00	2013-03-31	Preliminary Tunnel Design Phase II	MBu, AGo	ASr, WSc	AGo
Rev	Date	Status	Prepared	Checked	Approved

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CLIENT:

Border Roads Organisation

श्रमेण सर्वम् साध्यम

Beacon

The Chief Engineer
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INDIA

PROJECT:

Consultancy Services for Detailed Feasibility Study and Framing up of Phase-wise proposal (DPR) for construction of two tunnels at Z-Morh and at Zojila for all weather connectivity from Srinagar to Leh in Jammu & Kashmir State

ZOJILA TUNNEL

TITLE:

Phase II: Detailed Project Report - Preliminary Tunnel Design

Volume II: Tunnel Design Report

Prepared by:	Burgstaller, Goricki	Date:	2013-03-31
Checked by:	Steindorfer, Schubert	Date:	2013-03-31
Approved by:	Goricki	Date:	2013-03-31

Contract No.:	CE (P) BCN/05/2009-10	File:	8482B-II-ZOT-rep-02-12-00
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1 CONSULTANTS TASK OF WORK

Border Roads Organization (BRO) assigned a consulting contract to Vayam Technologies Ltd (formerly iBilt Technologies Ltd.) for Detailed Feasibility Study and Framing up of Phasewise proposal (DPR) for construction of the Zojila Tunnel. 3G Gruppe Geotechnik Graz ZT GmbH (3G) prepared this Phase II report (DPR) based on the specifications of the consulting contract mentioned above.

Project History

In the following the design phases prior to this Technical Report for the Conceptual Tunnel Design of Phase II are summarized chronologically.

a) Documents of the consultancy contract
b) Conceptual Tunnel Design Phase I, Part I and II
c) Update of Conceptual Tunnel Design Phase I, Part I, Revision 00 based on SASE report with separate parallel egress tunnel as per decision of BRO
d) Additional Cost and Time Evaluation for different Scenarios as Requested by the Client
e) Tunnel alignment approval by BRO (letter "40578/Zozila DGBR/12/Brs & Tnls" from 03rd of January 2013)

Ad a) Consultancy Contract

In the tender documents for the consultancy contract a very preliminary tunnel alignment for the Zojila Tunnel was proposed, including locations for both tunnel portals. According to these tender documents, the Zojila Tunnel will have a length of approximately 12 km with the western portal (Srinagar) on a tentative elevation of 3150 m and the eastern portal (Leh) with 3250 m.

The horizontal alignment for Zojila tunnel shall be designed preferably straight. For the vertical alignment a 1.5 % upward gradient towards the tunnel centre from both portal ends shall be designed to facilitate the longitudinal drainage.

Ad b) Phase I report

In Phase I, geological studies and site investigations are carried out to provide the necessary geological and geotechnical information for the design works for all project relevant aspects. Data evaluation and interpretation shall allow the assessment of all necessary geotechnical parameters for design calculations and the prediction of ground conditions and distribution of rock and soil types and classes. As part of Phase I a conceptual design for Zojila tunnel was submitted. The conceptual design included the following issues:

- A study of tunnel alignment alternatives.

- A study of different tunnel systems such as two lane single tube tunnel and bi-directional traffic in comparison with two independent, uni-directional traffic tunnel tubes.
- The design of typical tunnel cross-sections for different tunnel systems.
- A conceptual tunnel design for a proposed (most favourable) tunnel alignment.
- A preliminary design of the tunnel ventilation system based on the preliminary traffic data.
- Excavation methods and preliminary proposals for support systems.
- Construction concepts as well as estimate construction schedule and time.
- A brief summary of technical specifications.

The conceptual tunnel design report of Phase I was submitted in June 2011.

<u>Ad c) Update of Conceptual Tunnel Design Phase I, Part I, Revision 00 based on SASE report, with separate parallel egress tunnel</u>

Based on the conceptual tunnel design of Phase I the Snow and Avalanche Study Establishment (SASE) submitted a report with proposals for further alternative tunnel alignments. Based on these additional data concerning avalanche zones in the project area an additional tunnel alignment study report was prepared by 3G.

Various preliminary alignments were compared with respect to the vertical and horizontal alignment, tunnel length, accessibility of portal areas and preliminary ventilation system.

At 9th of March 2012 BRO decided to change the tunnel system to separate, parallel egress. An updated Conceptual Tunnel Design Phase I, Part I with separate parallel egress tunnel was prepared by 3G based on the Client's decision and submitted in August 2012.

<u>Ad d) Additional Cost and Time Evaluation for different Scenarios as Requested by the Client</u>

Based on the Conceptual Tunnel Design Phase I, Part I, Revision 00 with separate parallel egress tunnel the Client requested additional Cost and Time Evaluation with respect to the construction schedule and the accessibility of the eastern and western portal and the duration of winter breaks respectively.

A construction time and cost evaluation was submitted in October 2012 including the scenarios with one additional construction shaft and the accessibility of the western portal. An additional construction time and cost evaluation was submitted in November ~~2013~~ including scenarios one additional construction shaft and the accessibility of the eastern portal as requested by the Client.

The Client decided that the general construction concept with an all-year accessible eastern portal and supply of the eastern portal from Leh in winter months shall be further developed. All other sites (western portal and intermediate construction shafts) are not accessible in winter during ~~five~~ months.

Ad e) Tunnel alignment approval by BRO

Based on the updated Conceptual Tunnel Design and the additional construction cost and time evaluation the Client decided on 03rd of January 2013 (refer to letter "40578/Zozila DGBR/12/Brs & Tnls") that the proposed alignment is approved and shall be further developed in Phase II.

2 GENERAL PROJECT DESCRIPTION

Road: Srinagar to Leh

Object: Single tube road tunnel with two traffic lanes in bi-directional traffic
Main structure: mined tunnel, separate egress tunnel, ventilation and construction shafts and ventilation caverns
Additional structures: portal structures, muck disposal areas

Location: India, Jammu and Kashmir

Client: Border Roads Organization (BRO)

Portals: West Portal in the area of Baltal approx. 60 km east of Kangan
East Portal approx. 30 km southwest of Dras

Elevation: West Portal at approx. 2900 m
East Portal at approx. 3310 m
Shaft 1 at approx. 3510 m
Shaft 2 at approx. 3490 m
Shaft 3 at approx. 3430 m

Main tunnel length: approx. 14.1 km

Egress tunnel length: approx. 14.2 km

Construction and ventilation shaft length: Shaft 1 approx. 484 m
Shaft 2 approx. 365 m
Shaft 3 approx. 208 m

Max. overburden: approx. 660 m

Gradient: continuous approx. +2.9 % (1:35) from the West Portal to the East Portal

Approach road: approx. ~~0.75 km from Baltal~~ to western tunnel portal
approx. 1.0 km from National Highway NH-1 to the Eastern Portal

3 REFERENCES

The documents considered in this report can be subdivided into three main groups and are listed below.

- Project Documents
- Standard and Guidelines
- Literature

3.1 Project Documents

[P1] Tender Documents: Contract CE (P) BCN/05/2009-10 (2008): Consultancy Services for Detailed Feasibility Study and Framing up of Phasewise proposal (DPR) for construction of two tunnels at Z-Morh and at Zojila for all weather connectivity from Srinagar to Leh in Jammu & Kashmir State. Border Roads Organization, India

[P2] Geological investigations Zojila Tunnel project Srinagar, (J&K), Report

[P3] Laboratory testing of rock samples for Zojila Tunnel, Baltal-Minamarg (J&K), Report

[P4] Zojila Tunnel: Conceptual Tunnel Design Phase I, Part I, 3G Gruppe Geotechnik Graz ZT GmbH & Vayamtech Ltd, Report, 2011

[P5] Zojila Tunnel: Conceptual Tunnel Design Phase I, Part I, Parallel Egress Tunnel, 3G Gruppe Geotechnik Graz ZT GmbH & Vayamtech Ltd, Report, 2012

[P6] Integrated avalanche hazard mitigation schemes for all weather connectivity of Srinagar-Leh Highway, Snow and Avalanche Study Establishment (SASE), report, 2011

[P7] Study of seismicity and seismo tectonics of Zojila Tunnel project area, G S GeoEnVirons Pvt. Ltd., 2011

3.2 Standard and Guidelines

[S1] EN 1990 (2004): "Eurocode 0 – Basis of Structural Design", 2004

[S2] EN 1990 A1 (2006): "Eurocode 0 – Basis of Structural Design (Ammandment)", 2006

[S3] EN 1991-1-1 (2010): "Eurocode 1 – Actions on Structures – Part 1-1: General Actions – Densities, Self-Weight, imposed Loads for Buildings", 2010

[S4] EN 1991-1-3 (2010): "Eurocode 1 – Actions on Structures – Part 1-3: Snow Loads", 2010

[S5] EN 1991-1-7 (2010): “Eurocode 1 – Actions on Structures – Part 1-7: General Actions – Accidental actions”, 2010

[S6] EN 1991-2 (2010); “Eurocode 1 – Actions on Structures – Part 2: Traffic Loads on Bridges”, 2010

[S7] EN 1992-1-1 (2011): “Eurocode 2 – Design of concrete structures – Part 1-1: General rules and rules for buildings”, 2011

[S8] EN 1997-1 (2004): “Eurocode 7 – Geotechnical Design – Part 1: General Rules”, 2004

[S9] EN 1998-1 (2010): “Eurocode 8 – Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings”, 2010

[S10] EN 1998-5 (2011): “Eurocode 8 – Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects, 2011

[S11] IRC Specifications, Standards, Design Codes and Special Publications. The Indian Roads Congress (IRC), India.

[S12] IRC:5 (1998): Standard Specifications and Code of Practice for Road Bridges. The Indian Roads Congress, India, 1998.

[S13] IRC:6 (2010): “Standard Specification and Code for Practice for Road Bridges, Section 2: Loads and Stresses (5th Revision)”, Indian Roads Congress, 2010

[S14] IRC:38 (1989): “Guidelines for the Design of Horizontal Curves for Highways and Design Tables (1st Revision)” Indian Roads Congress, India, 1989

[S15] IRC 58 (2002): “Guidelines for the Design of Plain Jointed Rigid Pavements for Highways” (2nd Revision), Indian Roads Congress, India, 2002

[S16] IRC:SP:23 (1983): “Vertical Curves for Highways”, Indian Roads Congress, India, 1983

[S17] IRC:SP:91 (2010): Guidelines for Road Tunnels. Indian Roads Congress, India, 2010

[S18] IS 1892 Part 1 (2002): “Criteria for Earthquake Resistant Design of Structures – Part 1: General Provisions and Buildings”, Bureau of Indian Standards, 2002

[S19] PIARC Road Tunnel Reports. Publications of the Committee on Road Tunnels, World Road Association (PIARC), France

[S20] PIARC Road Tunnel Report 05.11.B: Cross-section Geometry in Unidirectional Road Tunnels. PIARC Technical Committee C5, France, 2001

[S21] PIARC Road Tunnel Report 05.12.B: Cross-section Design for Bi-directional Road Tunnels. PIARC Technical Committee C5, France, 2004

[S22] PIARC Road Tunnel Report 05.14.B: Road Tunnels: Vehicle Emissions and Air Demand for Ventilation. PIARC Technical Committee C5, France, 2004

[S23] PIARC Road Tunnel Report 05.16.B: Systems and Equipments for the Fire and Smoke Control in Road Tunnels. PIARC Technical Committee C5, France, 2007

[S24] RVS – Guidelines and Specifications for the Design, Construction and Maintenance of Roads. Austrian Association for Research on Road - Rail - Transport (FSV), Austria

[S25] RVS 03.03.23: Alignment. FSV, Austria, 2001

[S26] RVS 8T: Technical Contract Conditions, Tunnel. FSV, Austria, 2004

[S27] RVS 08.15.01: Technical Contract Conditions, Unbound Sub-bases. FSV, Austria, 2010

[S28] RVS 08.16.01: Technical Contract Conditions, Requirements for Bituminous Courses. FSV, Austria, 2010

[S29] RVS 08.17.02: Technical Contract Conditions, Concrete Pavement Construction. FSV, Austria, 2011

