राष्ट्रीय राजमार्ग एवं अवसंरचना विकास निगम लिमिटेड

NATIONAL HIGHWAYS & INFRASTRUCTURE DEVELOPMENT CORPORATION LTD.

BUILDING INFRASTRUCTURE - BUILDING THE NATION

FINAL DETAILED PROJECT REPORT

April 2020

CONSULTANCY SERVICES FOR PREPERATION OF DETAILED PROJECT REPORT AND PROVIDING PRE-CONSTRUCTION ACTIVITIES IN RESPECT OF THE FOLLOWING STRETCH ON NH-244 (OLD NH-1B) IN THE STATE OF JAMMU AND KASHMIR.

(1) SUDHMAHADEV- DRANGA TUNNEL OF APPROX. LENGTH 4.5 KM AND ITS APPROACH ROAD ON CHENANI - SUDHMAHADEV- GOHA ROAD PORTION.

(2) VAILOO TUNNEL OF APPROX. LENGTH 10.0 KM UNDER SINTHAN PASS AND ITS APPROACH ROAD ON GOHA-KHELLANI- KHANABAL ROAD PORTION.

(3) ROAD PORTION FROM 82.675 TO 82.925 AT KM 83 ON BATOTE-KISHTWAR ROAD SECTION OF NH-244.

(4) EXTENDED ROAD SECTION FROM GOHA TO KHELLANI OF 30 KM LENGTH

KHELLANI TUNNEL & ITS APPROACH ROAD
PACKAGE - II (KM 29.030 to KM 31.449)
VOLUME - II - DESIGN REPORT (TUNNEL)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. FOREWORD AND DOCUMENT CONTENT

This document has been elaborated as a Part of the Final of Detailed Project Report (DPR) of Goha- Khellani Bypass Tunnel.

The presented Tunnel Design Report for Goha- Khellani Bypass Tunnel has been incorporated as a main chapter in the **Part-I** of the **DPR, Volume-II DESIGN REPORT**, and has been prepared in full swing with Bridge and Roads Designs included in the volume, taking into account the live interaction with them.

The detailed contain of the Final DPR submission is as follows:

I) Volume-I Main Report:

II) Volume-II Design Report

Part-I Design of Project Structures

i. Design of Bridges

ii. Design of Tunnels

Part-II Design of Road Parameters and Pavement Composition

III) Volume-III Materials Report

IV) Volume-IV Environmental Assessment Report including Environmental Management Plan (EMP) & Resettlement Action Plan (RAP)

V) Volume-V Technical Specifications

VI) Volume-VI Rate Analysis

VII) Volume-VII Cost Estimates

VIII) Volume-VIII Bill of Quantities

IX) Volume-IX Drawing Volume

2. OBJECTIVES OF TUNNELS DESIGN

The aim of this report is the definition of all aspects of the Goha-Khellani Bypass Tunnel Design with enough accuracy to proceed with the socio-economic analysis, the financial analysis and the cost estimate for the Project, also to serve as a base support for the development of Preconstruction Activities provision.

Tunnel as underground infrastructure is located in hilly terrain. This tunnel is the part of Goha to Khellani Road.

The Tunnel Design depends in first instance on the tentative new road alignment, which is conditioned by the existing road network in the area and traffic data, presence of natural hazards (landslides, flash floods, snow avalanches, etc., especially at the portals), variation of local climatic conditions with the altitude, orographic constraints, Construction practical consideration, and socio-environmental concerns.

3. BASIC DESIGN FACTORS FOR TUNNEL

This chapter of present document covers basic factors influencing to the preliminary design of tunnels, which in fact is linked directly to the expected Construction Methodology. Therefore, it is explained the main reasons to foresee a tunnel construction in this hilly area taking into account the existing constraints.

3.1 Tunnel Construction Need and Benefits

A tunnel has been proposed to bypass the congested area of Khellani town and also to avoid sharp bend of existing road. The proposed Khellani bypass tunnel will cater the traffic from Sudhmahadev – Dranga Tunnel alignment as well as traffic coming from Batote (NH-244).

3.2 Applicable Specifications & Standards, Codes and Regulations, their Priority

Specifically, for tunnel design and construction there are some references on Specifications and Standards to be observed, which consist in National & International Codes of Practice, Rules, Directives, Regulations and Recommendations. Although it is convenient to give priority to the Indian National Specifications & Standards, in case of being silent or under omission of particular technical aspects International codes and regulations shall be referred to.

As a first reference, it has to be cited the Indian Roads Congress manual **IRC: SP:91-2010 Guidelines for Road Tunnels** which serves as a guidance for tunnel aspects like types and geometry of tunnels, terrain investigation procedures, planning and design criteria, methodology of construction and safety during construction, implementation of MEP systems, and Operation & Maintenance overview. It also includes a list of main IS codes for tunnelling works.

There are also some IRC codes for reference to general road design in hilly areas, and manuals mentioned by the Client in the ToR for Consultant's guidance. They can be cited as under:

- **IRC:73-1980 Geometric Design Standards for Rural (Non-urban) Highways**, reprinted in June 2011 and digitalized in 2014
- **IRC: SP:48-1998 Hill Road Manual**

- **IRC: SP:73-2007 Manual of Standards & Specifications for Two Laning of State Highways on B.O.T. Basis**, reprinted in October 2010, digitalized in 2014

Additionally, among the National Codes from BIS (Indian Standards) which may be used as reference, but not limited to, are following:

- **Regarding tunnel Design:**
  - **IS 13365 Quantitative classification system of rock mass – Guidelines:**
    - **Part 1:1998 RMR for predicting of Engineering Properties**
    - **Part 2:1992 Rock mass quality for prediction of support pressure in underground openings**
  - **IS:4880** – 1971 to 1987 **Code of Practice for Design of Tunnels Conveying Water** (Part I to VII), but only applicable to other tunnel structures:
    - **Part I General Design**
    - **Part IV Structural Design of Concrete Lining in Rock**
    - **Part V Structural Design of Concrete Lining in Soft Strata and Soils**
    - **Part VI Tunnel Supports**
  - **IS:1893-1984_Criteria for Earthquake resistant design of Structures**, regarding only general seismic principles and design criteria
- **Regarding tunnel Construction and Safety:**
  - **IS 15026:2002 Tunneling Methods in Rock Masses – Guidelines**
  - **IS:5878 –** 1970 to 1976 **Code of Practice for Construction of Tunnels conveying water** (Part I to VII), including only parts applicable to other tunnel structures:
    - **Part I Precision Survey and Setting Out**
    - **Part II Underground Excavation in Rock, Section 1 Drilling and Blasting**
    - **Part II Underground Excavation in Rock, Section 2 Ventilation, Lighting, Mucking, and Dewatering**

- **Part II Underground Excavation in Rock, Section 3 Tunneling Method for Steeply Inclined Tunnels, Shafts and Underground Power Houses**
- **Part III Underground Excavation in Soft Strata**
- **Part IV Tunnel Supports**
- **Part V Concrete Lining**
- **Part VII Grouting**

- **IS:4756 – 1978 Safety Code for Tunnelling Works**
- **IS:4081 – 1986 Safety Code for Blasting and related Drilling Operations**

It has to be highlighted here that depending on the development of ultimate tunnel technologies or design methodologies as State of the Art, in case of no incorporation of such items by the above-mentioned National Codes and Guideline, it may be required to call for International Specifications and Standards.

Furthermore, most of the regulations, manuals and guidelines are not mandatory/compulsory, and therefore they form part of suggestions and recommendations to follow.

Among the International Regulations and Standards, from contrasted Technical Organizations or Countries Governments (in their normalization efforts), it can be cited in order of preference:

Online **"Road Tunnels Manual"**, World Road Association (PIARC), last update 2015 (Seoul), focused on Tunnel Operation & Safety, and related transverse aspects like general design of the tunnel. In this manual there are many references to Technical Reports edited by the PIARC Technical Committee on "Road Tunnel Operations" which can be considered as included in the references.

Directive 2004/54/EC of the European Parliament and of the Council on **"Minimum Safety Requirements for Tunnels in the Trans-European Road Network"**, 2004

"Guidelines for the Design of Tunnels", ITA (International Tunnelling Association) WG on General Approaches to the Design of Tunnels, 1988 – Tunnelling and Underground Space Technology, Vol. 3, No. 3, pp 237-249

"Recommendations on the development process for Mined Tunnels", ITA Report

No. 17 WG 14 Mechanized Tunnelling & 19 Conventional Tunnelling, 2016. This report contains considerations for the selection of most appropriate Tunnelling method in Projects

"General report on Conventional Tunnelling Method", ITA Report No. 2 WG 19 Conventional Tunnelling, 2009

"TBM Excavation of Long and Deep Tunnels Under Difficult Rock Conditions", ITA Report No. 19 WG 17 Long Tunnels at Great Depth, 2017

"Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation", Austrian Society of Geomechanics, 2010

"Monitoring and Control in Tunnel Construction", ITA Report No. 9 WG 2 Research, 2011

"Seismic design and analysis of underground structures", ITA WG 9 on Seismic Effects, 2001 – Tunnelling and Underground Space Technology, Vol. 16, No. 4, pp 247-293

EN1990:2002 "Eurocode 0: Basis of structural design", European Committee for Standardization (CEN), 2002

EN1991-1:2002 "Eurocode 1: Actions on structures", CEN, 2002

EN 1992-1-1 Part 1-1:2004 "Eurocode 2: Design of concrete structures– Part 1-1: General rules and rules for buildings, CEN, 2004

EN 1992-1-2:2004: "Eurocode 2: Design of concrete structures - Part 1-2: General rules – Structural fire design", CEN, 2004

EN 1997-1:2004 "Eurocode 7: Geotechnical design – Part 1: General rules", CEN, 2004

EN 1998-1:2004 "Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings", CEN, 2004

EN 1998-5:2004 "Eurocode 8: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects", CEN, 2004

Other relevant normative corresponds to international Tunnel Design Manuals and Construction procedures provided by individual countries. It can be mention, among others:

“Technical Manual for Design and Construction of Road Tunnels – Civil Elements”, U.S. Department of Transportation, Federal Highway Administration (FHWA), 2009

“Specification for tunnelling”, The British Tunnelling Society and the Institution of Civil Engineers, Thomas Telford, London, 2000

Engineering Manual EM 1110-2-2901 “Engineering and Design Tunnels and Shafts in Rock”, U.S. Army Corps of Engineers, 1997

3.3 Tunnel Geometry and Space Configuration, Safety Aspects

The tunnels space configuration depends on the selected more favorable alignment, traffic requirements, reference to standards (related to clearances among others) and incorporation of different systems inside the typical cross section. Following are the main aspects to be considered.

3.3.1 Tunnel Length and Number/Type of Lanes. Shoulders, Walkways and Cross Passages Provision

The twin tube tunnel layout with two unidirectional lanes (one traffic lane-on the left plus one emergency lane - on the right per tube) has been proposed. As the tunnels present a straight alignment, it is required to maintain constant the distance between tubes, around 30 m, keeping in view of the concentration of stresses in the pillar between tubes. This is shown in below figure:

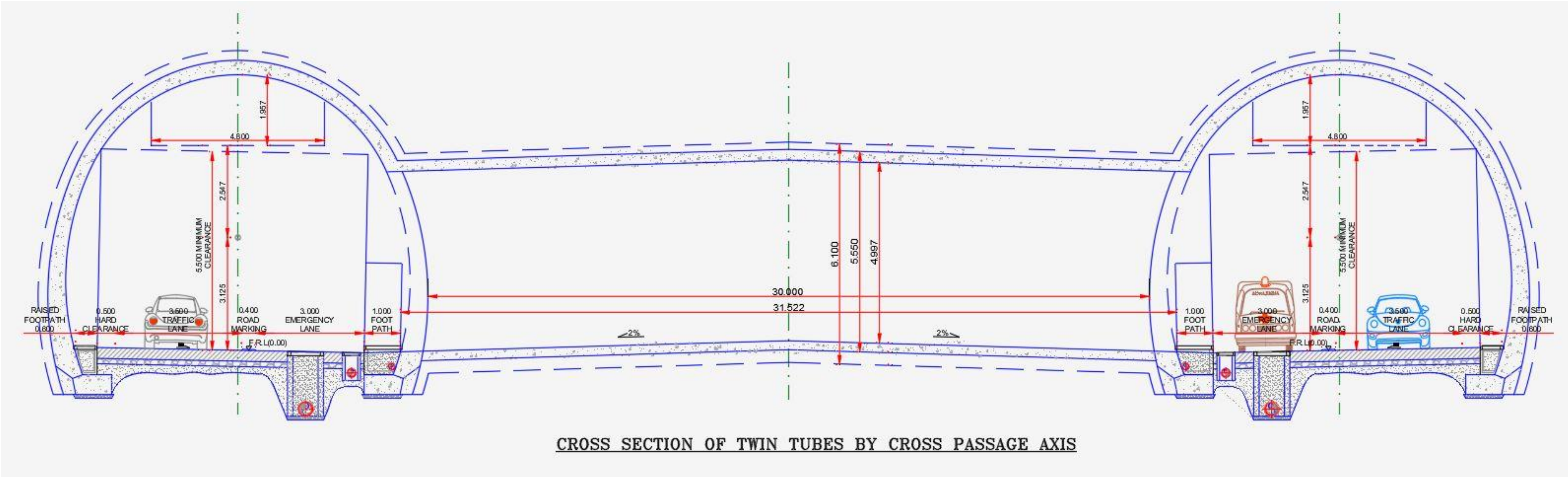


Figure 1: Two Twin Tubes Configuration for Khellani Tunnel

Although the stipulations verted in the IRC:SP:91-2010 includes spacing between 0.5 and 2.0 times the width of tunnels regarding clear distance between the tubes, in the Consultant's experience, during design and construction of other Projects in Himalayas and Sub-Himalayas region, the rule of thumb for tunnels with varied rock quality and huge overburden, around 1 km or more, is 2.5 D minimum. With reference to the safety, tubes with unidirectional traffic are less prone to generation of accidents/incidents.

Moreover, the presence of an emergency lane per tube is more favorable in case of vehicles breakdowns, because they can stop at any location (except cross passages intersections), instead of lay bays sections (refuges), which should be spaced a minimum of 750 m, as per IRC:SP:91-2010.

The configuration of unidirectional tubes contributes also to impulse longitudinal air circulation through drag effect of traffic movement, which is added to the effect of jet fans operation.

Regarding tunnel road cross section configuration, it is proposed a traffic lane 3.50 m wide accompanied by an emergency lane of width 3.00 m, with hard clearance of 0.5 m at the left side (traffic lane) only, and accompanied by a footpath 0.6 m wide, incorporating a slightly elevated strip with rollover kerb stone. Between the traffic and emergency lane it is foreseen a road marking with double continuous line, with a width of 0.4 m, and incorporation of rumble strip for safety reasons This road section conforms to the prescriptions given for Highways in the **IRC:SP:73-2007**, **Manual of Standards & Specifications for Two Laning**, Section "2 GEOMETRIC DESIGN AND GENERAL FEATURES", point "2.4 Lane width of Carriageway", which are normally applicable to bidirectional roads. In the next table it is shown a summary of road cross section configuration:

Table 1: Summary of Road Cross Section

Cross Section Element	Width
Walkway	0.60m
Hard Shoulder	0.50m
Driving Lane	3.50m
Road Marking	0.40m
Emergency Lane	3.00m
Walkway	1.00m
Overall	**9.00m**

There is provision for elevated (20 cm above carriageway level) walkway at right sidewall (escape route to cross passage side), above cable channel slab covers, with horizontal clearance of 1.0 m and vertical of 2.3 m.

Emergency escape routes are provided by the incorporation of cross passages connecting both the tubes, with orientation normal to tunnel horizontal alignment, and spacing of around 250 m between them. This arrangement conforms to the Indian code but is stricter than international guidelines and directives, and the main reason for its selection is that the type of ventilation system assumed for Tunnel, a longitudinal TVS system, conforms to safety requirements but near to the admissible limits, therefore it has been selected this spacing to match desirable safety requirements.

3.3.2 Horizontal and Vertical Alignment

Horizontal Alignment

The tunnel is aligned keeping in view of the topography, length and the location such that tunnel passes through the region having adequate cover all around. The length of tunnel tube-1 and tube-2 is 1541m and 1574m respectively. The western portal is located about 45 m away from NH-1B on the existing village road at an El. 1176.98m. Eastern portal is located near the Khellani town near the highway (NH-1B) at an El. 1129.90m. This tunnel traverses straight towards Khellani town with no curves and acts as a Bypass to Khellani town.

Vertical Alignment

Western portal & Eastern portal of tunnel have been kept at El. 1176.98m and El. 1129.90m respectively. Slope of 3% has been provided in the tunnel.

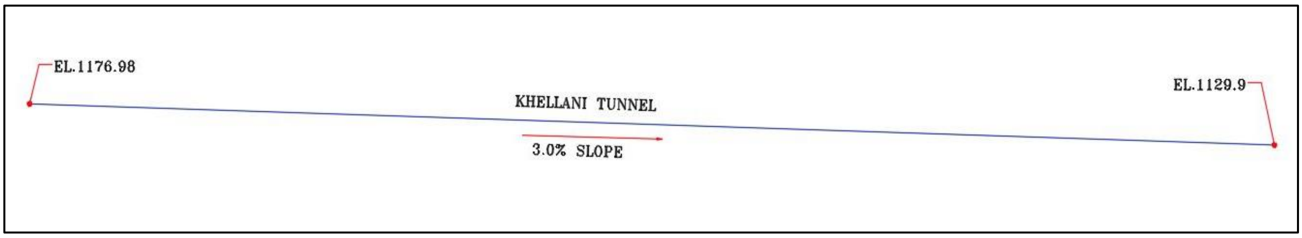


Figure 2: Tunnel Elevation

3.3.3 Tunnel Dimensions: Clearances

As per above explained tunnel road cross section, horizontal clearance of tunnel carriageway is 6.5 m, plus elevated walkways at right sidewall 1.0 m wide, and vertical clearance 5.5 m, as per IRC: SP:91-2010 stipulations. The vertical clearance provided in the pedestrian walk paths is 2.3 m, according to some international standards.

Regarding to cross passages between tubes, the recommended clearance profile will be 5.0 m horizontal (carriageway) by 3.0 m vertical to cope with emergency or maintenance (if decided) vehicular transit, during the construction works and further in operation stage.

