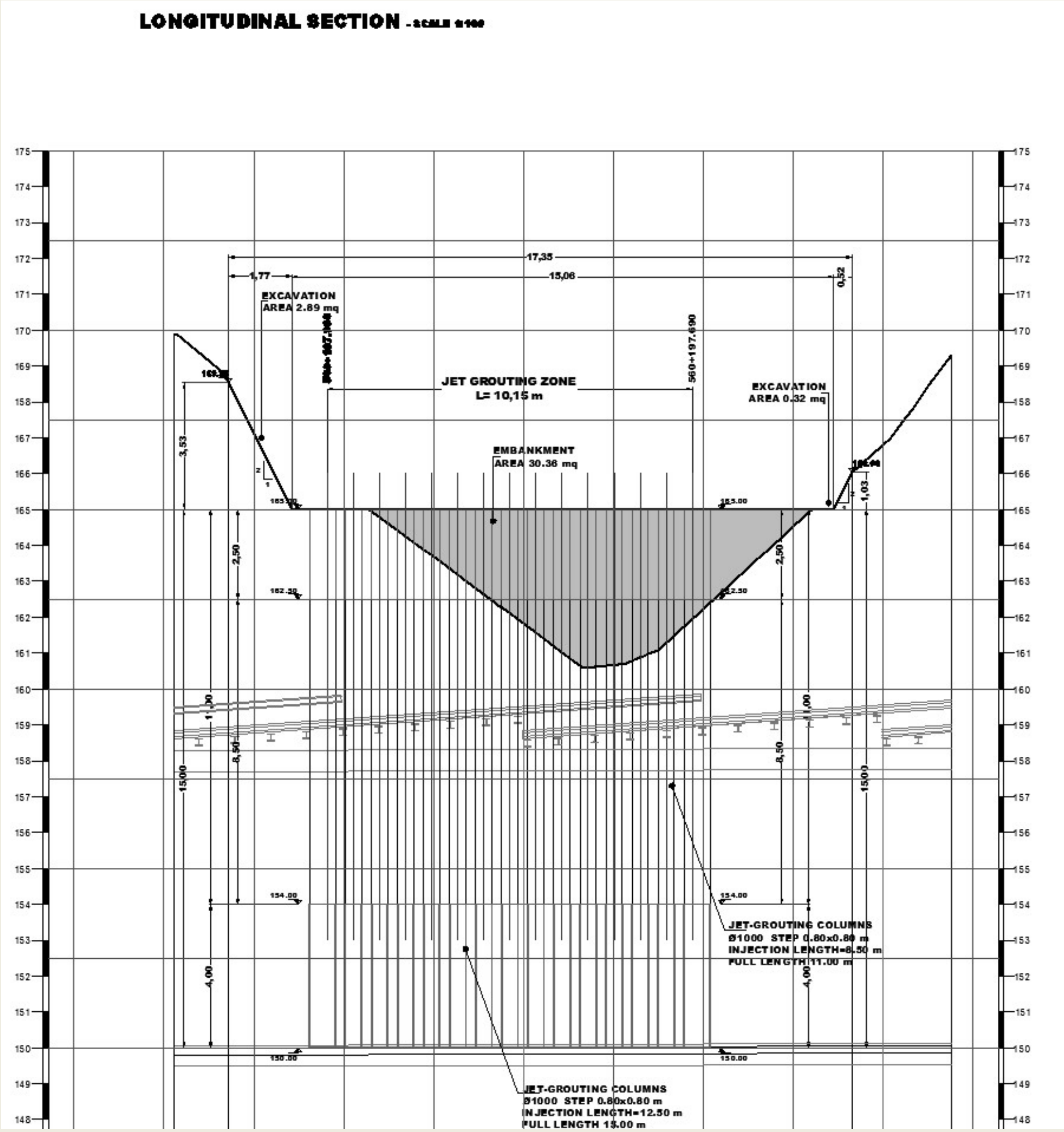
This aspect lead to a modification of design to improve safety conditions for men and machinery: it has been designed an artificial soil cover above the tunnel (where natural cover is not sufficient) combined with soil improvement by means of jet grouting columns made from the ground level. This jet grouting intervention extends 10 m in the tunnel and overlaps with section type III B, as shown in the following pictures.



Recent investigations



Recent investigations



Recent investigations

2. Geotechnical survey

During the 2018 survey, 9 new boreholes (S1-S1A-S2-S3-S4-S5-S6-S7-S8) were realized along Batuta tunnel, including the entrance and exit portals. Then, after Curtici portal, 2 additional boreholes were made (S9 and S10). The position of the boreholes is illustrated in pictures at the beginning of this paper, for further details prease refer to specific drawings. Considering the competence area of the new boreholes, refence can be made to the following table:

Competence Area	Borehole/s
Simeria portal	S1
Tunnel between Simeria portal and central part	S1A
Central part of tunnel	S2-S3-S4
Tunnel between central part and Curtici portal	S5-S6-S7
Curtici portal	S8

The global interpretation of the geotechnical survey results confirm the already existing geotechnical sequence from the Simeria portal to the central part of tunnel, but highlights new features for what concerns the remaining part of tunnel.

