Original scientific paper

Received: Feb 15, 2017
Accepted: Jun 09, 2017
DOI: 10.1515/rmzmag-2017-0015

Experience in design and construction of the Log tunnel

Izkušnje pri načrtovanju in gradnji predora Log

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Abstract

A twin highway Log tunnel is a part of a new motorway connection between Maribor and Zagreb, section Draženci–Gruškovje, which is located towards the border crossing between Slovenia and Croatia. The tunnel is currently under construction, and only the excavation works have been completed during the writing of this paper. The terrain in the area of the Log tunnel is diverse, and the route of the highway in its vicinity is characterised by deep excavations, bridges or viaducts. The Log tunnel is approximately 250 m long, partly constructed as a gallery. The geological conditions are dominated by Miocene base rock, featuring layers of well-connected clastic rocks, which are covered by diluvium clays, silts, sands and gravels of different thicknesses. Due to the short length of the tunnel, the usual separation of the motorway route to the left and the right tunnel axes was not carried out. Thus, the tunnel was constructed with an intermediate pillar and was designed as a three-lane tunnel, including the stopping lane. The construction of the tunnel was carried out using the New Austrian tunnelling method (NATM), in which the central adit was excavated first and the intermediate pillar was constructed within it. The excavation of the main tubes followed and was divided into the top heading, bench and the invert, enabling the intermediate pillar to take the load off the top heading of both tubes. The secondary lining of the tunnel is currently under construction. The experience of the tunnel construction gathered so far is presented in the paper. The main emphasis is on the construction of the intermediate pillar, which had to take the significant and asymmetrical ground load.

Key words: tunnel, rock–structure interaction, NATM, drill and blast, intermediate pillar

Izvleček

Dvocevni predor Log je del nove avtocestne povezave Maribor – Zagreb, odsek Draženci – Gruškovje, ki poteka proti meji med Slovenijo in Hrvaško. Predor je trenutno v fazi gradnje, pri čemer so v času pisanja članka bila končana le izkopna dela. Značilnost trase območja na katerem se nahaja predor Log je razgiban relief, zato je potek AC v njegovi bližini predviden večinoma v globokih vkopih ali preko premostitvenih objektov. Predor Log je približno 250 m dolg, pri čemer je deloma zasnovan kot galerija. Za geološke pogoje na trasi predora je značilna podlaga iz miocenskih dobro vezanih klastičnih kamnin, ki jo prekrivajo deluvialne gline, melji, peski in grušči spremenljive debeline. Zaradi majhne dolžine predora razmika cevi na trasi ni bilo smiselno izvesti, zato je predor Log izveden kot dvocevni, dvopasovni predor z odstavnimi pasovi v polnem profilu AC z uporabo centralnega vmesnega stebra. Gradnja predorskih cevi je potekala po principih NATM, pri čemer je bil najprej izkopan sredinski rov, v katerem je bil zgrajen vmesni steber. Izkopni profil glavnih ceveh je bil deljen na kaloto, stopnico in talni obok pri čemer je vmesni steber prevzel obremenitev s kalote z ene in druge cevi. Trenutno je predor v fazi izgradnje sekundarne obloge. V članku so prikazane dosedanje izkušnje, ki so bile pridobljene pri gradnji predora, pri čemer je poudarek podan izgradnji vmesnega stebra, ki je prevzel značilno, asimetrično obtežbo hribinske mase.

Ključne besede: predor, interakcija konstrukcije in hribine, NATM, vrtanje in miniranje, osrednji steber

Introduction

A part of the Draženci–Gruškovje motorway, which is situated in the area of the Gruškovje border crossing with Croatia, runs in the deep excavation zone and through several bridging structures. A strongly diverse relief designates the terrain of the Log tunnel area. Despite this, only one twin-tube tunnel is foreseen on this section. With an approximate length of 250 m, the Log tunnel is currently the shortest tunnel along the entire Slovenian road network. Regardless of a relatively short length, the tunnel represents a demanding structure, particularly due to the specific conditions of the construction. The geographical location of the Log tunnel is shown in the map given in Figure 1.

Due to the short length of the tunnel, the deviation of the motorway axis, which is usually made in order to provide sufficient spacing between the tunnel tubes, was not carried out. This ensured that the course of the hard shoulder lanes was not altered along the motorway inside the tunnel. Therefore, the total width of the roadway in the tunnel remained 10.5 m and included the hard shoulder for the emergency stop, in comparison to the usual 7.70 m width typically used for road tunnels with two traffic lanes. The spacing between the tubes remained only 16 m, defining the space reserved for the central intermediate pillar. The purpose of the central pillar, made of reinforced concrete, was to accept the internal forces coming from the lining of the left and the right tunnel tubes. The Log tunnel is the third tunnel within the Slovenian motorway network, which was built using a central pillar constructed within the pre-excavated intermediate adit. Before that, the tunnels Vodole and Cenkova had been built in the same manner, but in less-demanding geological conditions.

The diverse morphology of the terrain dictated the complex boundary conditions for the construction of the central pillar. These conditions were reflected through the need for accepting an asymmetric load, which originated from different overburden heights above the left and the right tunnel tubes. The maximum height of the overburden in the Log tunnel is approximately 25 m above the left tunnel tube and approximately 35 m above the right tunnel tube, which is an approximately 30% difference. The emphasis of this article is on the construction of the central pillar, for which demanding technological conditions and limited access area inside the pre-excavated intermediate adit had to be overcome.

