Construction of the Šentvid tunnel

Gradnja predora Šentvid

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Abstract: Construction of the Šentvid Tunnel is one of the toughest tasks on the 5.5 km long motorway from Šentvid to Koseze that will connect the north-western motorway with the Ljubljana ring which links the motorway between the Northeast to Southwest and Northwest to Southeast of Slovenia. The tunnel connects Šentvid with Pržanj and consists of two tubes of 1030 m (left) and 1060 m (right). The contract for its construction was signed on November 4, 2004 between DARS and SCT d.d. Ljubljana (the leading partner) and Primorje Ajdovščina. Construction of the three-lane tunnel with connecting caverns and ramp tunnels is a major challenge for SCT d.d. engineers, both in terms of building such an unique object and excavating it in highly tectonized Permo-Carboniferous rocks. Constant adjustments in construction technology had to be made, due to complex geological conditions in the rock mass. It was necessary to proceed the excavation with reinforced forepoling and pipe roof, as well as to systematically stabilize the working face by a great number of rock bolts, even under a pipe roof. The number of excavation sequences in the top heading was increased, round lengths were shortened, as well as lengths between the top-heading and the invert. The support elements designed in the tunnel profiles needed reinforcing during execution of the works.

Izvleček: Predor Šentvid je najzahtevnejši objekt na 5,5 kilometra dolgem avtocestnem odseku Šentvid-Koseze, ki bo povezal gorenjsko avtocesto z ljubljanskim avtocestnim obročem in s tem sklenil avtocestni križ na območju Ljubljane. Predorski cevi potekata med Šentvidom in Pržanjem v dolžini 1030 m (leva cev) in 1060 m (desna cev). Pogodbo za gradnjo predora je DARS 4. novembra 2004 sklenil z izvajalcema SCT d.d. Ljubljana (vodilni partner) in Primorje Ajdovščina. Za predorske strokovnjake SCT d.d. je gradnja tropasovnega predora s kaverno in polnim priključkom na Celovško cesto že od vsega začetka velik izziv, ne le zaradi tako edinstvenega objekta, ampak predvsem zaradi zahtevnosti gradnje v močno tektoniziranih permokarbonskih kamninah. Prav zaradi kompleksnih geoloških razmer je bilo treba stalno prilagajati tehnologijo gradnje predora. Za napredovanje izkopa je bilo potrebno ojačevanje stropa in bokov predora z vgradnjo sulic

Review paper

ali cevnega ščita in sistematično varovanje izkopnega čela z vgradnjo sider. Izkop smo izvajali v bistveno več fazah, podaljšali smo odseke z začasnim talnim obokom, skrajšali korake napredovanja v kaloti, stopnici in talnem oboku ter skrajšali razdaljo kalota – talni obok in primarno podgradnjo ojačevali z dodatnimi sidri.

Key words: three lane tunnel, cavern, phase excavation, tectonized rocks, geological overbreaks, adjustment of support measures

Ključne besede: tripasovni predor, kaverna, fazni izkop, tektonizirane kamnine, geološki zruški, prilagajanje podpornih ukrepov

Introduction

Preliminary geological-geotechnical research for the Šentvid Tunnel was carried out between 1991 and 2003. Geological and hydrogeological mapping, drilling, in situ analyses of the exploration wells (i.e. pressiometric and water level measurements), geophysical measurements (seismicity and electricity) and laboratory analyses of rock samples were all included in these studies[1,2]. Estimated values of the geomechanical parameters of the rock mass were the basis for the tunnel design and for selecting the appropriate excavation method. The important characteristics for designing a tunnel in fault zones are: rock mass strength, deformation characteristics of the rocks, and primary stress conditions in the rock mass[3].

In the tender documents, double two-lane tubes were planned or, in the case of favourable geological and geomechanical conditions, the left tube as a two-lane tube and the right one as a three-lane tube with cavern and ramp tunnel[4]. SCT d.d. Ljubljana, as the leading partner, and Primorje Ajdovščina signed the contract with DARS on November 4, 2004. In the tender documents it was determined that the investor will decide on the final design of the tunnel during its construction. The investor ordered additional geological-geomechanical investigations to study the feasibility of the caverns and to select their most favourable locations. SCT d.d. started excavating the exploration gallery in April 2004 and finished it in December 2004; final reports on this investigation were published in January and March 2005. SCT started with the excavation of the two-lane tunnel from the Šentvid direction in November 2004. Additional studies of the traffic in this location, as well as results of geological, geomechanical and hydrogeological conditions obtained from the exploration gallery, were the main reason for the investor's decision that both tubes would be three-lane with cavern and the ramp tunnels. SCT d.d. started with excavation of both three-lane tubes from the Pržanj direction in June 2005.

Šentvid Tunnel is constructed according to the New Austrian Tunnelling Method (NATM). Continuous monitoring of deformation of the primary tunnel lining and deformation of the rock mass around the tunnel is performed to check the stability of the primary tunnel lining. Study of the secondary stress and deformation field around the primary tunnel lining enables timely and adequate adjustments of the support measures and the excavation method. Using this method the most stable and economical tunnel lining is achieved.

Geological structure of rocks in the tunnel alignment

Geological structure in the tunnel alignment was interpreted in the tender documents (PZR) as a synclinal fold of Permo-Carboniferous layers, deformed by the thrusting of three tectonic units and by movements along subvertical faults of NW-SE, NE-SW and N-S direction[4]. Mudstone and clayey slate (mu-gs CP), alternation of clayey slate and clayey siltstone (cm-dm) with sandstone (pem CP), and tectonic clay were foreseen in the tunnel alignment[1,2,4].

The fact that the geotectonic composition of the Šentvid hill is much more complex than foreseen in the tender documents was already known at the time of excavation of the exploration gallery, which was excavated to study the feasibility of the caverns and to find the most suitable location according to geological composition of the rock mass. The first results of this research were published in January 2005 [5], although SCT d.d. had already been introduced into the excavation works in November 2004. Tectonized rocks were excavated very frequently in both main tubes. Many faults and thrusts cross the tunnel alignment, with cracked and crushed rocks. The main tubes were frequently excavated in the major fault or thrust zones, where rocks were changed into tectonic clay with the worst mechanical characteristics[6]. Additional obstacles were minor water inflows, which made the geomechanical characteristics of tectonized rocks even worse.

Part of the longitudinal geological profile of the left tube from the chainage between 1090 and 1340 m is shown in Figure 1 [4]. On the section between 1150 and 1200 m are layers of mudstone and clayey slate with the direction of the schistosity, and layers of 140-170°/20-30°. The actual geological composition in section A (Figure 1) in the smaller scale is shown in the rectangle below the longitudinal profile. In the top-heading along the whole section A there is a thrust zone parallel to the tunnel axis, filled with tectonic clay (winding, interrupted lines), while rocks in the vicinity of the thrust zone are crushed (small black crosses). Between 1150 and 1161 m there are layers of shaly siltstone with subordinated layers of clayey slate and sandstone with a direction of 100-180°/10-30° and with two systems of cracks 210°/85° and 300°/80° [6]. Between 1161 and 1176 m there is a steep fault zone directed to the south, filled with tectonic clay, cracked rocks and folded layers of shaly siltstone and clayey slate. Between 1176 and 1200 m sub-horizontal layers of shaly siltstone and clayey slate predominate over thin layers of sandstone. In this section there are many faults parallel to the layers (thrusts). At 1194 m there is a fault transverse to the layers, along which rocks are crushed (small black crosses) [6].