Recent investigations

Indeed, after a first part of “deluvium” (clayey-silty soil with fragment of rock) the rock found in the new boreholes is the following:

- BASALT in boreholes S1 and S1A;
- SCHYSTS in the remaining boreholes (from S2 to S9)/

Boreholes S2, S3 and S4 confirm that in the central part of the tunnel there is alteration of rock due to the presence of a fault. After the results of the last investigation, a new geomechanical and geotechnical profile has been defined and it can be considered fairly representative of the effective soil conditions since the investigation has regarder the whole area of the tunnel (before 2018 the area was not all available for deep investigation and the boreholes were a few).

3. New definition of rock classes

According to the Bieniawski classification based on Rock Mass Rating System, rock mass is defined in the investigated area as follows in the next table.

Recent investigations

BOREHOLE	S1	S1A	S2-S3-S4	S5	S6	S7	S8
UCS (Mpa)	100-250 (4-10 point load)	>250 Mpa	25-50 Mpa	25-50 Mpa	25-50 Mpa	50-100 Mpa	50-100 Mpa
n1	12	15	4	4	4	7	7
RQD	<25	50-75	<25	25-50	<25	<25	<25
n2	3	13	3	8	3	3	3
spacing of discontinuities	0.06-0.2	0.2-0.6	0.06-0.2	0.06-0.2	0.06-0.2	0.06-0.2	<60 mm
n3	8	10	8	8	8	8	5
conditions of discontinuities	slickensided	slightly rough surfaces, separation <1mm highly weathered walls	soft gouge >5mm thick	slickensided	slightly rough surfaces, separation <1mm highly weathered walls	separation 1-5 mm	soft gouge >5mm thick
n4	10	20	0	10	20	10	0
ground water	damp	wet	damp	wet	wet	wet	damp
n5	10	7	10	7	7	7	10
orientation of discontinuities	favourable	favourable	-	fair	fair	fair	fair
n6	-2	-2	0	-5	-5	-5	-5
RMR	41	63	25	32	37	30	20
Class	III	II	IV	IV	IV	IV	V
SECTION TYPE	SIMERIA PORTAL	SEC II	SEC III B + JET	SEC I A	SEC I A	SEC I A	CURTICI PORTAL

4. Proposal for the new section 1A

Due to the fact that in the part of tunnel between the middle and the Curtici portal the rock quality is lower than the expected one, an additional excavation section has been proposed. This new section can be excavated at full face (as also numerical analysis confirm) and the excavation is done using:

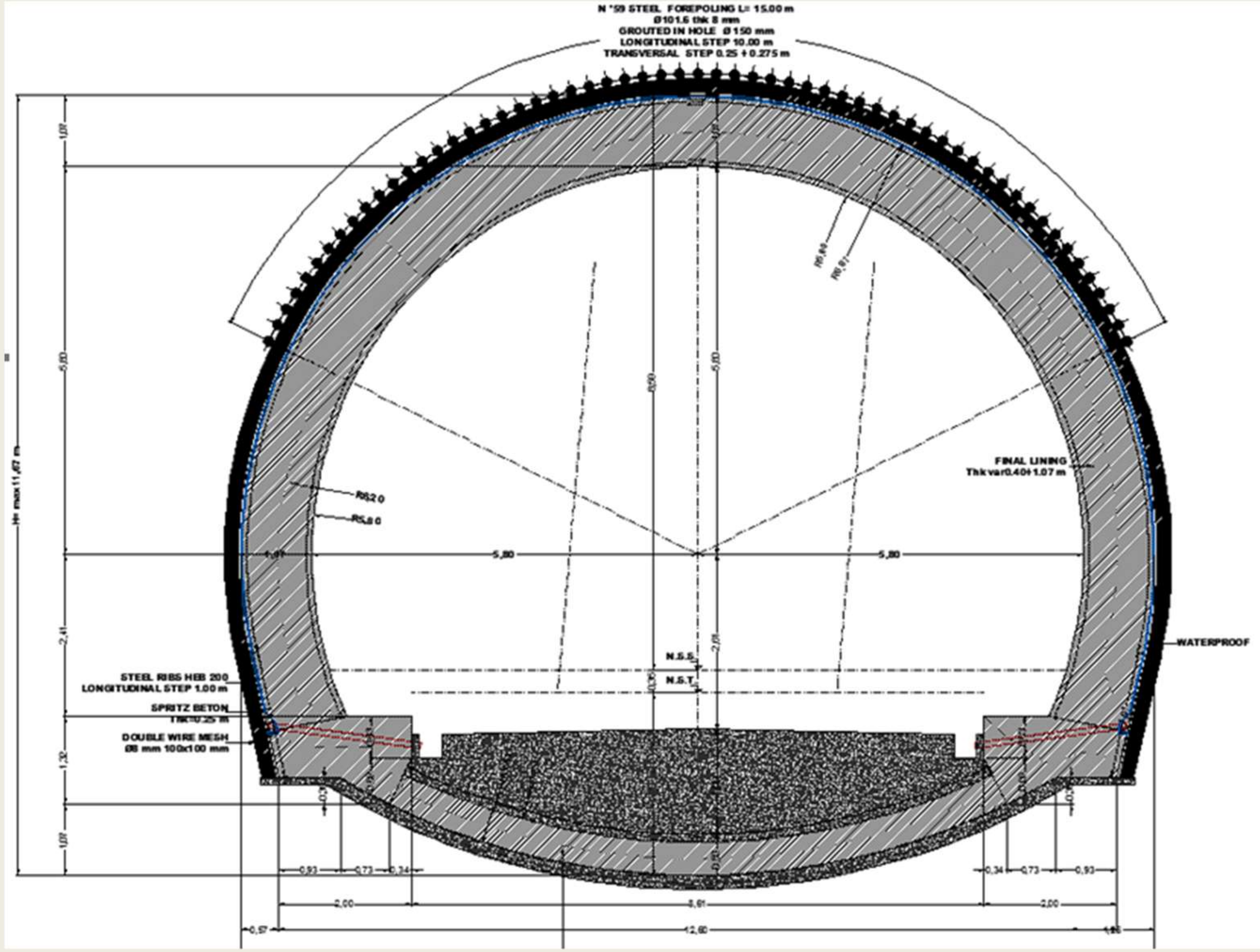
- Steel ribs HEB200
- Micropile umbrella in the crown