Figure 1: *Location of the Log tunnel.*

Basic technical data for the Log tunnel

The need for deep excavations of up to 27 m at the north side and up to 36 m at the south side is a significant feature of the tunnel construction. The terrain morphology at both excavation sites dictates heavy and asymmetric dead load to be transferred by the embankment to the reinforced concrete gallery below, which makes up a part of the tunnel's portal structures. The galleries, together with the vaulting reinforced concrete structures, represent a "cut and cover" part of the tunnel. In this sense, the Log tunnel and the cut and cover galleries represent the concentration of demanding geotechnical structures located along only a 250-m-long section of the motorway, including the following: a) excavation for the tunnel with intermediate pillar, b) portal cut and cover structures, c) reinforced concrete galleries and d) high retaining walls. Thus, the right tunnel tube with the portal and the gallery has a total length of 250 m, in which the tunnel's part of the tube is 105 m long, the south portal structure is 22 m long, the north portal structure is 21 m long, the south gallery is 40 m long, the north gallery is 35.5 m long, the south side wall is 13 m long and the

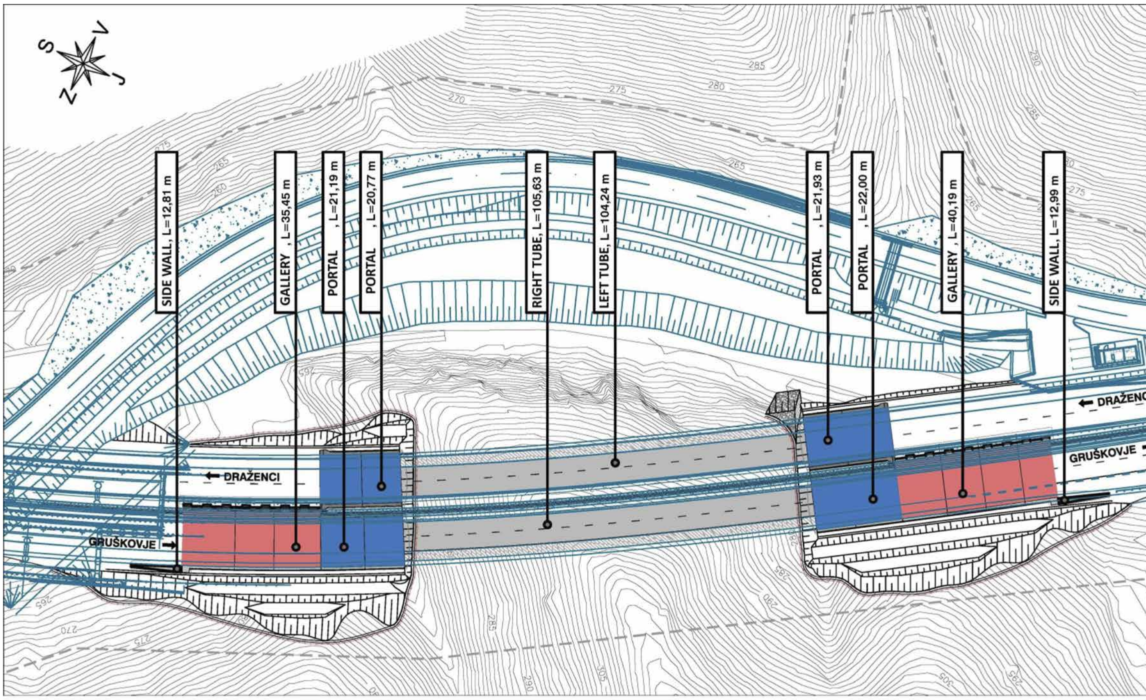

Figure 2: *Situation of the Log tunnel [1].*

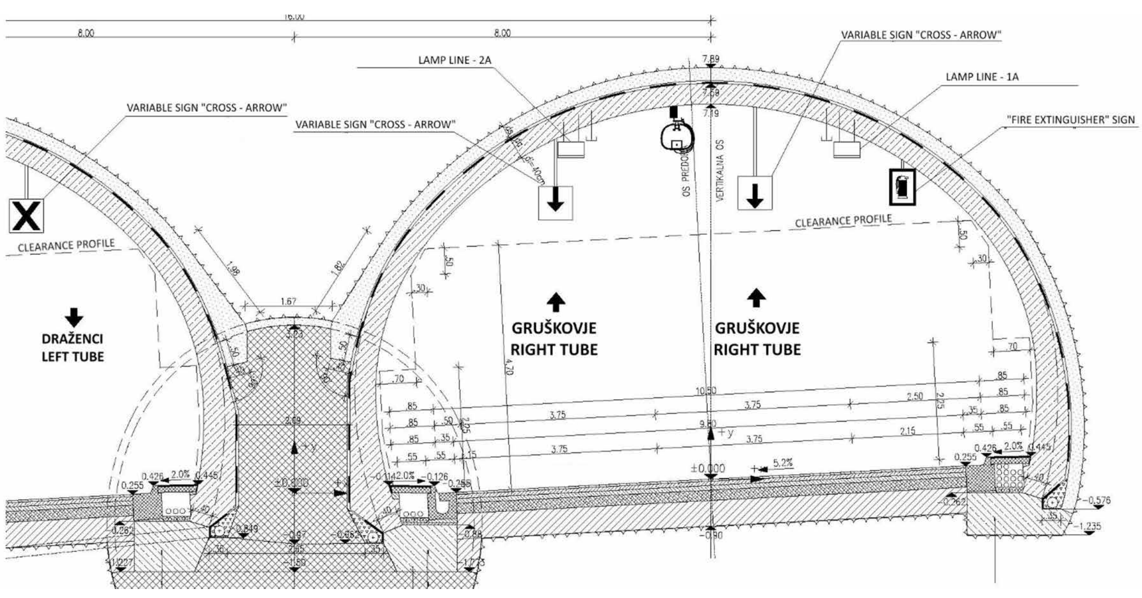

Figure 3: *Typical cross-section of the right tube of the Log tunnel [1], including the intermediate pillar.*

north side wall is 12.8 m long. The left tunnel tube with portal has a total length of 147 m. The tunnel's part of the tube is 104 m long, the south portal structure is 22 m long and the north portal structure is 21 m long. The ground plan of the Log tunnel, referring to the Log tunnel design documentation [1], is shown in Figure 2.

