MINED SECTIONS OF THE TUNEL POVÁŽSKÝ CHLMEC – EXPECTATIONS AND REALITY

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ABSTRACT: This paper is focused on the bid preparation and the construction of the Povážský Chlmec tunnel situated on the section Žilina (Strážov) – Žilina (Brodno) of the highway D3. The tunnel has two double-lane tubes of length 2 x 2.2 km, the tunnel is excavated using NATM with the tunnel face sequencing to top heading and bench.

The tunnel construction started in May 2014 and tunnel opening for operation is expected in June 2017. Due to extremely short time schedule the excavation was allowed from 8 faces (two faces from the west portal, two faces from the east portal and 4 faces from the central pit), maximally 6 excavations were ongoing in one time. Now (end of January 2016) all NATM excavations between the central pit and the west portal were completed. Also top heading excavation between the central pit and the east portal was completed. Thus only about 380 m of top heading in the North tunnel tube (NTT) between the central pit and the east portal has to be finished.

The tunnel was tendered using Yellow FIDIC Book, therefore contractor is responsible for detail technical solutions. Thus contractor Hochtief CZ utilised companies 3G Consulting Engineers and IKP for assistance with the bid preparation and during the tunnel construction. The paper is focused on interpretation of site investigation and optimisation of excavation and support classes prior the bid submission. Consequently optimisation of NATM excavations during tunnel construction is described.

1. BASIC PARAMETERS OF THE TUNNEL

The tunnel Povážský Chlmec is situated on the section Žilina (Strážov) – Žilina (Brodno) of the highway D3. This section of the highway (Fig. 1) with the length 4 250 m goes over the bridge (1500 m long) across the water reservoir Hričov on the river Váh (Fig. 2). Consequently the highway goes to the west portal of the tunnel Považský Chlmec. The tunnel includes two curves with opposite directions. From the east tunnel portal the highway continues via 400 m long bridge across the river Kysuce.

The Povážský Chlmec contains two tubes with opposite direction of traffic, two lanes will be in each tube, the tubes are connected with cross-passages. The tunnel is excavated using New Austrian Tunnelling Method (NATM) with tunnel face sequencing to top heading and bench. The tunnel construction started in May 2014 and tunnel opening for operation is expected in June 2017. The excavation was allowed from 8 faces due to extremely short time schedule (two faces from the west portal, two faces from the east portal and 4 faces from the central pit). Cut and cover sections are in area of portals and also in the central pit. The South tunnel tube (STT) is 2186.5 m long including 2120.5 m long mined section. The North tunnel tube (NTT) is 2249 m long including 2200 m long mined section. The tunnel face area varies from 83.1 m^2 (the NATM class 4.1 without invert for the best ground) to 105.2 m^2 (the NATM class 6.3 with invert for the worst ground).

The maximum tunnel overburden is about 125 m. Surface above the tunnel is covered by meadows, forests, cottages, various ways, and water supply pipes. The tunnel level lies in altitude 341 to 352 m above sea level. Cut and cover sections were partly realised using the turtle method (tunnel excavation under ceiling generated from monolithic reinforced concrete) [1]. The turtle construction was used on the west portal (37.5 m on the STT and 50.0 m on the NTT). The turtle construction was also used in the central pit on the NTT in direction to east in length 34.5 m.