In case of cross passages for pedestrian use only, the recommended clearance profile will be 2.5 m (H) x 2.5 m (V). This tunnel has not envisaged pedestrian cross passages to allow vehicular transit during works.

3.4 Geological Constraints and Description along Proposed Alignment

In this valley, the project area around tunnel alignment, gneiss, biotite gneiss, quartzite, mica schist, granitic gneiss, porphyritic granitic gneiss, inpure limestone with intercalation of quartz veins of Salkhala Formation of Precambrian age and Kaplas Granite & Bhalla Granite lithounits of Lower Palaeozoic (?) age (Vaid & Lal, 1990-91, GSI). These are best exposed along the main highway and connecting road to main highway.

3.5 Methodology of Construction and Design Basis

Based on the above description regarding tunnel solution and its design, along with described external factors which influence on the same, it is explained briefly in the next paragraphs the main aspects of Tunnel Construction and Design.

3.5.1 Discussion on Construction Methodology

For the excavation and support/lining of the Project tunnels it could be proposed several Construction methodologies, like following:

Mechanized Tunnelling methods: These include TBM and Shielded machines, which allow removal of excavation by pipes, conveyor belts or rail transport, as well as tunnel support and/or lining in the tail of the advancing machine. In this case it is considered only integral machines with full face excavation capacity, although there are also for partial face excavation.

Conventional Tunnelling methods: Drill & Blast and/or mechanical excavation (except above mentioned) including required cycle of construction activities for excavation, removal of muck and support, also final lining separated by a space/time gap.

The Conventional Tunnelling Method (Drill & blast combined with mechanical localized excavation whenever required) is proposed for the construction of tunnel. Tunnel is designed with the principles of NATM.

3.5.2 Tunnel Functional Section to Accommodate Road Cross Section and MEP Systems

The geometric requirements for a determined functional section are subjected to the following facts:

- Tunnel clearance box dimensions, which depends on road cross section provisions and allowance for ODC consignments.
- Presence of curves and its alignment parameters.
- Carriageway super elevation (cross slope gradient of the pavement).
- Distribution of in situ stress field around the cavity (linked to the tunnel shape) and related ground conditions.
- Accommodation and/or dedicated spaces in the cross section for MEP systems to be installed.

According to the methodology of construction, NATM, the use of horseshoe tunnel shape has been sufficiently contrasted as efficient and accepted worldwide. So it has been worked out for this Project, in order to cope with the underground pressures developed in situ.

For the Khellani unidirectional twin tubes tunnel, the cross section with a geometry as shown in the images below, for functional sections without and with invert:

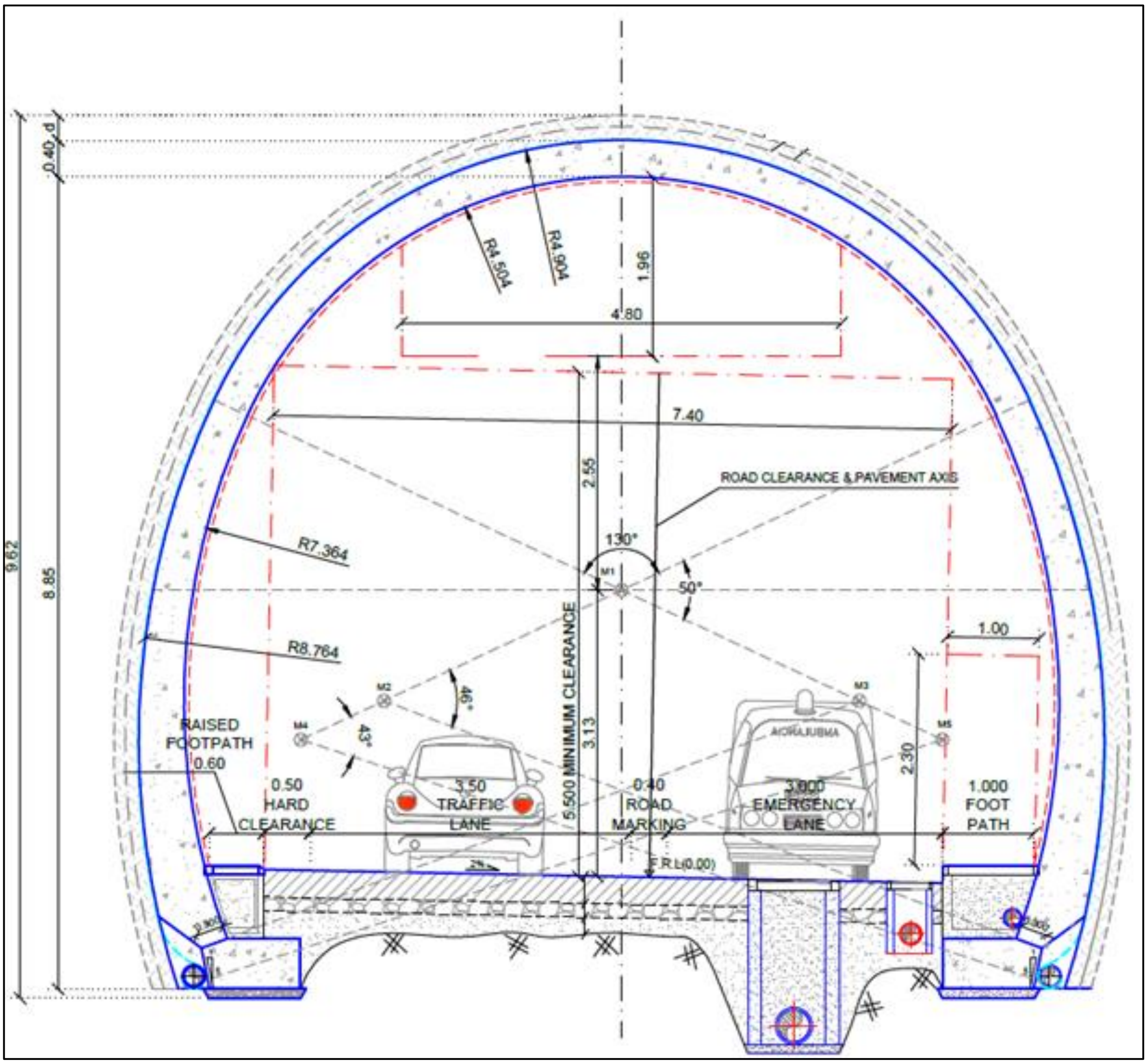


Figure 3: Typical Section of Tunnel (Twin Tubes) without Invert

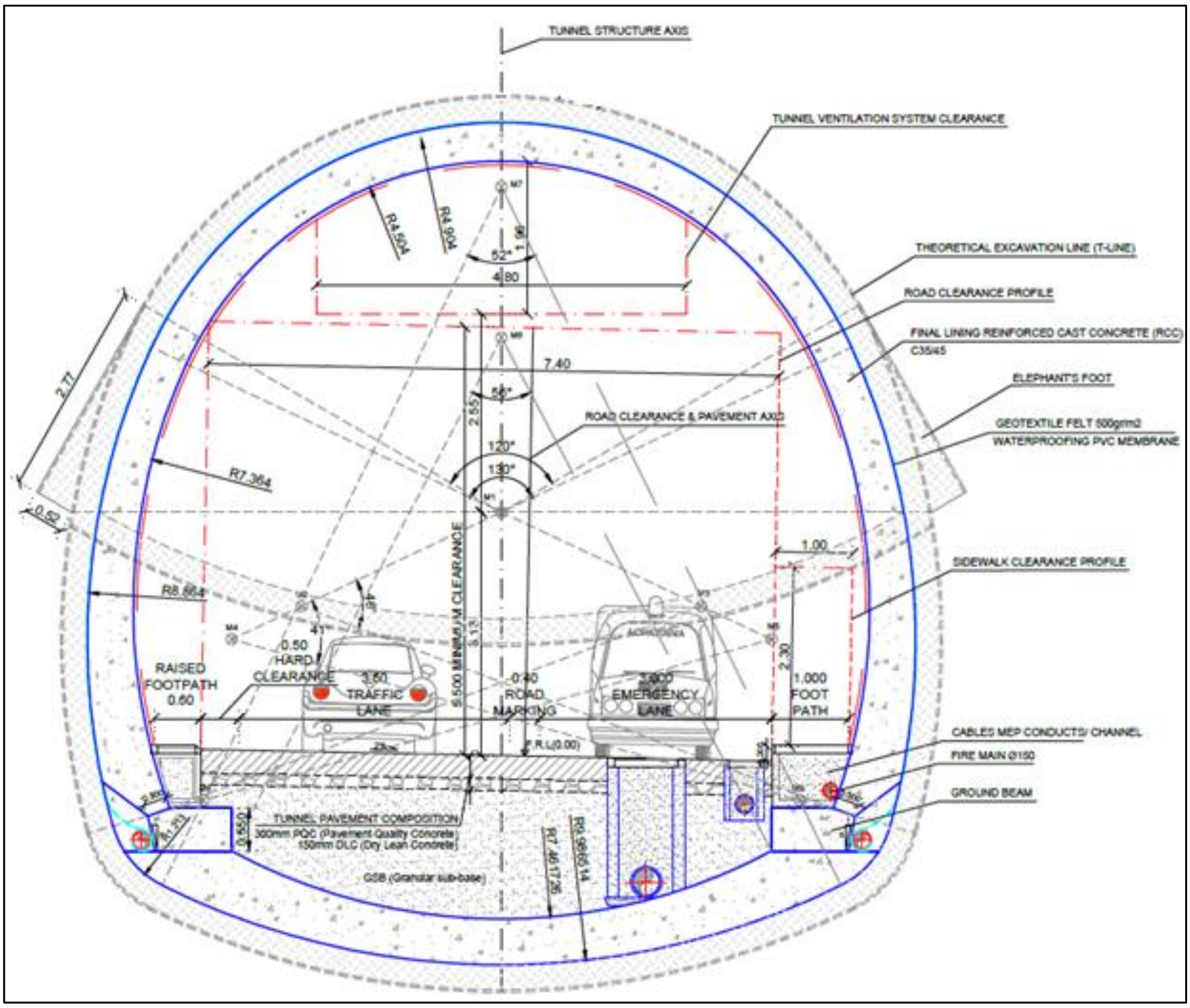


Figure 4: Typical Section of Tunnel (Twin Tubes) with invert (Rock Classes 4 and 5)

The regular geometry of this section has been adapted to a longitudinal ventilation system with two jet fans symmetrically located at both sides of crown axis, allowing at the same time space for cable/pipe channels at right side edge above respective ground beam, with their covers forming part of foot path, for PQC pavement 300 mm thick and subjacent layers composition, for cable pipes below the left side edge, and for pipes included in the tunnel drainage system (surface drainage plus rock mass drainage) with their respective manholes and fire kill boxes, for required traffic signs, and for other elements/components/devices of Traffic Control System and ITCS.

3.5.3 Cross Passages Implementation and Main Features

As indicated above, there is provision of Cross Passages every 250 m to allow emergency egress for the users in case of any incident/event which recommends the evacuation of people from the tunnel tube. Additionally, to interconnect also both the tunnel tubes during construction stage, and also during development of operation & maintenance activities inside tunnel.

It is not at all advisable to follow the stipulations of the IRC: SP:91-2010 regarding the orientation of the cross passage related to the tunnel tubes alignment, due to following reasons:

- The cross-passage length is more in case of skewed direction related to tunnel alignment
- With 30º of angle as shown in the scheme (point 2.8.2.5 of guidelines) two out of four corner for the junction rock pillars will be very sharp, which is not convenient due to stress concentration
- In case of twin unidirectional tubes, the emergency/authorized vehicles will be driven towards opposite direction to the traffic, without possibility to maneuver (turn) towards the correct traffic direction.

Therefore, it is strongly advised the cross-passage orientation as much as possible normal to tunnel axis.

The cross passages are suggested to be designed allowing chamfered junctions with the tunnel tubes in order to serve as a connecting path between tubes for the machinery during construction stage, and also allow turning of authorized/emergency vehicles coming from emergency lane in the tunnel tube. The use of bevel edges helps to distribute stresses.

The decision on how many cross passages will be only for pedestrian use and how many for emergency vehicular use may depend on safety requirements and construction program, and in this case construction planning criteria rule, which enhances safety level. This layout matches with the stipulations included in the IRC: SP:91-2010 for cross passages provisions, that incorporates one traffic lane plus edge strips and walkways at both the CP sides. Nevertheless, no clearances have been specified in this code.

At this point, it is important to highlight that cross-passage clearance shall not interfere with MEP installations and rooms for E&M equipment like Low tension panels and battery banks, transformers stations, etc.

In the preliminary design, it may be made provision for dedicated niches to accommodate E&M equipment and installations, and the driving lane width is 3.5m, with edge strip of 1.0 m at left side. The incorporation of elevated walkways along CP's side has been regarded as well.

According to above considerations referred to cross passages and emergency egress, the functional cross section for the cross passages is same both for vehicular and pedestrian access. In next figures are shown functional sections for cross passages without (above) and with invert (next page):

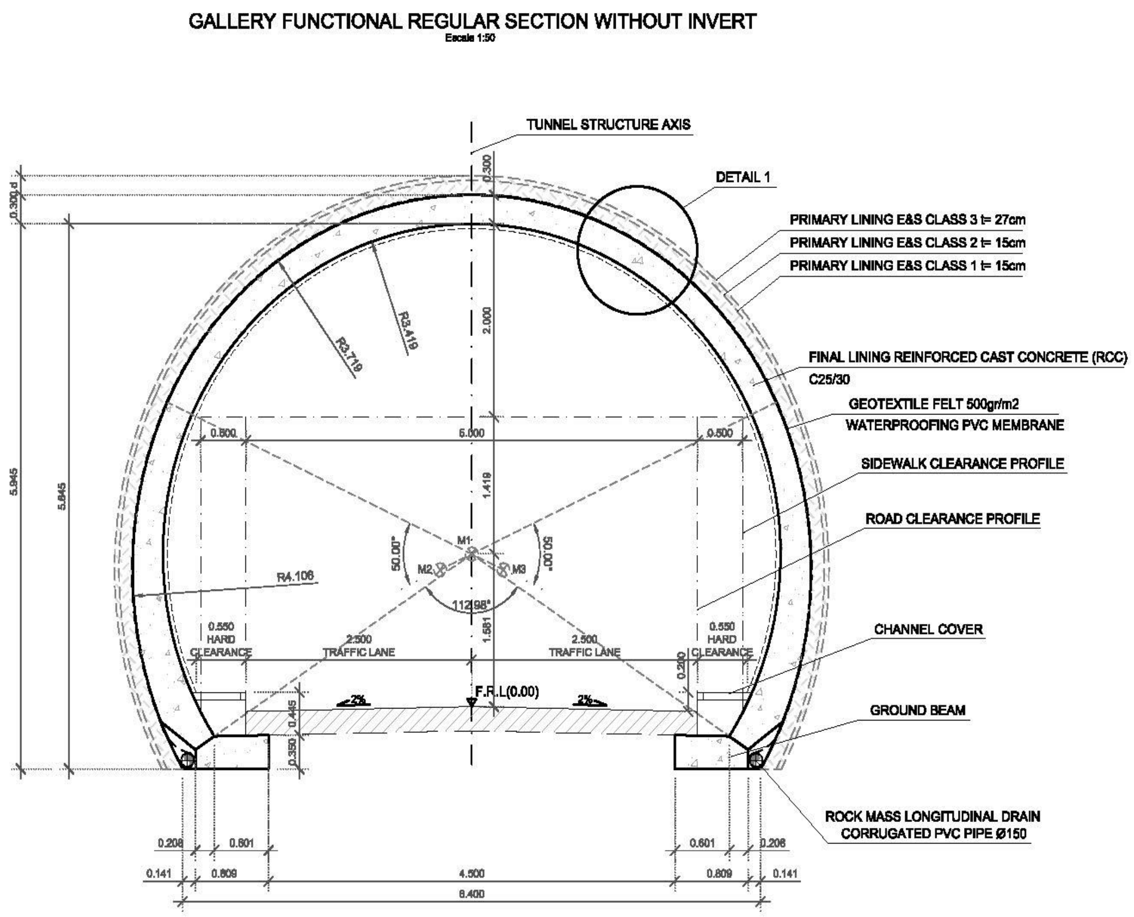


Figure 5: Typical Section of Cross Passage Gallery without Invert (Rock Class 1 to 3)

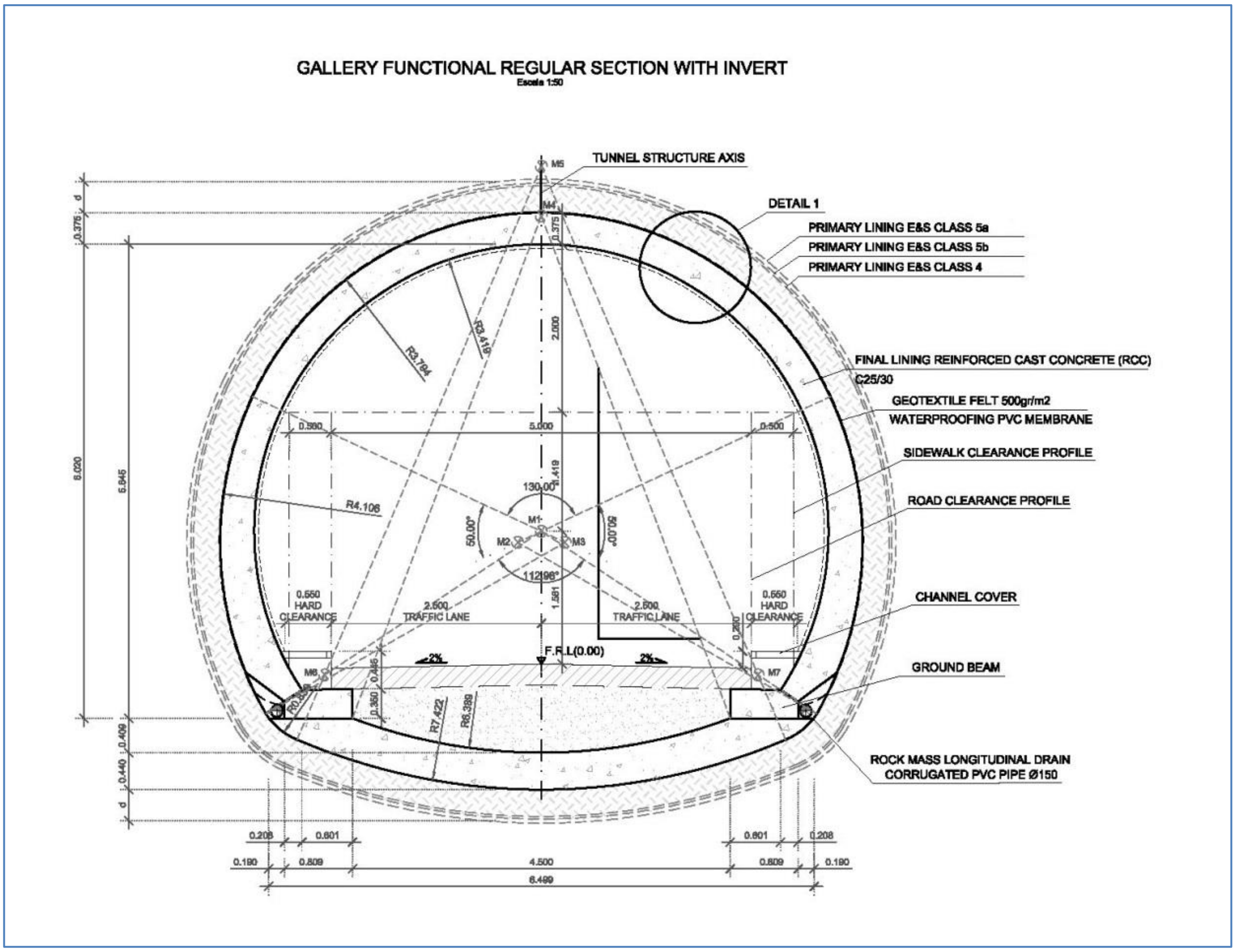


Figure 6: Typical Section of Cross Passage Gallery with Invert (Rock Class 4 and 5)

The corners of the pillars in the junctions between main tunnel and cross passages should be chamfered, in order to facilitate the turning of emergency/authorized vehicles, and also the maneuvers of construction vehicles/machinery. This smoothed shape will allow also redistribution of in situ stresses in the junction.