The typical cross-section of the right tunnel tube, including the central pillar, is shown in Figure 3. The twin-tube, double-track tunnel of the extended profile with the carriageway width is 2×3.75 m, the hard shoulder for emergency stop is of width 2.50 m and the extra width is 2×0.50 m, with height clearance of 4.7 m. The excavation and construction of the central tube, as well as the excavation of the left and the right tubes, have been completed so far. Currently, construction of the secondary lining

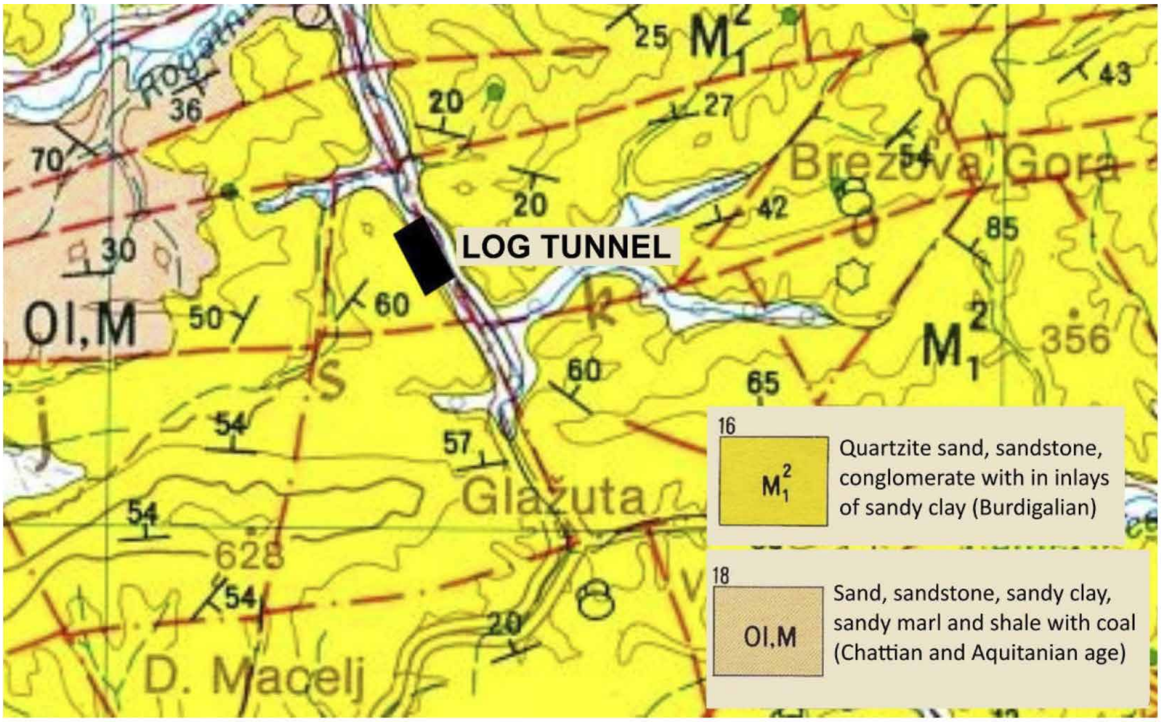

Figure 4: *Micro-location of Log tunnel in the geological map [2].*

is in the working phase. In continuation, some characteristics of the up-to-date construction of the tunnel are described. Emphasis is given to the construction of the central pillar and the excavation of the central tube.

Geological–geotechnical conditions of Log tunnel construction

The bedrock at the location of the Log tunnel consists of well-bound clastic rocks of the lower Miocene age. It is overlaid by diluvium clays, silts, sands and gravels of variable thicknesses. In the northern pre-cut area, the thickness of diluvium ranges from 1.5 to 5.0 m, while in the area of the tunnel, it ranges from 1.5 to 3 m. Miocene layers are composed of grey to dark grey mica and sandy marlstones, siltstones and sandstones. Sandstones dominate, while marlstones and siltstones are mostly present in the form of thin layers of 0.5-m thickness and are located between the sandstone layers. The ratio of sandstone to siltstone is typically 70%: 30% in the northern and southern pre-excavation sites and approximately 85%: 15% in the area of the tunnel excavation. The stratification in the bedrock is not clearly expressed, but a general dip of the layers was detected towards N–NE. In the area of the northern pre-cut site, the bedrock is located at the depth of 1.5–3.0 m, while in the area of the tunnel excavation, the bedrock is located at depths ranging from 2.5 to even 19 m, i.e. in the area in which the small gorge appears. In the area of the southern pre-cut site, the bedrock mass is located at the depth of 3–6 m. The geological map of the area near the Log tunnel is shown in the image presented in Figure 4.

In the area of the tunnel and the pre-cuts, several geological faults were mapped. The fault zones were of negligible thickness of a few metres. Generally, the rock mass is heavily cracked around faults and in the wider zones of the gorge beside the portals. Rough and graduated cracks prevail, featuring several discontinuity systems. They are the main reason for the fall of the larger blocks of volume 2–3 m^3 during the excavation of the left tube. Around the fault zones, the cracks were denser and smoother, while around the weathered rock in the area of the left tunnel tube, discontinuities were loose and filled by the clay binder. The level of underground water was 3–6 m above the roadway. Due to the lower permeability of the Miocene bedrock and the relatively low overburden

Table 1: *The parameters of the materials obtained from the geological units and used in numerical analyses.*

Layer	Material	γ, kN/m³	c, kPa	φ, °	E_{oed}, MPa
1	Diluvium	20	0–5	29	20
2	Weathered sandstone	24	80	36	115
3	Sandstone	26	3000	38	6000

Table 2: *The material and geometrical properties of the support elements used in numerical analyses (values for EA and EI are given per metre of tunnel length).*

Type	Material	EA, kN/m	EI, kN·m²/m
Primary lining	Shotcrete C20/25, d_s = 10 cm	2.50E6	2.08E3
Rock bolt	SN anchor 250 kN, L_s = 2.00 m	67.50E3	–

above the tunnels, there were no large inflows of water detected in the tunnel.

The mineralogical analysis of samples from the tunnel area showed no presence of montmorillonite or swollen minerals of smectite. Analysis of the sulphide and sulphate mineral samples taken from the track of the tunnel showed presence of potentially active pyrite. The samples of the underground water, analysed using standard SIST EN 206-1 procedures (Concrete – Part 1: Specification, performance, production and conformity), showed no corrosion potential of groundwater on reinforced concrete. More details about the geological structure in the area of the Log tunnel can be found in the Geological–Geotechnical Interpretative Report for Log Tunnel [2].