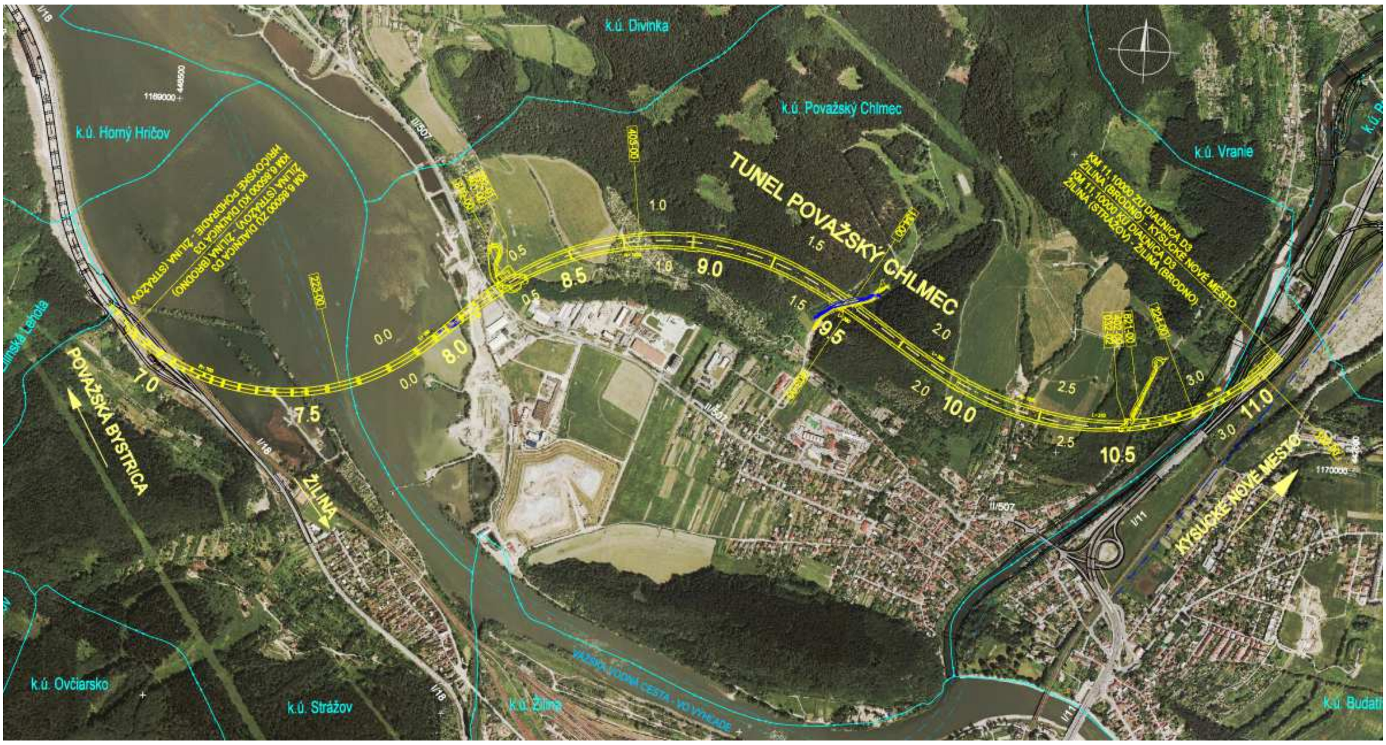

Figure 1: Plan of the new section of the highway D3 including the Povážský Chlmec tunnel


Figure 2: Construction of the bridge over the water reservoir Hričov on the river Váh

The client of the new D3 highway section is Národná diaľničná spoločnosť (NDS), the contractor is JV of companies Eurovia SK, Hochtief CZ and Stavby mostov Slovakia. The tunnel Povážský Chlmec is constructed by Hochtief CZ, which executed 4 excavations from the central pit. Excavations from the west portal and the south portal were executed by TuCon (subcontractor of the Hochtief CZ). The detail documentation was prepared by IKP Consulting Engineers and Hochtief CZ. Geotechnical supervision of the tunnel excavation is done by 3G Consulting Engineers which are together with Hochtief CZ responsible for decision about application of designed NATM classes. Geotechnical monitoring and tunnel face mapping is done by Arcadis. Surveying works (tunnel alignment control, monitoring of the tunnel lining deformations, monitoring of overbreaks, etc.) is done by Angermeier Engineers. Construction supervision for client is done by JV of EUTECH&ESP&MULLER&API-D3.

2. GEOTECHNICAL CONDITIONS

The Považský Chlmec tunnel is situated in the Pieniny Klippen Belt. The northern and southern part of the tunnel route is formed of Pieniny formations with flysch beds of calciferous claystones and sandstones. In their upper part (along the corridor axis), there are spots of exotic conglomerates (age: Coniacian – Lower Santonian). The topmost part of the Pieniny beds is lined by exotic conglomerates in the south. The southern side of the Pieniny beds is lined by beds of varied marls (age: Upper Santonian

– Maastrichtian). The maximum thickness of the flysch bed with inserts of varied marls and with exotic conglomerates is around the village of Divinka (1,500 m). Its thickness is decreasing eastward, ca. 400 m. In the Kysuca unit of the Pieniny Klippen Belt, there are sandstones on top – 10 to 16 cm. These are grouped into smaller megacycles consisting of 3 to 9 beds. In the zone of thicker beds of up to 200 mm, the sandstones are solid in the whole thickness. Solid beds are frequent in complexes where sandstones prevail over claystones (in a ratio of 5:1). Laminated layers present in the marlstones are of siltstones. It is characteristic of the Pieniny Klippen Belt that the thickness of the individual beds is invariable. The main component of the sandstones is quartz, fragments of carbonaceous rocks, granitic and metamorphic rocks and fragments of volcanic rocks. The cement is carbonic, the share of clay matrix is from 0 to 13%. According to distribution of the main components, the sandstones are typical calciferous lithic sandstones. Conglomerate flysch of the Kysuca unit is very coarse. It consists of clusters and grains of large size, 100 – 400 m, and volume of 5 to 8 cubic kilometres, often with blocks and boulders. The individual rock bodies are 2 to 12 m thick, they are often gradually layered or with an inversion of the gradation with rounded boulder-sized fragments (up to 2.5 m) to fine powder. Flysch conglomerates (Fig. 3) are immature, both in terms of their petrographic composition and structure. Fragments of labile rock complexes mixed with lower quantities of plutonic rocks and metamorphic rocks are predominating in them. In the conglomerates, carbonaceous fragments prevail over volcanic rocks, clastic rocks, and intrusions and metamorphic rocks. Quartzite fragments and quartz conglomerates of significant sizes are present as well and locally also vein quartz.