No lateral nails are used, since they would be useless given the alteration of rock which lead also to determine a plastic radius which goes beyond the standard length of nails.

The alteration of rock, especially in the crown area, lead to use the micropile umbrella which will protect the upper part during excavation.

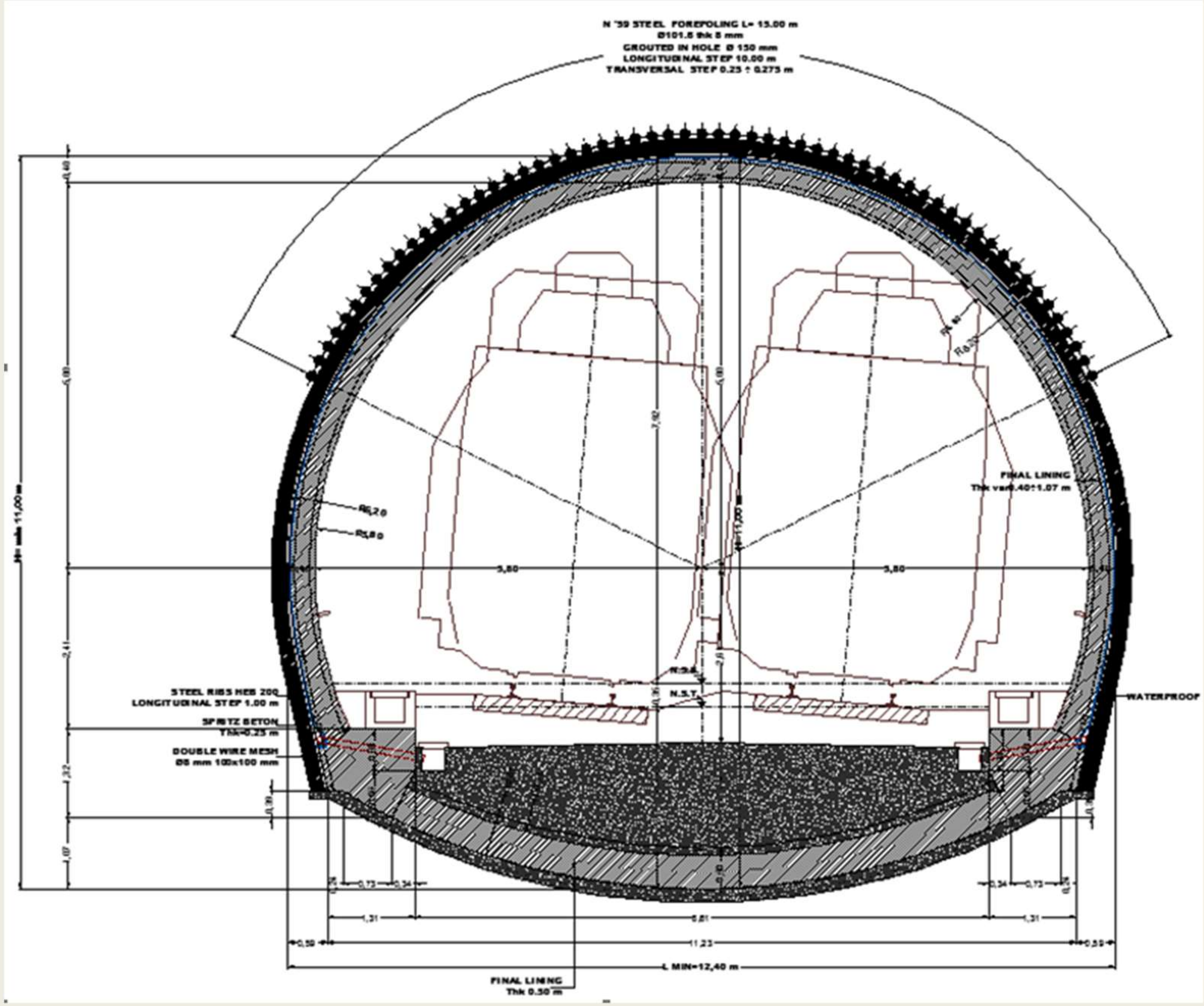
Recent investigations

The final lining has a variable thickness from 40 cm to 107 cm, the invert has a costant thickness of 50 cm. Section 1A is sketched in the following pictures.



Section 1A – maximum section

Recent investigations



Section 1A – minimum section

Forces evaluation – Section 1A