3.5.4 Tunnel Pavement Design

It is included in this Project the suggested provision of rigid pavement, as PQC quality concrete, which must be adjusted according to the traffic features and intensity, as well as the sequence of subjacent layers composition.

The rigid pavement is rather more expensive than the flexible (bituminous) pavement, but in return usually requires much less repairing/maintenance tasks (black topping, resurfacing, and drainage issues) along with its disturbing consequences inside tunnel, if properly and carefully executed.

In the next scheme it has been included the rigid pavement composition. Rigid pavement conforms to the recommendations verted in the IRC: SP:91-2010 regarding tunnel pavements. This code cites the harmful effect of seepage water in the pavement.

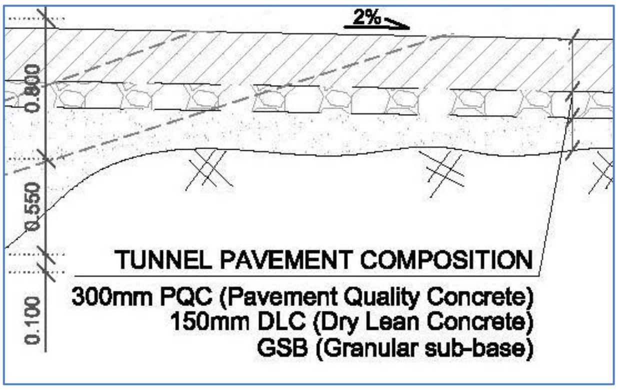


Figure 7: Scheme Section of Tunnel Pavement

3.5.5 Overview of Drainage System

The Project tunnels have been considered as fully draining tunnels, not watertight tunnels, concerning to the underground water, so a drainage system has been envisaged in the periphery of tunnel cavity, which includes an outer drain-collecting layer of geotextile felt for the surrounding rock mass seepage water, a PE or PVC waterproofing membrane, and a drain slotted/perforated & corrugated pipe Ø250 mm at the back toe of both the sidewalls, behind the inner lining ground beam.

Depending on the water flow quantities expected as average per tunnel meter, and the length of the tunnel, it has been analyzed the requirement of a main tunnel drainage pipe below the center line of the emergency lane. This arrangement facilitates the execution in two parts of the pavement subgrade, pavement composition layers and PQC concrete with the required steel reinforcement, during the construction stage.

Apart from this, a surface drainage system has been incorporated as habitual practice for drainage system, to collect water from road pavement and tunnel lining periphery, if required. The design of this drainage includes slot gutters and/or manholes with grid/slotted covers to collect all the surface water.

It has been foreseen the allowance of dangerous goods vehicles transporting hydrocarbon liquids with limited capacity, hence it must be conceived the incorporation of Fire-kill boxes at suitable spacing in the surface drainage pipe, in order to prevent spreading of flammable and toxic liquids along this pipe or to other tubes. The Fire-kill manhole possesses a particular design, with separated compartments and up to down level barriers to avoid HC propagation to next tube section.

3.5.6 Tunnel Safety Provision

The **twin tubes tunnel configuration** allows the unidirectional one lane traffic in each tube, which **reduces the risk of accident inside tunnel**.

The **provision of emergency lane (right side) has an advantage regarding vehicle breakdown and other incident** involving vehicle emergency stop, which can be done at any point, except cross passage entrance locations.

Also **O&M teams and staff can circulate through emergency lane without disturbance of traffic**. In this sense it is convenient to place the drainage access manholes covers &slotted gutters, along with most critical MEP services cables, conducts, pipes in the emergency lane side.

The **use of emergency lane by the tunnel customers in case of an emergency could involve complications for the emergency services access**, so unless specified in special circumstances, in principle it is not foreseen. In the present situation, this lane will be of exclusive use of O&M authorized vehicles and emergency vehicles.

Cross passages at spacing intervals of 250 m are envisaged in order to allow access to rescue/authorized/emergency vehicle and provide escape pedestrian route to the tunnel users in case of emergency.

The **diversion of traffic to the cross passages in case of accident/incident is not contemplated** in principle, due to interference with evacuation by emergency/rescue services, risk of smoke propagation from disturbed tube to evacuation tube. Only extreme situations permitted by the competent Authority and checked through risk analysis may allow this emergency operational practice.

In fact, for safety purposes it is proposed the adoption of some **safety measures related to the commuter guiding before and/or entering the tunnel in order to avoid the improper overtaking or invasion of emergency lane**. Such type of measures is based on road marking and traffic signs, mainly, supplemented by some features of traffic control system in the tunnels. Following may be taken into account:

- Rumble strip included in a road marking white coloured of 400 mm width, consisting on two continuous lines 150 mm wide each plus an space between them 100 mm wide: The rumble strip produces a sound and vibration sensation when wheels circulate over it, and prevents the crossing to emergency lane advising to the user of wrong maneuvering. Double continuous line indicates already to the commuter the prohibition to trespass such line while driving. It has to be added that this marking line should not be classified as a median (as per IRC:35-1997), but with similar adapted features.

- Road signs indicating circulation forbidden all along the emergency lane and provision for restriction of overtaking: In this case, it is considered that overtaking prohibited sign is confusing to the drivers, and can lead to some people to initiate the forbidden action, so the most convenient signal proposed is the lane closed sign preferably at the tube entrance, as shown below, according to the figure 15.38 in the IRC:67-2012. It must be noticed that in the tube there is only a traffic lane (open lane).

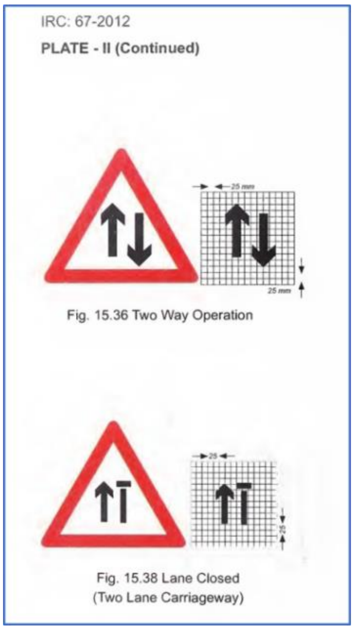


Figure 8: Lane Closure Sign as indicated in IRC:67-2012

Nevertheless, and at infrastructure owner discretion it could be analyzed the use of overtaking prohibited signs inside the tunnels, during the detailed design stage regarding traffic signs and road marking layout, taking into account experiences on user's behavior and reaction.

Use of Entrance Variable Message signs (EVS) and Tunnel Variable Lane signs (TLS) applied to the two foreseen lanes: In this case the criteria for display of lighting (LED) symbols in the dynamic panel hanged from the tunnel crown should be a prohibited entrance sign for the emergency lane, and a green downward arrow for the traffic lane in normal operation conditions, in case of EVS panels (tunnel entrances), whilst a red cross for emergency lane, and a green downward arrow for the traffic lane in normal operation condition, in case of TLS panels (inside tunnels). All these traffic lighting signs must be driven by the Traffic Control System (TCS) as a subsystem of the ITCS system. One example of 500 mm square combo display panel in metal body for is shown below, and also the signs options for EVS panels:

Figure 9: Examples of TVLS Signal (left) and Scheme for EVS Signal Panel with for Symbols

- Some additional reinforcement measure could consist on the use of delineation elements and markers (raised pavement retroreflective markers or cat's eyes), guide posts (flexible), flexible barriers (wire rope barriers, able to be opened)

Contrarily to expected, as per PIARC above mentioned Manual, wire rope barriers used to separate traffic flows may show a reduction in collisions, fatalities and serious injuries, including motorcycles, in a study at Holland

Changing the topic and as explained before, the unidirectional flow contributes in some extent to longitudinal ventilation.

In the next page tables, extracted from the "Directive 2004/54/EC of the European Parliament and of the Council on minimum Safety requirements for tunnels in the Trans-European road Network" dated 29-04-2004, it has been reflected all recommendable structural conditionings and aspects of geometric design depending on road tunnel length.

As it can be noticed, the maximum spacing between transverse cross galleries for evacuation which has been indicated is 500 m, less exigent than in the case of IRC code, whilst the distance between lay-bays shall not exceed 1000 m in new bidirectional tunnels longer than 1,500 m, if there is no emergency lane.

The emergency exits, corresponding to cross passages, shall be required as cross connections for emergency vehicles at least every 1500, so cross passages may include both pedestrian and vehicular.

This Directive states also that the main criteria for deciding whether to build a single bidirectional or a twin-tube tunnel shall be projected traffic volume and safety. The traffic Projection of reference corresponds to a 15 years forecast with daily traffic volume of 10,000 vehicles/lane, not converted to PCU, but this reflects a mandatory condition for election of unidirectional twin tunnels if the same is exceeded.

It has to be highlighted that in this Project the prevalent criteria has been the safety concept of tunnel, and the predicted future use as National Highway combined with the life span of such structure.

SUMMARY OF MINIMUM REQUIREMENTS ● mandatory for all tunnels ❍ not mandatory ✱ mandatory with exceptions ☯ recommended			Traffic ≤ 2,000 vehicles per lane		Traffic > 2,000 vehicles per lane			Additional conditions for implementation to be mandatory, or comments
			500-1,000 m	>1,000 m	500-1,000 m	1,000 – 3,000 m	>3,000 m	
Structural measures	2 tubes or more	§2.1						Mandatory where a 15-year forecast shows that traffic > 10,000 vehicles per lane.
	Gradients ≤ 5 %	§2.2	✱	✱	✱	✱	✱	Mandatory unless not geographically possible.
	Emergency walkways	§2.3.1 . §2.3.2	✱	✱	✱	✱	✱	Mandatory where there is no emergency lane, unless the condition in §2.3.1 is respected. In existing tunnels where there is neither an emergency lane, nor an emergency walkway additional / reinforced measures shall be taken.
	Emergency exists at least every 500 m	§2.3.3 - §2.3.9	❍	❍	✱	✱	✱	Implementation of emergency exists in existing tunnels to be evaluated case-by-case.
	Cross-connections for emergency services at least every 1,500 m	§2.4.1	❍	❍ / ●	❍	❍ / ●	●	Mandatory in twin-tube tunnels longer than 1,500 m.
	Crossing of the central reserve outside each portal	§2.4.2 .	●	●	●	●	●	Mandatory outside twin- or multi-tube tunnels wherever geographically possible.
	Lay-bys at least every 1,000 m	§2.5	❍	❍	❍	❍ / ●	❍ / ●	Mandatory in new bi-directional tunnels > 1,500 m without emergency lanes. In existing bi-directional tunnels > 1,500 m: depending on analysis. For both new and existing tunnels, depending on extra usable tunnel width.
	Drainage for flammable and toxic liquids	§2.6	✱	✱	✱	✱	✱	Mandatory where transport of dangerous goods is allowed.
	Fire resistance of structures	§2.7	●	●	●	●	●	Mandatory where a local collapse can have catastrophic consequences.

SUMMARY OF MINIMUM REQUIREMENTS

● mandatory for all tunnels ❍ not mandatory
✱ mandatory with exceptions ☯ recommended

			Traffic ≤ 2,000 vehicles per lane		Traffic > 2,000 vehicles per lane			Additional conditions for implementation to be mandatory, or comments
			500-1,000 m	>1,000 m	500-1,000 m	1,000 – 3,000 m	>3,000 m	
Lighting	Normal lighting	§2.8.1	●	●	●	●	●	
	Safety lighting	§2.8.2	●	●	●	●	●	
	Evacuation lighting	§2.8.3	●	●	●	●	●	
Ventilation	Mechanical ventilation	§2.9	❍	❍	❍	●	●	
	Special provisions for (semi-) transverse ventilation	§2.9.5	❍	❍	❍	❍	●	Mandatory in bi-directional tunnels where there is a control centre.
Emergency stations	At least every 150 m	§2.10	✱	✱	✱	✱	✱	Equipped with telephone and 2 extinguishers. A maximum interval of 250 m is allowed in existing tunnels.
Water supply	At least every 250 m	§2.11	●	●	●	●	●	If not available, mandatory to provide sufficient water otherwise.
Road signs		§2.12	●	●	●	●	●	For all safety facilities provided for tunnel users (see the Third Schedule)
Control centre		§2.13	❍	❍	❍	❍	●	Surveillance of several tunnels may be centralised into a single control centre.
Monitoring systems	Video	§2.14	❍	❍	❍	❍	●	Mandatory where there is a control centre.
	Automatic incident detection and/or fire detection	§2.14	●	●	●	●	●	At least one of the two systems is mandatory in tunnels with a control centre.
Equipment to close the tunnel	Traffic signals before the entrances	§2.15.1	❍	●	❍	●	●	
	Traffic signals inside the tunnel at least every 1,000 m	§2.15.2	❍	❍	❍	❍	☯	Recommended if there is a control centre and the length exceeds 3,000 m.
Communication system	Radio re-broadcasting for emergency services	§2.16.1	❍	❍	❍	●	●	
	Emergency radio messages for tunnel users	§2.16.1	●	●	●	●	●	Mandatory where radio is re-broadcasted for tunnel users and where there is a control centre.
	Loudspeakers in shelters and exists	§2.16.3	●	●	●	●	●	Mandatory where evacuating users must wait before they can reach the outside.
Emergency power supply		§2.17	●	●	●	●	●	To ensure the functioning of indispensable safety equipment at least during evacuation of tunnel users.
Fire resistance of equipment		§2.18	●	●	●	●	●	Shall aim to maintain the necessary safety functions.

Figure 10: Summary Table with Safety and MEP Installation Requirement as per European Directive2004/54/EC

All the MEP provisions related to safety requirements and safety tunnel concept are developed in the next paragraphs.

3.5.7 Ventilation System

There are different systems for tunnel ventilation, each one with its own advantages and disadvantages. A complete description of the possible systems can be found in NFPA 502.

The following lines will serve as a simple introduction, with the minimum concepts necessary for the comprehension of the document.

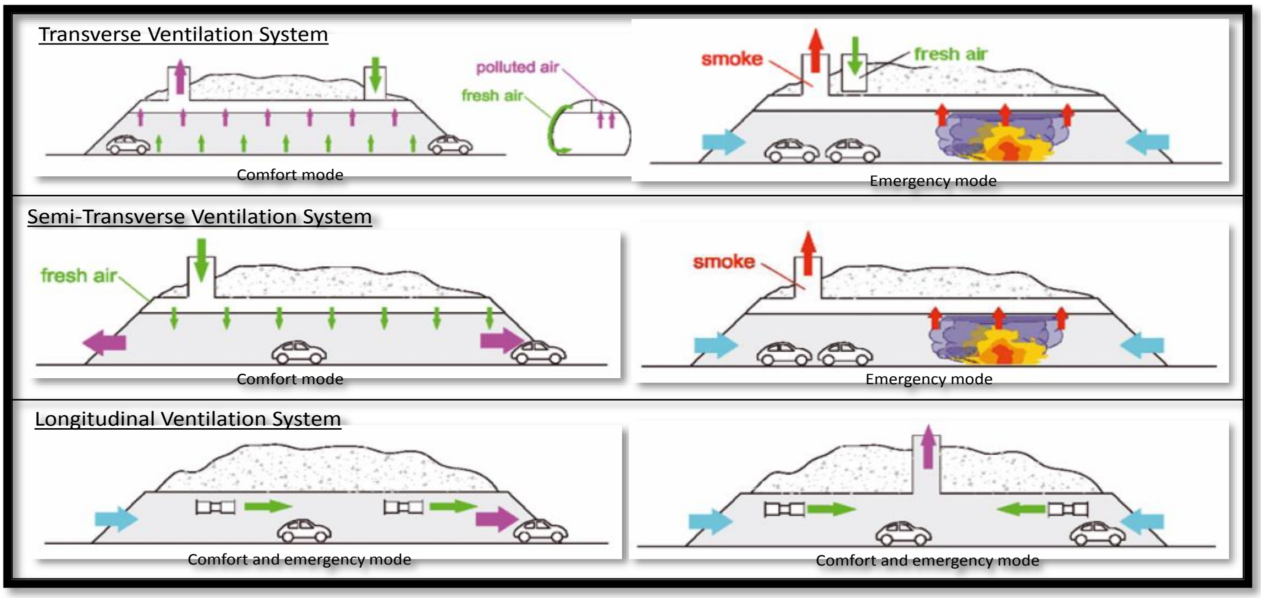


Figure 11: Types of ventilation Systems. Source: PIARC

Transverse ventilation

A fully transverse system consists in 2 different ducted ventilation systems, one for fresh air injection (preferable at floor level) and another for exhaust (at the ceiling), evenly distributed along the tunnel.