Calculation of tunnel stability and structural design of central pillar

Numerical analyses were carried out using the finite element method and PLAXIS 2D software. The two-dimensional (2D) finite element mesh comprised 15-node triangular elements, featuring the total fixity along the lower boundary ($u_x = u_y = 0$) and the horizontal fixity along the left and the right boundaries ($u_x = 0$). The material parameters of the geological units, which were used for the geotechnical model, are shown in Table 1. The material parameters for sandstone were determined based on the laboratory test results. The basic classification of the rock mass was made for the weathered rock using the Geological Strength Index (GSI) approach of indexing in terms of the methodology proposed by Hoek et al. [3] and Marinos and Hoek [4] for rock mass systems similar to flysch. The hardening soil (HS) constitutive model was used for modelling soil and rock mass.

The concrete of the central pillar was modelled using 2D linear–elastic elements with structural stiffness of E_{Young}=30 GPa. The primary lining was modelled using one-dimensional linear–elastic beam elements, capable of taking axial forces and bending moments. The rock bolts were modelled using one-dimensional linear–elastic rod elements, capable of taking only axial forces in tension. Using the calculations of the stability conditions, the stress–strain conditions in the rock mass and the influences in the support elements of the tunnel were defined for all phases of excavation and primary support. The material and the geometrical properties of the characteristic elements used for modelling the primary tunnel support are given in Table 2.

In terms of the static calculation, the following aspects were considered: a) geometry of tunnel excavation, b) support measures valid for different rock mass type behaviours and c) geological conditions defined in terms of the geological–geotechnical report. In total, five analyses were made in the typical cross-sections of the tunnel, which were reciprocally apart for 20 m. The analyses were performed in the following stages: a) determination of the initial stress

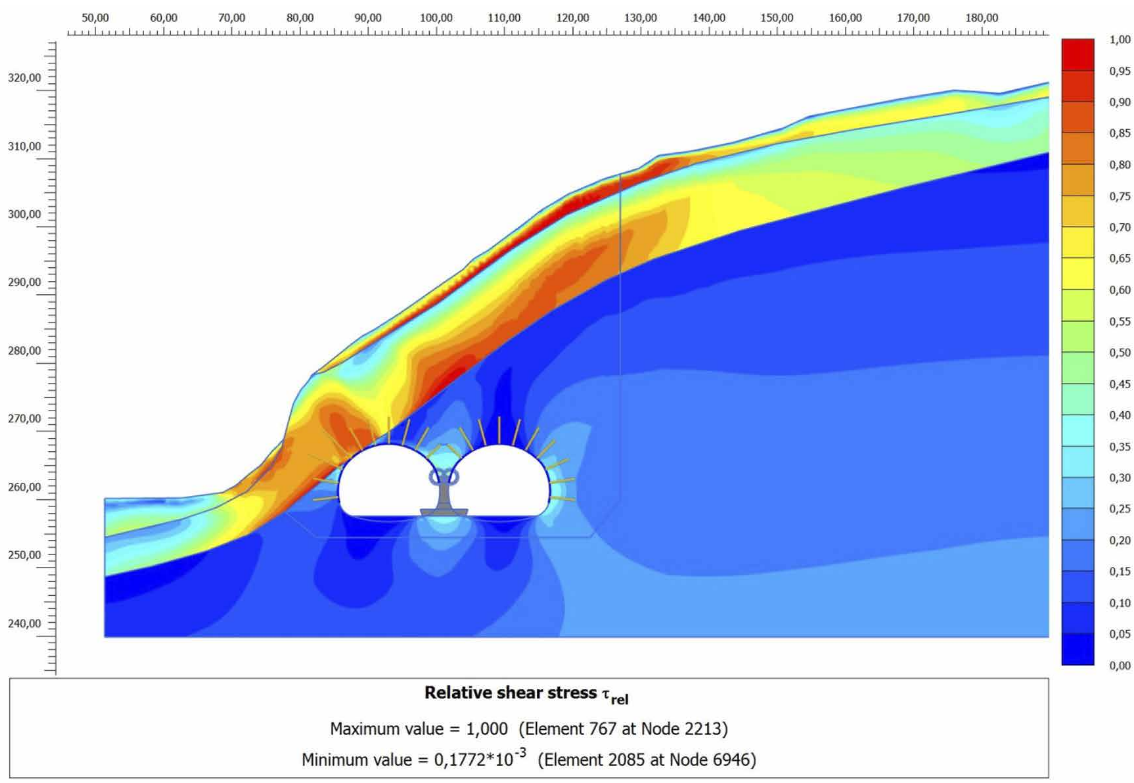

Figure 5: *Contour forms of relative mobilisation of shear stresses in rock mass around the Log tunnel [1].*

state, b) excavation and installation of the support measures for the central tube, c) execution of the central pillar, d) excavation and installation of the support measures for the left (outer) tunnel tube and e) excavation and installation of the support measures for the right (inner) tunnel tube.

Due to the extreme asymmetric load caused by the different heights of overburden above the left and the right tubes, it was determined by the analysis that is better to execute the outer tube first (with smaller overburden) and then the inner tube. The calculation results of the tunnel excavation for the critical section, in which the asymmetric load towards the support elements in the tunnel profiles were the highest, are shown in the contour forms in Figure 5 as the relative mobilisation of shear stresses around the tunnel. It is clearly seen in Figure 5 that the bedrock is at the point of low mobilisation, whereas the layer of weathered rock above the left tube is only conditionally stable, due to the existing high slope inclination. The potential critical point above the left tube on the contact between the tunnel perimeter and the weathered rock, seen in Figure 5, did not actually materialise in the form of instability during the excavation of the tunnel.