In the left tube at the chainage 1161 m one of the biggest (100 m^3) overbreaks oc-

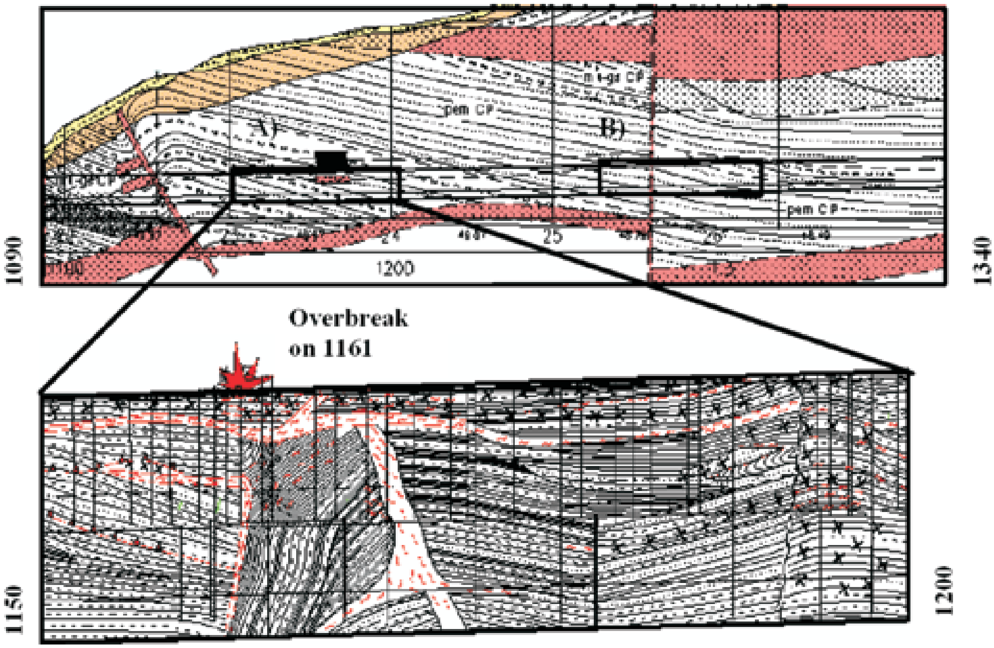

Figure 1. Longitudinal geological profile[4] of the left tube between 1090 and 1340 m that as foreseen in the tender documents (above) and the actual geological composition of the section A between 1150 and 1200 m (below)

Slika 1. Zgoraj je predviden vzdolžni geološki profil[4] za levo cev na stacionažah med 1090 in 1340, spodaj (A) pa dejanska geološka zgradba na stacionažah med 1150 in 1200

curred on February 22nd, 2005. Instability of the top-heading occurred in the region of tectonic zone, with the water inflow of up to 48 L/min. Overbreak occurred despite that excavation face was protected with a great number of rock bolts (on the average 6 IBO rock bolts of l = 12 m per 7 m), despite that excavation was proceeded with reinforced forepoling (average 30 pc SN, l = 3 m per 1 m) and despite that excavation works in the top-heading were proceeded on the average in 7 phases. Excavation works were stopped for 8 days.

In section B (1260-1310 m), between 1260 and 1274 m, layers of sandstone and siltstone with direction of 140-170°/20-30° were foreseen. Between 1274 and 1284 m a sub-vertical fault zone was foreseen, between 1284 and 1289 m alternation of clayey slate and shaly siltstone (cm-dm) with sandstone (pem CP), while between 1289 and 1310, layers of clayey slate between the layers of sandstone and siltstone with direction 150°/10-15° were foreseen (Figure 1). Actually, in the top-heading between 1260 and 1284 m is tectonic clay, crashed clayey slate and shaly siltstone with thin layers of sandstone. In this section there are a fault zone with direction 300-320°/60° and parallel thrust zones with direction to the east that are filled with tectonic clay, while rocks in the vicinity are crushed (small black crosses on the Figure 2) and locally folded. In the region of tectonically crashed rocks in the top-heading at 1273.6 m, an overbreak of 30 m^3 occurred on July 15th, 2005, when the excavation works were stopped for 6 days (Figure 2). Between 1284 and 1310 m shaly siltstone prevails over the sandstone. Thrusts in the top-heading have the direction 110°/5-15° and 40-50°/12-20°, faults have the direction 300-320°/40-60°, schistosity has the direction NE-SE/5-25°, while a system of cracks has the direction 280-290°/60-70° (6). In crushed rocks of the top-heading at 1301.1 m an overbreak of 13 m^3 occurred on August 9, 2005, when the excavation works were stopped for 5 days.

The geotechnical model was made based on geological and geotechnical monitoring during the excavation of the exploration gallery and both main tubes of the tunnel. The purpose of the model was to foresee the geotechnical conditions for widening the caverns[7,8]. This research showed that the tectonic model of the rock mass is much more complex than foreseen. The accuracy of the predicted geological models was assessed in the range between 1 and 10, where the accuracy of the model 2002, known at the time of tender documents, was assessed as 3; accuracy of the geological model 2005, known after excavation of the exploration gallery, was estimated as 7; while accuracy of the model 2006, known after excavation of the main tubes, was estimated as 9.

Rock mass categories: Tender-Actual

Based on the Austrian standard ÖNORM B 2203 it was foreseen in the tender documents that Šentvid tunnel would be excavated in rock mass category PC in the region of portals, SCC in the region of shallow cover class, B2 in the range where rock mass is strongly structurally damaged, C2 in the rock mass where increased stress-strain conditions occur during the excavation, and C3 in the rock mass where greatly increased stress-strain conditions

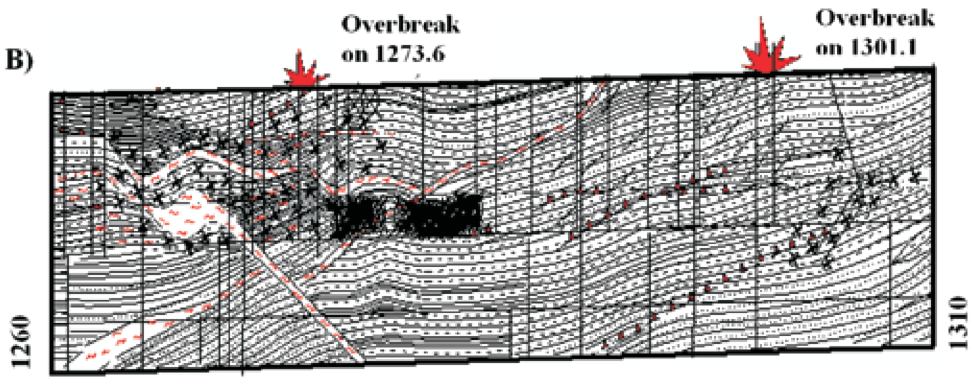

Figure 2. Actual geological composition in the left tube between 1260 and 1310 m (B)
Slika 2. Dejanska geološka zgradba v trasi leve predorske cevi na stacionažah med 1260 in 1310 (B)

occur during the excavation. A parking bay niche was designed in the two lane tube while, in the contact between the ramp tunnel and the main tube, a cavern was designed. Rock mass categories were adjusted according to actual geological conditions. Comparison between predicted and actual rock mass categories for the two- and three-lane tunnel is presented in Figures 3-6.