For the evaluation of the strain-stress behaviour of soil and structures, numerical analyses simulating the excavation of tunnel have been done with the Finite Element Method, in 2D conditions, using the program PLAXIS v.9.

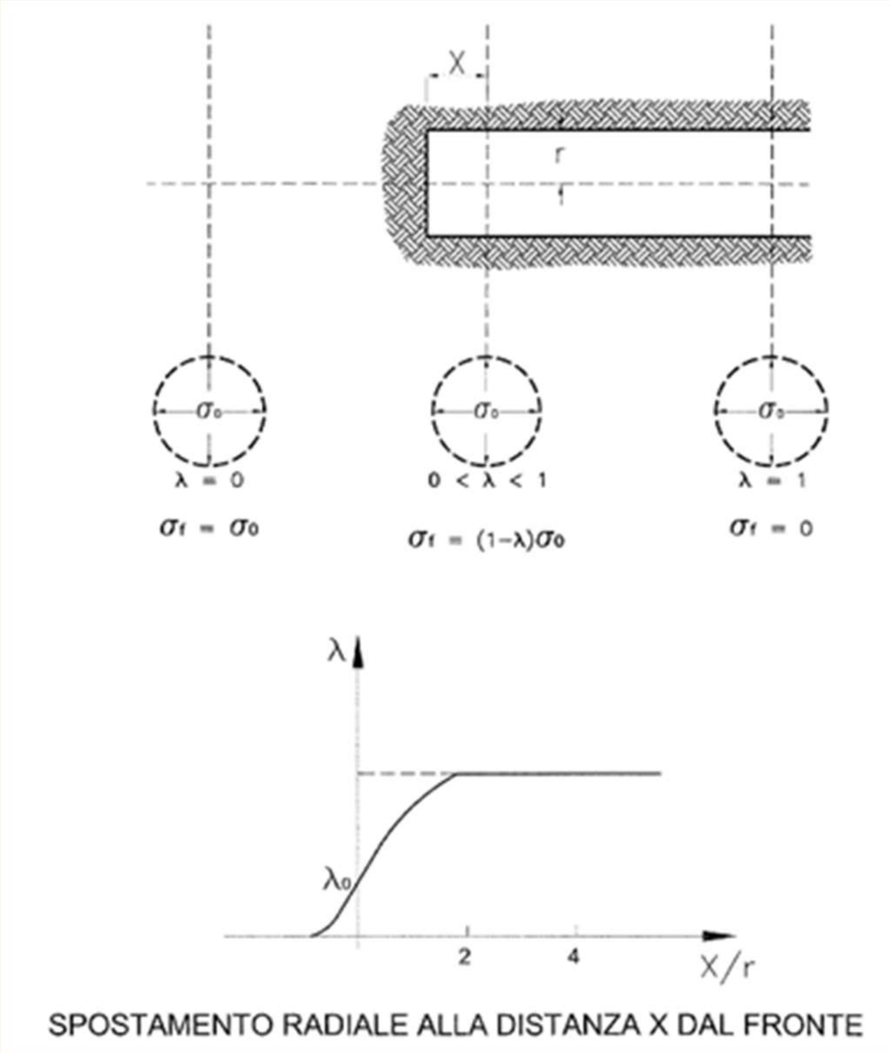
The finite element method in 2D conditions allows the numerical evaluation of the stress state and displacements both in soil and in structures, considering an initial anisotropic stress state and the effective geometrical layout and the time sequence of excavation phases.

To simulate the tensional effects induced by excavation, given the fact that the matter is 3D, a common simulation criteria has been used in the calculation of tunnel: this consists in applying a progressive release of forces initially acting on soil (Barla and Jarre, 1986).