Figure 3: Tunnel face with exotic conglomerates

The water table was identified only locally at the depth ranging from 4m to 15m, on the base of terrace sediments, or in the underlying layers of the Mesozoic complex. When the hydrogeological survey was being carried out, not a single sample of water exhibited aggression to concrete structures.

3. BID PREPARATION

The contract for the construction of the D3 motorway section between Žilina (Strážov) and Žilina (Brodno) went out to tender according to the FIDIC Yellow Book. The tunnelled section forms 50% of the alignment and its cost forms a significant part of the overall tender cost. Therefore the company Hochtief CZ a. s. utilised external partners for the bid preparation. The company 3G Consulting Engineers s.r.o. interpreted the results of the site investigation and optimised the NATM classes. The most important result of 3G Consulting Engineers s.r.o. was expected utilisation of tunnel invert which has a very important impact on the final tunnel cost. The company IKP Consulting Engineers, s.r.o. optimised the scope and method of the support of construction pits, the scope of cut-and-cover tunnel sections, the tunnel cross-section and the final lining dimensions, to forecast the application of the unreinforced final lining, to optimise the block diagram and safety elements (the number and location of cross passages, emergency stopping lay-bys, fire hydrant niches, SOS boxes, drainage cleaning recesses etc.). A prognosis of tunnel sections with various final lining reinforcement contents or an unreinforced final lining was developed on the basis of the prognosis of the division of the mined tunnel part into excavation support classes. The Germany-based Hochtief head office also participated in the bid preparation.

The company 3G Consulting Engineers realised namely the following tasks [5]:

- Analysis and interpretation of geological conditions with regard to the tunnel NATM excavation
- Evaluation of the swelling risk, presence of clay minerals
- Optimisation of designed NATM classes, volumes and prices of proposed support measures
- Evaluation of geotechnical conditions and optimisation of NATM classes along the STT and NTT
- Evaluation of the further muck utilisations
- Numerical modelling of the primary lining in 2D (5 models in various cross-sections)

The result of distribution of various NATM classes along the STT and the NTT is presented in Tab. 1 and 2. The most important impact on the proposed tunnel cost had a length of section with and without tunnel invert. The distribution of NATM classes with and without invert proposed by 3G Consulting Engineers is shown in Tab. 1 and 2. [5]:

South tunnel tube (STT):

- 1631 m (79%) without tunnel invert (originally in tender documentation expected 47%)
- 438 m (21%) with tunnel invert (originally in tender documentation expected 53%)

North tunnel tube (NTT):

- 1735 m (82%) without tunnel invert (originally in tender documentation expected 43%)
- 475 m (18%) with tunnel invert (originally in tender documentation expected 57%)

The presented proposal was discussed during meetings in German central office of Hochtief. German colleagues saw proposal as very optimistic and risky, thus during a bid preparation was adopted more conservative proposal (with higher utilisation of the tunnel invert). Realised NATM excavations of the Považský Chlmec tunnel show even better geology in comparison to 3G proposal, it looks that tunnel invert will not be utilised at all.