Rock mass category C2 in the two-lane tunnel was shortened from 49 % to 17 % of the tunnel length (status end of May 2006), (Figure 3 and 4). Rock mass category C3 was foreseen in 23 % of the tunnel length, and was installed in 18 % of the tunnel length whereas, in addition, in 33 % of the length much more reinforced C3 was installed – the so-called modified C3 category.

5 % of rock mass category B2 was foreseen in the tender documents in the two-lane tube, but it was not installed until the end of May 2007. Category PC was extended by 122 %. In 88 % of the parking bay niche a pipe roof was additionally installed. A pipe roof was foreseen only in the category PC (Figure 3), i.e. on 7 % of the tunnel length, but actually it was installed also in some parts of C2, C3 and the parking bay niche, altogether in 62 % of the tunnel length (status end of May 2006), (Figure 4).

C2 rock mass category in the three-lane tunnel (left and right tube together) was shortened by 7 % (Figures 5 and 6), whereas in an additional 13 % of the tunnel length much more reinforced C2 – modified category was installed. C3 category was shortened by 17 %, but an additional 8 % of much more reinforced C3

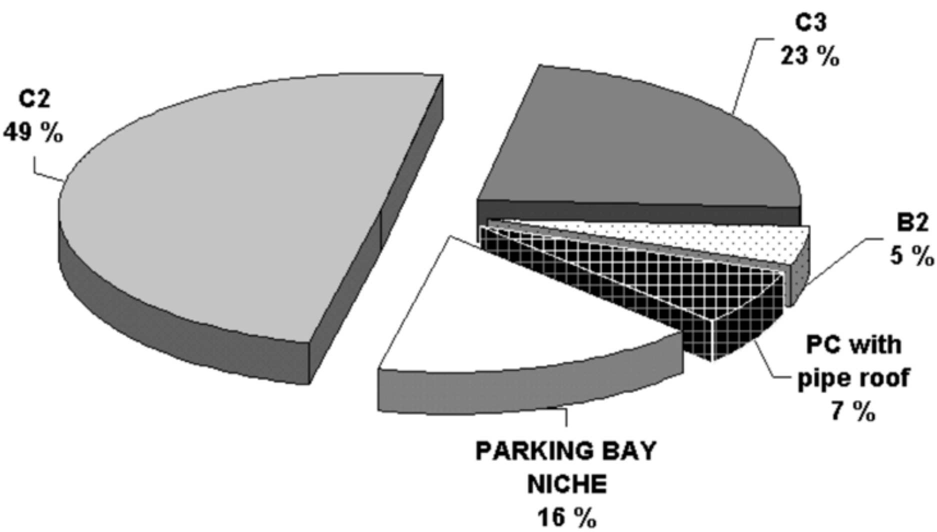

Figure 3. Rock mass categories in tender documents in 608 m of the two-lane tunnel (status end of May 2006). Netlike hatching indicates a pipe roof.
Slika 3. Hribinske kategorije po PZR na 608 m dvopasovnega predora (stanje do konca maja 2006). Mrežasta šrafura označuje cevni ščit.

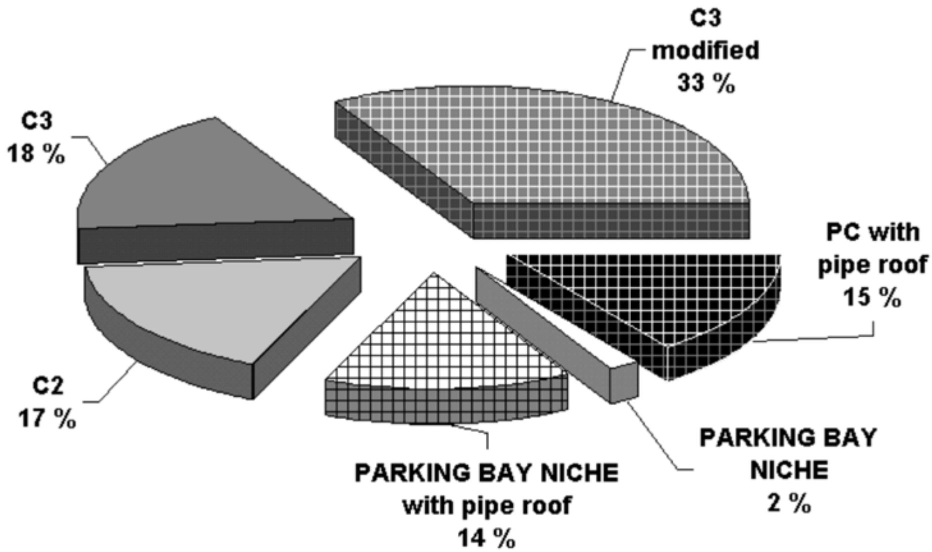

Figure 4. Actual rock mass categories in 608 m of the two-lane tunnel (status end of May 2006). Netlike hatching indicates a pipe roof.
Slika 4. Dejanske hribinske kategorije na 608 m dvopasovnega predora (stanje do konca maja 2006). Mrežasta šrafura označuje cevni ščit.

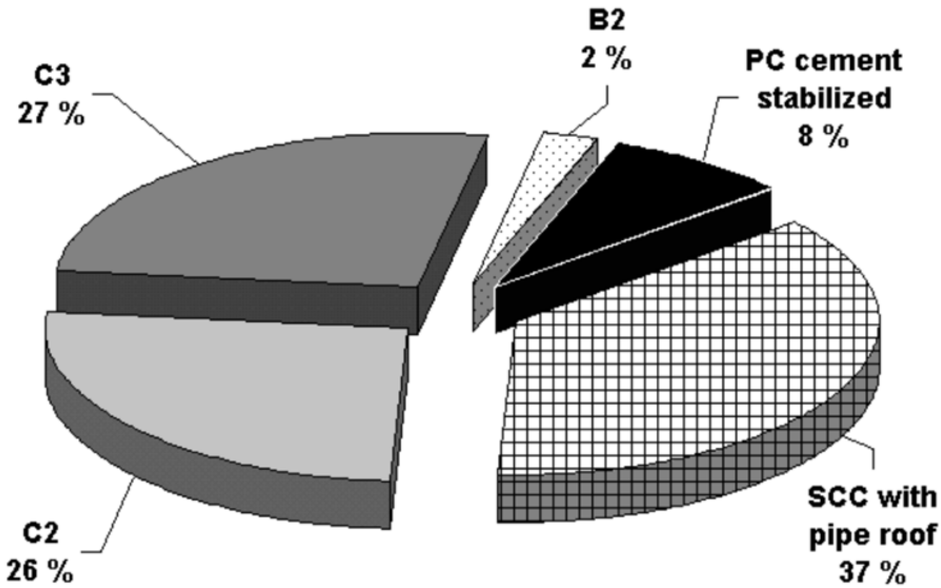

Figure 5. Rock mass categories in tender documents in 759 m of the three-lane tunnel (status end of May 2006). Netlike hatching indicates a pipe roof.
Slika 5. Hribinske kategorije po PZR na 759 m tripasovnega predora (stanje do konca maja 2006). Mrežasta šrafura označuje cevni ščit.