The sustain effect on the excavation, due to the fact that the matter is 3D, is introduced in analysis by grading the equivalent forces system on the surface of excavation, according to the foreseen excavation phases.

The percentage of excavation forces is variable, depending on the distance from the excavation face, as illustrated in the following picture. The progressive release of forces is modeled in PLAXIS by means of the Mstage parameter, which varies from 0 (no release of forces) to 1 (complete release of excavation forces).

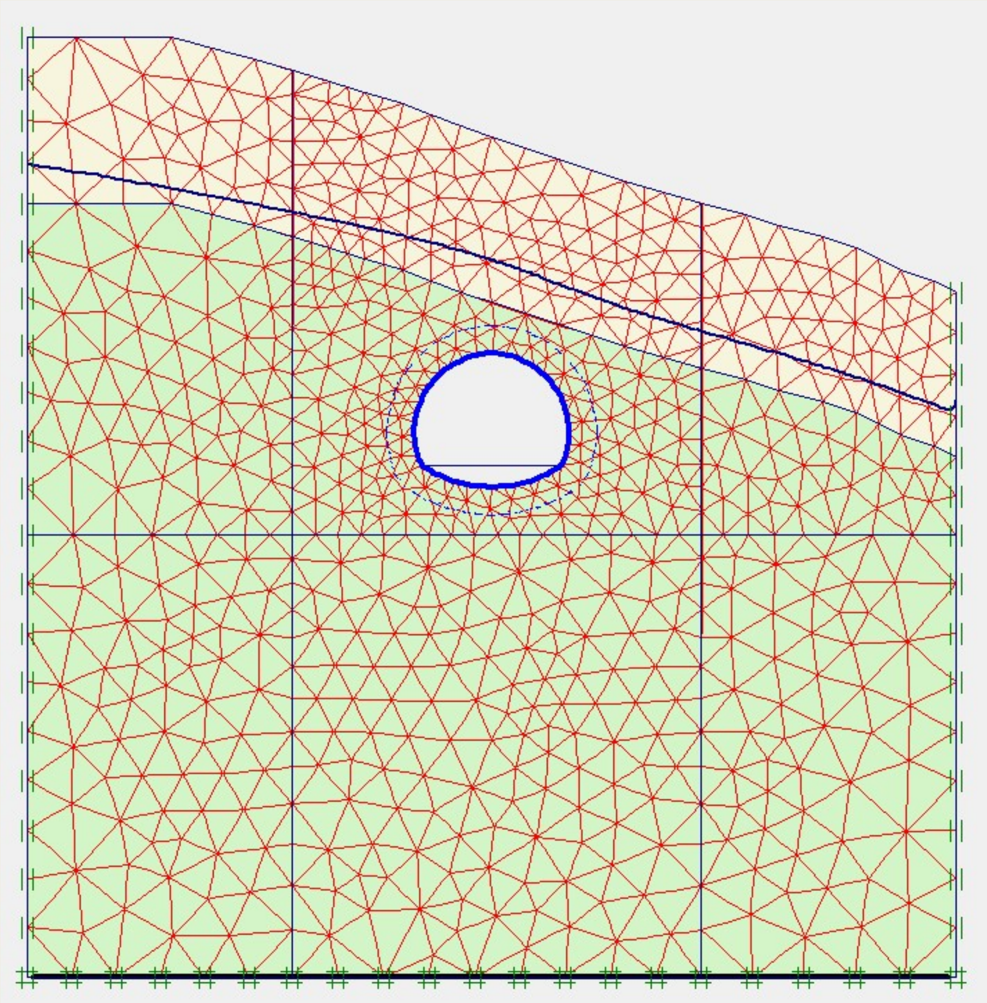
Forces evaluation – Section 1A



Progressive release of forces during tunnel excavation.

Forces evaluation – Section 1A

Section 1A has been calculated considering conservatively the less confined situation (lower value of soil cover approx 17 m). The model is illustrated in the following picture.