Table 1 Proposed distribution of NATM classes in the STT

Kvazihomogenous block	J - ZP	J - 1	J - 1	J - 2	J - 3	J - 4	J - 5	J - 6	J - 7	J - 8	J - 9		J - U		J - 10
Section from - to (km)	0,493 (0,540) - 0,590	0,590 - 0,650	0,650 - 0,890	0,890 - 0,980	0,980 - 1,050	1,050 - 1,130	1,130 - 1,200	1,200 - 1,225	1,225 - 1,350	1,350 - 1,500	1,500 - 1,565	1,558 - 1,578	1,565 - 1,640	1,632 - 1,652	1,640 - 1,680
Section lenght (m)	97	60	240	90	70	80	70	25	125	150	65		75		40
Overburden (m)	0 - 14	14 - 43	14 - 43	43 - 49	49 - 60	60 - 67	52 - 65	65 - 66	66 - 94	34 - 97	7.34		0 - 7		7.30
Geology	Cl, CG, Ie, Pz, Iz, Ie	In, Iz, Pn, Pz	In, Iz, Pn, Pz	ZPn, ZPtp, In, Pn	ZPn	ZPn	ZPn, In, Pn	In, Pn, ZPtp	In, Pn, ZSn	ZSn, In, ZPn	ZSn, ZStp	ZSn, ZStp	Cl, CG, ZPz, ZSz	ZPn, ZPtp	ZPn, ZPtp
Size of blocks (mm)	5 (<60)	4(3) (200-60) (600-200)	4(3) (200-60) (600-200)	5-4 (<60-60-200)	3 (600-200)	3-2 (200-600-2000)	3-4 (600-200-60)	5-4 (<60-60-200)	4-3 (60-200-600)	3-2 (200-600-2000)	3-4 (600-200-60)	3-4 (600-200-60)	4-5 (200-60- <60)	4-3 (60-200-600)	4-3 (60-200-600)
RQD (%)	5-4 (0-50)	3 (50-75)	3 (50-75)	5 (0-25)	3-4 (75-25)	2-3 (50-90)	4-3 (25-75)	5-4 (0-50)	3-4 (75-25)	2-3 (50-90)	4 (25-50)	4 (25-50)	4-5 (50-0)	4-3 (25-75)	4-3 (25-75)
Degree of weathering	3 (W5)	2 (W3-W4)	2 (W3-W4)	2-3 (W3-W4-W5)	2-1 (W4 až W1)	1-2 (W1 až W4)	2-1 (W4 až W1)	2 (W3-W4)	1-2 (W1 až W4)	1 (W1-W2)	2 (W3-W4)	2 (W3-W4)	2-3 (W3-W4-W5)	2 (W3-W4)	2 (W3-W4)
UCS (MPa)	0,5/8 (F6,F2 ; R6-R4)	8/42 (R4-R3)	8/42 (R4-R3)	6/15 (R4)	9/35 (R4-R3)	60/110 (R2)	9/35 (R4-R3)	6/15 (R4)	5/45 (R4-R3)	60/120 (R2)	9/45 (R4-R3)	9/45 (R4-R3)	0,5/7 (F6,F2 ; R6-R4)	9/45 (R4-R3)	9/45 (R4-R3)
E_{def} (MPa)	12/30	70/800	70/800	100/325	250/600	800/3000	250/600	100/325	250/600	800/3000	250/600	250/600	12/30	250/600	250/600
φ (°)	22/28	28/35	28/35	26/33	28/35	36/45	28/35	26/33	28/35	36/45	28/35	28/35	22/28	28/35	28/35
c (MPa)	0,006/0,012	0,050/0,250	0,050/0,250	0,010/0,075	0,050/0,250	0,500/0,800	0,050/0,250	0,010/0,075	0,050/0,250	0,500/0,800	0,050/0,250	0,050/0,250	0,020/0,070	0,050/0,250	0,050/0,250
ν	0,42/0,27	0,30/0,23	0,30/0,23	0,35/0,26	0,30/0,23	0,20/0,17	0,30/0,23	0,35/0,26	0,30/0,23	0,20/0,17	0,30/0,23	0,30/0,23	0,42/0,27	0,30/0,23	0,30/0,23
ÖNORM B 2203	P	C2:B3/40:60	C2:B3/40:60	C2:B3/60:40	B3:B2/70:30	B2:A2/50:50	B3:B2/70:30	C2:B3/70:30	B3:B2/80:20	B2:A2/50:50	B3:B2/70:30	B3:B2/70:30	P	B3:B2/60:40	B3:B2/60:40
Kvazihomogenous block	P	M3	M3	M4	M3	M1	M3	M4	M3	M1	M3	M3	P	M3	M3
Section lenght (m)	50	60	240	98	62	80	68,75	30	121,25	150	65		27		37,3
Tender documentation 2006	MP1 (60)	6/1 (70), 6/2 (130), 6/3 (90)		6/2 (48), 6/3 (50)	5/1 (62)	4/1 (80)	5/1 (68,75)	6/2 (30)	5/1 (121,25)	4/2 (150)	5/1 (65)		6/1 (27)		5/1 (37,3)
Section lenght (m)	50	60	240	90	70	80	70	25	125	150	65		75		40
Section lenght (m)	50	60	240	90	70	80	70	25	125	150	58	20	54	20	28
3G Consulting Engineers 2013	6/2	6/2	5/2	6/2	5/1	4/1	5/1	5/1	5/1	4/1	5/1	6/2	Cut and Cover	6/2	5/1