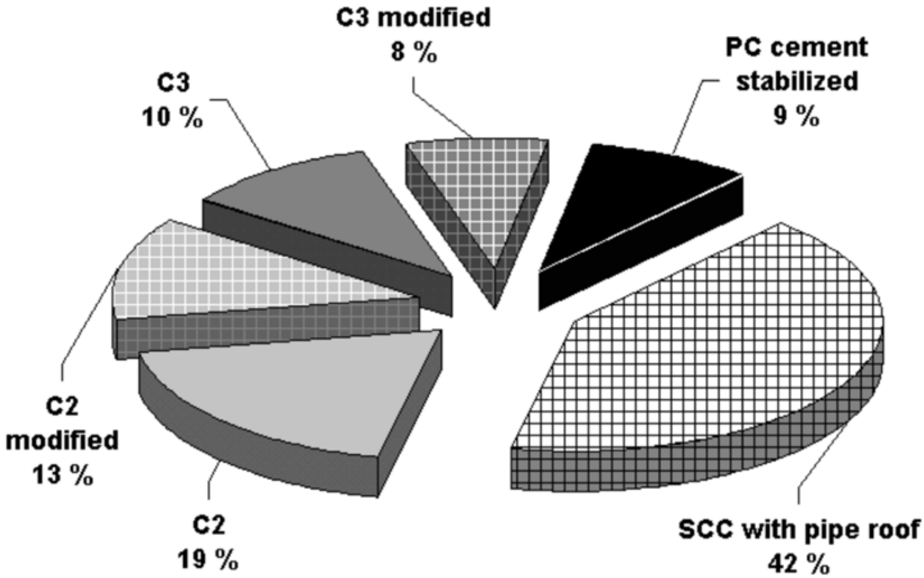

Figure 6. Actual rock mass categories in 759 m of the three-lane tunnel (status end of May 2006). Netlike hatching indicates a pipe roof.
Slika 6. Dejanske hribinske kategorije na 759 m tripasovnega predora (stanje do konca maja 2006). Mrežasta šrafura označuje cevni ščit.

modified category was installed. The B2 category foreseen in the tender documents in the three-lane tunnel was not installed until the end of the May 2006.

Category SCC with pipe roof was extended by 5 % and category PC by 1 %. Pipe roof was foreseen in the tender documents in the three lane tunnel only in the category SCC, i.e. on 37 % of the tunnel length, whereas it was actually installed also in the sections C2 and C3, altogether in 63 % of the tunnel length.

Substantial reinforced profiles were installed in 55 % of the two-lane tunnel length and in 26 % of the three-lane tunnel length, altogether in 39 % of the whole tunnel (status at the end of May 2006).

Adjustments of support measures and methods of construction

Excavation of the tunnel in tectonized Permo-Carboniferous rocks was possible only with constant adjustments of the construction methods. Further, additional support measures were carried out according to geological conditions to achieve stability of the primary tunnel lining and the working face and to ensure safe working conditions. Comparison of the support measures foreseen in the tender documents with those that were actually installed was carried out on the basis of longitudinal profiles for both tubes. Support measures and construction methods were compared between each section of actual rock mass category and the corresponding section of the tender rock mass category.

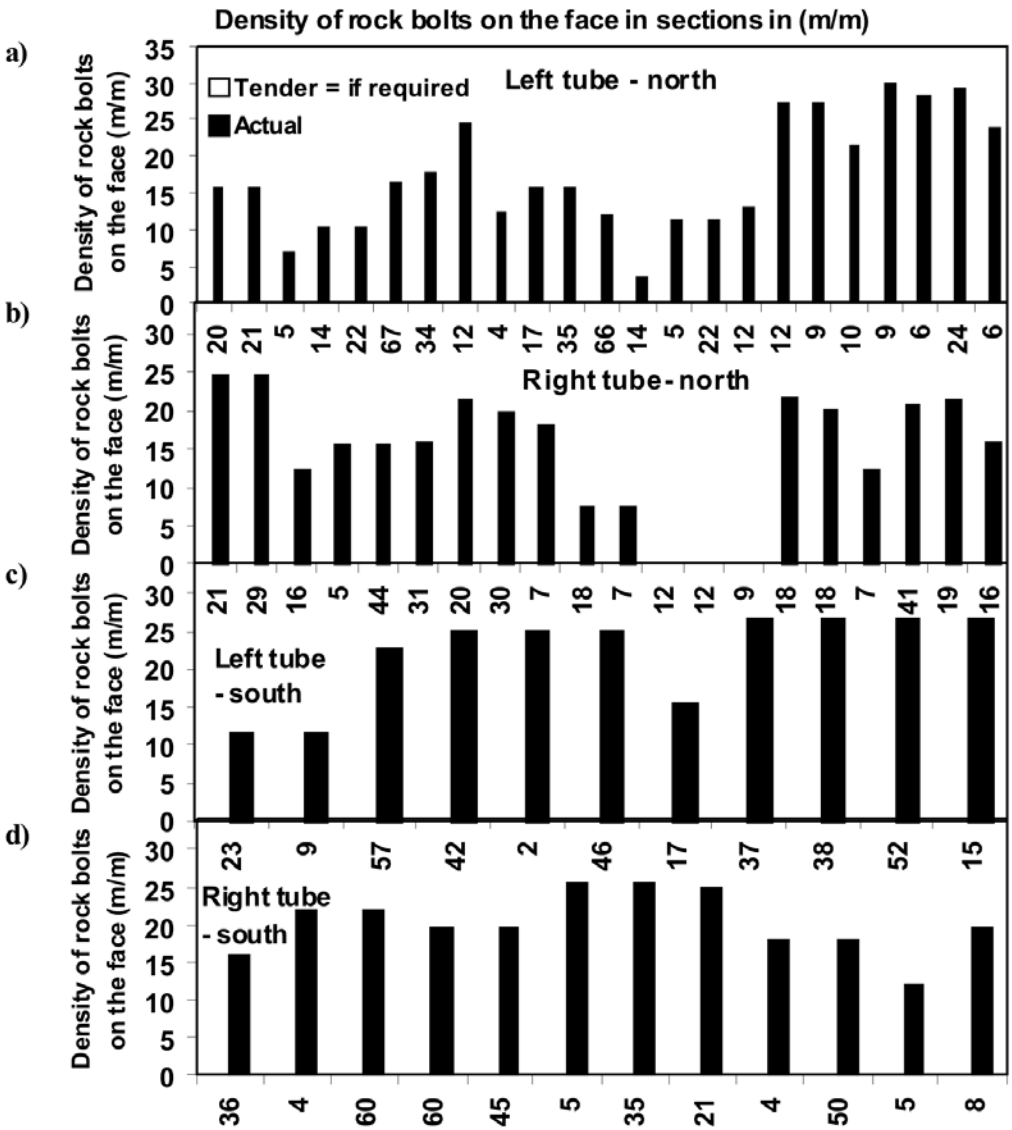

Figure 7. Actual density of rock bolts on the working face in sections. Face bolting in the tender documents was foreseen only »if required« with no given quantities: (a) left tube – north, (b) right tube – north, (c) left tube – south, (d) right tube – south