Plaxis model for section 1A

Forces evaluation – Section 1A

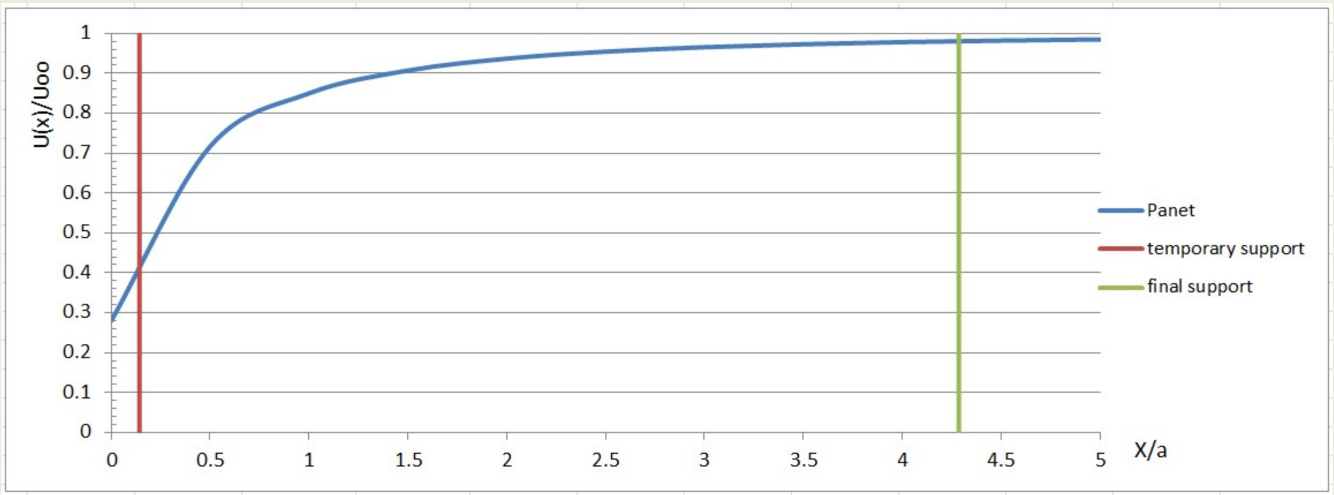
The model is plane-strain, it consists of 1652 15-noded elements with an average element size of 2 m (adopting appropriate local refinition of mesh around the tunnel shape). The model layout is built starting from the topographical survey data.

The stratigraphy consists of 2 layers:

- Deluvium : γ = 21 kN/mc; c ’= 15 kPa; ϕ’ = 27° ; E = 25 Mpa.
- Altered schysts γ = 23 kN/mc; c’ = 90 kPa; ϕ’ = 28° ; E=750 Mpa.

Water level is considered as it has been detected in the new boreholes. Schists’ friction and cohesion have been considered from literature typical values.

The calculation phases follow the excavation layout of the tunnel with section 1A, considering the 3D effect through the following curve (Panet).



Forces evaluation – Section 1A

Temporary support is installed 1 m distant from the tunnel face, corresponding to a release of excavation forces of 0.398. The final lining is installed at a maximum distance of 30 m from tunnel face, corresponding to a release of excavation forces of 0.95.

In Plaxis the M stage values are relative to the next calculation phase, it means that they are scaled to the previous one values. In the following table the M stage values are determined for the calculation phases:

phase	release	M stage
excavation	0.4	0.4
Steel ribs	0.96	(0.96-0.4)/(1-0.4)=0.93
Final lining	1	1

It means that the implemented phases are the following:

Phase #1: geostatic - Geostatic stress state is calculated with the "gravity loading" procedure: the K0 procedure cannot be used since it might lead to not-realistic results because of the not-horisontality of layers.

Phase #1: full face excavation - De-activation of the cluster in the tunnel face, M stage = 0.398.

Forces evaluation – Section 1A

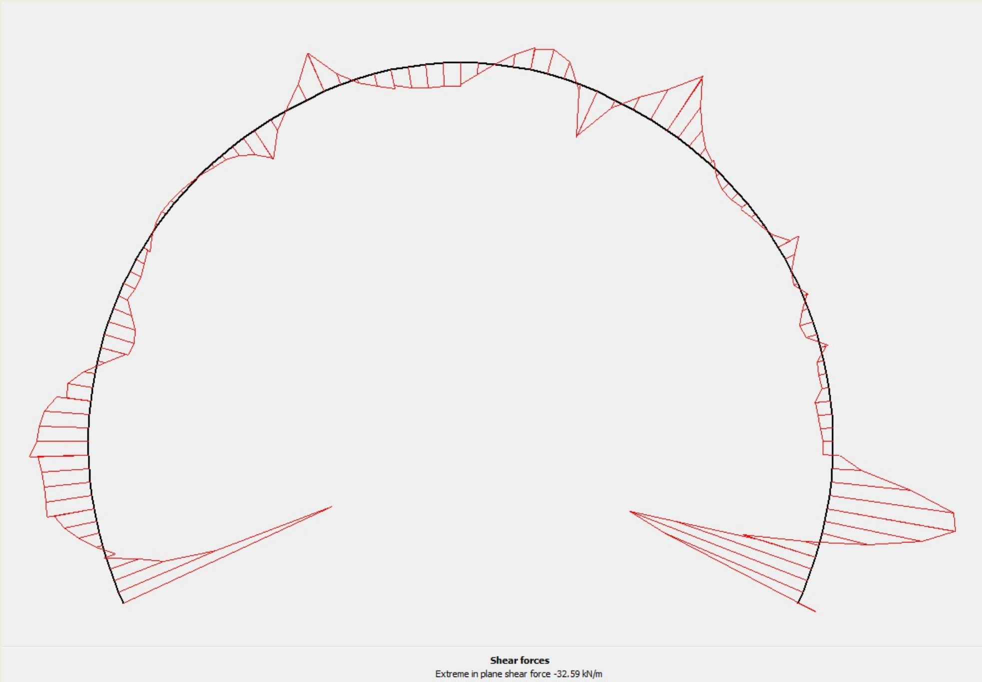
Phase #1: installation of temporary lining HEB200 steel ribs - Activation of HEB200 beam elements, M stage = 0.92.