In case of fire, only the exhaust dampers close to the fire are remotely opened, and fresh air injection must be stopped.

This system is the best for contaminants control and the safest in case of fire if correctly operated, as it exhausts the smoke locally near the fire, maintaining clear of smoke the rest of the tunnel. Its main disadvantage is the high cost involved due to the complex and large civil infrastructures needed (shafts, ventilation buildings, ducts).

Semi-transverse ventilation

In this case there is only a ventilation duct along the tunnel, which can work either injecting fresh air for contamination control or exhausting smoke in a similar way as a transverse system.

The problem of this system is that normal operation is usually fresh air injection, as it works better than exhausting polluted air. In case of fire the system has to stop, open/close the adequate dampers and reverse the flow. This can take some time, and during that period the system is working in the worst possible way for a fire: injecting fresh air at the smoke layer, thus feeding oxygen to the fire and breaking stratification of the smoke.

Longitudinal ventilation

This is the simplest tunnel ventilation system, and the most used nowadays, and it consist mainly in developing an air flow inside the tunnel by means of jet-fans or Saccardo nozzles, so that fresh air comes in at one side and polluted air / smoke goes out through the other end of the tunnel.

On certain occasions, this longitudinal air flow may be achieved by means of exhaust shafts that create flow at both sides of the shaft towards it (maybe with the help of jet-fans); or even with both intake and exhaust shafts that divide the tunnel in ventilation sections (push-pull system). This system is typical in subway infrastructures.

In case of a fire, unlike transverse or semi-transverse systems where smoke is directly extracted by the system regardless of its heat release rate (HRR), the main objective of a longitudinal ventilation system is usually reaching the Critical Ventilation Velocity (VC), or the velocity that just impedes back layering of smoke (smoke moving backwards against the airflow), considering that ventilating over that velocity smoke stratification is unlikely.

Ventilation System Selection

The Austrians guidelines RVS 09.02.31 [3] determine special ventilation systems for certain tunnel and traffic configurations. The field of application of tunnel ventilations systems is shown in below Table.

Table 2: Field of Application of Tunnel Ventilations Systems

Traffic Situation	AADT/Lane [Vec/24h]	Tunnel Length [m]	Ventilation System
Uni-directional Traffic	-	< 500	Natural Ventilation
	< 5.000 & Low Traffic Jam Frequency	< 700	Natural Ventilation
	> 5.000 bis < 10.000 & Middle Traffic Jam frequency	500 to < 3.000	Longitudinal Ventilation
	> 5.000 & High Traffic Jam frequency	500 to < 1.500	Longitudinal Ventilation
	> 5.000 & High Traffic Jam	1.500 to <	Longitudinal Ventilation & point

Traffic Situation	AADT/Lane [Vec/24h]	Tunnel Length [m]	Ventilation System
	frequency	3.000	smoke extraction (max. 750m distance)
	-	> 3.000	Exhaust extraction with false ceiling
Bi-directional Traffic	-	< 500	Natural Ventilation
	< 2.000	< 700	Natural Ventilation
	< 5.000 & Low Traffic Jam Frequency	500 to < 2.000	Longitudinal Ventilation
	< 5.000 & Middle Traffic Jam Frequency	500 to < 1.500	Longitudinal Ventilation
	> 5.000	1.500 to < 3.000	Longitudinal Ventilation & point smoke extraction (max. 750m distance)
	-	> 3.000	Exhaust extraction with false ceiling

The Khellani Tunnel has a Length of about 1.5 Km with Uni-directional traffic. Therefore, a longitudinal ventilation system according to RVS 09.02.31 is provided. Longitudinal ventilation is the most adequate ventilation system from a cost-effective point of view, provided the following assumptions are met:

- Unidirectional tunnel, so that vehicles would only stop inside the tunnel at one side of an accident
- No traffic jams expected inside the tunnel, because of low traffic is expected and/or a traffic control system at entrance (barriers) is provided
- Relatively short distance between emergency exits (500 m maximum, preferable about 250 m)
- Appropriate control system to avoid counter flow due to unfavourable weather conditions (high wind at exit portal, high atmospheric pressure difference between portals)
- Pollutants concentration design levels can be maintained for normal operation (sanitary ventilation). This is limited by the length of the tunnel and the traffic expected, unless air can be renewed by means of intermediate ventilation shafts.

Khellani Tunnel fully comply with these assumptions, so a longitudinal ventilation system is considered to be adequate at these infrastructures.

Pressurization of Escape Routes

In order to ensure a safety scape of the users of the tunnel in case of a fire, the cross – passages will be pressurized with fans. The ventilation system of the emergency passageways will be defined according to the standard EN 12101-6: 2006.

This project will follow the next criteria:

- Difference of pressure between the cross - passage and the tube where there is fire will be 50 Pa.
- The cross – passages will be used for evacuating the users and for firefighting services access. Therefore, the air velocity with one door open will not be less than 2 m/s to prevent the smoke to enter the passage.

The fans will be defined in order to be able to work continuously during 2 hours and they will be installed above the entrance of the cross - passage from the tunnel. The system will have also fire dampers in the air conduits to keep the fire rate of the egress path and for preventing the entrance of smoke inside the cross – passage.

Jet-fan

The system proposed is based on the installation of jet-fan pairs along the tunnel, preferably near the transformer room due to electrical limitations (entrances or centre of tunnel).

3.5.8 Specifications for Fire Detection and Firefighting System

The facilities described in this chapter follow the next standards:

- The Manual of Specifications and Standards for two/ four/ six laning of highways published by IRC.
- Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on 'minimum safety requirements for tunnels in the Trans-European Road Network'
- NFPA Standards (National Fire Protection Association). In particular: NFPA-502 'Standard for Road Tunnels, Bridges, and Other Limited Access Highways' and NFPA 14 'Standard for the Installation of Standpipe and Hose Systems'

All tunnel tubes will be equipped with a linear **fire detection** system, capable of identifying the location of a fire with high precision, while the technical rooms will have conventional fire detection control units with distributed detection, activation and warning elements.

According to the latest guidelines for Road Tunnels published by the Indian Roads Congress (IRC), the **firefighting system** of the tunnels must be equipped with:

- Hand – Operated Fire Extinguishers
- Fire Hydrants
- Water Reservoir
- Fire – Hose Coil with Supply
- Sprinkled (if used)
- Closed Drainage System
- Fire Engines (if owned)

According to the Directive 2004/54/EC, the distance between hydrants must be less than 250 meters. Whereas the NFPA 502 indicates a maximum distance between hydrants of 305 meters, as well as it mentions a maximum distance between fire extinguishers of 90 meters and between hose connections of 85 meters.

Therefore, this project will follow the most restrictive standards for all equipment. The fire hydrants will be installed at the entrance of the tunnels and every 250 meters in the right side along the tunnel, where the emergency lane and the cross - passages are located. Furthermore, the hand – operated fire extinguishers will be mounted every 83.33 meters and the hose connections will be fixed every 83, 33 meters between hydrants.

3.5.9 Lighting System Requirements

The Lighting system will be designed according to the Guide for Lighting Road Tunnels and Underpasses CIE 88/2004. Also the Guidelines for Road Tunnels IRC:SP:91-2010 will be taken into account.

The Lighting system will be divided into different zones, in order to facilitate the visual adaptation of the drivers to the low level of light inside the tunnel:

- Threshold zone
- Transition zone
- Interior zone

The interior zone will determine the structure of the rest of the lighting zones, due to the fact that it will be installed all along the tunnel defining the base (permanent) lighting. The emergency lighting system will be designed in order to provide light in case of failure of the main power supply.

Not only the interior lighting of the tunnels needs to be designed but also the outdoor lighting, covering from the entrance and exit of the tube an approximate distance of 320 meters.

3.5.10 Power Supply Requirements

The **power supply system** will be designed to provide the energy for all the tunnel systems, and it needs to be reliable. It will basically consist of high voltage power supply from electrical distribution company networks, voltage transformers, diesel generators for backup supply and UPS system (Uninterruptible Power Supply) for all those systems whose continuity of operation should be ensured in case of interruption of the company's supply.

Standard Compliance and Best Practices

There is no specific national standard that fully regulates the power supply system of road tunnels in India.

The following list compiles the compulsory requirements demanded by the applicable regulation and best practices according to international standards and reports that will serve as the basis for the design of the system.

- **IRC (Indian Road Congress)**

The report IRC:SP:91-201 “Guidelines for Road Tunnels” stablishes that every tunnel shall have an emergency power system, but there is no information on the systems that shall be connected to it or the capacity of the system.

PIARC Guidelines in general are mentioned as applicable for tunnel design.

- **PIARC**

PIARC Road Tunnels Manual does not stablish detailed requirements for power supply. Essential requirements are as follows:

- Supply safe and sufficient power to allow all the equipment to operate
- Meet the needs under all operational situations (normal, degraded, critical).

General principles for the system design are:

- The presence of a standby power supply (double supply, diesel generator, etc.),
- The installation of a device allowing remedying a total loss of power supply. This system (uninterruptible power supply (UPS), diesel generator...) supplies electricity to equipment critical for safety, during a limited period of time.

- **European Directive 2004/54/EC**

The following points are applicable:

2.8.2. Safety lighting shall be provided to allow a minimum visibility for tunnel users to evacuate the tunnel in their vehicles in the event of a breakdown of the power supply.

2.8.3. Evacuation lighting, such as evacuation marker lights, at a height of no more than 1, 5 metres, shall be provided to guide tunnel users to evacuate the tunnel on foot, in the event of emergency

2.17.1. All tunnels shall have an emergency power supply capable of ensuring the operation of safety equipment indispensable for evacuation until all users have evacuated the tunnel.

It is assumed that all the emergency and safety systems shall be connected to UPS or equivalent power source.

- **NFPA-502**

According to NFPA-502, the electrical systems shall maintain ventilation, lighting, communications, drainage, a fixed fire-extinguishing system, fire alarm, and fire detection, exit signs, traffic control, and all the systems at areas of refuge, exits and exits routes, under all normal and emergency modes associated with the facility.

All road tunnels exceeding 240 m length shall be equipped with emergency power system. The systems connected to the emergency power systems shall be:

- Emergency lighting
- Tunnel closure and traffic control
- Exit signs
- Emergency communication
- Tunnel drainage
- Emergency ventilation
- Fire alarm and detection
- CCTV
- Fire fighting

General System Characteristics

In order to fulfil the requirements stablished by the different standards, the power supply system shall consist of the following elements:

- Double external power supply, one for each tunnel, connected to a different HV transmission lines.
- Distributed transformer rooms, with redundant transformer (standby transformer)
- Diesel generator for 100% of the power supply and 48 hours of fuel capacity available at full load
- UPS 10 minutes for the following systems:
  - Emergency and evacuation lighting
  - Tunnel closure and traffic control
  - Exit signs
  - Emergency communication
  - Tunnel drainage

- Fire alarm and detection
- CCTV
- SCADA and control systems

Cabling for all the emergency systems shall be fire-resistant, with a minimal fire rating of 2 hours.

Low Smoke Zero Halogen (LSZH) Cable shall be used in the tunnel.

3.5.11 Other Tunnel Facilities Requirements

The tunnels will have not only ventilation system, firefighting system and lighting system but also with other different facilities such as:

- Signage system
- Traffic Control system: traffic lights, lane-use signals, variable message signs, vehicle detector loops, etc.
- Communications systems: CCTV/AID (Automatic Incident Detection) systems, VA/PA (Voice Alarm / Public Address) system and Radio Rebroadcast system
- Control network

All these facilities will be designed in order to ensure the safety of the users in the tunnels.

The **signage system** will be based on different signals that will indicate the presence of emergency equipment and evacuation routes that should be used in case of an incident in the tunnel. Depending on what they represent, there will be two types: Reflective Traffic Signs (RTS) or Luminous Traffic Signs (LTS).

The **traffic control system** will be designed in order to manage the tunnel traffic in case there is an incident that leads to a change in circulation. The traffic control system will be operated by the integrated tunnel control system following the tunnel operator's interventions through interactive control system terminals. The equipment that will be necessary to implement the traffic control system is listed below:

- Traffic Lights - Three Coloured (R-A-G)
- Traffic Lights - Amber (A-A)

- Variable Message Signs (VMS)
- Tunnel Variable Lane Signs (TVLS)
- Speed Limit Variable Sign (SLVS)

The **communication system** will consist of CCTV/AID systems, VA/PA system and Radio Rebroadcast system.

The CCTV system enables the surveillance of the tunnel portals as well as the continuous monitoring of the road and its surroundings by four revolving (360º) cameras located in front of each one of the entrances of the tunnels and a series of fixed cameras installed along the tunnel. The Automatic Incident Detection System (AID) consists of the implantation of an AID card for each camera, which performs the video analytics.

A Public Address (PA) system will be installed in order to allow the broadcast of messages in case of an emergency; this is why the sound pressure must be enough to overcome the existing noise levels and obtain a correct degree of intelligibility of the message.

The tunnel will have a Radio Rebroadcast System for the emergency services as well as for emergency communications with the users of the tunnel. There will be main racks fixed at the Technical Rooms of the portals and signal amplifiers in every Technical Room in the tunnels. The Control Centre will communicate with the main racks by a single – mode fibre optic. The amplifiers will be connected between them by radiant cable along the tunnel, as well as by single – mode fibre optic to the main racks.

There will also be an installation for avoiding intrusions, sabotage and accidents. The installation of an access control system allows restricting access to the tunnel and its dependencies (technical rooms), so that only authorized personnel can access.

The **Control Network** will be monitored by the Main Control Centre. Each Technical Room will have Remote Terminal Units (R.T.U.) and Data Acquisition Stations (D.A.S.), connected by fibre optic, which will communicate with the Programmable Logic Controller. The P.L.C will be installed at every cross – passages connected to the switches fixed all along the tunnel for gathering all the information of the equipment.

4. DESIGN OF PRIMARY SUPPORT SYSTEM

4.1 Objective

The objective of the present report is to provide DPR level design of rock support for Khellani Bypass Tunnel.

References

a. Reference book, Practical Rock Engineering (2000ed.) - by Dr. Evert Hoek.

b. Geotechnical Investigation Report for Tunnel-T2

c. Introduction to Rock Mechanics, by R. E. Goodman

d. Rock mechanics design in mining and tunnelling by: ZT Bieniawski (1976)

e. User's Guide Phase2

f. Rocdata Manual

g. IS 14448 (1997) - Code of Practice for Reinforcement of Rock Slopes.

h. IS 1893:2002(Part-1)-Code of Practice of Earthquake Resistant Design of Structures

4.2 Geological/Geotechnical Conditions of Project Area

The proposed alignment comprised of single tunnel of length 495 m. The shape of tunnel is modified Horse Shoe and its internal finished dimension have been kept such that to accommodate two lane traffic. The Clear width for tunnel has been fixed to accommodate a rectangular box of 8m x 5.5m at finished road level (proper allowance for ventilation, lighting and drainage has been kept).

The project area around the tunnel alignment comprises of mica schist with intercalation of quartz veins and quartz pophyries and schistose gneiss/ biotite gneiss of Salkhala Formation of Precambrian age (Raina & Aalok, 1968-69, GSI). These are best exposed along the main highway and connecting road to main highway. Exposed rock is observed all along the tunnel alignment.

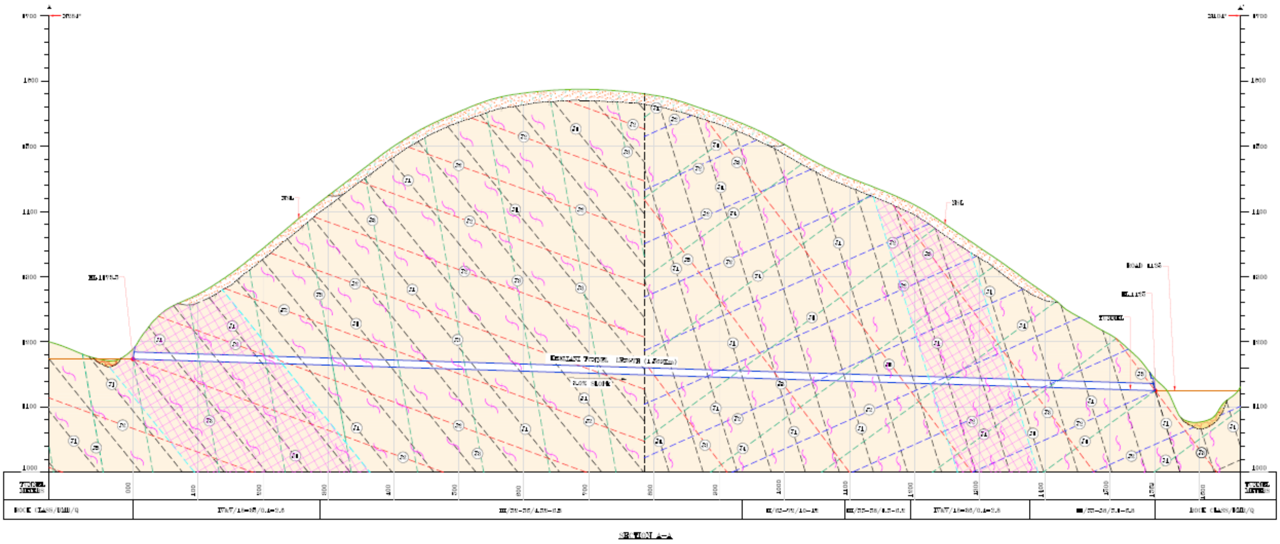


Figure 12: Geological Section along the Tunnel

Analysis of Discontinuity Data

The discontinuity data collected during the time of detailed geological mapping from rock outcrops has been analyzed with the help of “DIPS” software.

Around western portal, rock is traversed by three sets of joints including foliation (175°/75°) with few random joints. Foliation is the most prominent discontinuity. Inter-folial shears and shear seams of thickness 1-5cm along joint set J1 and J2 have been observed during detailed surface geological mapping. About 4m to 5m to thick shear seam is observed around the portal area. The details of the joint sets are given in **Table 3 & 4** and the corresponding Stereographic Plot for major discontinuity planes is shown in **Figure-13**.