Kvazihomogenous block	J - 11	J - 12	J - 13	J - 14	J - 15	J - 16	J - 17	J - 18	J - 19	J - 20	J - 21		J - 22		J - VP
Section from - to (km)	1,680 - 1,725	1,725 - 1,750	1,750 - 1,815	1,815 - 1,935	1,935 - 2,105	2,105 - 2,150	2,150 - 2,210	2,210 - 2,270	2,270 - 2,335	2,335 - 2,400	2,400 - 2,445	2,445 - 2,525	2,445 - 2,640	2,640 - 2,663	2,640 - 2,682
Section lenght (m)	45	25	65	120	170	45	60	60	65	65	45		195		42
Overburden (m)	30 - 49	49 - 61	61 - 94	88 - 94	68 - 88	60 - 88	49 - 60	29 - 49	19 - 29	28 - 43	43 - 50		9.55		0 - 9
Geology	ZPn, Pn, ZSn	In, Itp, ZPtp	In, ZPn, Pn, ZSn	In, Pn, ZPn, ZSn	ZPn, In, Pn	ZSn, In, Pn	ZStp, ZSn, In	In, ZSn, Pn	ZPl, ZPtp, ZStp, ZSz	ZSn, In, Pn	In, Itp, ZSn, Ptp	In, Itp, ZSn, Ptp	ZStp, Itp, Ptp, ZSz	Cl, CG, ZStp, Ie, ZSz, Iz	Cl, CG, ZStp, Ie, ZSz, Iz
Size of blocks (mm)	3-4 (600-200-60)	3-4 (600-200-60)	3 (600-200)	3-4 (600-200-60)	3 (600-200)	4 (60-200)	4 (200-60)	4-3 (60-200-600)	4 (200-60)	3-4 (600-200-60)	4-3 (60-200-600)	4-3 (60-200-600)	4 (200-60)	4-5 (200-60-<60)	4-5 (200-60-<60)
RQD (%)	3 (50-75)	4 (25-50)	3 (50-75)	3 (50-75)	3 (50-75)	4 (25-50)	4 (25-50)	4-3 (25-75)	4-5 (50-0)	3-4 (75-25)	4 (25-50)	4 (25-50)	4-5 (50-0)	5 (0-25)	5 (0-25)
Degree of weathering	1-2 (W1 až W4)	2-1 (W4 až W1)	1 (W1-W2)	1-2 (W1 až W4)	1 (W1-W2)	2-1 (W4 až W1)	2 (W3-W4)	2-1 (W4 až W1)	2 (W3-W4)	1-2 (W1 až W4)	2-1 (W4 až W1)	2-1 (W4 až W1)	2 (W3-W4)	2-3 (W3-W4-W5)	2-3 (W3-W4-W5)
UCS (MPa)	15/65 (R3-R2)	5/40 (R4-R3)	20/65 (R3-R2)	10/40 (R4-R3)	23/62 (R3-R2)	9/40 (R4-R3)	7/20 (R4-R3)	10/40 (R4-R3)	7/15 (R4)	20/70 (R3-R2)	9/40 (R4-R3)	9/40 (R4-R3)	7/20 (R4-R3)	1/25 (F6,F2 ; R6-R3)	1/25 (F6,F2 ; R6-R3)
E_{def} (MPa)	500/2150	250/600	500/2150	250/600	500/2500	250/600	100/325	250/600	100/325	500/2150	250/600	250/600	70/390	25/250	25/250
φ (°)	30/37	28/35	30/37	28/35	30/37	28/35	26/33	28/35	26/33	30/37	28/35	28/35	24/31	24/31	24/31
c (MPa)	0,200/0,525	0,050/0,250	0,200/0,525	0,050/0,250	0,200/0,525	0,050/0,250	0,010/0,075	0,050/0,250	0,010/0,075	0,200/0,525	0,050/0,250	0,050/0,250	0,010/0,075	0,010/0,075	0,010/0,075
ν	0,22/0,19	0,30/0,23	0,23/0,19	0,30/0,23	0,23/0,19	0,30/0,23	0,35/0,26	0,30/0,23	0,35/0,26	0,22/0,19	0,30/0,23	0,30/0,23	0,35/0,26	0,42/0,27	0,42/0,27
ÖNORM B 2203	B3:B2/20:80	B3	B2:B1/50:50	B3:B2/70:30	B2:B1/50:50	C2:B3/20:80	C2:B3/70:30	B3:B2/60:40	C2:B3/60:40	B3:B2/30:70	C2:B3/20:80	C2:B3/20:80	C2:B3/60:40		
Kvazihomogenous block	M2	M3	M2	M3	M2	M3	M4	M3	M4	M2	M3	M3	M4		P
Section lenght (m)	45	25	62,4	126,75	167	43,85	60	56,15	68,85	65	45		195		23
Tender documentation 2006	4/2 (45)	5/1 (25)	4/2 (62,4)	5/1 (96,75), 5/2 (30)	4/2 (70), 5/1 (97)	5/2 (43,85)	6/2 (60)	5/2 (56,15)	6/2 (53,85), MP1 (15)	5/2 (65)	5/2 (45)		6/1 (60), 6/2 (70), 6/3 (70)		MP1 (23)
Section lenght (m)	45	25	65	120	170	45	60	60	65	65	45		195		42
Section lenght (m)	45	25	65	120	170	45	60	60	65	65	45	80	115	23	19
3G Consulting Engineers 2013	4/2	4/2	4/2	4/2	4/2	5/1	6/2	5/1	5/2	5/2	5/2	5/2	6/2	6/2	Cut and Cover

Table 2 Proposed distribution of NATM classes in the NTT

Kvazihomogenous block	S - ZP	S - 1		S - 2		S - 3	S - 4	S - 5	S - 6	S - 7
Section from - to (km)	0,544	0,620	0,675	0,840	0,900	0,975	1,100	1,175	1,290	1,370
Overburden (m)	x-18	18-46		46-57		57-86	86-94	88-113	113-126	77-124
RQD (%)	0-50	50-75		0-50		50-75	25-75	50-90	25-75	50-75
Degree of weathering	W5	W3-W4		W3-W5		W1-W4	W3-W4	W1-W2	W1-W4	W1-W4
Kvazihomogenous block	P	M3		M4		M2	M3	M1	M3	M2
Section lenght (m)	76	55	165	60	75	125	75	115	80	110
Tender documentation 2006	MP1	6/3(40)+6/2(80)+6/1(103)		6/3(60)+6/2(53)+5/2(20)		4/2(102)+4/1(35)	5/1	4/2(75)+4/1(40)	6/2(40)+5/1(40)	5/1(70)+4/2(40)
3G Consulting Engineers 2013	6/2	6/2	5/2n	5/2n	6/2	4/2	4/2	4/1	4/2	4/2