Slika 7. Dejanska gostota sider za varovanje izkopnega čela po odsekih: (a) leva cev – sever, (b) desna cev – sever, (c) leva cev – jug in (d) desna cev – jug

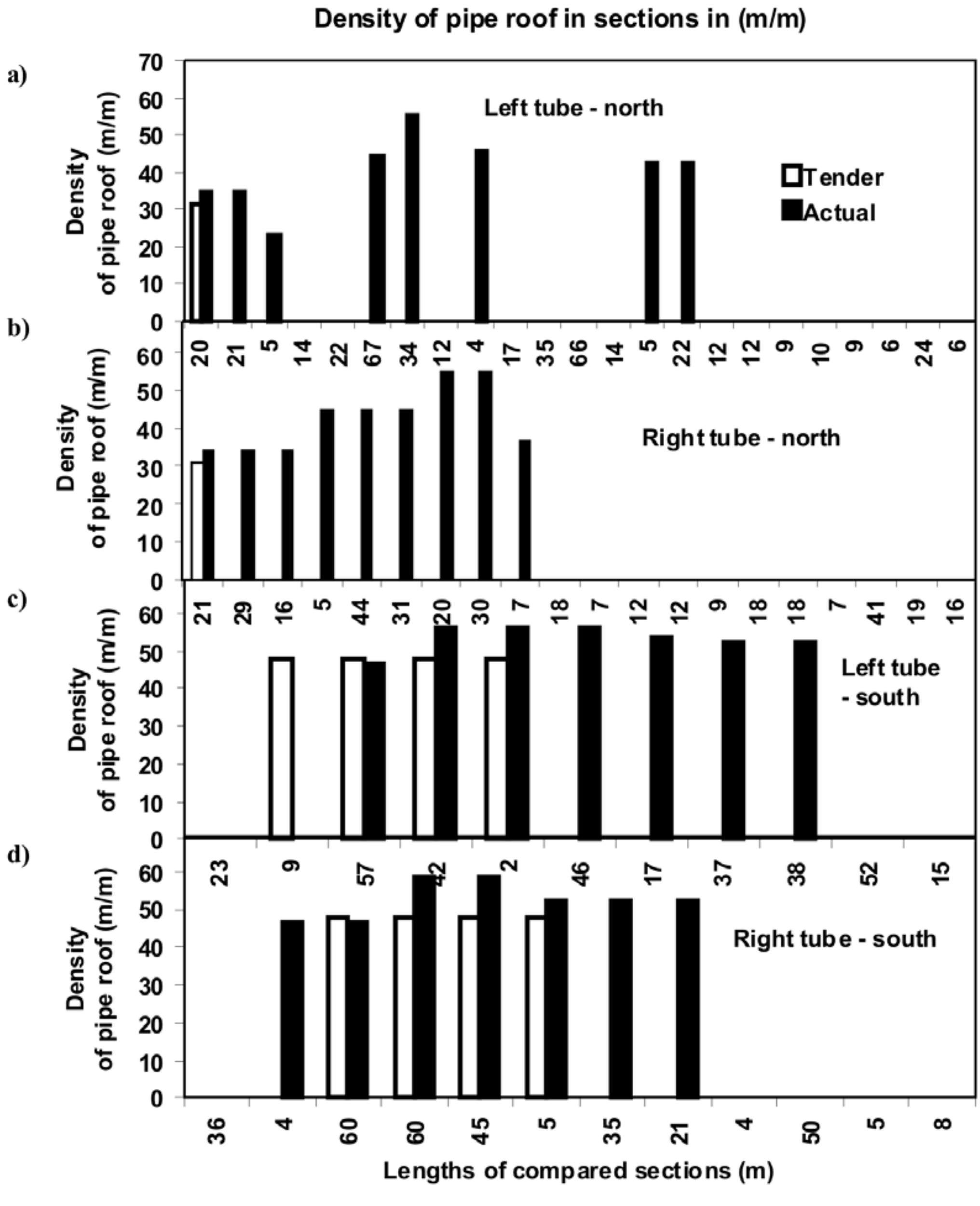

Figure 8. Actual sections with pipe roof (black columns) and those foreseen in the tender documents (white columns): (a) left tube – north, (b) right tube – north, (c) left tube – south, (d) right tube – south

Slika 8. Odseki s cevnim ščitom (črni stolpci) in tisti predvideni po PZR (beli stolpci s črno obrobo): (a) leva cev – sever, (b) desna cev – sever, (c) leva cev – jug in (d) desna cev – jug

Table 1. Density of rock bolts in the caverns (m/m)
Tabela 1. Gostota sider v kavernah (m/m)

Density of rock bolts in the cavern in tender (m/m)						Actual density of rock bolts in the cavern (m/m)					
left			right			left			right		
K-1A	K-2A	K-3A	K-1A	K-2A	K-3A	K-1A	K-2A	K-3A	K-1A	K-2A	K-3A
400.4	398.3	340	336.6	337.8	282.4	372	463.6	418.6	450.8	437.1	389.4
Difference in density of rock bolts: actual – tender in (m/m)						-28	65.3	78.6	114.2	99.3	107
Difference in density of rock bolts: actual – tender in (%)						-7	16	23	34	29	38

It was necessary to stabilize the working face systematically by a large number of rock bolts on 98 % of the excavated tunnel, whereas face bolting in the tender documents was foreseen only if required, without specifying the quantity (Figure 7).

Systematic rock bolting of the working face was carried out, even under the pipe roof. The average density of the rock bolts was 4–30 m/m. It was necessary to proceed the excavation with reinforced forepoling and pipe roof (Figure 8), or in some sections (C2, C3 and parking bay niche) also to replace forepoling pipes with pipe roof.

Pipe roof was foreseen in the tender documents only in the PC and SCC categories (Figures 3-6 and 8) over a length of 320 m, whereas it was actually installed also in sections C2, C3 and the parking bay niche; altogether over a length of 850 m (status end of May 2006).

Support for the primary tunnel lining was reinforced with additional rock bolts on 65 % of the tunnel's length (situation at the end of May 2006). Table 1 presents the reinforcement of the primary tunnel lining in caverns. The density of rock bolts in the right cavern in all sections A (K-1A, K-2A and K-3A) was higher by up to 99-114 m/m, whereas in the left cavern it was higher in 70 % of its length by up to 65-79 m/m.

In the left tube – north, 18 % more rock bolts were installed than foreseen in the tender documents. In the right tube – north, 36 % more were installed and, in the right tube – south, 8 % more, whereas only in the left tube – south were fewer rock bolts installed than foreseen in the tender (Figure 9), (status end of May 2006).

In 34 % of the tunnel's length (status end of May 2006), increased deformation of the primary tunnel lining occurred, so that special measures were carried out to stabilize it using a large number of rock bolts, wire mesh and shotcrete.