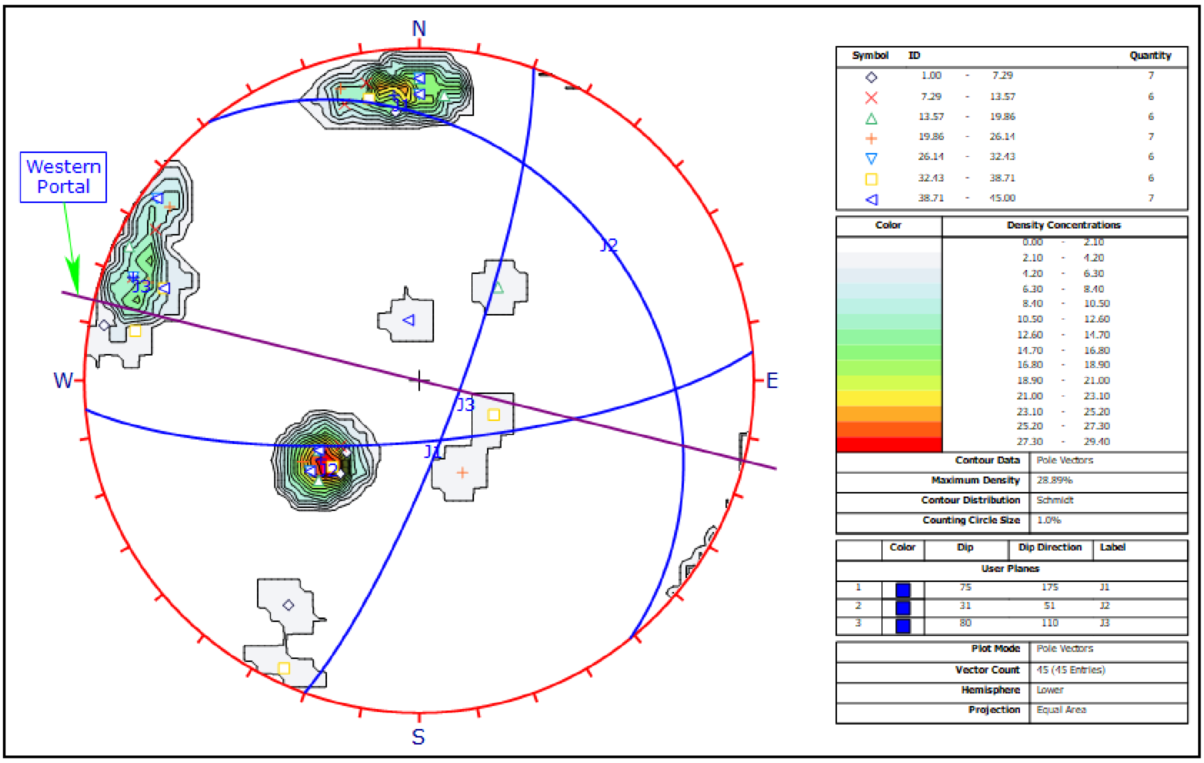


Figure 13: Stereographic plot of major planes of discontinuities of rock along tunnel (western portal)

The analysis of data on discontinuities traversing the rock mass collected during detailed geological mapping **(Figure 13)** in and around the portal area and accessible rock outcrop along the tunnel alignment and existing road and is summarized in **Table 3 and 4**.

Table 3: Range of Discontinuity along Tunnel alignment (western portal)

Set	Strike		Dip Direction		Dip Amount	
	Range	Average	Range	Average	Range	Average
J1*	070° - 100°	085°	160° - 190°	175°	65° - 85°	75°
J2	115° - 166°	141°	025° - 076°	051°	15° - 45°	31°
J3	000° - 040°	020°	090° - 130°	110°	70° - 90°	80°

J1* oriented along foliation

Table 4: Details of Discontinuities along Tunnel alignment (western portal)

Set	Strike	Dip Amount	Dip Direction	Continuity (m)	Spacing (cm)	Aperture (mm)	Roughness	Alteration	Filling
J1*	085° - 265°	75°	175°	>20	Closely to widely spaced	Tight-Partly open	SU*/RP*	Slight on surface	NIL to clay

Set	Strike	Dip Amount	Dip Direction	Continuity (m)	Spacing (cm)	Aperture (mm)	Roughness	Alteration	Filling
J2	141° - 321°	31°	051°	03-20	10-50	Tight to 5.0	RU*/RP*	Slight on surface	NIL to Clay
J3	110° - 290°	80°	110°	03-10	50 to 100	Tight to 5.0	RU*/ RP*	NIL	NIL

J1* oriented along foliation, **SU** Smooth Undulating, **RU** Rough Undulating,

RP Rough Planar

Detailed geological mapping carried out in and around western portal and along the existing road and accessible rock outcrop along the tunnel alignment indicates that the bedrock exposed at the site is traversed by three major sets of discontinuities in addition to some random joints. Out of these, those aligned parallel to the foliation are most prominent. The joints oriented along the foliation, in general, on an average strike 085° - 265° in direction and dip by 75° towards 175°. The bedrock is also traversed by two more prominent sets of joints in addition to foliation joint. The joints belonging to sets J2 and J3 dip on an average by 31° towards 051° and 80° towards 110° respectively.

It is observed that the foliation J1 dips towards south side of the structure with steep angle, J2 is dipping towards north-east side of the structures with low angle and J3 dips towards south-east side with steep angle.

It is observed from **Table 4** that the joints belonging to set J1 have high persistence are closely to widely spaced and have smooth planar and undulating as well as rough undulating surface with tight to partly open aperture and occasionally clay filling & surface staining on surface. Along the road cutting of National Highway (NH-1B), due to steep angle and smooth planer surface along the major joint set, planar failure along this joint set is observed. Joints belonging to set J2 medium to high persistent with tight to partly open and staining on surface. Joint sets belonging to J3 is low to medium persistent, moderately to widely spaced with tight aperture, no filling & alteration.

Around eastern portal, rock is traversed by four sets of joints including foliation (170°/83°) with few random joints. Foliation is the most prominent discontinuity. Inter-folial shears and shear seams of thickness 1-5cm along joint set J1 and J2 have been observed during detailed surface geological mapping. The details of the joint sets are given in **Table 5 & 6** and the corresponding Stereographic Plot for major discontinuity planes is shown in **Figure 14.**

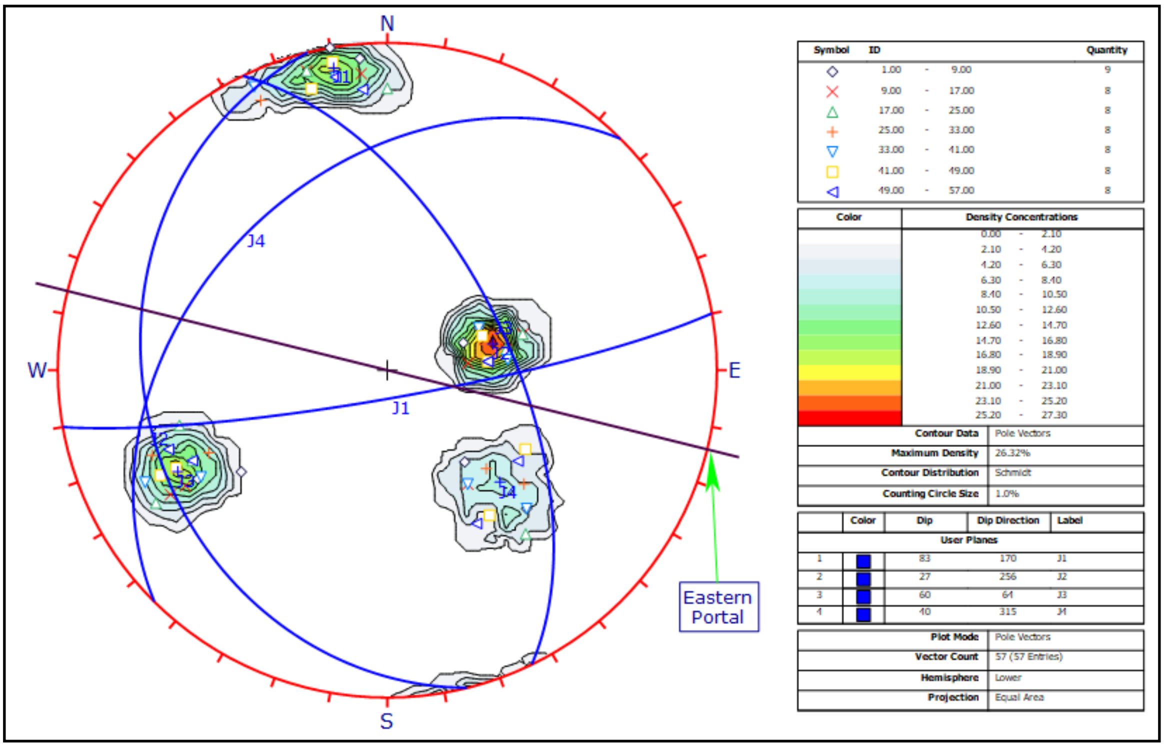


Figure 14: Stereographic plot of major planes of discontinuities of rock along tunnel (eastern portal)

The analysis of data on discontinuities traversing the rock mass collected during detailed geological mapping **(Figure 14)** in and around the portal area and accessible rock outcrop along the tunnel alignment and existing road and is summarized in **Table 5 and 6**.

Table 5: Range of Discontinuity along Tunnel alignment (eastern portal)

Set	Strike		Dip Direction		Dip Amount	
	Range	Average	Range	Average	Range	Average
J1*	060° - 100°	080°	150° - 190°	170°	70° - 90°	83°
J2	140° - 192°	166°	230° - 282°	256°	15° - 40°	27°
J3	140° - 170°	154°	050° - 080°	064°	45° - 75°	60°
J4	205° - 245°	225°	295° - 335°	315°	25° - 55°	40°

J1* oriented along foliation

Table 6: Details of Discontinuities along Tunnel alignment (eastern portal)

Set	Strike	Dip Amount	Dip Direction	Continuity (m)	Spacing (cm)	Aperture (mm)	Roughness	Alteration	Filling
J1*	080° - 260°	83°	170°	>20	Closely to widely spaced	Tight-Partly open	RU*/RP*	Slight on surface	NIL to clay
J2	166° - 346°	27°	256°	03-20	10-50	Tight to 5.0	RU*/SU*	Slight on surface	NIL to Clay
J3	154° - 334°	60°	064°	03-10	50 to 100	Tight to 5.0	RU*/ RP*	NIL	NIL
J4	045° - 225°	40°	315°	03-5	50 to 200	Tight	RU*	NIL	NIL

J1* oriented along foliation, **SU** Smooth Undulating, **RU** Rough Undulating, **RP** Rough Planar

Detailed geological mapping carried out in and around eastern portal and along the existing road and accessible rock outcrop along the tunnel alignment indicates that the bedrock exposed at the site is traversed by four major sets of discontinuities in addition to some random joints. Out of these, those aligned parallel to the foliation are most prominent. The joints oriented along the foliation, in general, on an average strike 080° - 260° in direction and dip by 83° towards 170°. The bedrock is also traversed by three more prominent sets of joints in addition to foliation joint. The joints belonging to sets J2, J3 and J4 dip on an average by 27° towards 256°, 60° towards 064° and 40° towards 315° respectively.

It is observed that the foliation J1 dips towards south side of the structure with steep to very steep angle, J2 is dipping towards western side of the structures with low angle, J3 is dipping towards north-east side of the structures with moderate to steep angle and J4 dips towards north-west side with moderate angle.

It is observed from **Table 6** that the joints belonging to set J1 have high persistence are closely to widely spaced and have smooth and rough undulating surface with tight to partly open aperture and occasionally clay filling & surface staining on surface. Along the road cutting of National Highway (NH-1B), at few locations planar failure is also observed due to high schistosity along the major joint set. Joints belonging to set J2 medium to high persistent with tight to partly open and staining on surface. Joint sets belonging to J3 and J4 is low to medium persistent, moderately to widely spaced with tight aperture, no filling & alteration.

4.3 Geological & Geotechnical Parameters & In-Situ Stresses

The shape of tunnel is modified Horse Shoe and its internal finished dimension has been kept such that to accommodate two lane traffic. Clear width for tunnel has been fixed to accommodate a rectangular box of 8m x 5.5m at finished road level (proper allowance for ventilation, lighting and drainage has been kept).

Two types of tunnel section has been planned one is with invert and other without invert. It is proposed that tunnel with invert will be used in stretches where rock mass encountered is very poor quality otherwise tunnel section without invert will be used. Two different shape of tunnel section has been shown below. Both the type of tunnel has lining of 350 mm thick above invert.

The tunnel shall be exacavated in two parts (heading and benching) for classes I, II & III and three parts (heading, benching and invert) for classes IV and V. A typical cross-section of the tunnel, including the stages of excavation is shown.