Phase #1: realization of final lining - Activation of reinforced concrete beam elements, M stage = 1.

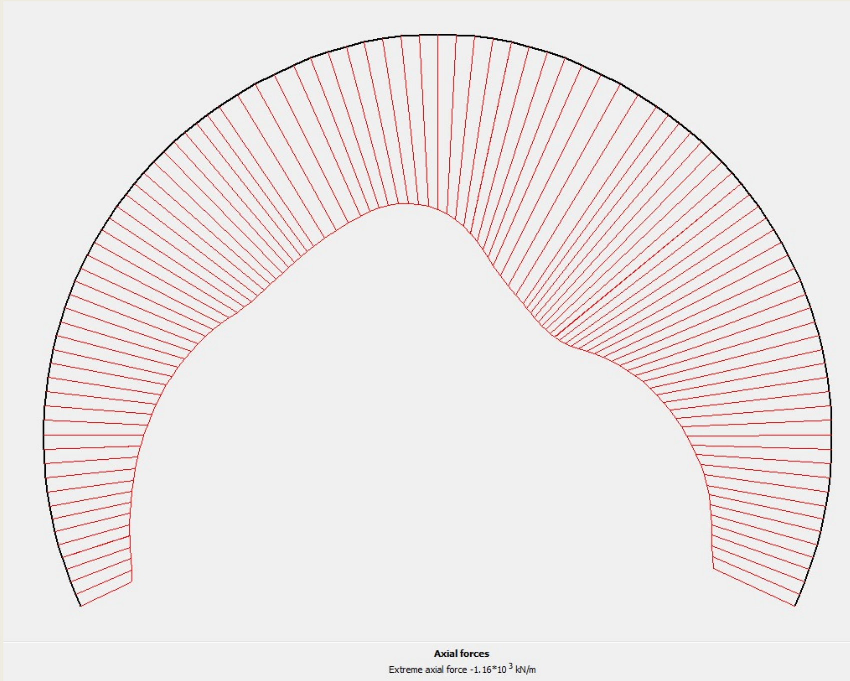
Temporary lining. In the following pictures are illustrated the bending moment, shear force and axial force acting on the temporary lining made of spritz beton and HEB200 steel ribs.

Bending moment in temporary lining

Forces evaluation – Section 1A



Shear in temporary lining.

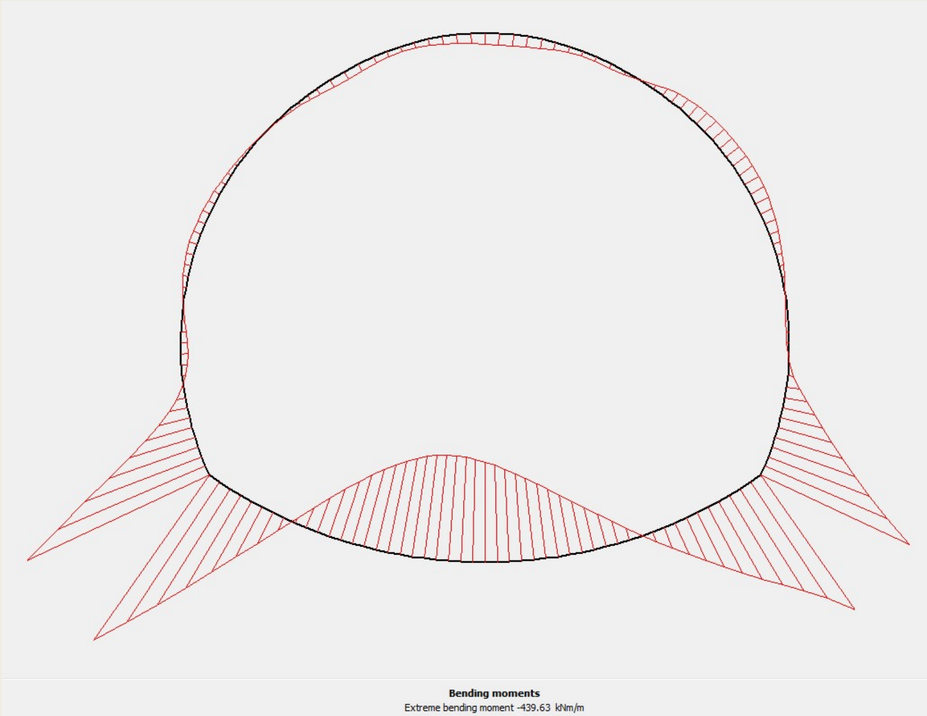


Axial force in temporary lining.