Despite the pre-supporting measures ahead of the front associated with systematic face bolting and very careful sequences of excavation, frequent overbreaks occurred at

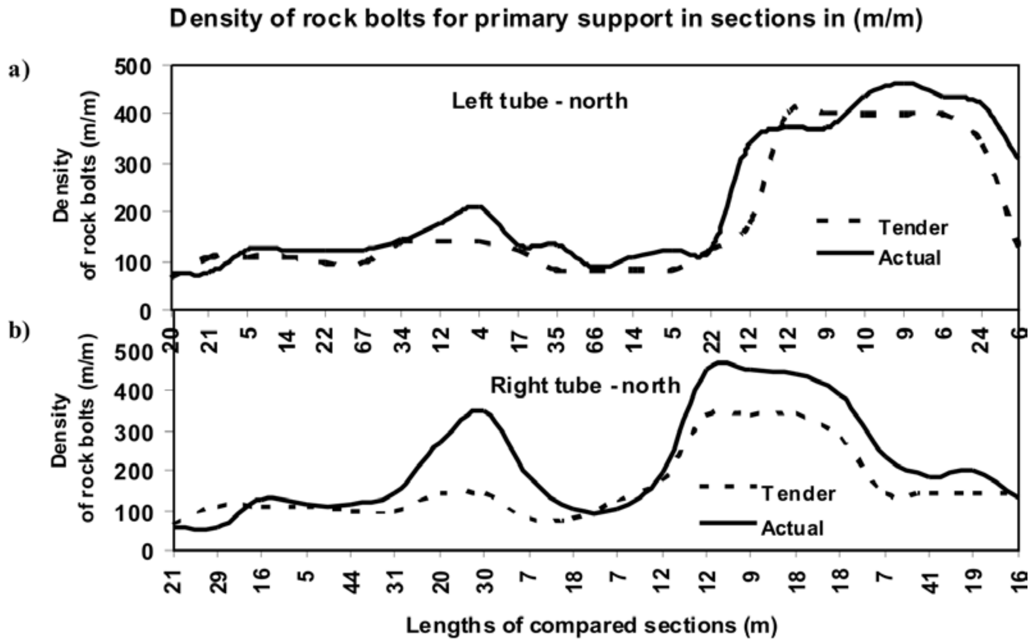

Figure 9. Comparison of tender and actual rock bolt density in particular sections: (a) left tube north and (b) right tube north

Slika 9. Primerjava dejanske in predvidene (PZR) gostote sider za primarno podgradnjo po odsekih: (a) leva cev sever in (b) desna cev sever

all four work sites, due to the very poor geological conditions, even under a pipe roof. Up to the end of May 2006; 14 overbreaks occurred in the left tube north (1 in the cavern), 4 in the right tube north (2 in the cavern), 4 in the left tube south and 5 in the right tube south. Special measures were carried out to stabilize the working face with additional installation of rock bolts, forepoling pipes, wire mesh, reinforcing steel bars, pipe roof and shotcrete.

Support measures and methods of construction were adjusted according to geological conditions in the rock mass. The consequence of these adjustments was the slower rate of the excavation works. Tunnel excavation in tectonized rock mass was possible only in phases (Figure 10). Excavation works in the top heading of rock mass category PC, C2, C3, parking bay niche and cavern A was planned to be carried out in 3 phases and in rock mass category SCC in 2 phases, while the support body in all mentioned rock mass categories was planned to be excavated in 1 phase according to tender documents. In fact, excavation of the top heading was carried out in 94 % of the tunnel length and of the support body in 72 % of the tunnel length, in more phases than foreseen in the tender documents (status end of May 2006). Excavation of the top heading in rock mass category PC was carried out on average in 7 phases and of the support body in 3-5 phases. Excavation in SCC was carried out on average in 11 phases and in the support body in 5-7 phases. Excavation in C2 of the two-lane tunnel was carried out on average in 7 phases, in rock mass category C2 with exploration gallery in 3 phases, and the support body was excavated in 4 phases. Excavation in category C2 of the three-lane tunnel was carried out in 4-9 phases and the support body was excavated in 2-6 phases. Excavation in the rock mass category C3 was carried out in 7-11 phases, in rock mass category C3 with the exploration gallery was carried out in 5-9 phases and the support body was excavated in 5-7 phases.

Round lengths in the invert were shortened in 67 % of the excavated tunnel; round lengths in the bench were shortened in 50 % of the excavated tunnel, while round lengths in the top-heading were shortened in 45 % of the tunnel length (status end of May 2006). Round lengths in the invert of the left tube north were on average 1.3 m shorter (Figure 11a), in the right tube north on average 1.7 m shorter (Figure 11b) and, in both tubes south, on average 1.5 m shorter than those foreseen in the tender documents (Figure 11c and 11d).

Temporal invert was foreseen in the tender documents only in the categories PC and SCC of the three-lane tunnel (round length of the temporal invert for PC of the two-lane tunnel was not given in the tender), whereas actually it was installed in 344 m of the two-lane tunnel. Altogether it was installed in 390 m more of the temporal invert than was foreseen in the tender.

In the tender documents, the distance between the top heading and the invert in the rock mass category B2 was 200 m, in C2 150 m, and in SCC 60 m, while in category PC and C3 it was 30 m. These distances were shortened in 96 % of the tunnel length (status end of May 2006) because of unfavourable geological conditions (Figure

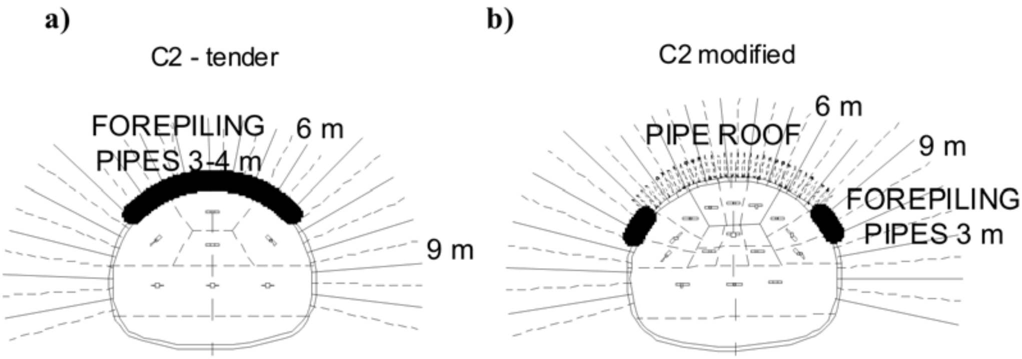

Figure 10. Excavation phases in the rock mass category C2 of the three-lane tunnel: (a) tender; 3 phases in the top heading and 1 phase for excavation of the support body, (b) actual; 9 phases in the top heading and 6 phases in the support body (drawing by Elea iC)

Slika 10. Izkopne faze kalote v hribinski kategoriji C2 tripasovnega predora: (a) PZR – 3 faze za izkop kalote in 1 faza za izkop podpornega jedra, (b) dejansko – 9 faz za izkop kalote in 6 faz za izkop podpornega jedra (avtor slike: Elea iC)