[S30] RVS 09.01.21: Alignment Regulations for Tunnels. FSV, Austria, 2007

[S31] RVS 09.01.22: Tunnel Cross-Sections. FSV, Austria, 2010

[S32] RVS 09.01.23: Tunnel Inside Structures. FSV, Austria, 2010

[S33] RVS 09.01.24: Tunnel, Structural Equipment. FSV, Austria, 2009

[S34] RVS 09.01.43: Tunnel, Concrete for Inner Lining. FSV, Austria, 2004

[S35] RVS 09.02.31: Tunnel Equipment, Ventilation – Basic Principles. FSV, Austria, 2008

[S36] RVS 09.02.32: Ventilation Design – Fresh Air Demand. FSV, Austria, 2005

[S37] DMRB – Design Manual for Roads and Bridges. Highway Agency, UK

[S38] BD 78/99 (DMRB 2.2.9): Design of Road Tunnels. Highway Agency, UK, 1999

[S39] TD 27/05 (DMRB 6.1.2): Cross-Sections and Headrooms. Highway Agency, UK, 2005

[S40] TD 9/93 (DMRB 6.1.1): Highway Link Design. Highway Agency, UK, 2002

[S41] Decision No 661/2010/EU of the European Parliament and of the Council of 7 July 2010 on Union guidelines for the development of the Trans-European Transport network

[S42] ÖVBB Österreichische Vereinigung für Beton- und Bautechnik: Guideline Sprayed Concrete, Austria, 2009

[S43] ÖVBB Österreichische Vereinigung für Beton- und Bautechnik: Guideline Design of Tunnel Dewatering, Austria, 2003

3.3 Literature

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[L2] Lama, R.D. & Vutukuri, V.S., 1978. Handbook on Mechanical Properties of Rocks. Vol II. Series on Rock and Soil Mechanics. Trans Tech Publications, Clausthal, Germany.

[L3] MAIDL, B. (1997): „Tunnelbau im Sprengvortrieb“, Springer, 1997

[L4] Steiner, A. 2005. Criteria for the Determination of Ground Behaviour Types, Diploma Thesis, Institute for Rock Mechanics and Tunnelling, Graz University of Technology, Austria.

[L5] Feder, G., Arwanitakis, M.: Zur Gebirgsmechanik ausbruchnaher Bereiche tiefliegender Hohlraumbauten, Berg- und Hüttenmännische Monatshefte, Heft 4, 1976.

[L6] Estermayr H., Achraintunnel – Mit der Brücke durch den Tunnel, Felsbau, No.25, 3, 2007, pp. 34

[L7] Kopswerke II, Issue 6, 2006

[L8] OLOFFSON, S. (1988): “Applied Explosives Technology for Construction and Mining”, Second Edition, Applex, Sweden

4 TUNNEL ALIGNMENT

4.1 General

In the following the portal locations, the proposed vertical and horizontal alignment with recommendations from Standards and Guidelines are presented.

4.2 Portals

A preliminary study of different portal locations has been provided in Phase I [P4] and [P5] of the Conceptual Tunnel Design. Subsequently the portal locations and the general boundary conditions are presented. For the detailed design of the temporary and permanent layout of the portals e.g. excavation analyses of the cuts, detailed description of the portal layout etc. refer to Volume III Portal Design Report.

4.2.1 Western Tunnel Portal (Srinagar)

The western portal is situated about 15 km east from the village Sonamarg. The western portal shall be connected to the National Highway NH-1 with an approach road. The basic information of the eastern portal is given below. An overview of the portal locations is given in drawing 8482B_II-ZOT_POR-01-12-00.

Elevation: approx. 2900 m
Location: 538871.9 m E and 3790008.2 m N (43 S - UTM coordinates)

The following criteria are considered in the Conceptual Tunnel Design Phase I, Part I Revision 00 for the decision about the location of the western tunnel portal:

- In order to decrease the gradient of the Zojila Tunnel the level of the western portal is chosen at a possible high elevation without conflicting to the following requirements.
- The longitudinal gradient of the approach road to the portal location shall not exceed 5 %.
- Additional engineering structures for the approach road construction (bridges, dams, culverts, etc.) shall be kept to a minimum.
- The portal area shall not be situated in zones with high avalanche risk.
- Disadvantageous geometrical situation of the cut-and-cover section should be avoided to reduce slope-cuts and retaining measures.
- Topographical and geological conditions at the tunnel portals shall be considered.

4.2.2 Eastern Tunnel Portal (Leh)

The eastern portal is situated approximately 30 km west from the village Dras in the vicinity of the existing National Highway NH-1. The basic information of the eastern portal is given below. An overview of the portal locations is given in drawing 8482B_II-ZOT_POR-08-12-00.

Elevation: approx 3310 m
Location: 549997.8 m E and 3797178.5 m N (43 S - UTM coordinates)

The following criteria are considered in the Conceptual Tunnel Design Phase I, Part I Revision 00 for the decision of the location of the eastern portal.

- In order to decrease the longitudinal gradient of Zojila Tunnel, the level of the eastern tunnel portal is chosen at a possible low elevation. Nevertheless the elevation of the portal is minimum 15 m higher than the river level to secure no water inflows during floods.
- Unfavourable geometrical situation of the cut-and-cover section should be avoided to reduce slope-cuts and retaining measures.
- Topographical and geological conditions at the tunnel portals shall be considered.

4.3 Horizontal Alignment

The horizontal alignment is governed by the design parameters given in 4.3.1. The Recommendations of Indian and International Standards based on the design parameters and the proposed alignment are given below.

4.3.1 Design Key Parameter

According to the tender documents [P1] design traffic of 2500 trucks (≥ 3 to) and 5000 passenger cars (< 3 to) per day in both directions shall be considered. These traffic numbers are used for conceptual design of Phase I [P5] as well as for the preliminary design of Phase II (this report). More detailed traffic studies are not available and shall be carried out in the detailed design phase.

The design speed for the tunnel is 80 km/h according to the tender documents [P1].

The maximum hourly design flow of one traffic lane can be investigated considering the percentage of heavy goods vehicles, the tunnel geometry and additional factors. For Zojila Tunnel the capacity can be estimated (e.g. according to PIARC, British or Austrian Standards) with a value of approximately 1000 vehicles per hour and lane.

The design parameters are summarized below:

Design Traffic:	2500 trucks (≥ 3 to) and 5000 passenger cars (< 3 to) as per tender documents [P1]
Design Speed:	80 km/h as per tender documents [P1]
max. flow/h:	1000 vehicles estimated according International guidelines

4.3.2 Recommendations from Standards and Guidelines

The following regulations and recommendations from Standards and Guidelines are discussed:

- PIARC Road Tunnel Report 05.12.B: Cross-section Design for Bi-directional Road Tunnels. PIARC Technical Committee C5, France, 2004. [S21]
- IRC:38 (1989): "Guidelines for the Design of Horizontal Curves for Highways and Design Tables (1st Revision)" The Indian Roads Congress, India, 1989 [S14]
- IRC:SP:91 (2010): Guidelines for Road Tunnels. The Indian Roads Congress, India, 2010 [S17]
- RVS 03.03.23: Alignment. FSV, Austria, 2001 [S25]
- RVS 09.01.21: Alignment Regulations for Tunnels. FSV, Austria, 2007 [S30]

General: A straight tunnel alignment is generally preferred according to Indian IRC:SP:91-2010 [S17]. However long straight tunnel stretches should be limited with a length of approx. 1500 m to avoid fatigue due to monotony as recommended in Indian and International PIARC Guidelines.

Portals: At the ends of the tunnel (portal zones) gentle curves should be designed in plan view providing sufficient visibility as recommended by Indian IRC:SP:91-2010 [S17] and PIARC report 05.12.B [S21]. In contrast, a straight alignment should be provided at the portal zones according to Austrian RVS 09.01.21 [S30]. For Zojila Tunnel adequate alignment solutions at the portals are chosen with respect to the geological and topographical ground conditions and requirements on approach road.

Curve Radius: Curves in tunnels should meet the minimum radius requirements for the tunnel design speed. The IRC:SP:91 [S17] standard does not provide any recommendations for minimum horizontal curve radii in tunnels. Nevertheless the requirements for curve radii for open roads from Indian IRC:38 [S14] should also be met in tunnels (Tab. 1).

According to the Austrian RVS 09.01.21 [S30] the minimum curve radii, which shall be provided in a tunnel, shall be determined with Equ. 1.

$$R_{min} = \frac{w_{cw}}{2} + \frac{s_{dis,req}^2 + 4 \cdot d^2}{8 \cdot d} \; in \; [m]$$

$$with: d = \frac{w_{cw}}{2} + w_{hc} + 1.0 \; in \; [m]$$

Equ. 1

R_{min}: minimum curve radius in [m]
w_{cw}: width carriageway in [m]
$s^2_{dis,req}$: required sight distance in [m]
d: distance of ray
w_{hc}: width hard clearance

Tab. 1 Minimum radius of horizontal curves for different terrain conditions and design speed

Design speed in [m]	Minimum design radius in [m]		
	Plain & rolling terrain	Mountainous and steep terrain	
		Snow bound are-as	non-snow bound areas
20	15	15	14
25	23	23	20
30	33	33	30
35	45	45	40
40	60	60	50
50	90	90	80
65	155	Speeds not applicable	
80	230		
100	360		

[1] where trucks ply on a road, a minimum 26 m radius should be provided to accommodate them

The required sight distance in tunnels can be determined according to RVS 09.01.21 [S30] with Fig. 1.

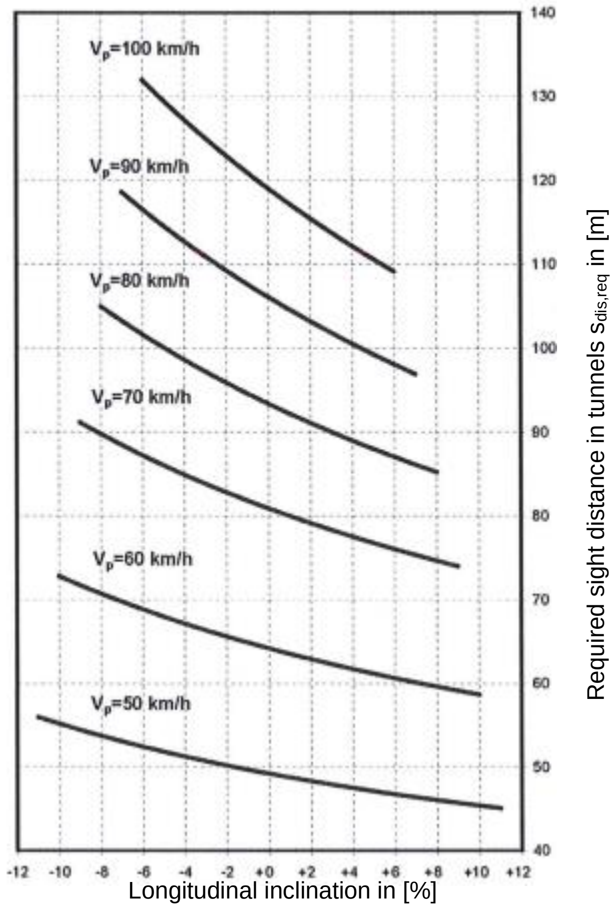


Fig. 1 Required sight distance in tunnels

Transition curve: Transition curves are situated between curves and straight road sections to provide a smooth intersection between the curve and the straight. According to IRC 38 [S14] the transition curve length shall meet requirements defined by:

- rate of change of centrifugal acceleration
- rate of change of superelevation

The minimum required transition length due to rate of change of acceleration can be determined with Equ. 2.

$$L_t = \frac{0.0215 \cdot V^3}{C \cdot R}$$

$$with\ C = \frac{80}{75 + V}$$

Equ. 2

L_t: length of transition curve in [m]
R: curve radius in [m]
V: design speed in [km/h]

Rate of change of superelevation should not be steeper than 0.66 % for roads in plain and rolling terrain and 1.66 % for roads in mountainous steep terrain. The minimum transition length due to rate of change of superelevation can be determined with Equ. 3.

$$L_t = \frac{{w_{cw}}/{2} \cdot |s_1 - s_2|}{0.0166\ or\ 0.0066}\ in\ [m]$$

Equ. 3

L_t: length of transition curve in [m]
w_{cw}: width of carriageway in [m]
s_1: superelevation before transition curve [%/100]
s_2: superelevation after transition curve [%/100]

According to RVS 03.03.23 [S25] the minimum length of transition curve shall be in compliance with Tab. 2.