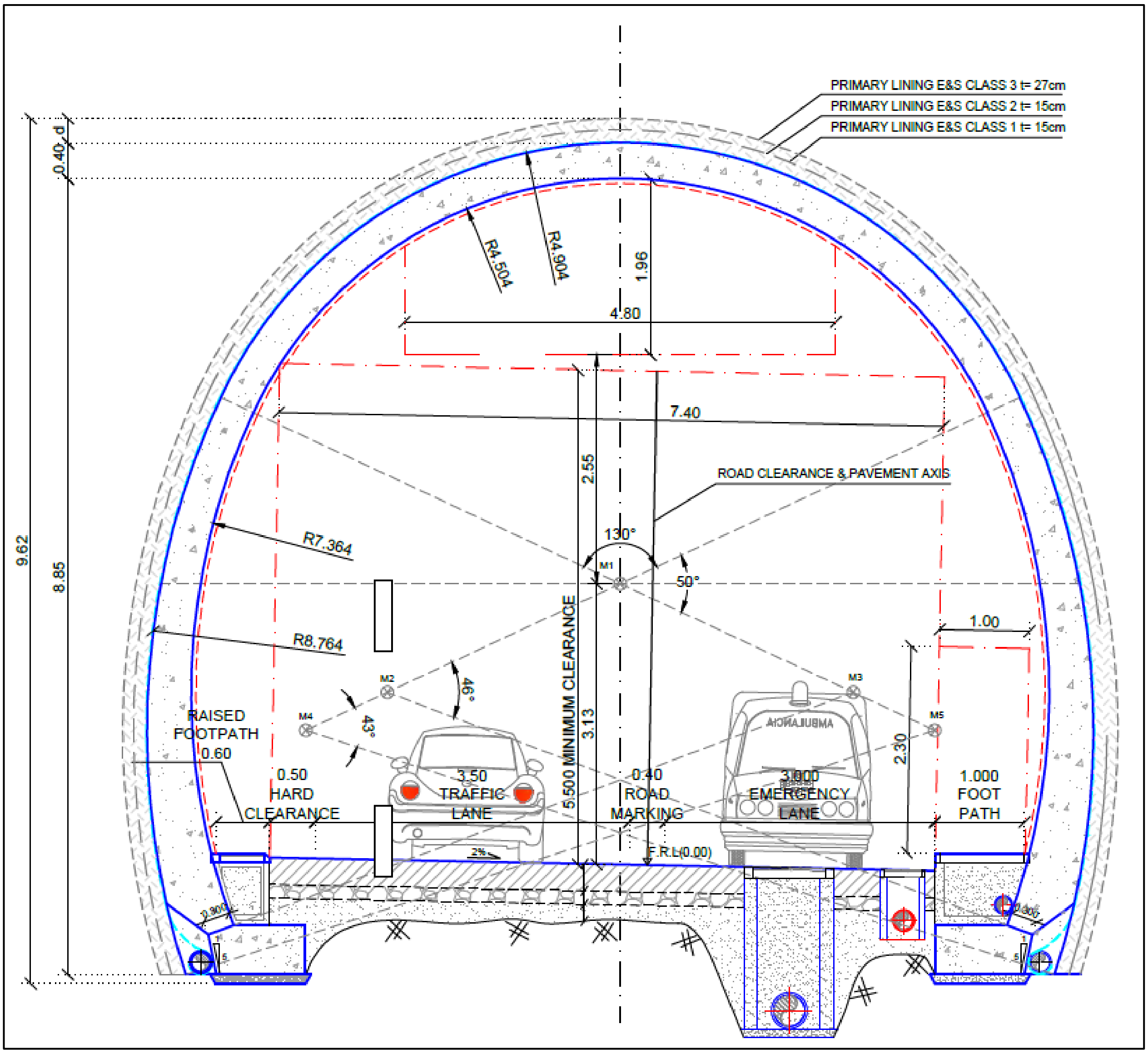


Figure 15: Tunnels Cross Section without and with invert

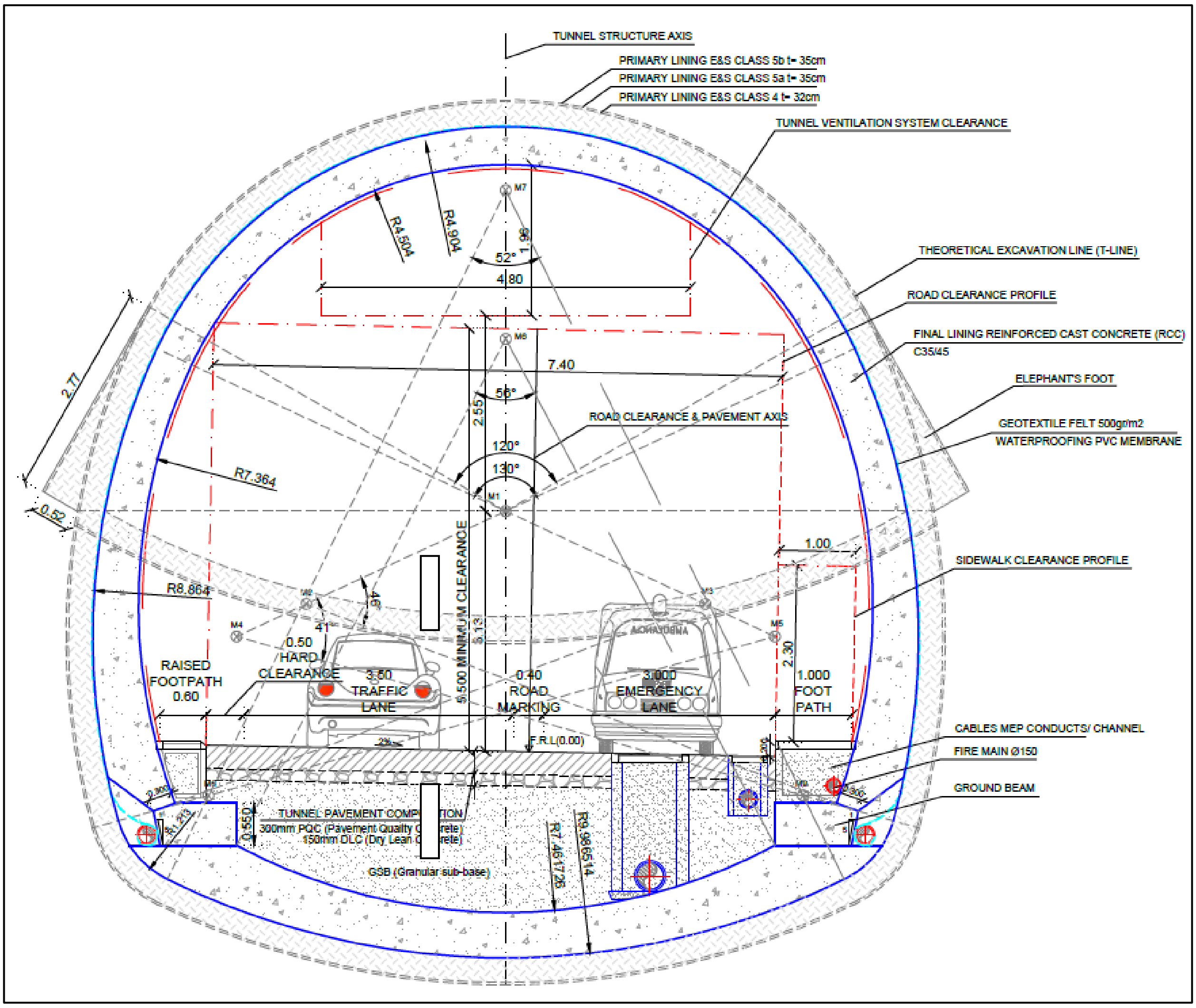
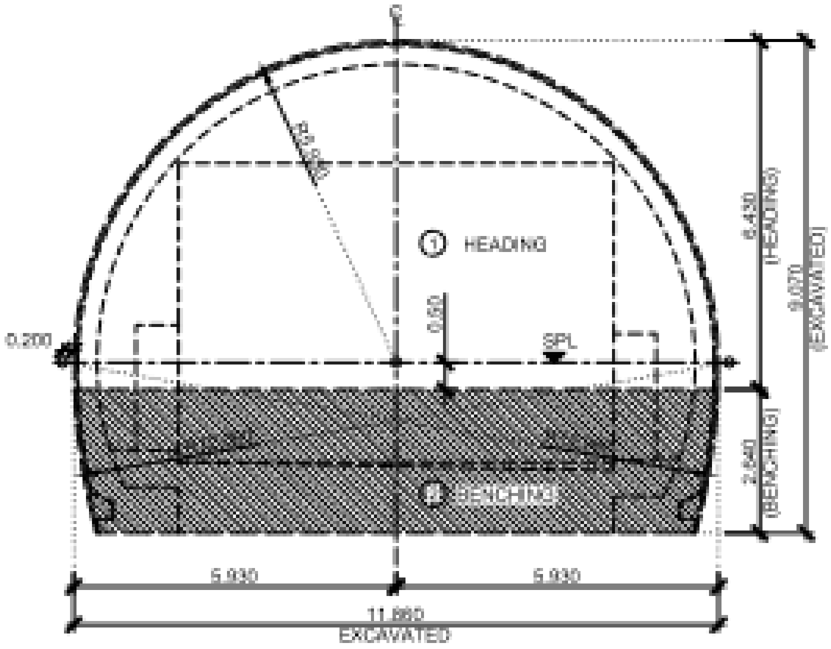
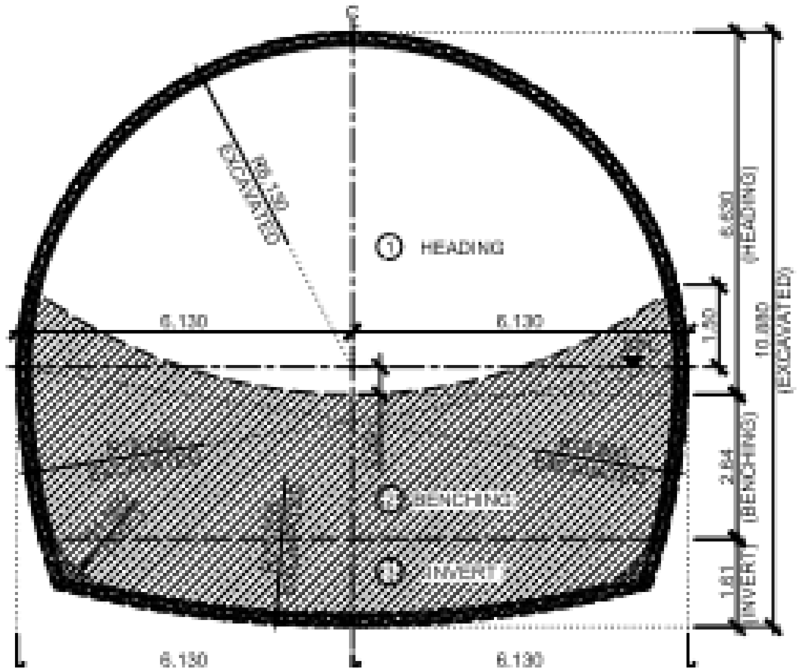


Figure 16: Tunnels Cross Section without and without invert



Stage 1: Heading, Stage 2: Benching for I, II & III classes

Figure 17: Tunnels Cross Section with Stages of Excavation



Stage 1: Heading, Stage 2: Benching & Stage 3: Invert for IV & V classes

Figure 18: Tunnels Cross Section with Stages of Excavation

4.4.1 Adopted Design Parameters

The design parameters adopted for T1 are as tabulated below which are derived based on existing investigation data and using Rocdata. As per geological report only fair to very poor rock is anticipated but from site condition rock class of very good and good can not be ruled out so it is included in analysis.

Table 7: Rock Mass Parameters for Tunnel

Description		Unit	Very Good rockmass (Rock Class I)	Good rockmass (Rock Class II)	Fair rockmass (Rock Class III)	Poor rockmass (Rock Class IV)	Very Poor rockmass (Rock Class V)
Intact Rock Properties	UCS	Mpa	50	50	45	35	30
	RMR		100-81	80-61	60-41	40-20	<20
	GSI		89	70	50	30	19
	mi		15	13.5	12	10.5	10
	MR		750	625	525	475	425
	Rock cover	m	353	353	421	221	75
	Ei	Mpa	37500	31250	23625	16625	12750
	µ		0.2	0.2	0.2	0.27	0.3
Undisturbed Rock mass parameters (D = 0 & D = 0.3)	c (peak)	MPa	4.4	2.15	1.41	0.56	0.2
	ø (peak)	deg	51.7	47.2	38.7	34.3	36
	c (residual)	MPa	4.18	1.95	1.25	0.48	0.16
	ø (residual)	deg	51.3	45.8	36.1	30.5	31.7
	Tensile strength	MPa	-1.36	-0.32	-0.064	-0.011	-0.004
	Deformation modulus	MPa	29500	17100	4700	920	425

The in-situ stress ratio for tunnel for design is taken as 1.0.

4.4.2 Support/Reinforcement Properties

Support in the form of rock bolting, shotcrete and lattice girders at appropriate spacing, is designed for tunnel. The following support properties are considered for the shotcrete, rockbolts/soil nails and lattice girders.

Shotcrete

The shotcrete is modelled as plastic standard beam element, so that the excess forces are transferred to the adjacent rock mass and support element, if the shotcrete yield at any point.

Table 8: Support/Reinforcement Properties

Grade of mix		C35/45
Characteristic Compressive strength(fck), Cylinderical	MPa	35
Residual Compressive Strength	MPa	5
Tensile strength	MPa	2.25
Young's Modulus	MPa	17000

Fully Grouted Rock Bolts

Diameter	mm	25
Steel Grade (Yield Strength)	MPa	500
Cross-sectional Area	mm^2	491
Yield Capacity	kN	245.43
Elastic Capacity (0.80x yield)	kN	196
Design Capacity Considered (approx)	kN	190
Length of Rock Bolt	m	5-6

Lattice Girder

Support type		Lattice Girder
Depth of section	mm	187
Cross-sectional Area	mm^2	1784
Moment of Inertia	m^4	1.16×10^{-5}
Modulus of Elasticity	MPa	200000
Characteristic Compressive stress	MPa	500
Characteristic Tensile stress	MPa	500

4.5 Methodology

Methodology adopted for designing rock support system for tunnel is described in detail in the following sections.

4.5.1 Tunnel Rock Support

The support design has been done by consideration of the rock mass type, rock mass quality and in-situ stress conditions expected to be encountered along the tunnel alignment as determined by review and assessment of available geotechnical data.

The support assessment has been primarily carried out using rock mass classification by RMR system (Bieniwaski 1976/2013). For the analysis, various parameters like rock strength, joint characteristics, ground water and orientation of discontinuities have been taken into consideration. Support recommendations are made, based on stress-deformation analysis using Phase 2 software. The possibility of any wedge formation and tunnel stability is also checked with Unwedge software.

The minimum length of the rock bolts is determined by following formulae:

Minimum length of rockbolt as per Barton's Formula:

L = 2 + 0.15*De

Minimum length of rockbolt as per Schach's Formula:

L = 1.4 + 0.184*W

where, De is Equivalent dimension=D/ESR; ESR=1.3 for transportation tunnels. Following table gives requirement of minimum length of bolt.

Table 9: Requirement of Minimum Length of Bolt

Rock Class	Maximum Excavated Width of Tunnel (m)	Length of Rockbolt as per Barton's Formula	Length of Rockbolt as per Schach's Formula
Class-I	10.63	3.23	3.36
Class-II	10.73	3.24	3.37
Class-III	10.83	3.25	3.39
Class-IV	11.23	3.30	3.47
Class-V	11.23	3.30	3.47

From the above table, it is evident, bolt length of 4m is sufficient to satisfy both the criterias (Barton & Schach), for all classes. However, rockbolts of length 5m have been used for Classes I to III and rockbolts of length 7m for Classes IV & V have been considered, to ensure anchorage outside the yield zone.

4.5.2 Assumptions for Designing Tunnel Support System

Following major assumptions were made while designing the support system for tunnel:

1. The geometry of the tunnel is same along the tunnel length, permitting the three-dimensional problem to be modelled in two dimensions.
2. The rock mass surrounding the tunnel is homogenous, isotropic in all directions.
3. Seismic loadings have not been considered in the present analysis due to the large extent of topographical cover for tunnel design.
4. To account for three dimensional effect the modulus of core is reduced to 30% for most conservative case (Based on the general practice it varies from 30 to 70%).

4.6 Design of Rock supports for Tunnel

4.6.1 Wedge Stability Analysis (Western portal)

Wedge analysis has been carried out by considering the alignment of tunnel in N284° - N104° direction with combination of joint sets J1, J2 and J3. The results of the analysis without any support are shown in following figures.

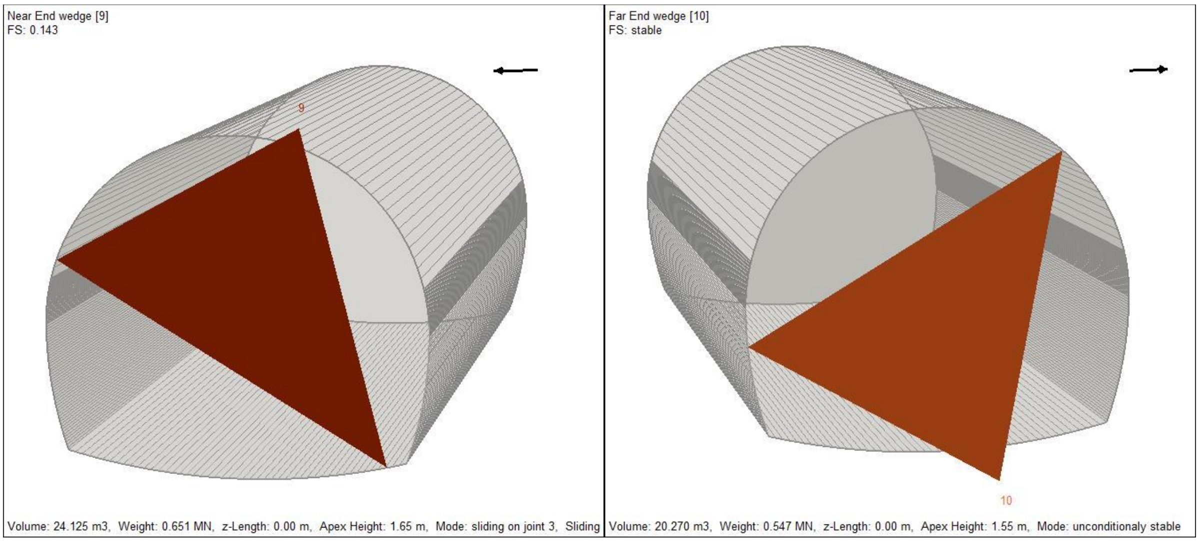


Figure 19:View of end wedges of Western Portal of Tunnel

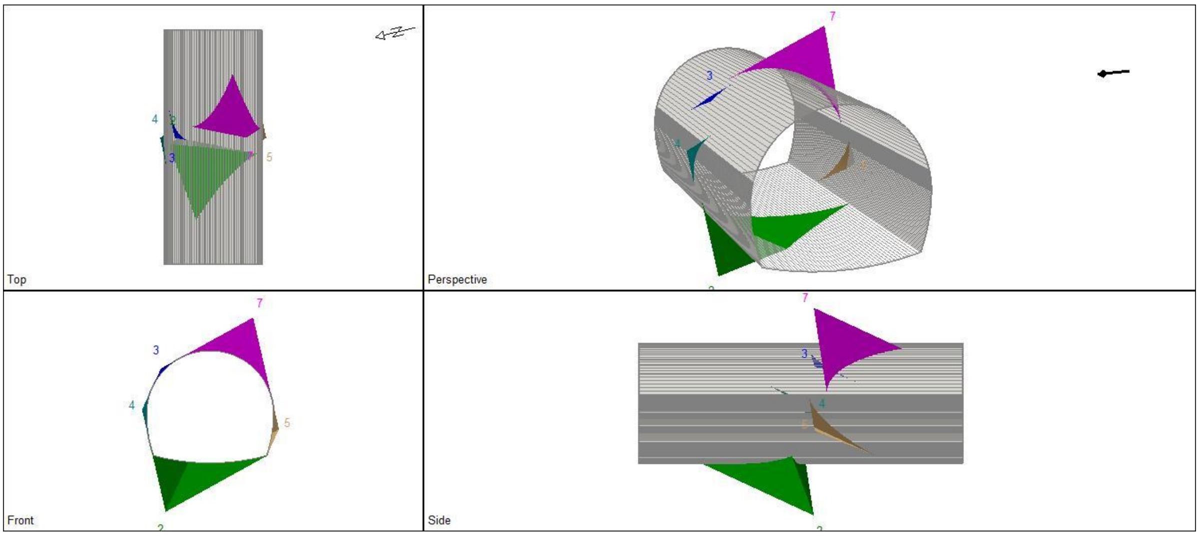


Figure 20: Perspective view of Wedges of Western Portal of Tunnel

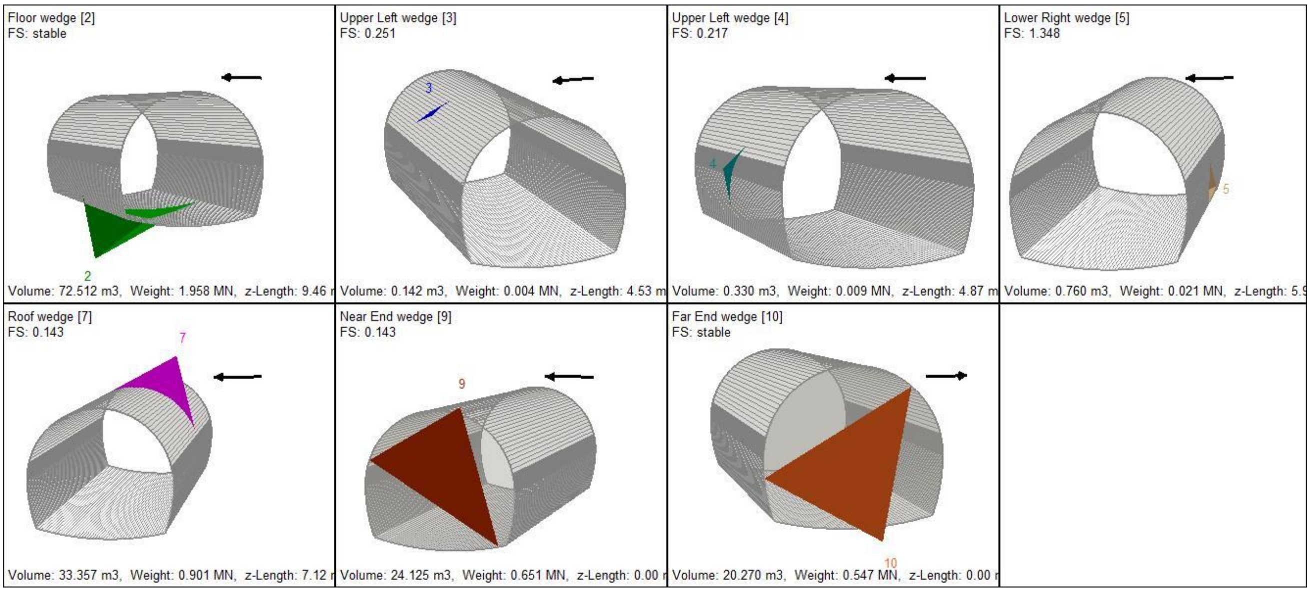


Figure 21: View of different Wedges of Western Portal of Tunnel

Wedge Information

	Floor wedge [2]	Upper Left wedge [3]	Upper Left wedge [4]	Lower Right wedge [5]	Roof wedge [7]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	stable	0.251	0.217	1.348	0.143	0.143	stable
Wedge Weight [MN]	1.958	0.004	0.009	0.021	0.901	0.651	0.547
Resisting Force [MN]	0.000	0.001	0.002	0.014	0.127	0.092	0.000
Sliding Direction (East, North, Up)		0.09, -0.25, -0.96	0.02, -0.26, -0.97	0.67, 0.54, -0.52	0.16, -0.06, -0.98	0.16, -0.06, -0.98	
Joint Shear Strengths [MN]	1) 0.000 , 2) 0.000 , 3) 0.000	1) 0.001 , 2) 0.000 , 3) 0.000	1) 0.002 , 2) 0.000 , 3) 0.000	1) 0.000 , 2) 0.014 , 3) 0.000	1) 0.000 , 2) 0.000 , 3) 0.127	1) 0.000 , 2) 0.000 , 3) 0.092	1) 0.000 , 2) 0.000 , 3) 0.000

Figure 22:Results of Wedge analysis of Western Portal of Tunnel

The results of wedge analysis of different wedges that would be formed by intersections have been shown in the above figures with their weights, FOS and direction of sliding trend. The upper left wedge [3], upper left wedge [4], lower right wedge [5], roof wedge [7] and near end wedge [9] weighing 0.004, 0.009, 0.021, 0.901 and 0.651 MN having 0.251, 0.217, 1.348, 0.143 and 0.143 factor of safety respectively. These wedges may be stabilized by providing shotcrete, rock bolt etc.