Two-dimensional numerical analyses of tunnel stability were carried out, in which a three-dimensional (3D) support effect provided by the unexcavated tunnel face, was taken into account [5–8]. The 3D effect is considered in such a way that stresses in the rock mass within the single excavation stage were partly relaxed proportionate to the length of the excavated step. Later, in the stage of support installation, when the tunnel face moves away and does not have any influence on the stress state around the tunnel, the stresses are then entirely released to simulate 2D conditions. The stresses released are directly related to the technological process of the tunnel excavation, and this represents one of the key design elements. The process was determined according to the method proposed by Chern et al. [9]. Accordingly, the ratio of the released stresses, λ, depends on the following parameters: overburden height, strength of the material, dimensions of the tunnel and the excavation step. The process of stress release, as used in the program PLAXIS 2D, is simulated by the parameter ΣM-Stage, which is equivalent to parameter λ, so that it governs the ratio of the released stresses in the selected stage. The results of all the stability analyses of the tunnel excavations were reviewed for the following parameters: a) degree of mobilisation of shear stresses in the rock mass, b) deformations of the rock mass (convergent movements on the tunnel circumference), c) internal forces in the tunnel lining, d) degree of mobilisation of other support elements and e) mobilised axial forces in rock bolts.

The allowed boundary values of the internal compression and the shear stresses for each phase of tunnel construction were checked for the central pillar. In addition, the equivalent internal forces in the pillar (axial force, bending moment and shear force) were checked at the critical section where the pillar is the narrowest. The dimensioning of the central pillar was carried out on the basis of the calculated internal forces using the valid standard Eurocode 2 [2] for reinforced concrete. The overall safety of tunnel construction was established using adequate design approaches for both the tunnel support elements and the central pillar.

Excavation of the central adit and construction of the central pillar

The central pillar is the basic supporting element of the Log tunnel. The purpose of the pillar is to take the load from the lining of both the right and the left tunnel tubes and then transfer it to the foundations. A central adit (a tunnel of smaller cross section) had been excavated to enable the construction of the central pillar. The excavated section of the central adit was 36 m^2, while the total length was 105 m. The typical cross-section of the central tube is shown in Figure 6 [1]. It can be seen that the upper two–third portion of the opening is circularly formed (approximate radius: 3.2 m), while the invert is flat due to suitable geological conditions (the width of the invert was 6.4 m).

At the narrowest section, the pillar is approximately 2.1 m wide. At the top of the pillar are symmetrically finalised slots so that linings of both the left and the right tubes can be directly installed on them, as indicated in Figure 6. The pillar is additionally widened at the bottom to ensure the smooth transition of high compression stresses into the approximately 60-cm-thick trapezoidal pedestal. The pedestal continues to the 1.0-m-thick foundation of the pillar, which spreads along the total width of the invert. Due to the significance of the central pillar, the construction of the adit and the pillar was challenging, requiring a high level of quality works within a very confined space.

The excavation and the support of the central adit were carried out as a single phase encompassing the top heading and the invert. Each phase was followed on by the immediate installation of the supporting elements, fully in line with the principles of the New Austrian tunnelling method (NATM) [11, 12]. The basic support elements were sprayed concrete, wire mesh and steel arches for tunnel lining and systematically radially installed passive rock bolts. During the design of the supporting elements, a so-called matrix method (matrix system) was used. The matrix system is based on two documents of Austrian standards for tunnelling: a) ÖNORM B 2203-1 [13], which deals with the definition of support types, measurements and payments of executed works and b) ÖGG dated 2001 [14], which deals with the types of ground behaviour and possible failure mechanisms.

The intention of the matrix system is to determine rock mass behavioural type (BT) during construction of the tunnel. The BTs are based on the overall geological conditions. The BTs define the support types, which are defined by the selection of support elements according to 'ÖNORM B 2203-1' featuring a specific supporting number. The supporting number is determined by summing the quantity of the support element (multiplied by the weighting factors), which is divided by the calculated excavation surface. Accordingly, the supporting number uniquely determines the type of the suitable support system for different types of rock mass behaviour. The matrix system is then formed using a set of supporting numbers and a set of lengths of the excavation steps, which are both inserted into a 2D matrix so that the combinations of the designed support measures are presented within a transparent table. Thus, the matrix method clearly displays the overall support system for the considered tunnel along the particular geological sequence.