Tab. 2 Minimum length of transition curve L_t [S25]

V in [km/h]	40	50	60	70	80	90	100	110	120	130
L_t in [m]	15	20	30	39	44	50	56	61	67	72

The transition curve length should not be greater than the maximum transition curve length as determined by Equ. 4 and according to RVS 03.03.23 [S25].

$$L_{t,max} = 2 \cdot L_t\ in\ [m]$$

Equ. 4

L_t: length of transition curve in [m]
$L_{t,max}$: maximum length of transition curve in [m]

4.3.3 Proposed Alignment

The general layout of the tunnel alignment considers the favourable location of tunnel portals and the construction and ventilation shaft locations, which are basic boundary conditions for the definition of the horizontal tunnel alignment.

The tunnel length is approximately 14150 m. The starting point of the horizontal alignment at the western side is approx. 13 m outside the tunnel portal. The western portal is situated in a straight section. After the western portal a curve with radius of 500 m is situated. In the tunnel curves are located between straight sections with radii between 750 m and 1250 m, so the straight sections do not exceed 1500 m according to [S17].

The required alignment elements from Indian and International Standards (as per 4.3.2) are given in Tab. 3 for the design key parameters and compared with the proposed alignment elements.

Tab. 3 Summary of horizontal alignment requirements and proposed horizontal alignment

Alignment element	Indian Standard	Austrian Standard	proposed alignment
Max. length of straight in [m]	1500	no recomm.	1475
Min. curve radius in [m]	230	350	500
Min. length of transition curve	22 (R=1000) 44 (R=500) 30 (change of superelevation)	44	60.5
Max. length of transition curve	no recomm.	88	60.5

The main points of the horizontal alignment are presented in Tab. 4.

Tab. 4 Horizontal main alignment points

ID	*Chainage*	*Section length [m]*	*Pos N UTM [m]*	*Pos E UTM [m]*	*RW [gon]*	*Radius [m]*
PS	KM 0.0+ 0.000	0.0	3790016.3	538861.8	142.675	0
TCS	KM 0.1+91.316	191.3	3789897.4	539011.7	142.675	0
CS	KM 0.2+52.566	61.3	3789860.3	539060.5	138.776	-500
CE	KM 0.9+24.963	672.4	3789899.7	539682.1	53.163	-500
TCE	KM 0.9+86.213	61.3	3789942.7	539725.8	49.264	0
TCS	KM 1.8+ 8.979	822.8	3790531.1	540300.8	49.264	0
CS	KM 1.8+69.471	60.5	3790575.0	540342.5	46.697	-750
CE	KM 1.9+88.208	118.7	3790669.1	540414.7	36.618	-750
TCE	KM 2.0+48.700	60.5	3790720.7	540446.2	34.051	0
TCS	KM 2.9+88.638	939.9	3791529.4	540925.3	34.051	0
CS	KM 3.0+49.130	60.5	3791581.0	540956.8	36.618	750
CE	KM 3.3+91.343	342.2	3791816.5	541201.0	65.666	750
TCE	KM 3.4+51.835	60.5	3791846.2	541253.7	68.233	0
TCS	KM 4.7+ 2.395	1250.6	3792444.6	542351.8	68.233	0
CS	KM 4.7+62.887	60.5	3792474.3	542404.5	65.666	-750
CE	KM 5.1+ 3.727	340.8	3792708.7	542647.9	36.735	-750
TCE	KM 5.1+64.219	60.5	3792760.2	542679.5	34.167	0
TCS	KM 6.5+28.062	1363.8	3793932.3	543376.9	34.167	0
CS	KM 6.5+88.562	60.5	3793984.1	543408.2	35.708	1250
CE	KM 6.8+55.331	266.8	3794193.2	543573.1	49.294	1250
TCE	KM 6.9+15.831	60.5	3794235.7	543616.1	50.835	0
TCS	KM 8.3+87.802	1472.0	3795262.8	544670.5	50.835	0
CS	KM 8.4+48.294	60.5	3795304.5	544714.3	53.402	750
CE	KM 8.8+57.217	408.9	3795483.5	545076.4	88.113	750
TCE	KM 8.9+17.709	60.5	3795493.1	545136.1	90.680	0
TCS	KM 10.1+58.162	1240.5	3795674.1	546363.3	90.680	0
CS	KM 10.2+18.654	60.5	3795683.7	546423.0	88.113	-750
CE	KM 10.4+39.801	221.1	3795756.0	546631.1	69.341	-750
TCE	KM 10.5+ 0.293	60.5	3795785.4	546684.0	66.774	0
TCS	KM 11.4+76.808	976.5	3796272.3	547530.5	66.774	0
CS	KM 11.5+37.308	60.5	3796302.0	547583.2	68.314	1250
CE	KM 11.8+71.431	334.1	3796420.6	547894.5	85.331	1250
TCE	KM 11.9+31.931	60.5	3796433.5	547953.6	86.872	0
TCS	KM 13.3+39.472	1407.5	3796721.7	549331.3	86.872	0
CS	KM 13.3+99.964	60.5	3796734.9	549390.3	84.304	-750
CE	KM 13.7+54.737	354.8	3796898.1	549701.6	54.190	-750
TCE	KM 13.8+15.229	60.5	3796939.2	549746.0	51.623	0
PE	KM 14.1+81.967	366.7	3797191.9	550011.8	51.623	0

PS…Project Start
PE…Project End
CS…Curve Start
CE…Curve End
TCS…Transition Curve Start
TCE…Transition Curve End

4.4 Vertical Alignment

The vertical alignment is governed by the design parameters given in chapter 4.3.1. The Recommendations of Indian and International standards concerning design parameters and the proposed tunnel alignment are given below.

4.4.1 Recommendations from Standard and Guidelines

Tunnel gradient: Tunnel gradients should be limited to about 3.3 % in long tunnels according to IRC:SP:91-2010 [S17]. Corresponding to PIARC report 05.12.B [S21] the longitudinal slope should not exceed 4 % in bi-directional tunnels. According to the Austrian Guidelines gradients more than 5 % are acceptable if unavoidable due to topographic conditions.

Steep tunnel gradients have to be considered in particular in the design of the ventilation system. PIARC report 05.12.B [S21] emphasizes, that high points in the tunnel shall be considered carefully in the ventilation design not to create problems. Low points in tunnels should generally be avoided.

The minimum gradient shall exceed 0.5 %, except in crest and sag curves and in exceptional cases.

Sag/Crest Curves: The change in gradient shall be designed with sag or crest curves. Neither IRC Standards nor PIARC reports provide values for sag and crest curves in tunnels. Nevertheless the requirements for minimum crest curve length for open roads from Indian IRC:SP:23 [S16] should also be met in tunnels (Tab. 5).

Tab. 5 Length of vertical curves for different design speeds when length of curve is greater than sight distance [S16]

Design Speed in [km/h]	Length of crest curve in [m] for			Length for sag curve in [m] for headlight distance
	Stopping sight distance	Intermediate sight distance	Overtaking sight distance	
20	0.9A	1.7A	-	1.8A
25	1.4A	2.6A	-	2.6A
30	2.0A	3.8A	-	3.5A
35	3.6A	6.7A	-	5.5A
40	4.6A	8.4A	28.4A	6.6A
50	8.2A	15.0A	57.5A	10.0A
60	14.5A	26.7A	93.7A	15.0A
65	18.4A	33.8A	120.4A	17.4A
80	32.6A	60.0A	230.1A	25.3A
100	73.6A	135.0A	426.7A	41.5A

A: differences in grades in [%]

The minimum length of vertical curves is indicated in Tab. 6 in compliance with IRC:SP:23 [S16].

Tab. 6 Minimum length of vertical curve [S16]

Design speed in [km/h]	Maximum grade change in [%] not requiring a vertical curve	Minimum length of vertical curve in [m]
30	1.5	15
40	1.2	20
50	1.0	30
60	0.8	40
80	0.6	50
100	0.3	60

Austrian Standards provide values for crest curves in tunnels depending on the design speed (Tab. 7). Sag curves in tunnel should be avoided.

Tab. 7 Minimum crest curve radius $R_{c,min}$

V [km/h]	50	60	70	80	90	100
$R_{c,min}$ [m]	2000	3000	4000	5000	6500	8000

Cross fall: According to RVS 09.01.22 [S31] and BD 78/99 [S38] the minimum cross fall of the carriageway in tunnels shall be 2.5 % for improved water drainage from one edge lane to the other. According to IRC:SP:91-2010 [S17] the cross fall in a tunnel shall be minimum 2 % from the centre of the carriageway outwards.

Superelevation: Superelevation may be required in curves situated in tunnels with small radii. The IRC:SP:91 [S17] Standard does not provide any recommendations for superelevation in tunnels. Nevertheless the requirements for superelevation for open roads from Indian IRC:38 [S14] should also be met in tunnels unless deviating from International Standards defining superelevation in road tunnels. As per IRC:38 [S14] The maximum superelevation for plain and rolling terrain is 7 % and the minimum superelevation is 1.7 % for open roads. In curves the superelevation can be determined with Equ. 5 for open roads.

$$s = \frac{V^2}{225 \cdot R} \; in \; [\%/100] \qquad \text{Equ. 5}$$

s: superelevation in [%/100]
V: design speed in [km/h]
R: radius of curve [m]

The Austrian Guideline RVS 09.01.21 [S30] provides a recommendation for superelevation for tunnel sections. The superelevation can be calculated as follows (Equ. 6). The maximum superelevation in tunnels is limited to 5 % (as per RVS 09.01.21 [S30]).

$$s = 0.359 \cdot R^{-0.638} \cdot V^{1.462} \; in \; [\%] \qquad \text{Equ. 6}$$

s: superelevation in [%]
V: design speed in [km/h]
R: radius of curve [m]

4.4.2 Proposed Alignment

A continuous gradient of +2.14 % from East Portal to the West Portal is designed due to the topographic conditions and the avalanche affected zones in the western portal area.

As Indian Standards do not provide recommendations for superelevation inside tunnels the recommendations from Austrian Guideline RVS 09.01.21 [S30] are considered.

A summary of all required alignment elements from Indian and International Standards (as per 4.4.1) are given in Tab. 8 and compared with the proposed alignment elements.

Tab. 8 Summary of vertical alignment requirements and proposed vertical alignment

Alignment element	Indian Standard	Austrian Standard	proposed alignment
Tunnel gradient min./max. in [%]	0.5/3.3	0.5/5.0	0.5/2.9
Min. sag/crest curves radius/length in [m]	no recomm./50	5000/no recomm.	no vert. curve designed
Min. crossfall in tunnel [%]	2.0	2.5	2.5
superelevation in curves in [%]	open roads: R=1250 m 2.3 % R=750 m 3.8 % R=500 m 5.6 %	tunnels: R=1250 m 2.3 % R=750 m 3.2 % R=500 m 4.1 %	tunnels: R=1250 m 2.5 % R=750 m 3.2 % R=500 m 4.1 %
min./max. superelevation in [%]	open roads: 1.7/7	tunnels: 2.5/5	tunnels: 2.5/5

5 TYPICAL CROSS SECTION

5.1 General

In the following the design requirements for the typical cross section (TCS), including Indian and International Standards are presented. Additionally the proposed typical cross section based on the design requirements is described in detail.

The typical cross section of a road tunnel depends on the following key parameters:

- size and shape of the clearance profile
- the provisions for the ventilation system
- requirements of the geotechnical design concerning the ground conditions
- requirements for the water drainage system
- tunnel installations
- electrical supply equipment including lighting etc.

Based on these requirements the typical cross section is defined for the tunnel systems.