Kvazihomogenous block	S - 8	S - 9	S - 10		S - U	S - 11		S - 12		S - 13
Section from - to (km)	1,480	1,530	1,590	1,634	1,664	1,719	1,749	1,760	1,770	1,800
Overburden (m)	56-77	32-56	8-32		0-8	5-27		27-50		50-99
RQD (%)	25-75	50-90	25-75		0-50	25-75		50-75		25-75
Degree of weathering	W1-W4	W1-W2	W3-W4		W3-W5	W3-W4		W1-W4		W1-W4
Kvazihomogenous block	M3	M1	M3		P	M3		M2		M3
Section lenght (m)	50	60	44	30	55	30	11	10	30	240
Tender documentation 2006	5/1	4/2	5/2		6/1	5/2(20)+5/1(15)		4/2		5/2(100)+5/1(134)
3G Consulting Engineers 2013	4/2	4/2	5/1	6/2	C and C	6/2	5/1	5/1	4/2	4/2

Kvazihomogenous block	S - 14	S - 15	S - 16	S - 17		S - 18	S - 19			S - VP
Section from - to (km)	2,040	2,170	2,290	2,360	2,400	2,450	2,480	2,530	2,600	2,680
Overburden (m)	61-85	35-61	23-35	27-47		47-51	13-58			13-x
RQD (%)	50-75	25-75	0-50	50-75		25-75	25-75			0-50
Degree of weathering	W1-W4	W3-W4	W3-W5	W1-W4		W1-W4	W3-W4			W3-W5
Kvazihomogenous block	M2	M3	M4	M2		M3	M4	M4	M4	P
Section lenght (m)	130	120	70	40	50	30	50	70	80	29
Tender documentation 2006	5/1(52)+4/2(80)	6/2(30)+5/2(89)	MP1(15)+6/2(55)	5/2		5/2	6/3(30)+6/2(141)+6/1(40)			MP1
3G Consulting Engineers 2013	4/2	4/2	5/2n	5/1	4/2	4/2	4/2	5/2n	6/2	6/2

4. REALISED NATM EXCAVATIONS

The tunnel construction started in May 2014. The NATM excavations of the tunnel started after constructions of the central pit and the west portal including turtle structures. The realised schedule of NATM excavations of the tunnel tubes was the following:

Excavations from the central pit:

- STT towards west started 16.2.2015, top heading excavation was finished 20.8.2015, excavated 567 m (including one emergency bay) – average progress about 95 m per month
- NTT towards west started 7.4.2015, top heading excavation was finished 26.9.2015, excavated 566 m (including one emergency bay) – average progress about 99 m per month
- STT towards east started 12.3.2015, top heading excavation was finished 6.1.2016, excavated 719 m (including one emergency bay) – average progress about 80 m per month
- NTT towards east started 27.4.2015, top heading excavation continues, k 31.1.2016 excavated 691 m (including one emergency bay) – average progress about 77 m per month

Excavations from the west portal:

- STT started 21.3.2015, top heading excavation was finished 18.8.2015, excavated 515 m – average progress about 103 m per month
- NTT started 29.3.2015, top heading excavation was finished 3.9.2015, excavated 590 m – average progress about 118 m per month

Excavations from the east portal:

- STT started 17.10.2015, top heading excavation was finished 15.1.2016, excavated 303 m – average progress about 101 m per month

Figure 4: Primary tunnel lining of an emergency bay with a cross-passage in the STT

Now (end of January 2016) all NATM excavations between the central pit and the west portal were completed. Also top heading excavation between the central pit and the east portal was completed, about 100 m of the bench excavation is not finished. Also about 380 m of top heading and 700 m of bench between the central pit and the east portal has to be finished (NATM excavation from the east portal has not started yet). The average progresses of NATM excavations were affected by available number of miners and machines, usually only 3 excavations were ongoing from the central pit in one time (one face was usually stopped), also all emergency bays (Fig. 4) were excavated from the central pit.

A very significant part of excavations was realised in the NATM class 4.1 with the length of advances in top heading up to 3.5 m. The NATM class 4.1 has one layer of meshes without lattice girders, 10 cm of sprayed concrete and 5/6 rockbolts with length 3 m. The accuracy of drilling works for explosives was extremely important due to higher length of advances (to minimise overbreaks). Boomers Atlas Copco were used with semiautomatic setting of drilling schemes. The software in boomers allowed comparison of theoretical and realised drilling schemes (Fig. 5). All excavated profiles are recorded by surveyors. Comparison of results of surveys with drilling records allows identifying reasons of overbreaks (geological or technological) and optimisation of excavations.