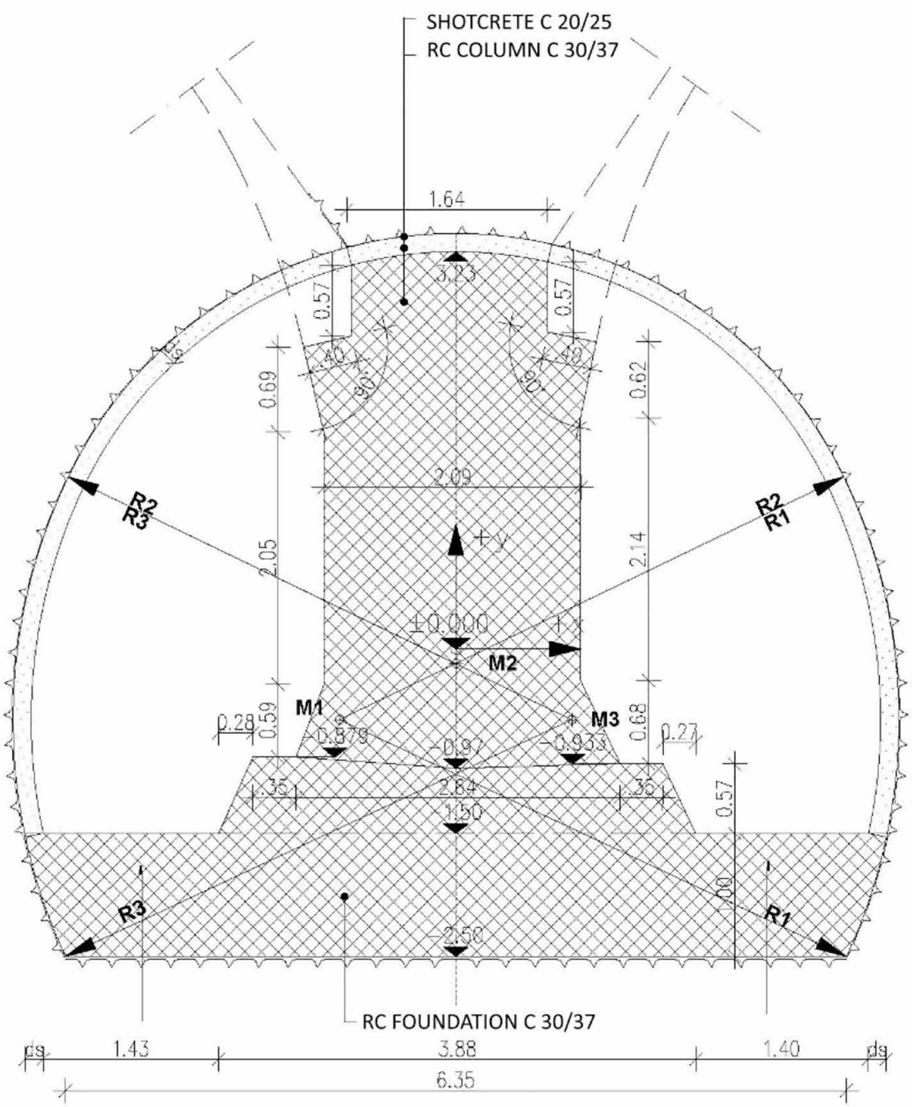

Figure 6: *Typical cross-section of the central tube and the central pillar [1].*

Austrian standard ÖNORM B 2203-1 [13] also specifies a method of payment for the excavation works and installation of the primary support in the tunnel. Thus, in the case that some support types that were not initially defined in the design phase are used, both the investor and the contractor will be able to determine the cost using the matrix method. Due to the relatively simple geological composition encountered during the construction of the Log tunnel, there were no deviations from the matrix of the defined supporting types.

There were three BTs foreseen for excavating the central adit. For the each BT, several support numbers were derived within the matrix system. Type BT1 was defined for the excavation in stable ground conditions. The top heading excavation had been performed using blasting with up to 3.0-m steps and the immediate installation of the support. The excavation was supported using a 10-cm-thick tunnel lining of sprayed concrete C20/25. If necessary, the SN rock bolts of 3-m length and bearing capacity of 250 kN were systematically installed in the raster range of 2.5 m to prevent some local instabilities. Type BT2 was defined for the excavation in stable ground conditions in which there was a danger of local blocks of rock instabilities, which demanded systematic installation of the support elements. The calculation

Table 3: *Calculation of the supporting number in BT2 for top heading and the bench at the excavation step of 2.6 m [1].*

Top heading		Unit	quantily	Rating factor per unit of quantity	Ratio
		t_d = 5,0 cm	K+S-3/1,95		
Excavation profile	29,75 m²	Round length	2,6 m		
Support elements (for 1 m of Tunnel)		Unit	quantily	Rating factor per unit of quantity	Ratio
Bolts	Friction bolts (Swellex or equivalent)	m		0.8	
	Grouted bolts	m	6,92	1.1	7,62
	Self- drilling bolts	m		1.7	
	Tube bolts	m		2.0	
	Prestressed grouted bolts	m		2.5	
Face Bolts	Number of bolts in the face	ST		8.0	
	Installation of face plates	ST		1.7	
	Installation of face plates plus prestressing	ST		5.0	
Spiles	Driven spiles	m		0.5	
	Non-grouted spiles	m		0.6	
	Friction spiles	m		0.8	
	Grouted spiles	m		0.9	
	Self drilling spiles	m		1.3	
	Grouted hollow bar spiles	m		1.6	
Grouting in excess of 10kg per m of bolt, spile, footing micropile		kg		0.1	
Wire mesh	Outside with steel arch	m²		1.0	
	inside with steel arch	m²		1.5	
	Outside without steel arch	m²		2.0	
	Top heading invert	m²		0.8	
	Additional reinforcement, face wire mesh	m²		2.0	
Arches and wall beams		m		2.0	
Shotcrete	Top heading and bench headings	m³		20.0	
	Top heading invert, top heading footing (elephant footing)	m³	2,02	12.0	40,41
	Face	m³		14.0	
	Filling spandrels and over excavation	m³		14.0	
Deformation gaps	withoute ductile elements	m		3.5	
	with ductile elements	m		5.0	
Steel-Sheet forepoling		m²		5.5	
Footing micro piles	micropiles dia. ≤ 38mm	m		4.5	
	micropiles dia. > 38mm	m		5.0	
Partial face excavation		ST		22.0	
Top heading footing (elephant's foot)		m		50.0	
Demolition of top-heading invert arch during bench excavation		m		50.0	
Summation					48,03
Rating area					24,67
Support number					1,95

of the supporting number for BT2 is shown in Table 3. The excavation was divided into two phases: a) excavation of the top heading and bench and b) excavation of the invert. The excavation of the top heading was performed in up to 2.6-m-long steps and was protected by installing the 15-cm-thick micro-reinforced sprayed concrete C20/25. The SN rock bolts of length 4.0 m and bearing capacity of 250 kN were installed one step behind the tunnel face at the mutual distance of 2.5 m. Type BT3 predicted for shallow shear failure in combination

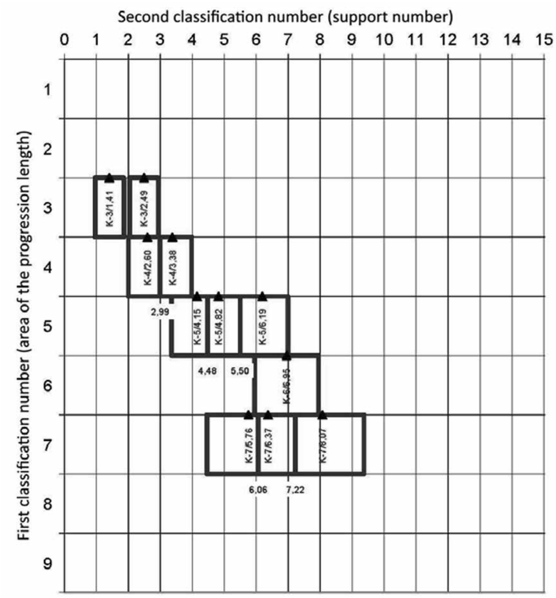

Figure 7: *Matrix of top heading for left tunnel tube [1].*

with the local failure along the rock discontinuities, which was not encountered during the excavation of the central adit. The construction of central adit was carried out according to the design under appropriate geological conditions, as predicted.