Generally the tunnel is designed with two types of lining, the primary shotcrete lining and the inner concrete lining. Between the primary and the inner lining a waterproofing along the vault down to the level of the sidewall drainage pipes is installed. Additionally invert drainage is designed at the lowest part of the tunnel cross section. The carriageway water is collected in slot channels on both tunnel sides.

The carriageway consists of the concrete pavement on top, followed by a dry lean concrete sub base layer and an unbound sub-base layer according to Austrian RVS 09.01.23. The design of the sub-base depends on various factors such as e.g. the geotechnical conditions (invert or no invert), the provision of a fresh air duct below the carriageway, required compaction etc.

5.2 Size and Shape of Clearance Profile

5.2.1 Specifications as per Client [P1]

In the following the requirements from the tender documents [P1] concerning the design of the tunnel cross section are given. These requirements mainly affect the size of the clearance profile.

The minimum horizontal width of the carriageway should be 4.00 m clear between the kerbs for single lane tubes and 8.00 m between kerbs for a double lane tube. The footpaths should have a width of minimum 1.00 m on both sides with minimum 2 % crossfall. The vertical clearance should be as per IRC 5:1995 with a minimum of 5.50 m from road level of the carriageway to the invert level of the tunnel at any point. Additional specifications concerning the typical cross section are not given in the tender documents. During preparation of the DPR discussion was held on the requirements of a mountable median strip between the two driving lanes in the tunnel. The Client requested the incorporation of a mountable median strip with a height of 7.5 cm and a width of 50 cm between the driving lanes.

5.2.2 Recommendations from Standards and Guidelines

Width of carriageway: According to the tender documents [P1] the width of the carriageway between the kerbs for a double lane, bi-directional tunnel should be 8.00 m. The IRC:SP:91 [S17] recommends a carriageway consisting of two traffic lanes with 3.50 m and minimum hard clearances on both sides of 0.50 m. The PIARC recommendations [S21] are maintained considering two reduced traffic lanes with 3.25 m for restricted design speed of 80 km/h plus minimum hard clearances on both sides of 0.75 m. The Austrian RVS 09.01.22 [S31] demands a traffic lane width of 3.75 m depending on the traffic data and the design speed plus 0.25 m hard clearance plus 0.50 m strip width between the bi-directional traffic lanes, so that the typical width would be 8.50 m. British DMRB TD 27/05 [S39] demands for a traffic lane width of 3.75 m and hard clearances of 1.00 m (on open roads), where hard clearances can be restricted for economic reasons in tunnels.

It has to be mentioned, that the minimum carriageway width required for a truck to overtake another vehicle that is stopped without completely interrupting traffic in the opposite direction, is 8.50 m according to international PIARC recommendations. If the roadway width is reduced an interference of the traffic flow in case of vehicle breakdown can occur. In some European countries the overtaking in case of breakdown is not allowed (by traffic control) and the traffic in this direction remains stopped until the breakdown is solved. Under such conditions the roadway width can be reduced.

Height of clearance profile for carriageway: The clearance profile height, available over the full width of the roadway shall be 5.50 m according to the requirement from the tender documents [P1] and corresponding to IRC:SP:91 [S17]. According to PIARC recommendations [S21] the clearance profile shall be min. 4.50 - 4.70 m height. In the Austrian Guideline RVS 09.01.22 [S31] a clearance profile height of min. 4.70 m is required.

Walkway: The walkway width is determined with 1.00 m according to the tender documents, which is international standard. The maintained headroom of walkways is determined with 2.30 m according to PIARC recommendations [S21]. Indian Standard IRC:SP:91 [S17] does not provide any specific data. In Austrian Guideline [S31] the height of the walkway clearance profile shall be min. 2.25 m. The crossfall of the walkways is 2 % towards the roadway as required in the tender documents [P1] and typically in various International Standards (e.g. RVS 09.01.22 [S31]). The height of the kerbs is proposed to be 15 cm corresponding to PIARC recommendations and Austrians RVS [S31] to enable parking of broken cars, the easily opening of car doors and easy access for passengers in case of emergency. Pedestrian use of the tunnel is strictly prohibited except during evacuation of the tunnel due to incidents. Due to this greater kerb heights are not required and therefore not considered.

A summary of the recommended dimension of the cross section elements is provided in Tab. 9.

Tab. 9 Comparison of different guidelines for cross section element requirements

Cross section element	IRC:SP:91 [S17]	PIARC [S21]	RVS 09.01.22 [S31]
Traffic lane width in [m]	3.5	3.25	3.75
Hard clearance width in [m]	0.5	0.75	0.25
Median strip [m]	no recomm.	1.0	no recomm.
Height of clearance profile carriageway in [m]	5.5	4.5 – 4.6	4.75
Walkway width in [m]	no recomm.	0.75	1.0
Height of clearance profile walkway in [m]	no recomm.	2.3	2.25
Cross fall of walkway in [%]	no recomm.	2.0	2.0

5.2.3 Proposed Clearance Profile

The proposed cross section of the carriage way consists of the following elements:

- Clearance profile as defined in Fig. 2
- Walkway: width = 1.0 m, curb height 15 cm, as mentioned above the pedestrian use of the tunnel is strictly prohibited except during evacuation of the tunnel in case of an incident. Due to this greater kerb widths separating the driving lane and the walkway are not required.
- Hard clearance: width = 0.50 m including edge lane marking (0.12 m) with longitudinal ribs (0.20 m x 0.15 m x 0.7 cm) which provides an acoustical signal if vehicles deviate from the driving lane
- Driving lane: width = 3.50 m
- Median mountable strip: An intermediate mountable strip is designed separating the two driving lanes. The strip is 7.5 cm high and 50 cm wide.

The proposed clearance profile for the bi-directional single tube Zojila Tunnel is given in Fig. 2.

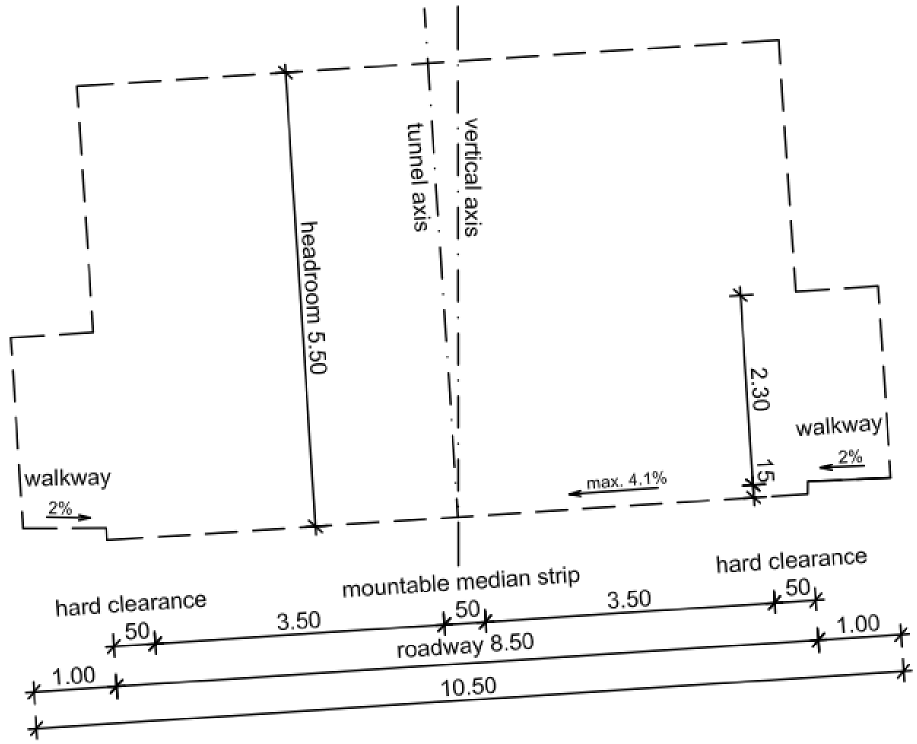


Fig. 2 Proposed clearance profile for bi-directional single tube tunnel

For the tunnel curves with a radius of 500 m, 750 m and 1250 m a superelevation of 4.1 %, 3.2 % and 2.5 % respectively is designed, which is below the maximum crossfall of 5 % according to Austrian Standard. In straight sections the crossfall of the road is generally 2.5 %. In the development of the tunnel cross section the maximum crossfall in curves of 5 % towards the inner curve line is considered.

The typical cross section geometry of the inner lining is a three-centred arch surrounding the clearance profile and the fresh air and exhaust air ducts.

Generally the tunnel is designed with two types of lining. The primary lining stabilizes the rock mass immediately after excavation. The (reinforced) concrete inner lining is designed to carry the loads permanently without considering the structural function of the primary lining. According to the geological and geotechnical conditions the tunnel linings are designed with various thicknesses and reinforcements.

Between the primary and the inner lining a water proofing system, consisting of a drainage and protection fleece and the sealing membrane, is installed. It is installed along the vault down to the level of the sidewall drainage pipes. This so called umbrella system seals the upper part of the tunnel from ground water inflows.

The typical cross sections for the main tunnel with and without invert are given in Fig. 3 and Fig. 4. More details concerning the typical cross sections of the main tunnel and the other tunnel elements are given in the drawings 8482B_II-ZOT_GEOM-01-12-00 to 8482B_II-ZOT_GEOM-21-12-00. The hydraulic system and the carriageway are described more detailed in the chapters below. The ventilation system is described in DPR Volume VIII: Ventilation design.

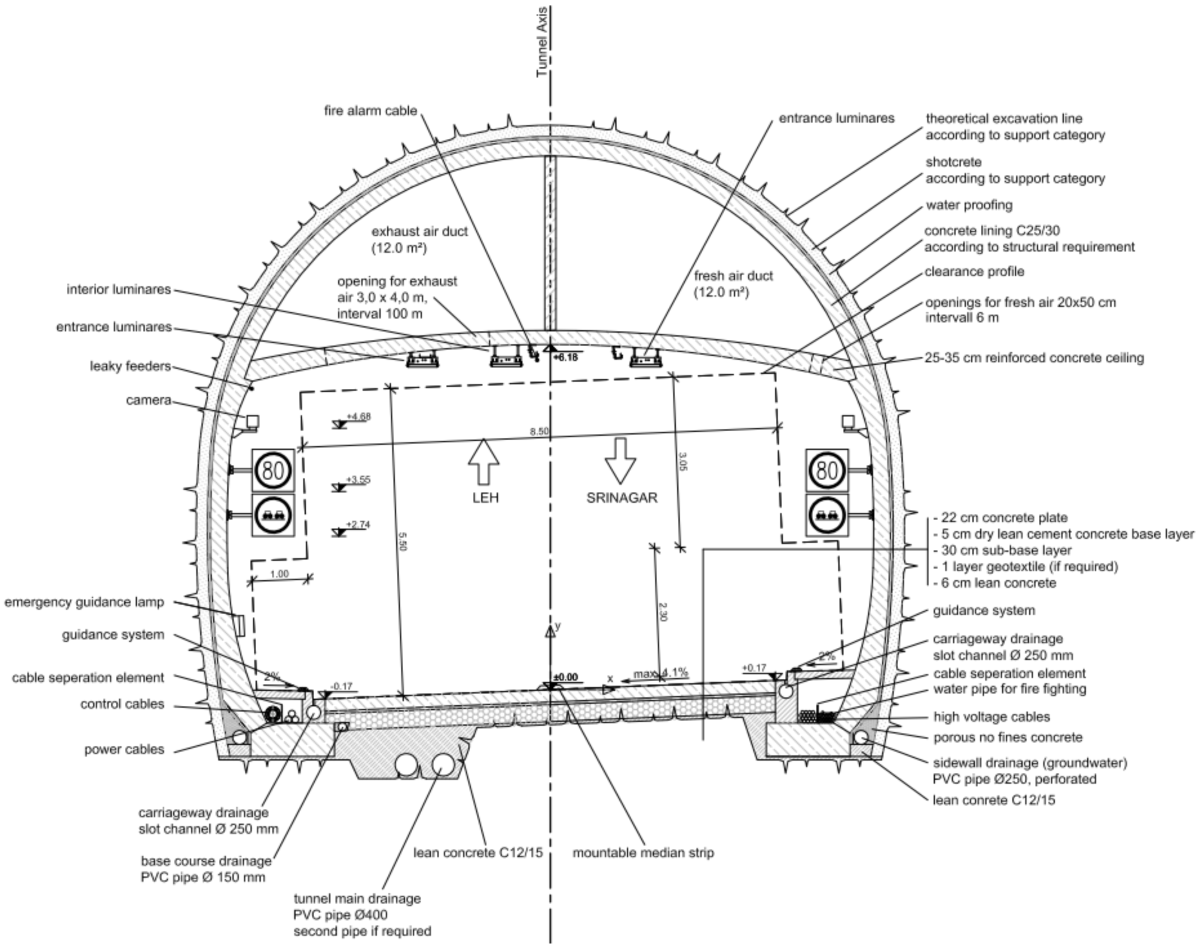


Fig. 3 Typical cross section for bi-directional single tube tunnel without invert