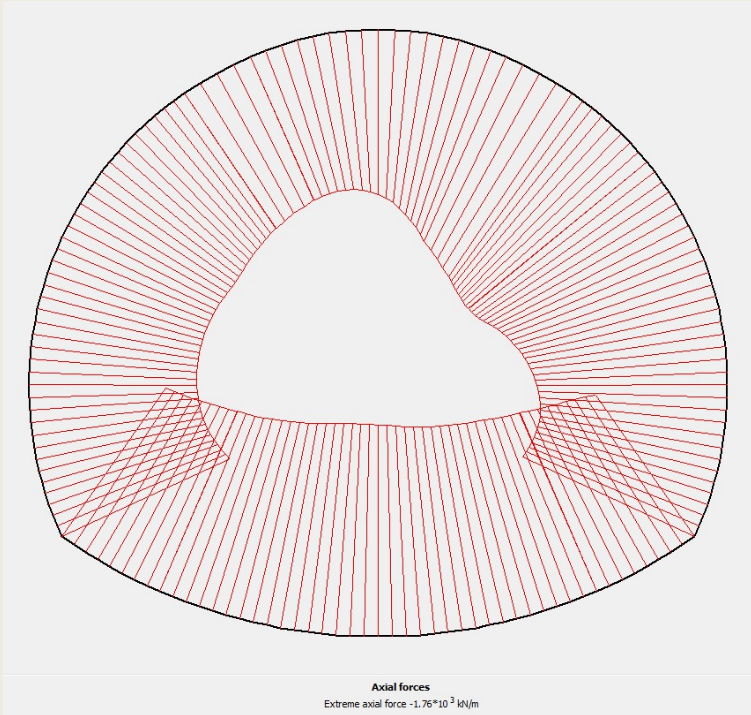
The above mentioned results are SLS values, then multiplied for the γ_g factor 1.35 determine the ULS values. The most stressed section is the one with the highest value of axial force, in which (SLU): M = 4.91 kNm and N = 1417 kN; σ = N/A + M/W = 2282 kg/cmp, where, for HEB200: A = 78.08 cmp and W = 569.6 cmc.

Forces evaluation – Section 1A

Final lining



Bending moment in final lining.



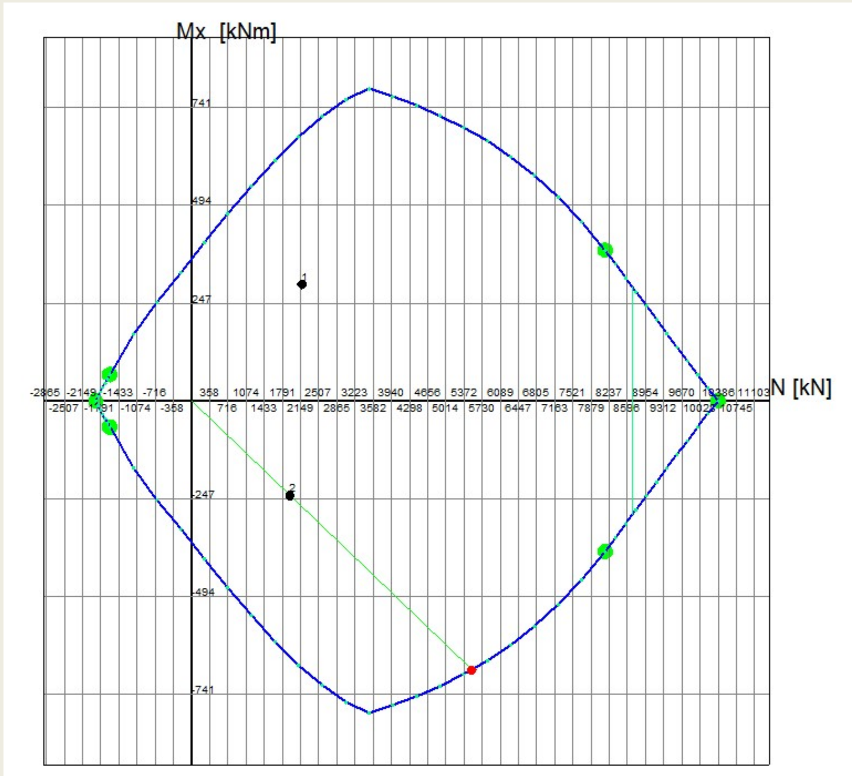
Axial force in final lining.

The most critical section to be verified is the invert, where the maximum values are:

M+: M=1.35*218.07 = 294.40 kNm & N = 1.35*1611.17 = 2175.08 kN;

M-: M=1.35*-176.92 = -238.8 kNm & N = 1.35*1438 = 1941.3 kN.

Forces evaluation – Section 1A



Shear force in final lining.

The verifications are satisfied.

Photo gallery

Photo gallery

Photo gallery

Photo gallery

Photo gallery

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Photo gallery