The construction of the foundations of the central pillar started after the breakthrough of the adit was completed. The construction of the foundation and the pillar was divided into several longitudinal sections. The typical length of the foundation segment was 4 m, with progress of one section/day. The typical length of the central pillar segment was 6 m, with slower progress of one section/3 days. While executing the upper third of the pillar, in which the primary linings of the left and the right tubes were to be installed, the critical activities comprised precise positioning of the formworks, quality of concreting and concrete care, all done within the very confined space.

Due to the technologically demanding execution, a very precise dynamics of the works was foreseen for the central pillar. The construction of the central adit began when the excavation and the support of the northern portal was finished. The breakthrough of the central adit was executed near the temporary portal at the south side, after the excavation and the support of the southern portal were finished to the extent that the central adit could have been excavated from the southern portal in the minimal length of 15 m. The excavation of the invert for the central pillar started only after the adit breakthrough. The execution of the central pillar only started when the invert for the intermediate pillar along the entire length of the tunnel had been accomplished. The contractor followed the foreseen dynamics of the works most of the time; only a few deviations were applied in order to increase productivity according to the mobilised working force and the equipment.

The excavation of the tunnel tubes

After the execution of the central pillar in the central adit, the excavation of the left (outer) and the right (inner) tunnel tubes followed. Due to the large size of the profile, the excavation of tunnel tube was divided into top heading, bench and invert. The construction of the tunnel was carried out in line with NATM principles and by active simultaneous adjustments to current geological conditions [15]. The excavation was carried out using the drill and blast method. In order to have the central pillar symmetrically loaded as much as possible, the left and the right tunnel tubes were excavated with appropriate delay. The excavation of the right tunnel top heading needed to be started with a delay after the excavation of the left tunnel tube; in terms of distance, the delay was not shorter than 10 m and not longer than 20 m. For the bench, it was foreseen that it would be carried out at a distance that was not shorter than 10 m and not longer than 30 m between the tunnel tubes. In doing so, it was considered that works in the left and the right tunnel tubes could have begun only when the concrete of the intermediate pillar was 28 days old.

The three BTs were foreseen for the excavation of the main tunnel tubes. For each BT, several supporting numbers were developed inside the matrix system derived for the entire tunnel. The matrix system was divided into the left and the right tubes separately, due to different boundary conditions, e.g. variations in geology and different overburden heights at separate chainages. As an example, the matrix for the left tube top heading of the Log tunnel is shown in Figure 7.

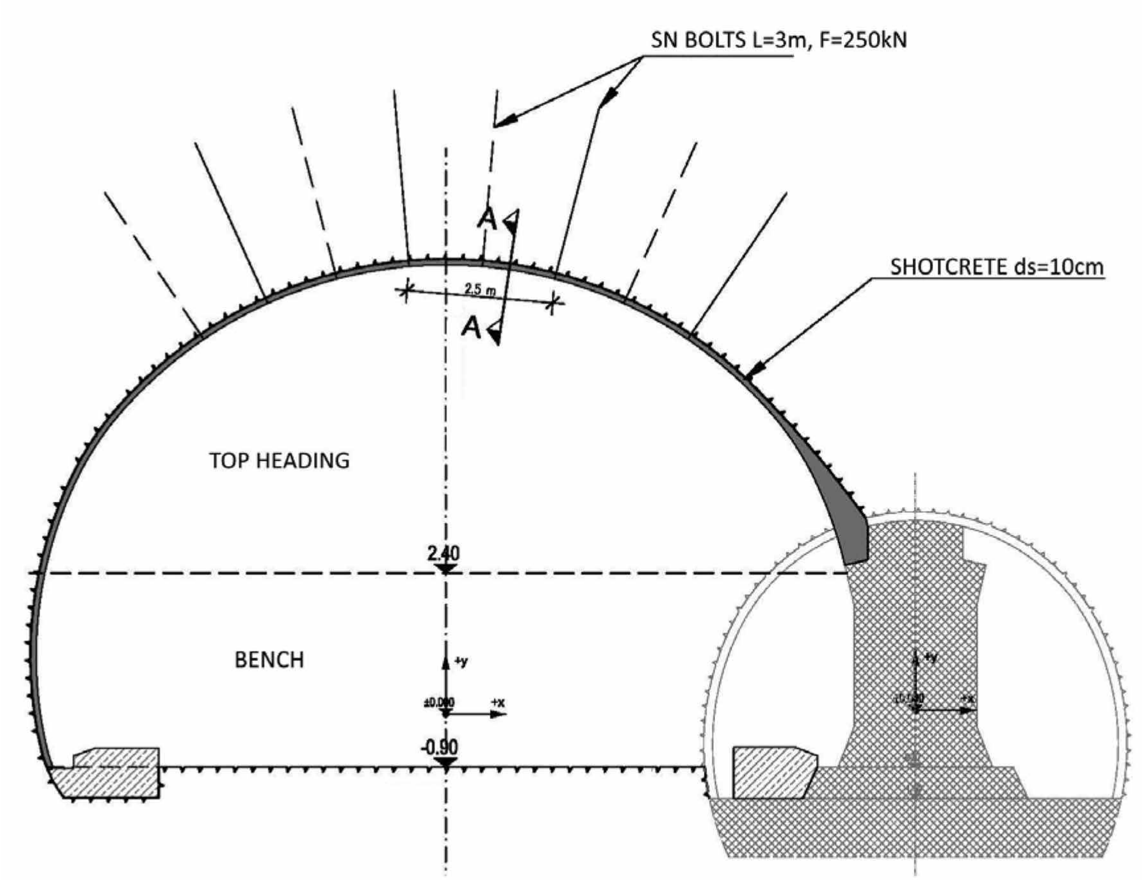

Figure 8: *Support elements of the left tube for BT1: K-3/1.41, S-2/0.29 and TO-1/1 [1].*