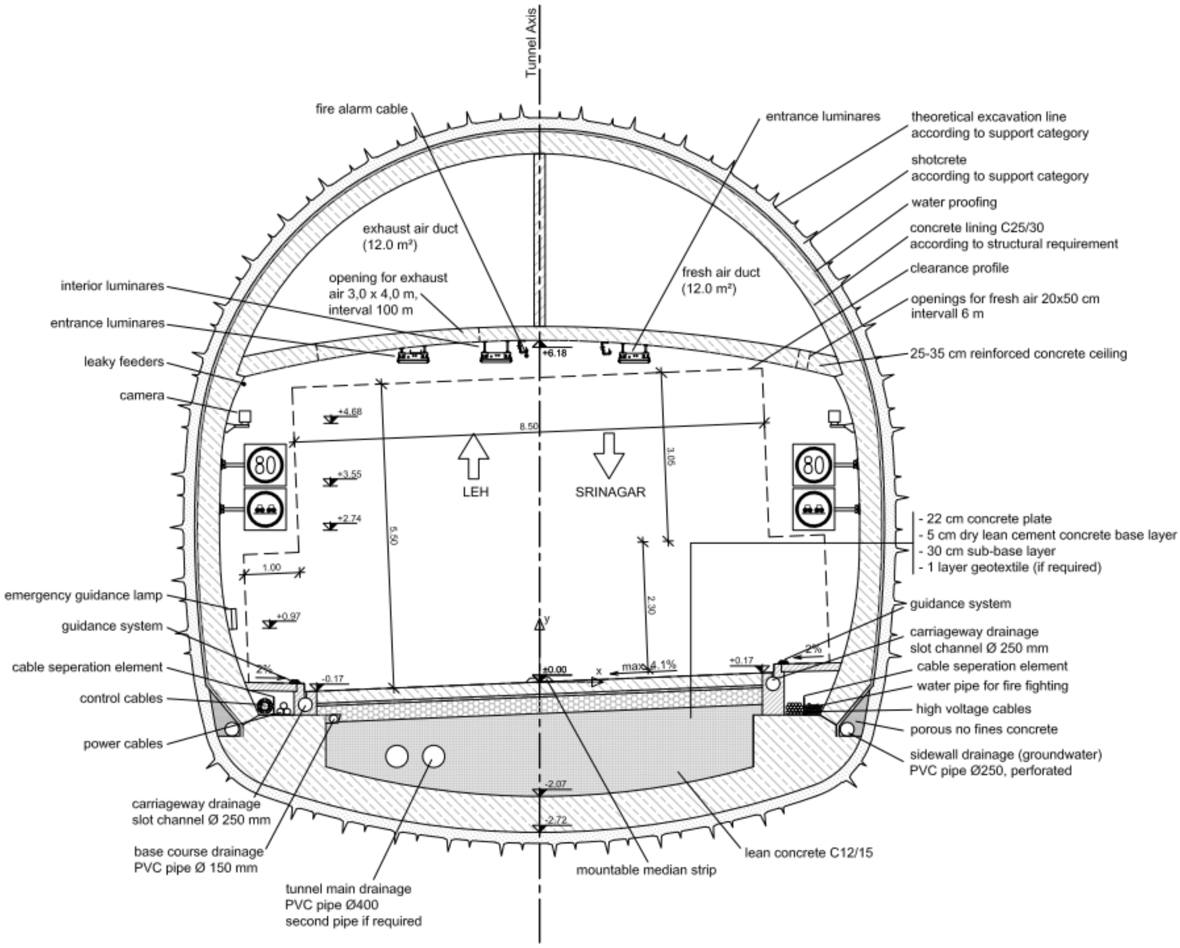


Fig. 4 Typical cross section for bi-directional single tube tunnel with invert

6 TUNNEL SAFETY CONCEPT

The main principles of the self-rescue system are laid down in Addendum 3 of this report. The general layout of the safety and operation facilities is given hereafter. A description and specifications of the electro-mechanical equipment is given in DPR Volume X: Technical Specifications Fixed Operating Equipment.

6.1 General

The provision of functional and safety facilities in tunnels varies in different countries. In UK a classification system is defined in BD 78/99 where required safety facilities are defined depending on the tunnel category. In Austria the tunnel is classified according to the result of a risk-analysis in a hazard category I-IV. Depending on this category the minimum provisions of tunnel facilities are defined.

A concept for the functional and safety facilities for Zojila Tunnel is proposed in the following clauses. The main structural tunnel facilities are depicted in the schematic drawing 8482B_II-ZOT_GEN-05-12-00.

The following safety and operation facilities are considered and presented in more detail below:

- Egress tunnel parallel to the main tunnel
- Cross passage driveable each 750 m
- Cross passage pedestrian each 250 m
- Lay-bys each 750 m
- Emergency telephone niche each 125 m
- Hydrant cabinets each 125 m
- Jet fan niche approx. each 750 m
- Electrical supply cabinet each 750 m

6.2 Emergency Exits and Egress Tunnel

In case of an incident the escape from the main tunnel to the outside will be done through a separate parallel egress tunnel. The required fresh air supply is provided by two longitudinal jet fans located at both tunnel portals. Additionally adequate lighting is provided.

The egress tunnel cross section shall be appropriate for pedestrian as well as for emergency vehicle use. Regulations of egress tunnel cross sections for emergency vehicle use are not given in Indian Standards. Due to this, the cross section is developed based on Austrian Guideline RVS 09.01.24 [S33], in which clearance profiles for egress tunnels, drivable with emergency vehicle, are given.

Additionally the egress tunnel shall be used for the construction of the main tunnel (site traffic etc.). Due to this adequate space is provided for bi-directional site traffic with a clearance profile of 6.0 m width and 3.5 m height. In case of variations of the construction sequence or construction equipment, the clearance profile may be adapted to the actual site conditions and equipment in a later design or construction phase.

Cross passages connect the main tunnel with the separate parallel egress tunnel. Two different cross passages with the given interval are proposed.

- Cross passages for pedestrian use are situated on one tunnel side with an interval of 250 m.
- Cross passages for pedestrian as well as for emergency vehicle use are situated at lay-bys on one tunnel side with an interval of 750 m.

The given values are in compliance with the recommended intervals from International Standards (500 m maximum distance between two emergency exits according to PIARC recommendations [S19] and RVS 09.01.24 [S33]).

Due to the distance of cross passages of max. 250 m, every passenger is able to reach an emergency exits within approx. 4 minutes, when average pedestrian velocity is predicted with 1 m/s. During this time period the ventilation system provides adequate fresh air and the capacity of the exhaust air fans is not reached.

Main tunnel and cross passages are separated through fire proof doors.

6.3 Lay-bys

Lay-bys are situated at both tunnel sides at an interval of approximately 750 m, which is in accordance with IRC:SP:91-2010. The interval is kept short due to the high percentage of heavy trucks (2500 trucks per day in both directions) using the route and the constant and relatively high tunnel gradient, which may cause breakdowns (overheating) more often. International Standards would allow bigger spacing, e.g. 1000 m interval according to Austrian RVS 09.01.24.

The lay-bys are designed according to Austrian Standard having a width of 3.0 m and a length of approx. 40 m corresponding well to Indian Standard (refuge to park for at least 6 vehicles).

At each lay-by a hydrant cabinet and an emergency telephone cabinet is provided at both tunnel sides and an drivable cross passage to the parallel egress tunnel is provided at one side of the lay-by. A power supply niche is additionally situated at each lay-by, except the lay-by at the ventilation cavern.

6.4 Fire Protection Concept and Hydrant Niche

An automatic fire detection system with line fire detectors is installed in the tunnel and connected to the tunnel control centre.

A fire main is provided in the general safety concept. It is permanently under pressure as a dry fire main would take too much time to be filled in long Zojila tunnel. A reservoir for the supply of the fire main is required. A removal quantity of 30 l/s shall be ensured at each point in the tunnel over duration of one hour and a minimum operating pressure according to the requirements of the local Fire Authority. According to this a capacity of 108 m³ is required as per Austrian Regulation. The required capacity shall be agreed with the local Fire Authority.

Hydrants are required by the fire brigade to be used for active fire fighting, for tunnel washing, drainage flushing or finishing fire extinguishing works. The spacing of hydrants shall be typically in the range of 50-250 m according to International Standards. For Zojila Tunnel hydrants are placed at each lay-by at an interval of 750 m at both tunnel sides and at a spacing of 125 m one tunnel side.

The active fire protection equipment (fire extinguishers, hose reels, hydrants, etc.) should generally be agreed with the relevant local Fire Authority. For Zojila Tunnel the accommodation of a local fire brigade close to the tunnel could be convenient.

Also possible is the combined assignment of the personal for road maintenance and for fire fighting in case that no fire brigades are locally established.

6.5 Emergency Telephone Cabinets

Emergency telephone cabinets are provided for Zojila Tunnel at emergency exits and in-between an interval of 125 m on one tunnel side, which is in the range of typical intervals between 50 and 200 m according to International Standard. Additionally emergency telephone niches are placed at both tunnel sides at lay-bys with an interval of 750 m. Emergency points contain emergency telephones and hand-held fire extinguisher.

6.6 Communication

Emergency telephones with digital voice transmission allow road users to communicate directly with the tunnel traffic control centre.

Radio rebroadcasting equipment is provided to enable emergency services and staff operating within the tunnel to maintain communications.

To warn guide and assist tunnel users public address systems (loud speakers) are provided.

6.7 Traffic Controls

Tunnel traffic control systems are provided such as equipment for measurement of traffic speed, density, traffic surveillance (CCTV) and control. Cameras are installed for closed circuit television (CCTV) to detect traffic jams, etc. A digital video storage system is used.

Traffic data recording is installed. For traffic control a system of signs and signals is provided. Variable message signing is located outside the tunnel portals and in the tunnel at a spacing of approx. 1500 m. Light-signalling devices are also situated in an interval of approx. 1500 m.

The signing for escape routes is provided by emergency exit signs.

As the projected percentage of heavy goods vehicles on the total traffic with approximately 30 % is very high, a kind of stop-and-go system would be reasonable for Zojila Tunnel. Heavy goods vehicles are stopped before the tunnel portal at assembly areas and are escorted through the tunnel at fixed time intervals or time schedules, while the traffic from the other direction could be stopped at the other portal side in the meantime. With this system the tunnel safety can be increased significantly.

6.8 Service Buildings

Tunnel service buildings are located close to both tunnel portals to house parts of the fully transversal ventilation system and to avoid excessive voltage drops in the electrical distribution system due to long service connection. For Zojila tunnel the service building is separated from the ventilation building at both portals for better access. The ventilation building houses have following equipment and installation (list not complete):

- ventilation ducts and shafts
- axial fans
- electrical supply installation

The distance from the exhaust shaft opening to the tunnel portal is > 50 m; the distance between fresh and exhaust air opening is > 30 m; vehicular access to the ventilation building and a crane is provided for revision works.

The following equipment and installation, contained in the service buildings, has to be provided (list not complete):

- facilities for the electrical power supply: main electricity substation, HV switchroom, LV switchroom, UPS room, battery room, space for transformers
- diesel generator, fuel tanks
- plant rooms for the tunnel maintenance and future requirements, stores
- toilet facilities (if building is manned)

A floor space of 800 m² in total is estimated to be required for each service building.