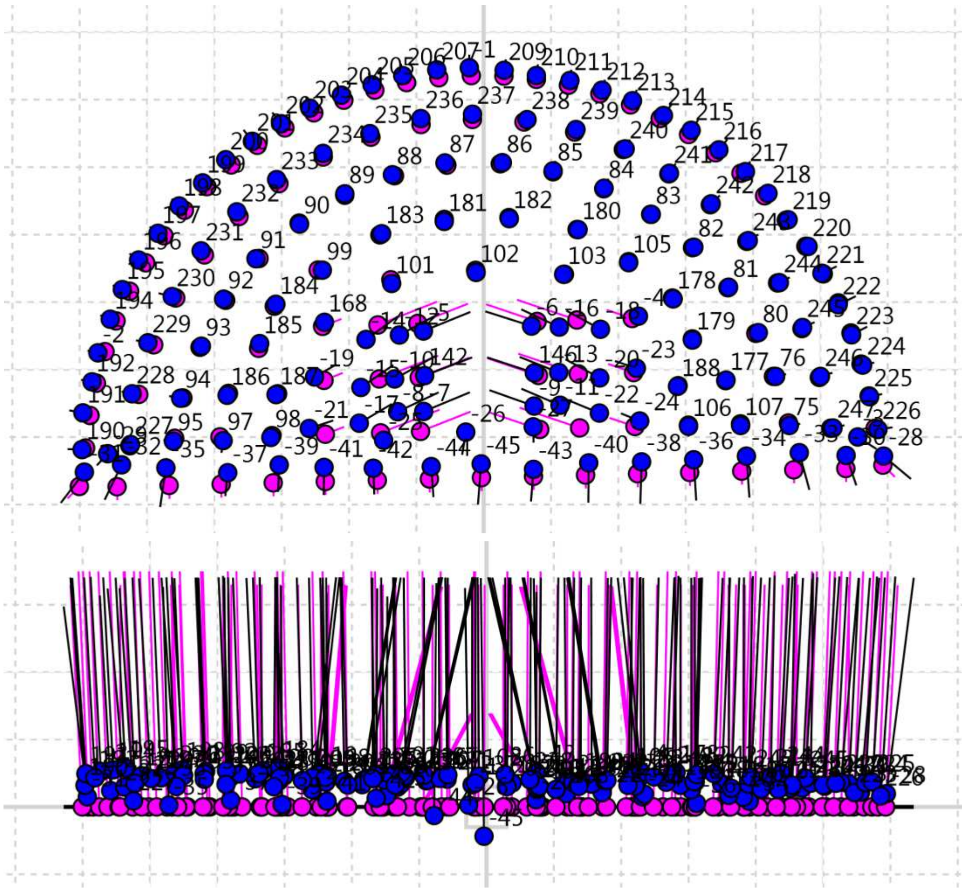

Figure 5: Comparison of theoretical drilling scheme (purple) with drilling record (blue) – vertical and horizontal view

As majority of excavations is completed, it is possible to compare expected and realised distribution of NATM classes. Excavations of the STT were completed, distribution of NATM classes in the NTT will be similar to the STT. Comparison of expected and realised distribution of NATM classes in the STT is presented in Tab. 3 and Fig. 6.

Table 3 Comparison of proposed and realised distribution of NATM classes of top heading in STT

	Tender documentation - 2006 (m)	Tender documentation - 2006 (%)	3G - 2013 (m)	3G - 2013 (%)	Reality 2015/16 (m)	Reality 2015/16 (%)
Cut and Cover section	27,0	1,3	73,0	3,4	66,0	3,0
Turtle section	0,0	0,0	0,0	0,0	37,5	1,7
MP 1 (with invert)	83,0	4,0	0,0	0,0	12,1	0,6
6/3 (with invert)	210,0	10,0	0,0	0,0	17,1	0,8
6/2 (with invert)	396,9	18,9	438,0	20,4	31,2	1,4
6/1 (with invert)	162,0	7,7	0,0	0,0	44,7	2,0
5/2 (with invert in TD, without invert in later stages)	240,0	11,4	495,0	23,1	143,1	6,6
5/1 (without invert)	573,1	27,3	481,0	22,5	586,7	26,9
4/2 (without invert)	327,4	15,6	425,0	19,8	599,9	27,5
4/1 (without invert)	80,0	3,8	230,0	10,7	644,0	29,5
TOTAL	**2 099,3**	**100,0**	**2 142,0**	**100,0**	**2 182,3**	**100,0**
With invert	**1 092**	**53**	**438**	**21**	**143**	**7**
Without invert	**1 007**	**47**	**1 704**	**79**	**2 040**	**93**