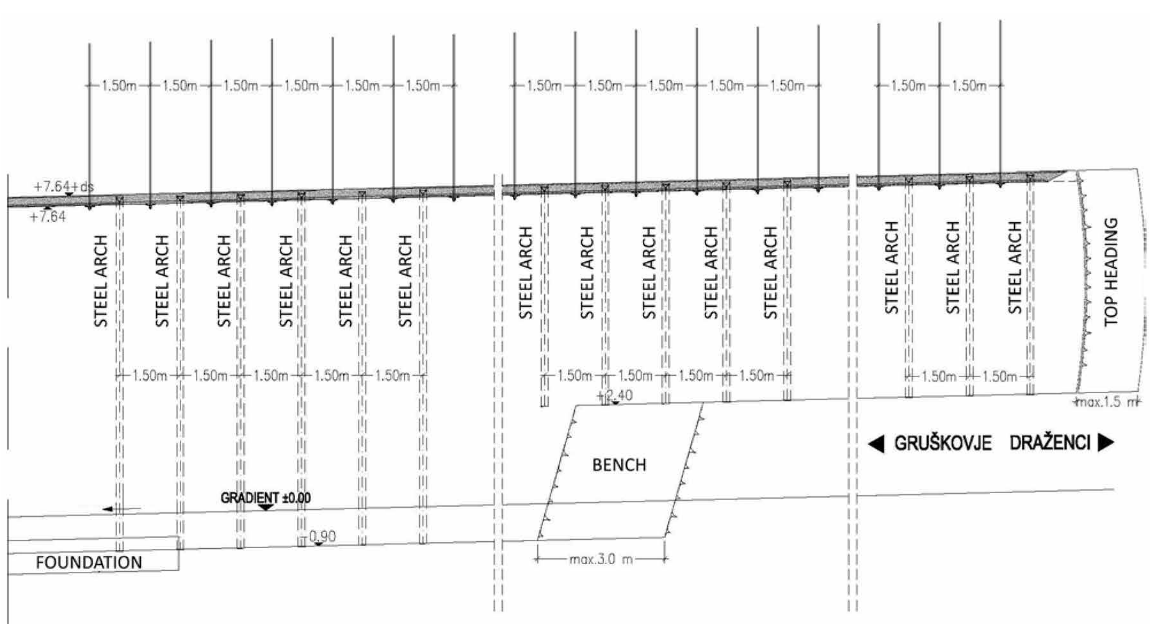

Figure 9: *Longitudinal section of the executed retaining measured for type BT2 [1].*

The excavation in stable conditions was predicted for BT1, in which smaller block instabilities were deemed possible; it represented a dominant support system for the construction of the Log tunnel. The excavation of the top heading was carried out in steps of 3.0 m, which was immediately followed by the installation of the prescribed support measures. The excavation was protected using 10-cm-thick sprayed cement concrete C20/25. When necessary, the 3-m-long SN rock bolts with bearing capacity 250 kN were installed in the top heading. The support of the top heading was followed by the excavation of the bench, which was carried out using the step length of 6.0 m. The excavation of the invert followed the support of bench at technologically optimised distances. The support elements, which were typical for rock mass BT1, are shown in cross-section in Figure 8, while the longitudinal section of BT2 is shown in Figure 9.

The BT2 support system was defined for stable conditions, in which potential block instabilities were regularly foreseen, so that the systemic installation of support measures was predicted. The excavation of top heading with bench in this category was carried out in steps up to 1.7 m long. The 4.0-m-long SN rock bolts with bearing capacity of 250 kN were radially installed at a distance of 2.0 m one step behind the excavation face. During the excavation in BT2, two instabilities of the large rock blocks of volume 1–2 m^3 occurred. Considering that block instabilities were expected, appropriate protective measures were taken so that there were no injuries of the work force or damages to the equipment. Due to the generally favourable geological conditions, the support measures for rock mass behaviour BT3 (shallow shear failure) were not used.

Summary and conclusion

Log is a twin-tube motorway tunnel that is currently under construction. The specific feature of the tunnel is the relatively short length of approximately 250 m; so, a deviation of the motorway axis, which is usually made in order to provide sufficient spacing between the tunnel tubes, was not carried out. Due to the short distance between the tunnel tubes, the tunnel was designed with a central pillar. The total width of the road in the tunnel is 10.5 m, including the hard shoulder for emergency stop, in comparison to the usual 7.70 m used for the motorway tunnels with two traffic lanes. The most significant feature of the Log tunnel is the construction of the central pillar, whose main purpose was to take the load off the right and the left tunnel tube linings, thus providing stability conditions for both tubes. The pillar was positioned centrally but was unequally loaded due to the heavily asymmetrical load that was caused by the different overburden heights above the left and the right tunnel tubes. Special attention was given to the design and execution of the central pillar, as the works required high-quality performance within the very confined space of the previously excavated central adit.

The geotechnical conditions of the Log tunnel were quite favourable and enabled effective progression of the works, first in the central adit and, then, after the construction of the central pillar, in both the main tunnel tubes. This article presented the processes of the design of the tunnel using the matrix method, with an emphasis on the stability analyses of tunnel excavation and the structural analyses of the central pillar. Due to the asymmetrical load acting on the pillar, it was necessary to check several different load cases and determine the optimal sequence of the work execution, which was critical to providing the required development of internal forces in the support elements.

The progression of the tunnel excavation and the installation of the primary lining were adjusted to the geotechnical conditions following the principles of NATM. Different stages of the excavation and the primary support were adjusted to the local geotechnical conditions on the site, while only a few deviations from the foreseen design solutions were applied. Suitable geological and geotechnical conditions and the relatively low presence of underground water contributed to the fact that works progressed as planned and without any major deviations. Active geotechnical supervision and qualitative professional cooperation among all the participants in the construction process were important to facilitate effective work, as well as to resolve the problems that occurred during the works.

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