The ventilation building is located above the cut and cover tunnel and is reduced to minimum space requirements.

The buildings have to be equipped with lighting (normal, emergency and standby lighting), a fire protection system, an intruder alarm system, heating to prevent condensation in all rooms, air conditioning, etc.

Outside the service building a vehicle hard standing is designed with access for fire fighting vehicles, equipment and personnel. Helicopter landing is possible as well. The service building is accessible from all sides.

6.9 Tunnel Remote Control Rooms

The tunnel remote control rooms for Zojila Tunnel are integrated in the western tunnel service building.

Systems relating to emergency points and the response to tunnel emergencies are linked with the tunnel plant monitoring and control centre as well as communication and traffic control devices. The redundant data transmission is done by glass fibre cables in a local area network (LAN). The control is carried out in hot standby execution and fully automatically with possible manual intervention.

The control room can be manned with two permanent staff members. The visualisation is provided by DLP-large scale display projectors for plant monitoring and CCTV. The operator workplace is equipped with LCD-displays. The central computer is carried out in hot standby execution with client-server configuration.

The control rooms have to be equipped with lighting (normal and emergency lighting), a fire protection system, an intruder alarm system, etc.

Outside the service building a vehicle hard standing is designed for fire fighting vehicles, maintenance vehicles, equipment and personnel.

7 VENTILATION SYSTEM

A detailed description of the preliminary ventilation design is given in DPR Volume VIII: Preliminary Ventilation Design Report. The technical specifications of the ventilation system are given in DPR Volume X: Technical Specification Fixed Operating Equipment, Addendum 1. A brief summary of the main ventilation elements are given hereafter.

7.1 Ventilation Concept

The ventilation system consists of a fully transverse ventilation system with eight ventilation sections, including one intermediate ventilation cavern and ventilation tunnel. The length of the ventilation sections and cross sections of the ventilation ducts are given below. The shaft lengths are not included in the below given values.

Ventilation section length:	Section 1 and 2:	approx. 2245 m
	Section 3 and 4:	approx. 1578 m
	Section 5 and 6:	approx. 1715 m
	Section 7 and 8:	approx. 1543 m
Ventilation cross section:	Exhaust air duct:	minimum 10.6 m²
	Fresh air duct:	minimum 10.6 m²

The exhaust and fresh air duct are situated above the carriageway. The carriageway is separated from the ventilation ducts by an intermediate concrete ceiling. In the fresh air duct higher air pressure than in the carriageway room is provided. Due to this the fresh air is pressed into the carriageway room through openings (20 x 50 cm every 6 m) in the concrete ceiling. In the exhaust air duct lower air pressure than in the carriageway room is provided, hence the air is sucked into the exhaust air shaft. Exhaust air openings are constructed in the tunnel ceiling every approx. 100 m with a cross section of 3.0 x 4.0 m. The openings can be controlled with electronic equipment (exhaust air dampers) and adjusted to the actual requirements. The exhaust air dampers are described in more detail in in DPR Volume VIII: Preliminary Ventilation Design Report. The exhaust air and fresh air duct are separated by a vertical concrete wall.

7.2 Ventilation Cavern

The ventilation caverns are situated perpendicular to the main tunnel at approx. km 4.489, km 7.646 and km 11.076 south of the lay-by, between the main tunnel and the separate egress tunnel, with a length of approx. 30 m. The main characteristics of the ventilation cavern are as follows.

Cavern excavation height:	approx. 15.0 m
Cavern excavation width:	approx. 21.0 m
Cavern length:	approx. 30.0 m
Excavation cross section:	approx. 185 m²

The ventilation cavern includes all electro mechanical installation for the ventilation and power supply system and can be accessed through the main tunnel or the separate parallel egress tunnel.

Rooms for electro mechanical equipment are situated at the level of the carriageway under the side axial fans. Above the E&M facility rooms the four axial fans, two for exhaust air extraction and two for fresh air supply, are installed. All axial fans are located at the same elevation. The fans and the E&M rooms are separated with a reinforced concrete ceiling. The typical layout of the cavern is given in drawings 8482B_II-ZOT_VEN-03-12-00 to 8482B_II-ZOT_VEN-05-12-00.

In the area of the fans the cavern cross section is heightened to provide enough space for gantry crane and maintenance personnel. The gantry crane is designed to be movable in both, longitudinal and cross sectional, direction of the ventilation cavern to ensure that each part of every ventilation fan is accessible. The gantry crane shall have a capacity of 12.5 tonnes with a span of approx. 20 m (Konecranes or equivalent).

Below the exhaust air fans openings in the concrete ceiling are designed with 5.0 m length and 3.0 m width, hence the exhaust air fans are lowered through these openings in case of requirement of maintenance work or replacement of an axial fan. The fresh air fans are replaced through the same openings, due to this one exhaust air fan has to be dismounted prior of fresh air fan replacement. The hydraulic aggregates are installed beside the axial fans in such way that the axial fans have not to be lifted above the hydraulic aggregates in case of axial fan replacement. Due to this the axial fan is only lifted approx. 0.5 m during replacement and the cavern height can be minimized.

The axial fan room is accessible for maintenance personnel through staircase from the E&M facility rooms. The different axial fans can be accessed with ladders and a walkway located above the ventilation ducts. Each ventilation duct room can be entered from the axial fan room with fire proof doors.

The exhaust air ducts as well as the fresh air ducts lead to the ventilation shaft in which the ducts lead to the fresh air intake and the exhaust air extraction respectively above ground elevation.

The cavern layout design shall be adjusted in the detailed design phase, based on electromechanical and ventilation requirements as well as the actual encountered ground condition.

7.3 Ventilation Shaft

Three ventilation shafts are required. The ventilation shafts are located above the caverns and connect the cavern to the ground. The shafts are located at approx. km 4.489, km 7.646 and km 11.076 of the tunnel alignment. The shafts have a depth of 484 m, 365 m and 208 m. The shaft 1 and 2 are designed to be additionally used as access shaft during the construction period. These shafts are excavated by conventional drill and blast methods top down. The layout of the construction shafts is given in drawing 8482B_II-ZOT_VEN-01-12-00 and 8482B_II-ZOT_VEN-01-12-00. The shaft #1 and #2 has an excavation diameter of approx. 14 m and an excavation cross section of 154 m² depending on the support category. The shaft #3 is only used for ventilation measures and is constructed with raise boring with a diameter of approx. 6 m and an excavation cross section of approx. 28 m².

8 HYDRAULIC DESIGN

The tunnel has two separate drainage systems, one to drain the ground water and another to dewater the carriageway. The tunnel high point is equal to the eastern portal, which leads to a drainage to the lower western portal (Srinagar) with a gradient of approx. 2.9 % along the entire tunnel length of approx. 14.1 km.

A schematic overview of the hydraulic design is given in drawing 8482B_II-ZOT_HYD-01-12-00.

8.1 Surface Water

No surface water shall flow into the tunnel. At the eastern portal (Leh) the carriageway water from the open road has to be collected in side drainage not to flow into the tunnel.

8.2 Ground Water

The ground water has to be collected and drained separately to the carriageway water (separate drainage system).

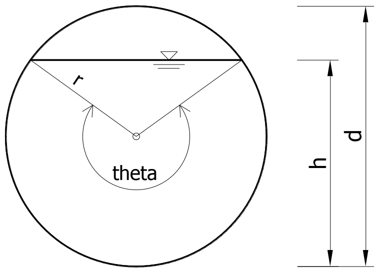
The tunnel is sealed against water inflows from the ground (mainly ground water flowing along singular joints) around the tunnel vault with a water proofing system. The so called umbrella system consists of a drainage and protection fleece and a sealing membrane.

It is installed along the vault down to the level of the ground water drainage pipes (side wall drainage $\Phi \geq 250$ mm, perforated) in the area of the footing of the upper vault of the inner lining. These pipes conduct the collected ground water along the tunnel. Maintenance ducts are situated in each revision niche (on average each 100 m as a multiple of block length of inner lining).

The drainage pipes conduct the ground water to the portals. The capacity of the side wall drainage is determined to 50 l/s (see Fig. 5) for a charge of 50 % (the lower half of the cross section of the perforated pipe is permitted to be used for water carriage, the upper half is required for water inflow into the pipe).

Project no.:	**8482B**	Revisor:	MBu
Project:	Zojila Tunnel	Date:	14.03.2013
Position:	**Side Wall Drainage**	Notes:	

Dimensioning of a channel



Geometry							
Ground				flow pipe			
altitude differenz	Δh_S	[m]	**0,029**	diameter	d	[mm]	**250**
length	s	[m]	**1**	radius	r	[m]	0,125
bed gradient	I_S	[-]	2,90%	operative surface finish	k_b	[mm]	**2**

Drainage							
full charge (v)				partial charge (t)			
				rate of flow	Q	[l/s]	**50**
rate of flow	Q_v	[m³/s]	0,098	rate of flow	Q_t	[m³/s]	0,050
speed	v_v	[m/s]	2,006	speed	v_t	[m/s]	2,018
cross-sectional area	A_v	[m²]	0,049	partial area	A_t	[m²]	0,025
wetted perimeter	$l_{u,v}$	[m]	0,785	wetted perimeter	$l_{u,t}$	[m]	0,395
hydraulic radius	$r_{hy,v}$	[m]	0,063	hydr. radius	$r_{hy,t}$	[m]	0,063
				hight of the filling	h	[m]	0,126
				angle of aperture (theta)	θ	[°]	180,88
					θ	[rad]	3,16
constants				parameters			
kinematic viscosity	ν	[m²/s]	1,31E-06		Q_t/Q_v	[-]	0,508
gravitational acceleration	g	[m/s²]	9,81		v_t/v_v	[-]	1,006
					h/d	[-]	0,504

Transportation of the bed load							
dredging force	τ	[N/m²]	18,213	max. flow time	t	[min]	0,01
average density of the bed load	ρ_K	kg/m³]	**2600**				
grain diameter	d_K	[mm]	25,79				

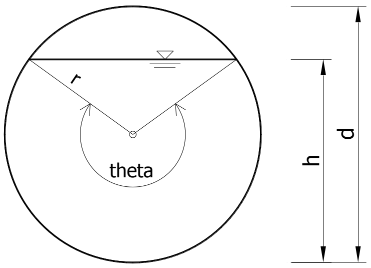
Fig. 5 Determination of side wall drainage capacity

Due to the length of Zojila Tunnel the maximum capacity of the side wall drainages may be insufficient for the inflowing ground water amount along the tunnel sections. Therefore an additional ground water collecting pipe (tunnel main drainage) on the tunnel base is designed (internal diameter of 400 mm). At each revision niche, with an interval of 100 m, the groundwater flowing in the side wall drainage pipes is discharged into the main tunnel drainage pipe.

The maximum capacity of the main tunnel drainage is determined to 425 l/s. If, during tunnel construction, the overall steady state water inflows are expected to be higher than the maximum capacity of the tunnel main drainage, additional drainage pipes shall be designed and installed.