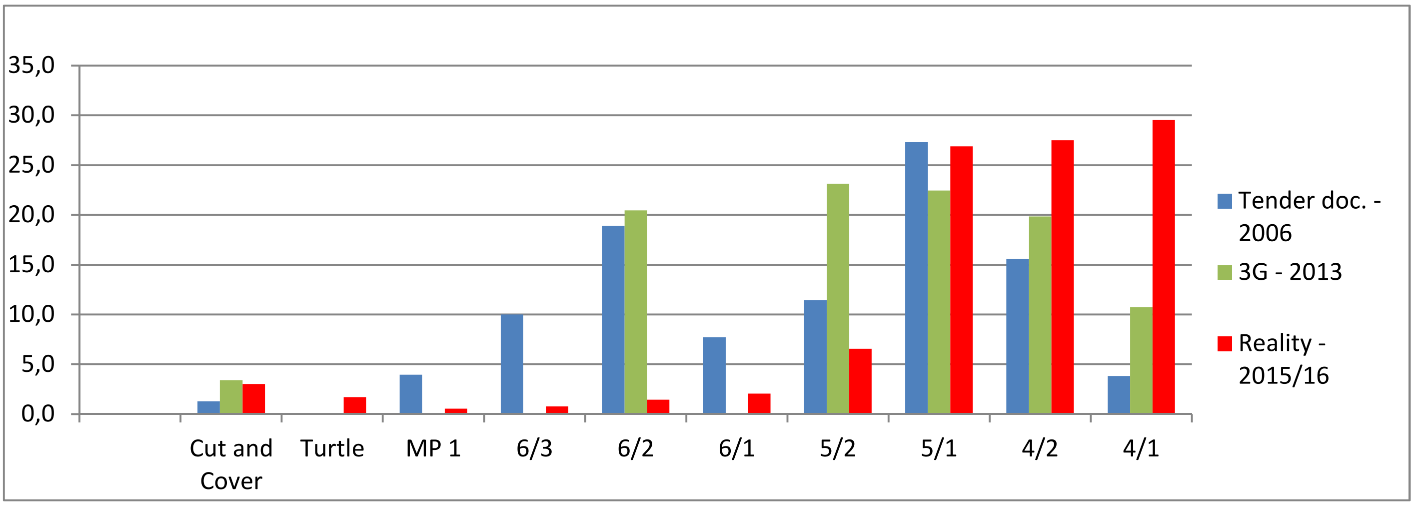

Figure 6: Comparison of proposed and realised distribution of NATM classes of top heading in STT (in %)

Tab. 3 and Fig. 6. Indicate that distribution of NATM classes in tender documentation was quite conservative. Tender documentation proposed utilisation of invert on 53% of the STT, in reality only 7% of STT was excavated in classes with proposed invert. But finally no invert will be applied at the STT, as all lower parts of the tunnel profile are in the reasonably strong rock and convergences stabilised on low values. Evaluation prepared by 3G Consulting Engineers prior start of excavations expected 21% of the STT with invert which is significantly closer to reality in comparison to tender documentation.

Company 3G Consulting Engineers assist to Hochtief CZ during excavations as geotechnical supervision of NATM excavations. This role includes namely these activities:

- Daily presence on the site during NATM excavations of the tunnel
- Optimisation of NATM tunnelling process and application of NATM classes
- Technical and administrative support of the tunnel contractor
- Assistance with solution of unexpected situations associated with NATM excavations
- Participation on meetings and preparation of documents for meetings
- Cooperation with designers, assistance with technical solutions
- Control of NATM excavations done by contractor and subcontractors
- Geotechnical support of contractor
- Evaluation of effectiveness and safety of NATM excavations
- Generation and utilisation of software for records of NATM excavations, evaluation of records to optimise speed and cost of excavations

Figure 7: Works on the final tunnel lining

5. CONCLUSION

Majority of NATM excavations of the Povážský Chlmec has already been completed and works on the final lining started at the end of 2015 (Fig. 7). Present experience from NATM excavations (end of January 2016) show that participation of external subjects can be beneficial for contractors in stages of the bid preparation and tunnel construction. It is quite standard approach in more developed tunnelling countries in Europe. Especially in case of the contract according the Yellow FIDIC book (e.g. Design and Build contract) the effectiveness of the tunnel excavation is extremely important for the final economical result.

Cost-effective NATM excavations (optimisation of advance length and applied support) can lead to higher risk (overbreaks, collapses). This factor should be compensated by involvement of external geotechnical experts, who are not directly financially involved on the speed and the cost of excavations, thus can be more objective in comparison to the contractor regarding acceptable risk. This approach had an impact on the completed NATM tunnel excavations, optimisation was done according behaviour of the open tunnel face together with monitoring results. Majority of NATM tunnel excavations could be realised with minimum support in NATM classes 4.1 and 4.2 with no significant overbreaks or collapses.

The Povážský Chlmec tunnel excavations are realised according original time schedule which is from the beginning very tight. The problems on the Povážský Chlmec tunnel are very small in comparison to other tunnelling projects near Žilina on the highways D1 and D3. After completion of all excavations it should be possible to justify, how much was this fact caused by favourable geology and how much was it affected by detailed preparation, optimal design and good construction management including external subjects.

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