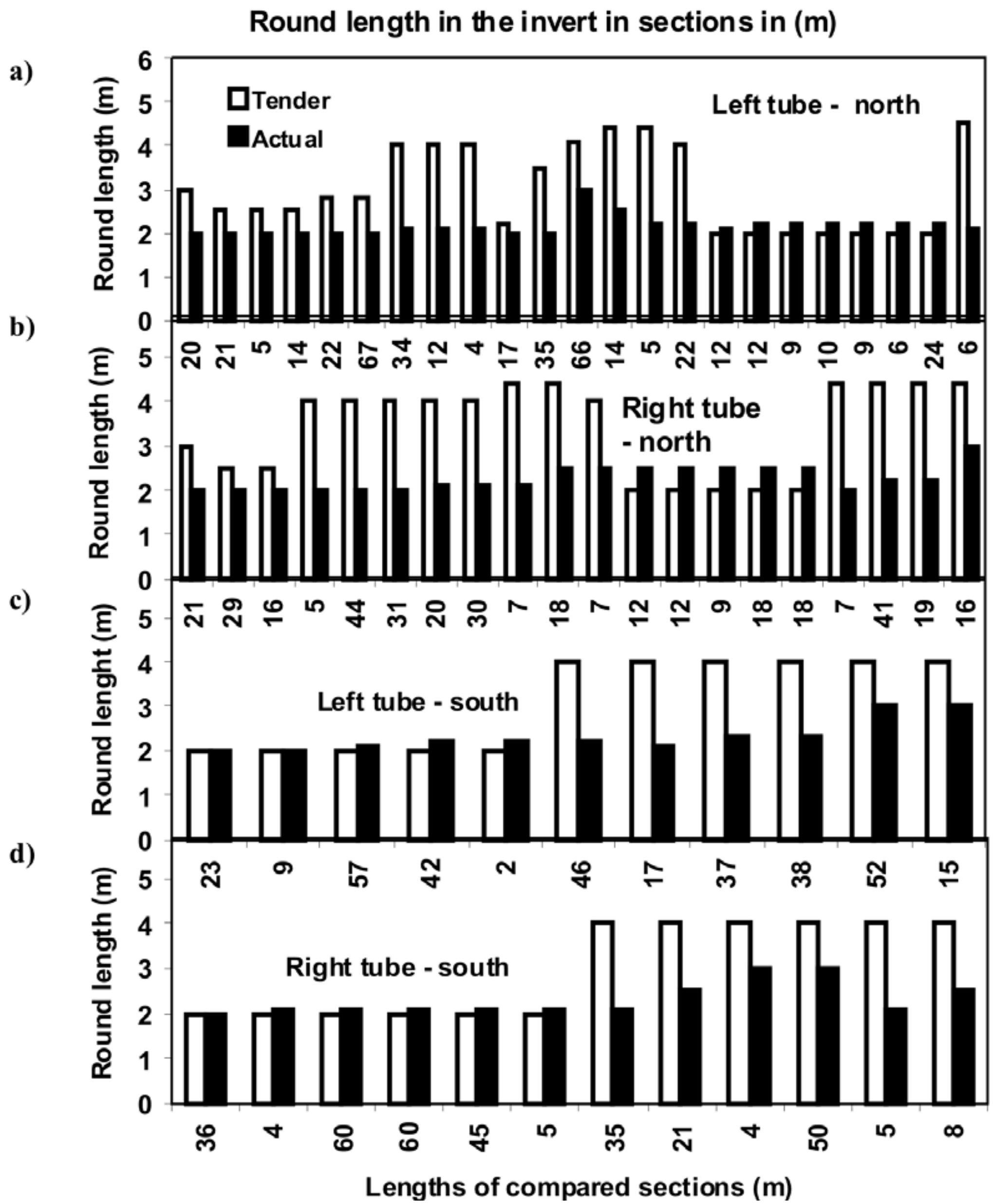

Figure 11. Round lengths in the invert (black columns) and those foreseen in the tender documents (white columns) in sections: (a) left tube north, (b) right tube north, (c) left tube south and (d) right tube south

Slika 11. Dolžine korakov v talnem oboku (črni stolpci) in dolžine predvidene po PZR (beli stolpci s črno obrobo) po odsekih: (a) leva cev – sever, (b) desna cev – sever, (c) leva cev – jug in (d) desna cev – jug

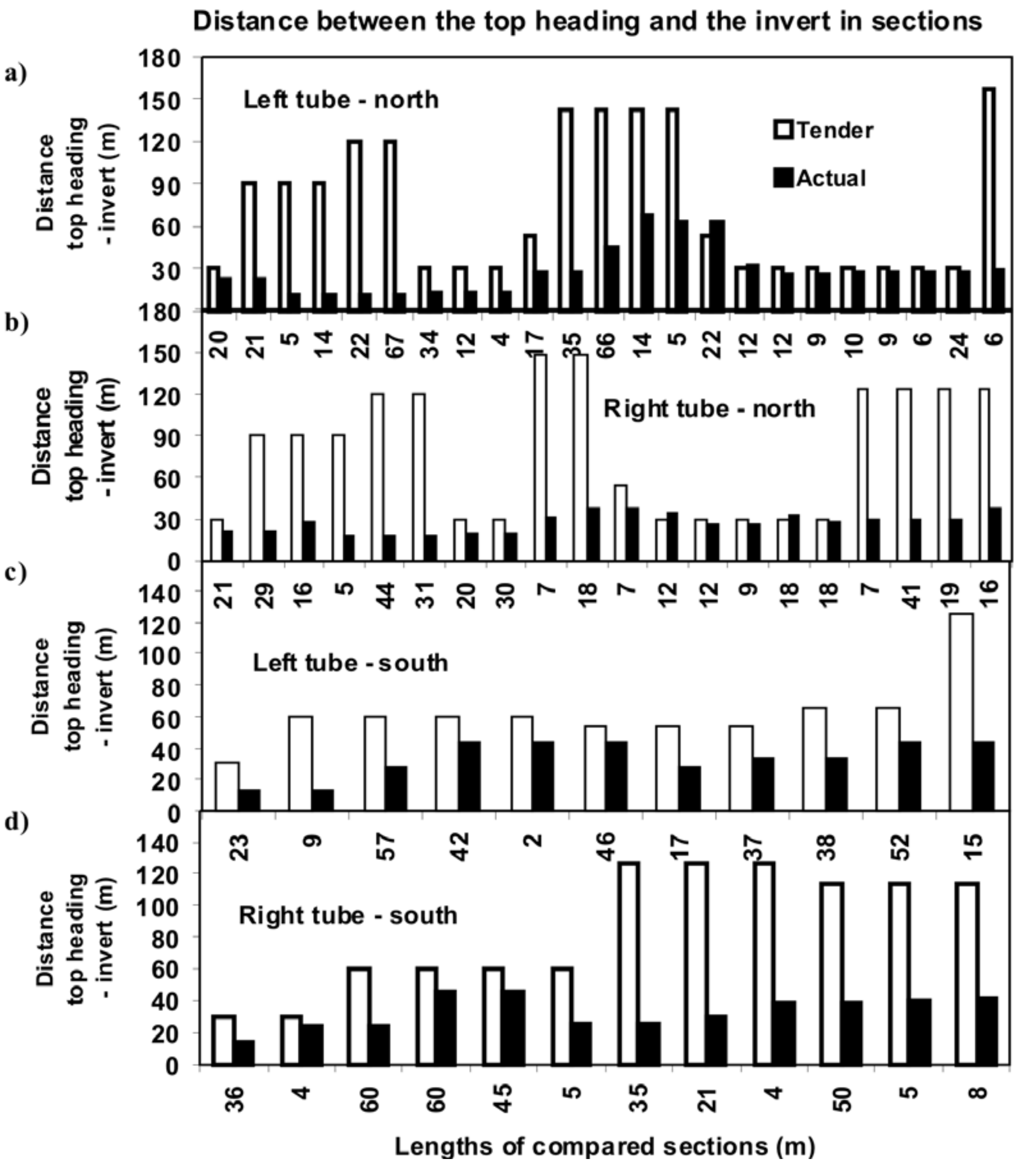

Figure 12. Actual distances between the top heading and the invert (black columns) and the distances foreseen in the tender documents (white columns) in sections: (a) left tube north, (b) right tube north, (c) left tube south and (d) right tube south