Project no.:	**8482B**	Revisor:	MBu
Project:	Zojila Tunnel	Date:	14.03.2013
Position:	**Main Drainage**	Notes:	

Dimensioning of a channel



Geometry							
Ground				flow pipe			
altitude differenz	Δh_S	[m]	**0,029**	diameter	d	[mm]	**400**
length	s	[m]	**1**	radius	r	[m]	0,2
bed gradient	I_S	[-]	2,90%	operative surface finish	k_b	[mm]	**0,5**

Drainage							
full charge (v)				partial charge (t)			
				rate of flow	Q	[l/s]	**425**
rate of flow	Q_v	[m³/s]	0,414	rate of flow	Q_t	[m³/s]	0,425
speed	v_v	[m/s]	3,293	speed	v_t	[m/s]	3,738
cross-sectional area	A_v	[m²]	0,126	partial area	A_t	[m²]	0,114
wetted perimeter	$l_{u,v}$	[m]	1,257	wetted perimeter	$l_{u,t}$	[m]	0,937
hydraulic radius	$r_{hy,v}$	[m]	0,100	hydr. radius	$r_{hy,t}$	[m]	0,121
				hight of the filling	h	[m]	0,340
				angle of aperture (theta)	θ	[°]	268,46
					θ	[rad]	4,69
constants				parameters			
kinematic viscosity	ν	[m²/s]	1,31E-06		Q_t/Q_v	[-]	1,027
gravitational acceleration	g	[m/s²]	9,81		v_t/v_v	[-]	1,135
					h/d	[-]	0,849

Transportation of the bed load							
dredging force	τ	[N/m²]	35,187	max. flow time	t	[min]	0,00
average density of the bed load	ρ_K	kg/m³]	**2600**				
grain diameter	d_K	[mm]	49,82				

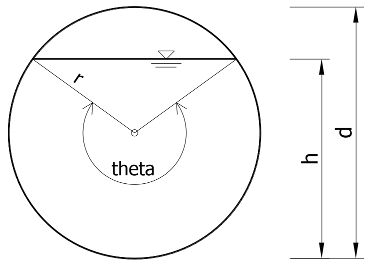
Fig. 6 Determination of main tunnel drainage capacity

Additionally a drainage pipe (sub-base drainage Φ ≥ 150 mm, perforated) is situated on one side of the carriageway under the un-bound sub-base layer of the pavement. The sub-base layer is inclined with min. 4 % to the drainage pipe, which collects the groundwater flowing into the sub-base layer from the jointed rock mass.

The capacity of the sub-base drainage is determined to 10 l/s (see Fig. 7, half of the cross section filled).

Project no.:	8482B	Revisor:	MBu
Project:	Zojila Tunnel	Date:	14.03.2013
Position:	**Sub-base Drainage**	Notes:	

Dimensioning of a channel



Geometry							
Ground				flow pipe			
altitude differenz	Δh_S	[m]	**0,029**	diameter	d	[mm]	**150**
length	s	[m]	**1**	radius	r	[m]	0,075
bed gradient	I_S	[-]	2,90%	operative surface finish	k_b	[mm]	**2**

Drainage							
full charge (v)				partial charge (t)			
				rate of flow	Q	[l/s]	**12,5**
rate of flow	Q_v	[m³/s]	0,025	rate of flow	Q_t	[m³/s]	0,013
speed	v_v	[m/s]	1,423	speed	v_t	[m/s]	1,425
cross-sectional area	A_v	[m²]	0,018	partial area	A_t	[m²]	0,009
wetted perimeter	$l_{u,v}$	[m]	0,471	wetted perimeter	$l_{u,t}$	[m]	0,235
hydraulic radius	$r_{hy,v}$	[m]	0,038	hydr. radius	$r_{hy,t}$	[m]	0,037
				hight of the filling	h	[m]	0,075
				angle of aperture (theta)	θ	[°]	179,37
					θ	[rad]	3,13
constants				parameters			
kinematic viscosity	ν	[m²/s]	1,31E-06		Q_t/Q_v	[-]	0,497
gravitational acceleration	g	[m/s²]	9,81		v_t/v_v	[-]	1,001
					h/d	[-]	0,497

Transportation of the bed load							
dredging force	τ	[N/m²]	10,837	max. flow time	t	[min]	0,01
average density of the bed load	ρ_K	kg/m³]	**2600**				
grain diameter	d_K	[mm]	15,34				

Fig. 7 Determination of sub-base drainage capacity

At the tunnel portals the ground water is collected from the side wall drainage and the main tunnel drainage. The groundwater at the western tunnel portal is discharged into an open channel. The open channel shall preferably aligned parallel to the approach road to the western tunnel and lead to the recipient nearby Baltal. At the eastern tunnel portal the groundwater is discharged into an open channel leading to the Sind River. The alignment of the open channels on both portals shall be designed along with the alignment of the open approach road sections.

The general hydraulic layout of the portals is given in drawing 8482B_II-ZOT_HYD-02-12-00 and 8482B_II-ZOT_HYD-03-12-00.

8.3 Carriageway Water

The carriageway water has to be collected and drained separately to the ground water (separate drainage system).

Due to the crossfall of the carriageway ≥ 2,5 % the carriageway water flows into slot channels (Ø 250 mm) in the area of the kerbs. The carriageway water collected in the slot channels flows from the eastern to the western portal due to the vertical tunnel gradient of approx. 2.9 %.

At the western tunnel portal the collected carriageway water will be diverted into a settling basin with a volume of min 50 m³ according to Austrian Standard, which secures that dangerous wastewater will not flow directly into the recipient (rivers, etc. next to the tunnel portals) in case of emergency. After sufficient settling of sediments and deleterious material the carriageway water is discharged from the settling basin into the open channel.

9 CONSTRUCTION CONCEPT

9.1 Tunnel and Portals

The Zojila tunnel will be constructed from the two tunnel portals and from two intermediate ventilation and construction shafts at approx. km 4.489 and km 7.646 of the Zojila tunnel. The construction and ventilation shafts are used for construction access during construction period and ventilation purposes during tunnel operation period.

First the site installation and the construction of the long approach roads at the west and east main tunnel portal are constructed. Subsequently to the construction of the site installation and the portal cuts the excavation of the separate parallel egress tunnel and the main tunnel as well as the intermediate ventilation and construction shafts shall be started. The parallel egress tunnel is driven in advance to the main tunnel with a distance of approx. 250 m. Due to this the ground conditions are well known when excavating the main tunnel and measures can be taken accordingly.

After completion of the intermediate construction shafts the main tunnel is excavated in six independent tunnel drifts, two from the main portals and four from the construction shafts.

The parallel egress tunnel is also used for site traffic during construction. The egress tunnel is connected with the main tunnel by drivable cross passages at an interval of approx. 750 m. Due to this the top heading of the main tunnel can be constructed simultaneously with the bench and the invert as well as tunnel inner lining. Due to the accesses form egress tunnel different construction areas can be operated almost independent with only minor interaction.

After the finalization of the excavation sequences the water proofing system, the inner lining invert, if required, and inner lining vault are installed.

As per proposal and decision of the Client the accessibility of the eastern portal and the connection to Leh for supply is given during the entire year without any winter breaks. Therefore the excavation of the tunnel from the eastern portal shall be done during the entire year, as all year connectivity from Leh to the eastern portal is considered to be feasible. The excavation from the western portal and from the intermediate construction shafts (as well as the construction of the intermediate construction shafts) will realistically not be feasible during the winter season due to closure of the National Highway and approach roads because of the risk of avalanches and consequently no material supply.

It is assumed, that the supply of materials (cement, etc.) will be done mainly from Srinagar area towards the construction site in summer time when the western portal is accessible and from Leh in winter time when only the eastern portal is accessible. The aggregates shall be produced in the area of the site installations to reduce transportation effort.

Finally the tunnel installations are installed. Most of these construction steps have to be done independently, which is very time consuming. Especially at the western portal and the intermediate construction shaft the construction time is limited due to the weather conditions in winter.

9.2 Site Installation

For the construction of the tunnel, in accordance to the construction concept described above, three to four independent site installation areas are recommended to be established. The main site installation shall be set up in the area of the western portal close to the National Highway NH-1. All staff accommodation, head office, main workshop and the concrete plant for all tunnel drifts will be installed here. The second site installation is planned at the eastern portal. The third and eventually fourth site installation shall be set up at the ventilation and construction shafts. Preliminary works such as minor excavation, filling and grading works will be required for the construction of platforms providing planar space for site installation.

At the eastern site sufficient space for the site installation is available, eventually the ground is to be elevated to lower the risk of floods in this area. The availability of the land has to be evaluated. A space of approx. 100000 m² is estimated to be required for the construction works. The site installation has to include all necessary facilities for the execution of the construction works. The main elements of the site installation are:

- Concrete plant including processing and storage of aggregates and cement
- Workshop, warehouse, storage, testing laboratory
- Office for Contractor and Client

- Accommodation, staff canteen
- Flood detention basin
- Registration, locker, sanitary area
- Gas station, explosives magazine
- Gate guard building, barrier, health and safety arrangements
- Access roads, construction roads
- Parking area

At the western portal sufficient space is available as well. It is proposed to develop the site installation northern of the tunnel portal. The risk of avalanches shall be assessed in detail prior to the design of the western portal site installation. The third site installation is developed at the construction and ventilation shaft 2 nearby Gumri. If required a fourth site installation can be designed in the area of the construction and ventilation shaft 1. A space of 50000 m² is estimated for each, the western and the intermediate construction sites.

The entire area is highly affected by avalanches. During winter it must be assumed that access along many roads will not be possible at all. The avalanche risk in the vicinity of the site installation is generally high. A more detailed investigation of the avalanche situation in the area of the proposed site installation must be done during detailed design.

10 CONSTRUCTION TIME

The construction time is evaluated for the bi-directional double lane, single tube tunnel based on the preliminary design as described in this Detailed Project Report. Construction breaks due to weather conditions, logistic problems and/or political difficulties are not considered in the schedule concerning the supply from Leh to the eastern portal. This means that it is assumed, that the road from Leh to the eastern portal is opened during the entire winter; any delays including possible winter breaks have to be added to the overall construction time. The winter closure of the highway road to the western portal and between western and eastern tunnel portal for a period of 5 months is considered in the construction concept.

The advance rates are evaluated for the different support categories based on continuous works in at least 2 shifts (day and night). The following basic input parameters are used for the evaluation of the construction time:

Top heading excavation in Support Category A,B,C:	7/5/3.5 m/day
Top heading excavation in Support Category D,E:	3/2.5 m/day
Top heading excavation in Support Category F,G,H:	2/1/1 m/day
Bench excavation compared to top heading:	double speed
Intermediate construction shaft:	1 m/day
Inner lining construction:	50 m/week

The construction time for niches and lay-bys are included in the above advance rate for the main tunnel excavation.

The finalization of the portals (construction C&C tunnel, backfilling etc.) is assumed to be done simultaneously to the E&M installations.

The mean advance rate for the top heading and bench/invert excavation are calculated for the main geological formations, based on the geological ground condition and the distribution of the Support Categories, as given in DPR Volume IV: Geotechnical Design Report and the corresponding drawings. As per Tab. 10 four mean advance rates are determined with respect to the main geological condition and the corresponding distribution of Support Categories.

The advance rate of the main tunnel top heading excavation and the full face egress tunnel excavation are assumed to be equal due to the similar cross section and generally similar round lengths. The advance rate of the full face egress tunnel excavation includes the construction of the cross passages.

Tab. 10 Determination of the mean advance rates

Main geological formation	Distribution of Support Category								Section length [m]	Mean advance rate [m/d]
	A	B	C	D	E	F	G	H		
Slope Debris & Talus Metrial	0	0	0	0	0	0	0	100	76	2
Green Schist	37,5	37,5	17,5	5,5	2	0	0	0	1640	5,4
Grey Phillite	0	0	6	34	30	20	10	0	5551	2,7
Green Schist	37,5	37,5	22	2,4	0,6	0	0	0	2217	5,4
Greywacke and Slates	0	0	15	52	28	5	0	0	1112	2,9
Green Schist	37,5	37,5	22	2,7	0,3	0	0	0	3487	5,4

The determined necessary construction time is given with approximately 84 months based on the tunnel design as presented in this design report (details are given in drawing 8482B_II-ZOT_GEN-06-12-00). It is assumed that the construction works will start in early spring with 7 months of working season and 5 months of winter break in the remote areas.

The construction time may vary based on further developed detailed design phase and of course based on actual weather conditions forcing the winter breaks.

11 PAVEMENT

The road pavement consists (from bottom to top) of the following layers:

- 30 cm unbound sub-base layer
- 5 cm dry lean cement concrete sub-base layer
- 22 cm concrete surface pavement

11.1 Unbound Sub-base Layer

Specifications for unbounded, granular sub-base layers which guarantee drainage are included in DPR Volume IX: Technical Specifications Civil Engineering. Natural as well as recycled and industrial produced granular material can be used. The material is constructed and compacted in layers with a maximum thickness as defined in the Technical Specifications.

11.2 Dry Lean Cement Concrete Sub-base Layer

Specifications for dry lean cement concrete sub-base layer are included in the Technical Specifications of the Detailed Design Project Report. Dry lean cement concrete sub-base layer shall be constructed and compacted as per DPR Volume IX: Technical Specifications Civil Engineering.