The results of wedge analysis with shotcrete are shown in following figures.

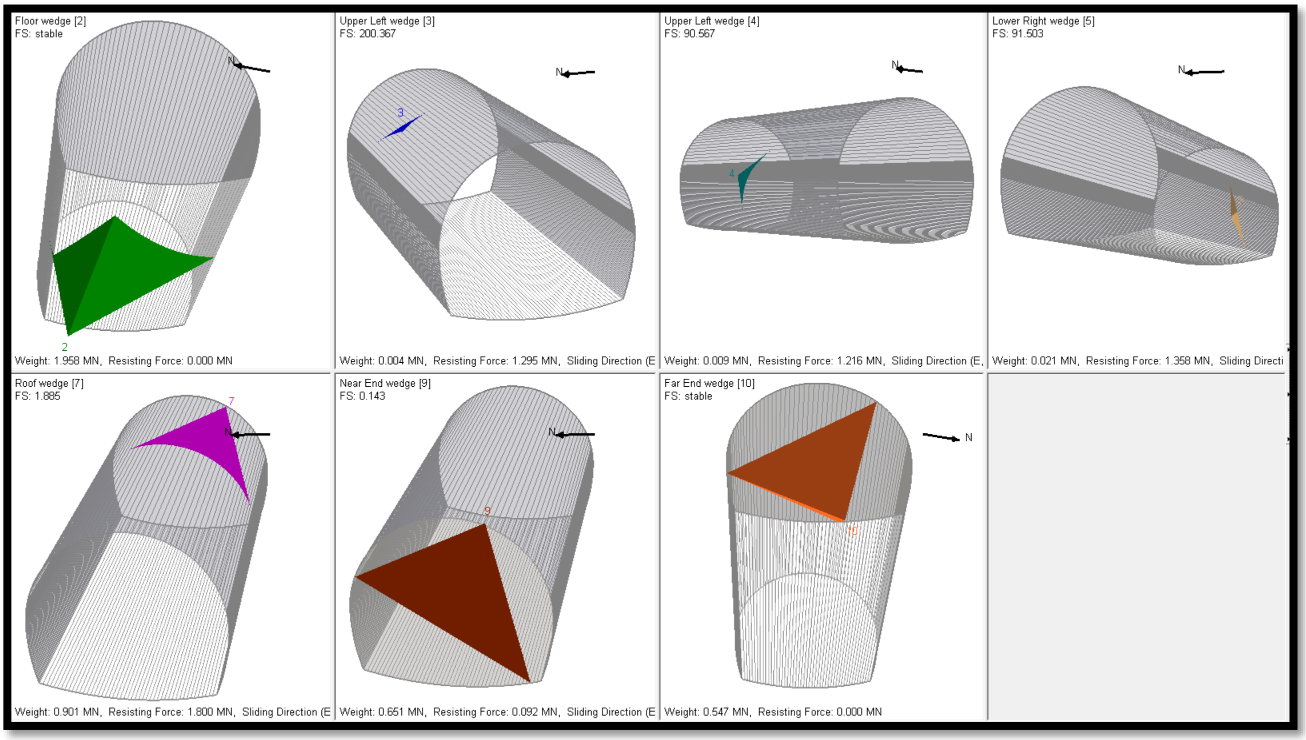


Figure 23:View of different Wedges of Western Portal of Tunnel after shotcreting

Wedge Information

	Floor wedge [2]	Upper Left wedge [3]	Upper Left wedge [4]	Lower Right wedge [5]	Roof wedge [7]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	stable	200.367	90.567	91.503	1.885	0.143	stable
Wedge Weight [MN]	1.958	0.004	0.009	0.021	0.901	0.651	0.547
Resisting Force [MN]	0.000	1.295	1.216	1.358	1.800	0.092	0.000
Sliding Direction (East, North, Up)		0.09, -0.25, -0.96	0.02, -0.26, -0.97	0.67, 0.54, -0.52	0.00, 0.00, -1.00	0.16, -0.06, -0.98	
Joint Shear Strengths [MN]	1) 0.000 , 2) 0.000 , 3) 0.000	1) 0.542 , 2) 0.000 , 3) 0.000	1) 0.825 , 2) 0.000 , 3) 0.000	1) 0.000 , 2) 0.573 , 3) 0.000	1) 0.000 , 2) 0.000 , 3) 0.000	1) 0.000 , 2) 0.000 , 3) 0.092	1) 0.000 , 2) 0.000 , 3) 0.000

Figure 24:Results of Wedge analysis of Western Portal of Tunnel after shotcreting

4.6.2 Wedge Stability Analysis (Eastern portal)

Wedge analysis has been carried out by considering the alignment of tunnel in N284° - N104° direction with combination of joint sets J1, J2 and J3. The results of the analysis without any support are shown in following figures.

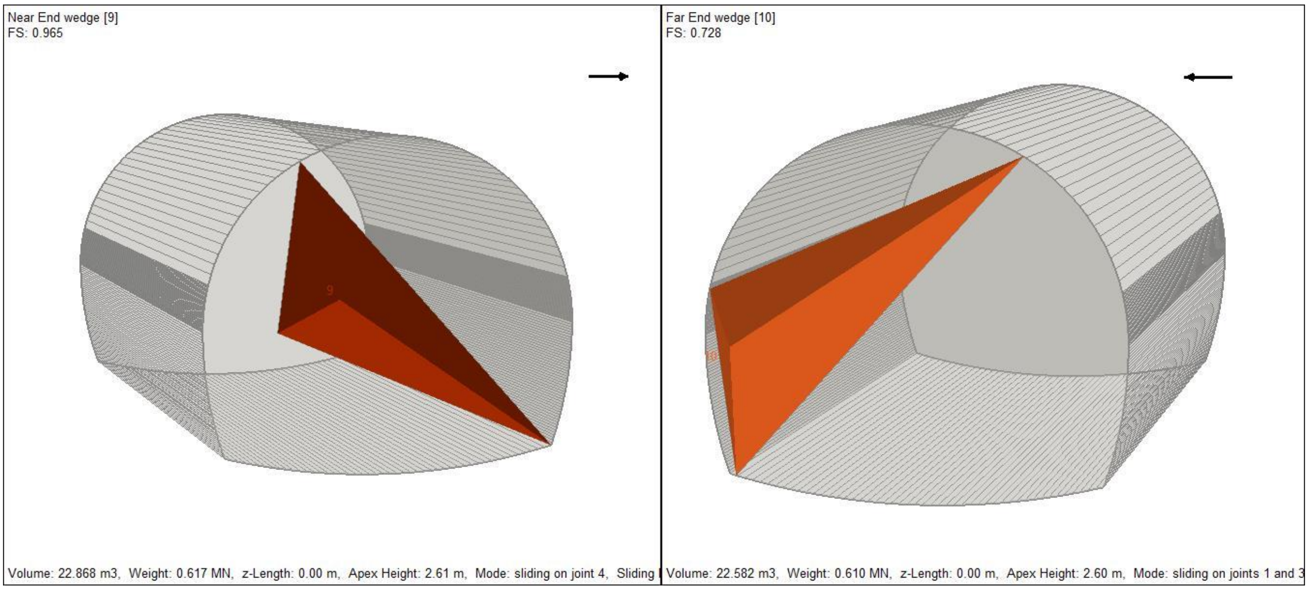


Figure 25:View of end wedges of Eastern Portal of Tunnel

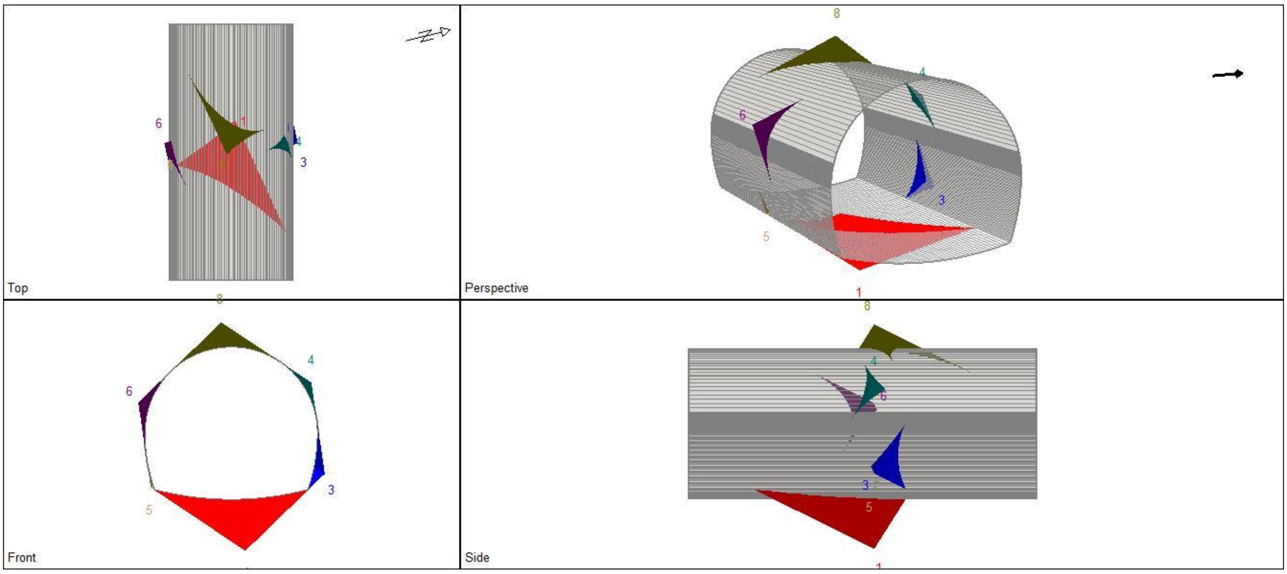


Figure 26: Perspective view of Wedges of Eastern Portal of Tunnel

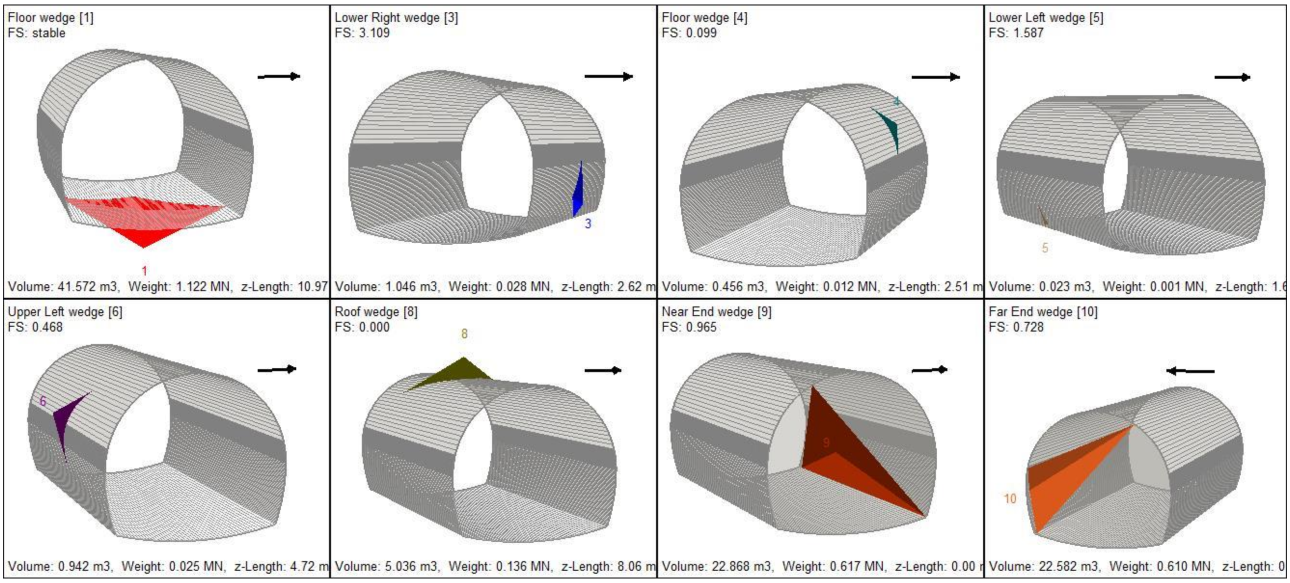


Figure 27: View of different Wedges of Eastern Portal of Tunnel

Wedge Information

	Floor wedge [1]	Lower Right wedge [3]	Floor wedge [4]	Lower Left wedge [5]	Upper Left wedge [6]	Roof wedge [8]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	stable	3.109	0.099	1.587	0.468	0.000	0.965	0.728
Wedge Weight [MN]	1.122	0.028	0.012	0.001	0.025	0.136	0.617	0.610
Resisting Force [MN]	0.000	0.036	0.001	0.001	0.010	0.000	0.383	0.373
Sliding Direction (East, North, Up)		-0.89, -0.21, -0.41	0.02, -0.12, -0.99	-0.06, 0.84, -0.54	0.45, 0.22, -0.87	0.00, 0.00, -1.00	-0.54, 0.54, -0.64	0.54, -0.01, -0.84
Joint Shear Strengths [MN]	1) 0.000 , 3) 0.000 , 4) 0.000	1) 0.013 , 3) 0.000 , 4) 0.023	1) 0.001 , 3) 0.000 , 4) 0.000	1) 0.000 , 3) 0.000 , 4) 0.000	1) 0.000 , 3) 0.010 , 4) 0.000	1) 0.000 , 3) 0.000 , 4) 0.000	1) 0.000 , 3) 0.000 , 4) 0.383	1) 0.107 , 3) 0.266 , 4) 0.000

Figure 28: Results of Wedge analysis from Eastern Portal of Tunnel

The results of wedge analysis of different wedges that would be formed by intersections have been shown in the above table with their weights, FOS and direction of sliding trend. The floor wedge [4], upper left wedge [6], roof wedge [8], near end wedge [9] and far end wedge [10] weighing 0.012, 0.025, 0.136, 0.617 and 0.610 tons having 0.099, 0.468, 0.0, 0.965 and 0.728 factor of safety respectively. All of the wedges are stable with higher FOS except roof wedges.

The results of wedge analysis with shotcrete are shown in following figures.

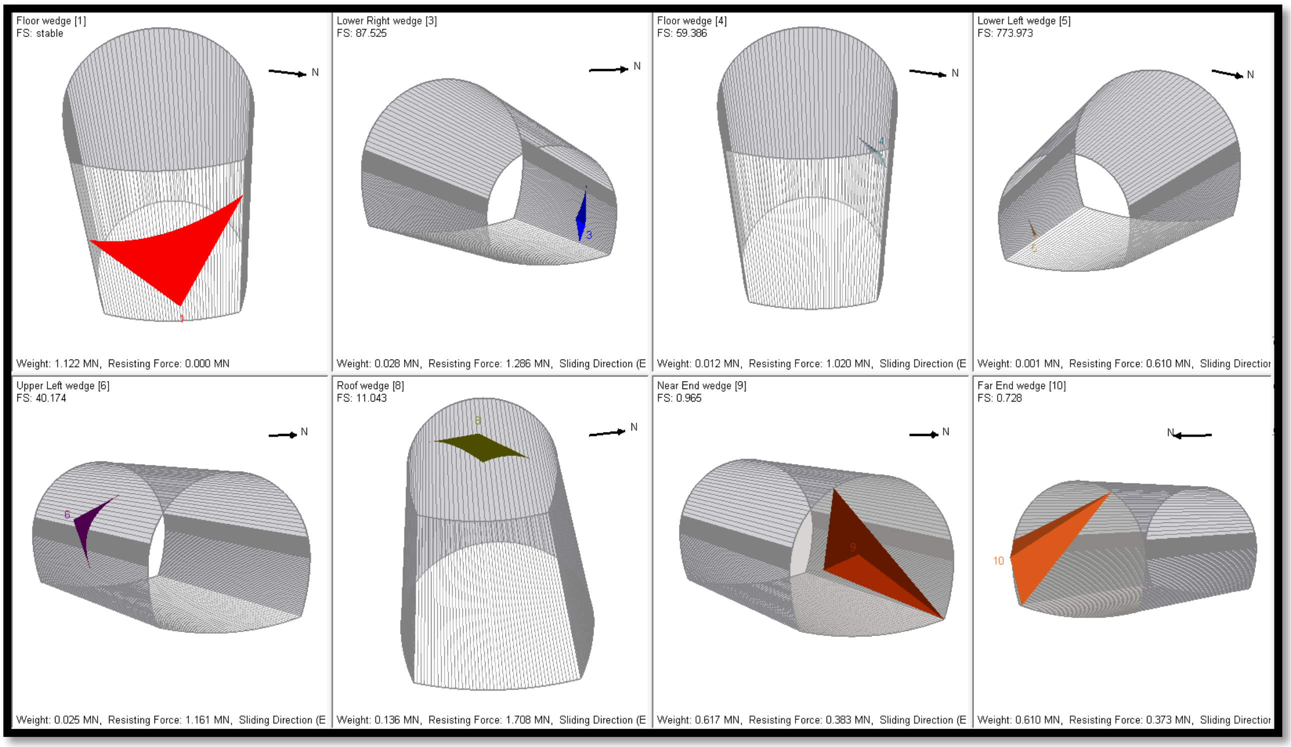


Figure 29: View of different Wedges of Eastern Portal of Tunnel after shotcreting

Wedge Information

	Floor wedge [1]	Lower Right wedge [3]	Floor wedge [4]	Lower Left wedge [5]	Upper Left wedge [6]	Roof wedge [8]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	stable	87.525	59.386	773.973	40.174	11.043	0.965	0.728
Wedge Weight [MN]	1.122	0.028	0.012	0.001	0.025	0.136	0.617	0.610
Resisting Force [MN]	0.000	1.286	1.020	0.610	1.161	1.708	0.383	0.373
Sliding Direction (East, North, Up)		-0.89, -0.21, -0.41	0.02, -0.12, -0.99	-0.06, 0.84, -0.54	0.45, 0.22, -0.87	0.00, 0.00, -1.00	-0.54, 0.54, -0.64	0.54, -0.01, -0.84
Joint Shear Strengths [MN]	1) 0.000 , 3) 0.000 , 4) 0.000	1) 0.770 , 3) 0.000 , 4) 0.185	1) 0.499 , 3) 0.000 , 4) 0.000	1) 0.000 , 3) 0.201 , 4) 0.134	1) 0.000 , 3) 0.410 , 4) 0.000	1) 0.000 , 3) 0.000 , 4) 0.000	1) 0.000 , 3) 0.000 , 4) 0.383	1) 0.107 , 3) 0.266 , 4) 0.000

Figure 30: Results of Wedge analysis of Eastern Portal of Tunnel after shotcreting

From Figures 19 to 30, it is seen that for the tunnel directions, most of the wedges are safe even without support system and with shotcrete, the factor of safety of the wedges increases significantly. If face stability problems are encountered at site, spot bolting/ shotcreting shall be provided as required. Hence, from the wedge formation perspective, the tunnel is safe under the joint sets and this tunnel alignment.