Slika 12. Dejanske razdalje kalota – talni obok (črni stolpci) in razdalje predvidene po PZR (beli stolpci s črno obrobo) po odsekih: (a) leva cev – sever, (b) desna cev – sever, (c) leva cev – jug in (d) desna cev – jug

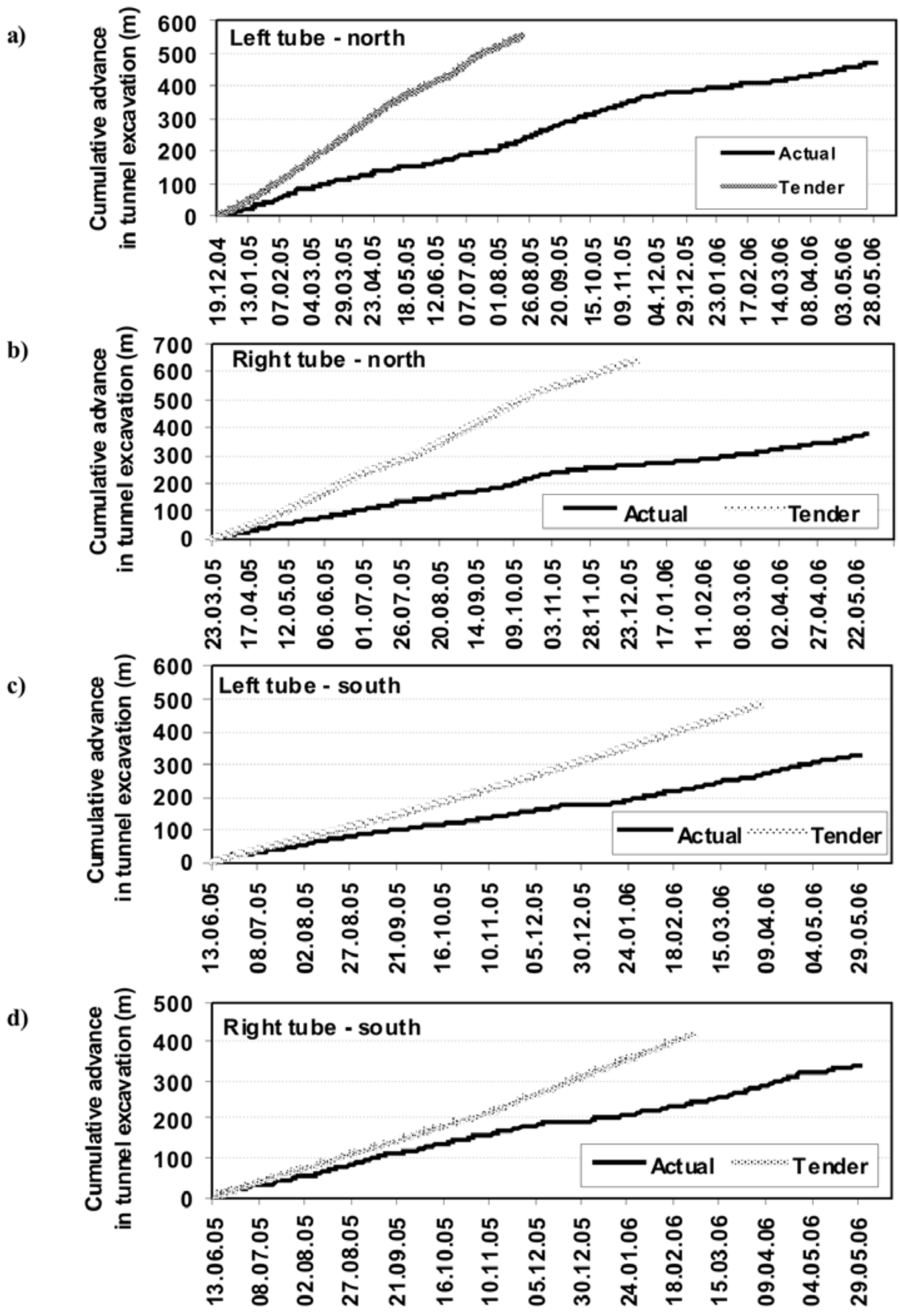

Figure 13. Cumulative advance in the Šentvid Tunnel: (a) left tube north, (b) right tube north, (c) left tube south and (d) right tube south
Slika 13. Kumulativni napredki izkopa predora Šentvid za vsa štiri napadna mesta: (a) leva cev – sever, (b) desna cev – sever, (c) leva cev – jug in (d) desna cev – jug

12). They were shortened by more than a half in 58 % of the tunnel length (status end of May 2006).

Constant adjustments of construction technology were carried out according to actual geological conditions. That is why the advance rate was less than that foreseen in the tender (Figure 13). Excavation of the tunnel with primary lining should have been finished in 8-10 months while, up to the end of May 2006, only 76 % of the left tube and 67 % of the right tube was excavated.

Conclusions

The constant adjustments in construction technology were due to the complex geological conditions in the rock mass. It was necessary to proceed excavation with reinforced forepoling and pipe roof (required only for some sections of SCC and PC) or even with substitution of the forepoling by a pipe roof in some sections of C2 and C3. Moreover, it was necessary to systematically stabilize the working face by a large number of rock bolts, even under a pipe roof. Despite the pre-supporting measures ahead of the front, associated with systematic face bolting and very careful sequences of excavation, frequent overbreaks due to the very poor geological conditions occurred in the four work sites. The number of excavation sequences in the top heading was increased; round lengths were shortened as well as distances between the top-heading and the invert, the sections with temporal invert were extended. The support elements designed in the tunnel profiles needed reinforcing during execution of the works. The consequence was a general decrease of the rate of advance and a corresponding increase in construction delays.

Povzetek

Gradnja predora Šentvid

Predor Šentvid je najzahtevnejši objekt na 5,5 kilometra dolgem avtocestnem odseku Šentvid-Koseze, ki bo povezal gorenjsko avtocesto z ljubljanskim avtocestnim obročem in s tem sklenil avtocestni križ na območju Ljubljane. Predorski cevi potekata med Šentvidom in Pržanjem v dolžini 1030 m (leva cev) in 1060 m (desna cev). Zaradi kompleksnih geoloških razmer je bilo treba stalno prilagajati tehnologijo gradnje predora. Za napredovanje izkopa je bilo potrebno ojačevanje stropa in bokov predora z vgradnjo sulic ali cevnega ščita in sistematično varovanje izkopnega čela z vgradnjo sider. Izkop smo izvajali v bistveno več fazah, podaljšali smo odseke z začasnim talnim obokom, skrajšali korake napredovanja v kaloti, stopnici in talnem oboku ter skrajšali razdaljo kalota – talni obok in primarno podgradnjo ojačevali z dodatnimi sidri.

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