11.3 Plane Jointed Rigid Concrete Pavement

The concrete pavement thickness is designed in compliance with the Indian Standard IRC:58-2002 [S15].

The design traffic key parameters are given in Section 4.3.1 and are summarized below. It is stated that these values are design values provided by the Client [P1].

Design Traffic:	2500 trucks (≥ 3 to) and 5000 passenger cars (< 3 to) in both directions
Design Speed:	80 km/h
max. flow/h:	1000 vehicles

The cumulative number of repetitions of axles C during design life can be determined with the design life n, the design traffic A (only design traffic of trucks is considered, damaging due to cars or other vehicle with weight < 3 to is very small and therefore negligible) and the annual rate of growth of commercial traffic r. According to IRC:58-2002 [S15] the annual rate of growth of traffic r can be estimated to 7.5 % per year when no actual data is available. Due to the fact that the design traffic is not the actual traffic on the existing road but the predicted traffic as per Client, no annual growth rate is considered in the pavement design. The design life n of the concrete pavement is proposed with 20 years.

$$C = 365 \cdot A \cdot n = 9.12 \cdot 10^6 [-] \qquad \text{Equ. 7}$$

No data of axle load spectrum for the designated area is available. Due to this the axle load is estimated with 10.2 tonnes for single axle and with 19 tonnes for tandem axle, which are the Indian maximum axle loads. It is assumed that 50 % of the cumulative number of repetition of axles is single axle (75 % 8 tonnes and 25 % 10 tonnes) and 50 % is tandem axles (19 tonnes).

The flexural strength f_{cr} can be determined with the characteristic compressive cube strength f_{ck} (=40 N/mm² for M40).

$$f_{cr} = 0{,}7 \cdot \sqrt{f_{ck}} = 4.43 \left[{}^{N}/_{mm^2}\right] = 44.3 \left[{}^{kg}/_{cm^2}\right] \qquad \text{Equ. 8}$$

The k value of the rigid pavement constructed above 50 mm dry lean cement concrete sub-base is estimated to 15 kg/cm² (CBR value of unbound base layer is min 7 %). Thus, as per IRC:58-2002 [S15] (see Fig. 8, Fig. 9 and Fig. 10), resulting to a flexural stress of the pavement with a thickness of 22 cm of 15.5 kg/cm², 18 kg/cm² and 15 kg/cm² for single axle load and tandem axle load respectively.

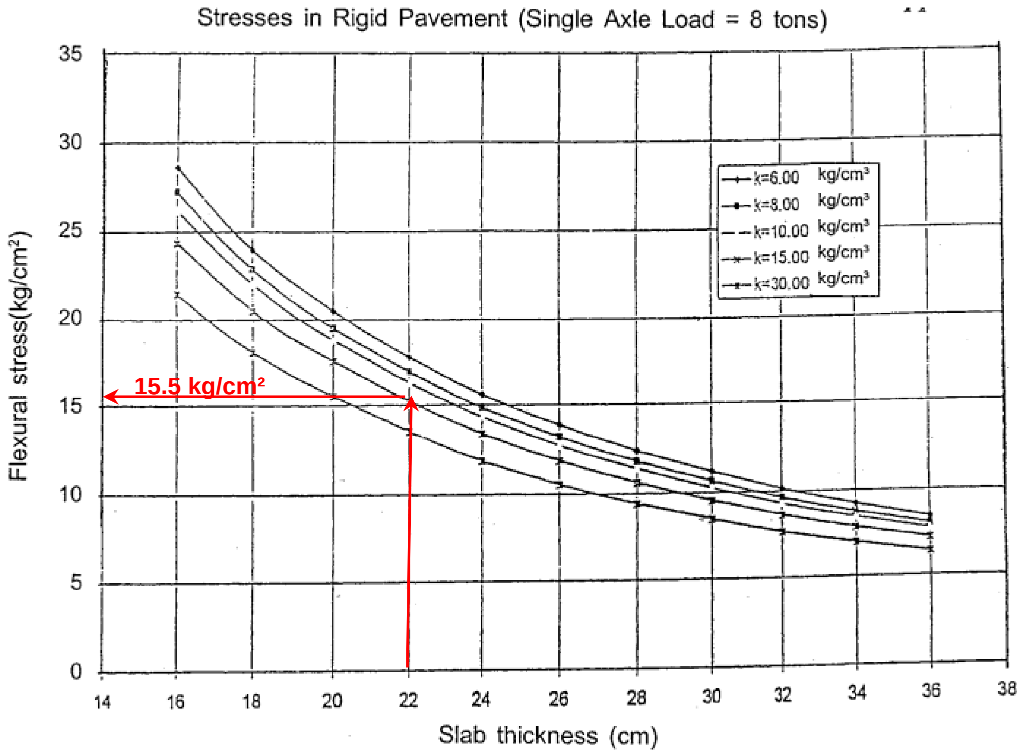


Fig. 8 Determination of flexural rigid pavement stresses due to axle load of 8 tonnes for single axles

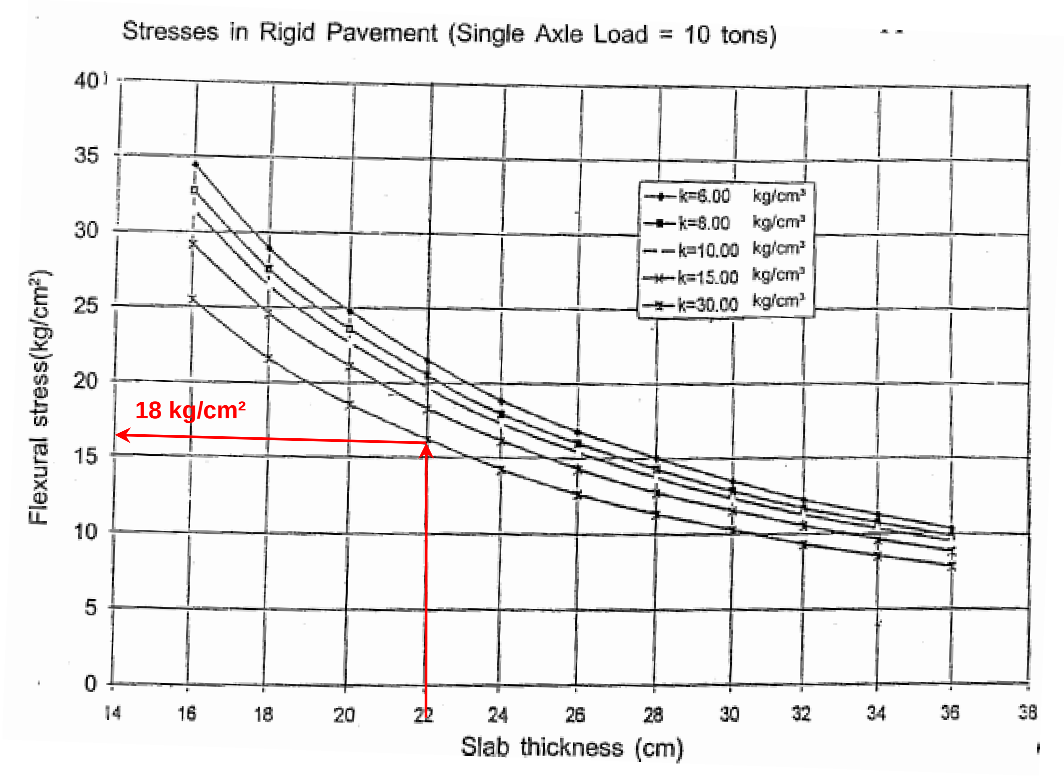


Fig. 9 Determination of flexural rigid pavement stresses due to axle load of 10 tonnes for single axles

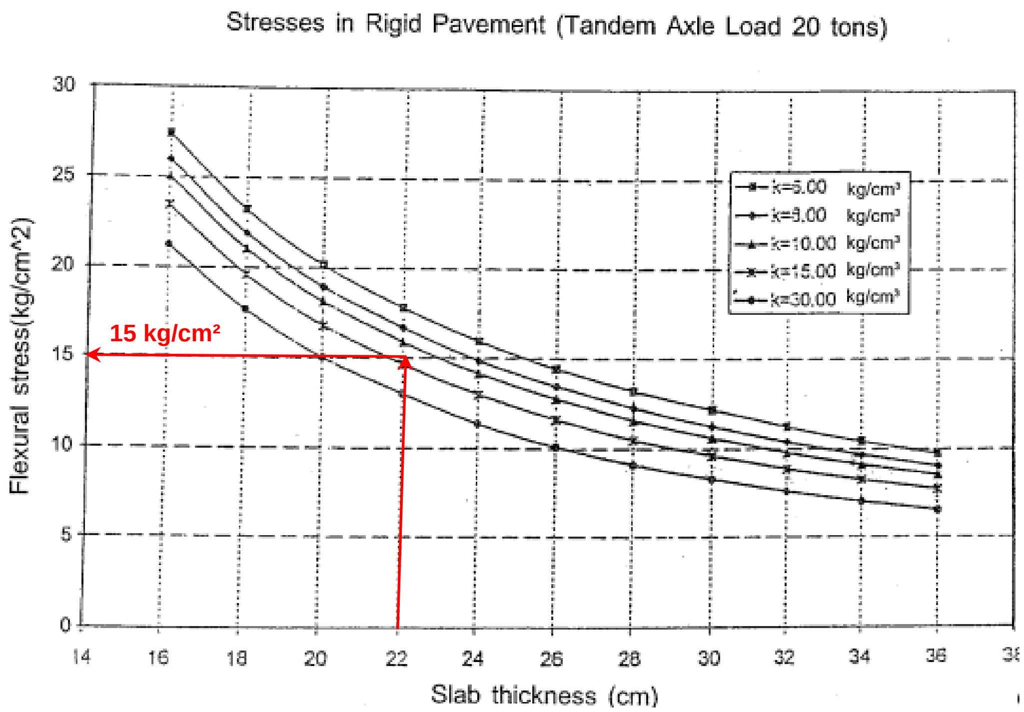


Fig. 10 Determination of flexural rigid pavement stresses due to axle load of 20 tonnes for tandem axles

The stress ration SR is the ration between the flexural stresses due to axle loading raised with the load safety factor AL of 1.2 and the flexural strength f_{cr} of the rigid pavement. The stress ration can be determined to 0.488 and 0.406 for single axle loading (10 tonnes) and tandem axle loading (20 tonnes).

$$SR = \frac{flexural\ stress \cdot 1.2}{f_{cr}} \qquad \text{Equ. 9}$$

The fatigue life N can be determined with following equation:

$$N = \begin{cases} unlimited\ for\ SR < 0.45 \\ \left(\frac{4.2577}{SR - 0.4325}\right)^{3.268} for\ 0.45 \le SR \le 0.55 \\ 10^{\frac{0.9718 - SR}{0.0828}}\ for\ SR > 0.55 \end{cases} \qquad \text{Equ. 10}$$

The fatigue life consumed N_{con} is the ration between the cumulative axle load repetitions for each axle load C and the fatigue life N for each axle load. The cumulative fatigue life consumed shall be smaller than 1.0, if this criterion is fulfilled the concrete pavement thickness and strength parameters are sufficient.

The fatigue life N and the consumed fatigue life N_{con} for each axle load are given in Tab. 11. The cumulative consumed fatigue is determined to 0.80, which is smaller than the maximum value of 1.0. Therefore the designed slab thickness of 22 cm is sufficient for the required design traffic and the design life of 20 years.

Tab. 11 Determination of consumed fatigue life N

Axle load	Cumulative axle load repetitions C in [-]	Stress ratio SR in [-]	Fatigue life N in [-]	Consumed fatigue life N in [-]
Single axle load 8 tonnes	$3.42 \cdot 10^6$	0.420	unlimited	0.0
Single axle load 10 tonnes	$1.14 \cdot 10^6$	0.448	$1.44 \cdot 10^6$	0.80
Tandem axle load 20 tonnes	$4.56 \cdot 10^6$	0.406	unlimited	0.0