4.6.3 Stress-Deformation Analysis

The stress-deformation analysis for the Tunnel is carried out for Rock classes I to V using Phase 2 software.

Excavation sequences in Phase2 is modelled as heading and benching for classes I, II & III and heading benching and invert for classes IV & V.

The results of the analysis are presented in the form of major principal stress contours, total displacement contours and yielded zones and support capacity plots for IV and V classes in Figures 31 to 45 for Rock classes I to V respectively.

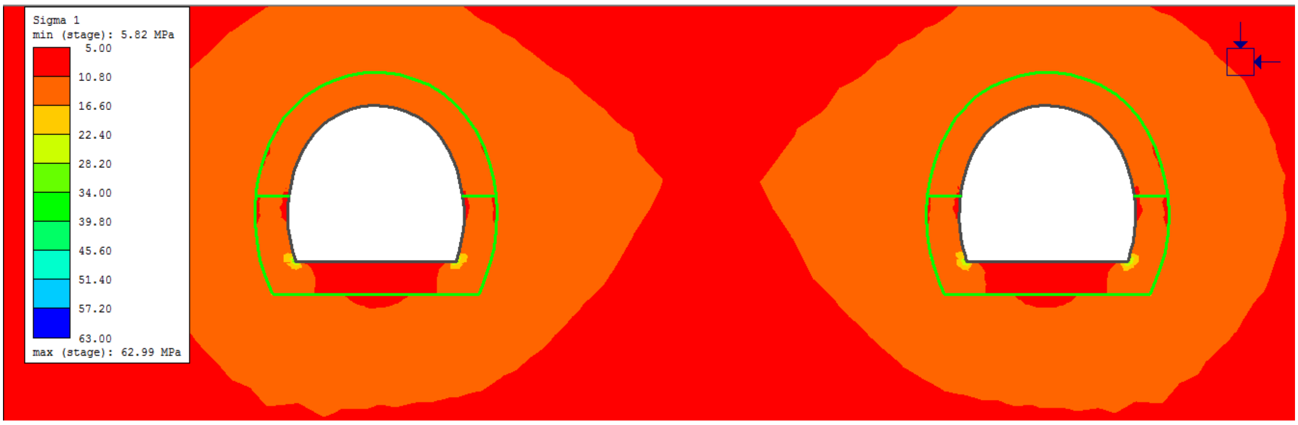


Figure 31: Major Principal Stress Contours for Rock Class I

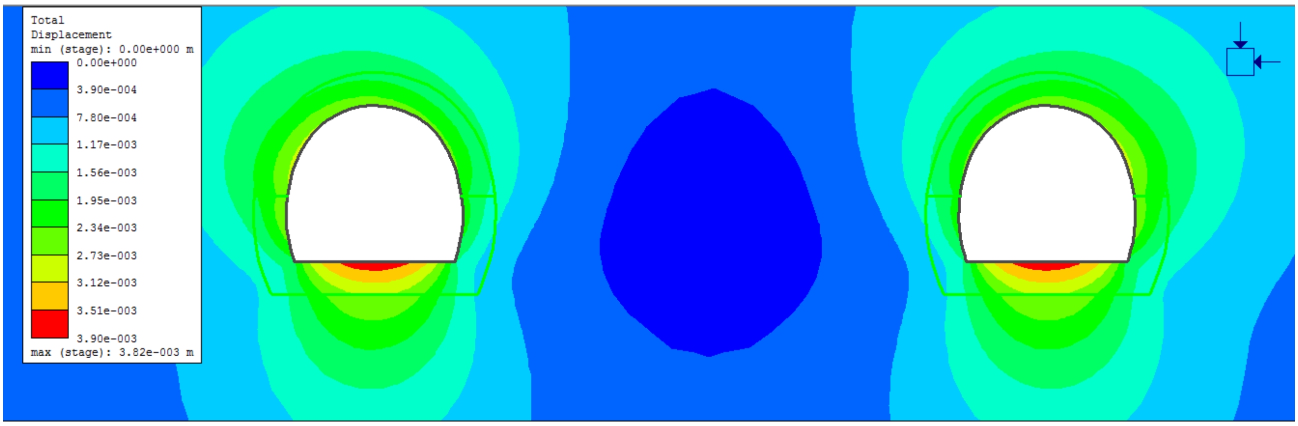


Figure 32: Total Displacement Contours for Rock Class I

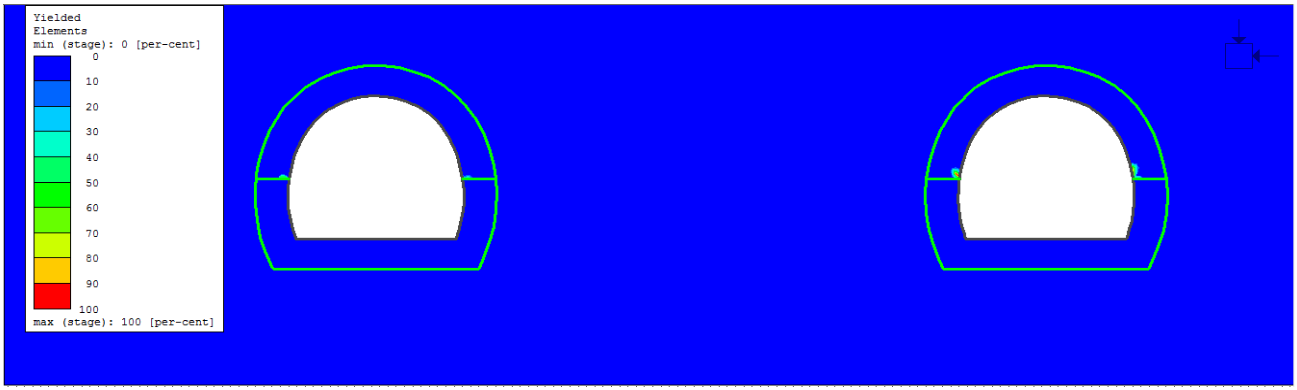


Figure 33: Yielded Zones and Strength Factor for Rock Class I

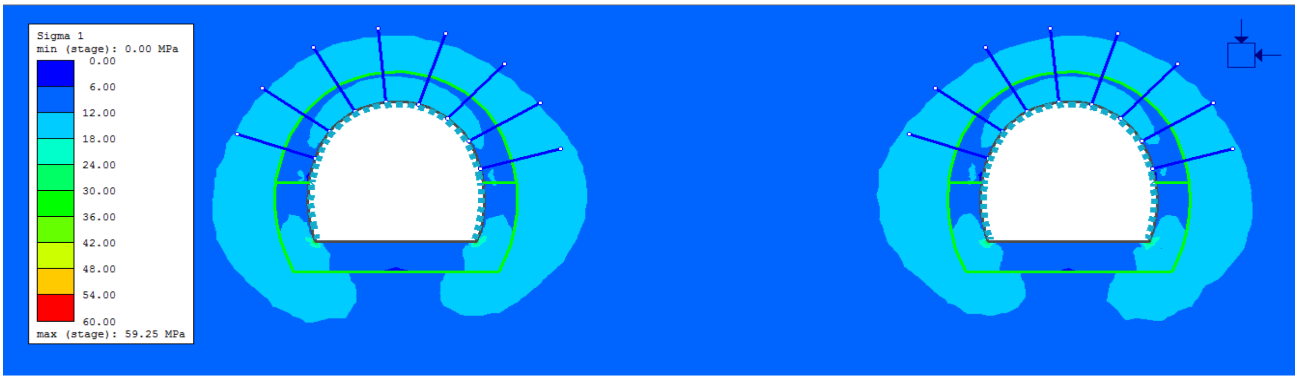


Figure 34: Major Principal Stress Contours for Rock Class II

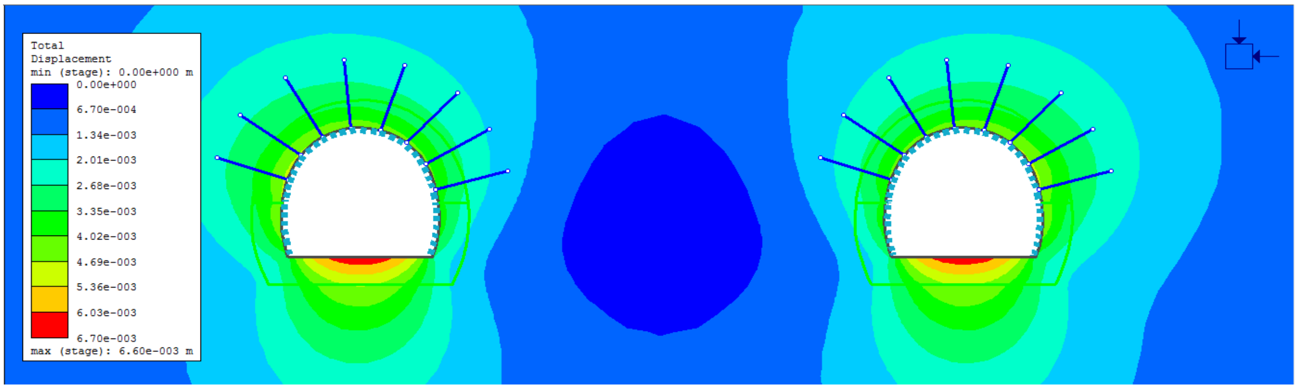


Figure 35: Total Displacement Contours for Rock Class II

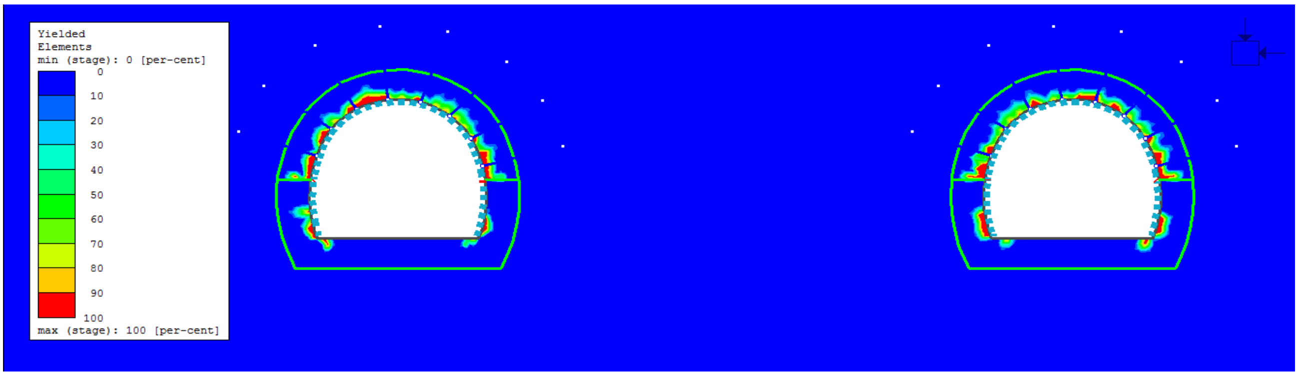


Figure 36: Yielded Zones and Strength Factor for Rock Class II

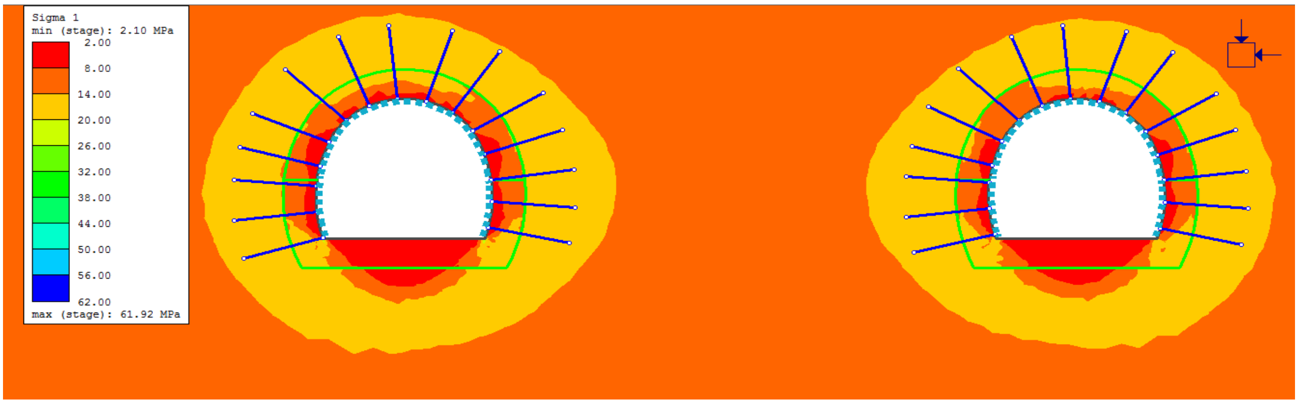


Figure 37: Major Principal Stress Contours for Rock Class III

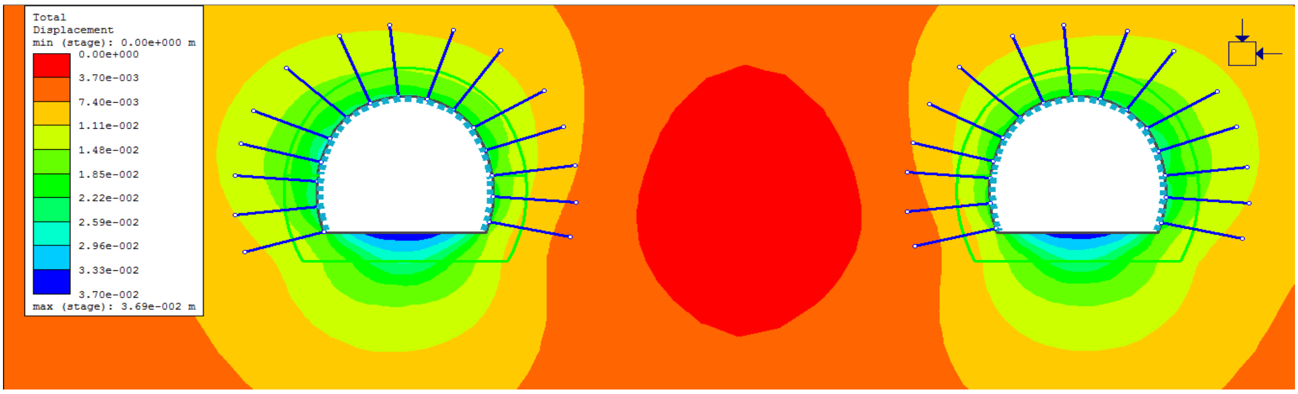


Figure 38: Total Displacement Contours for Rock Class III

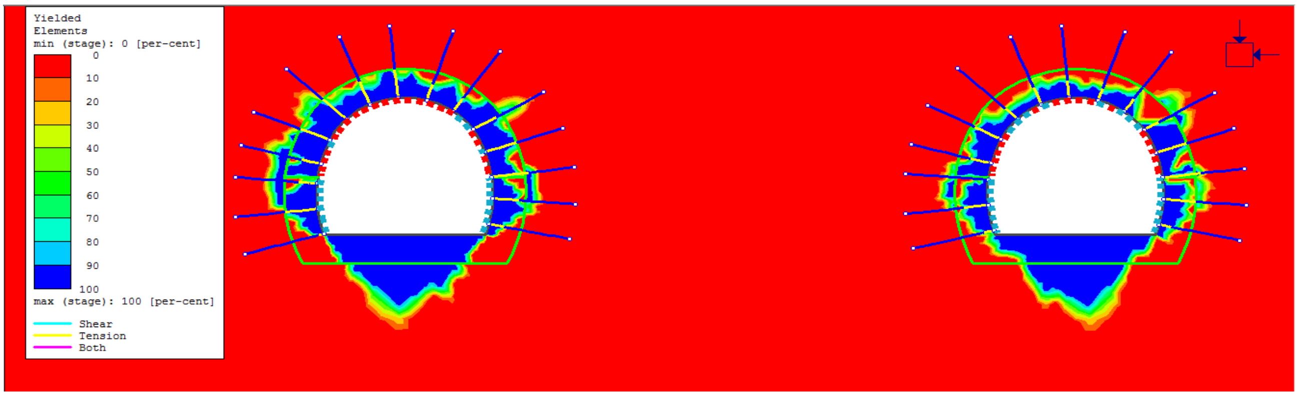


Figure 39: Yielded Zones and Strength Factor for Rock Class III

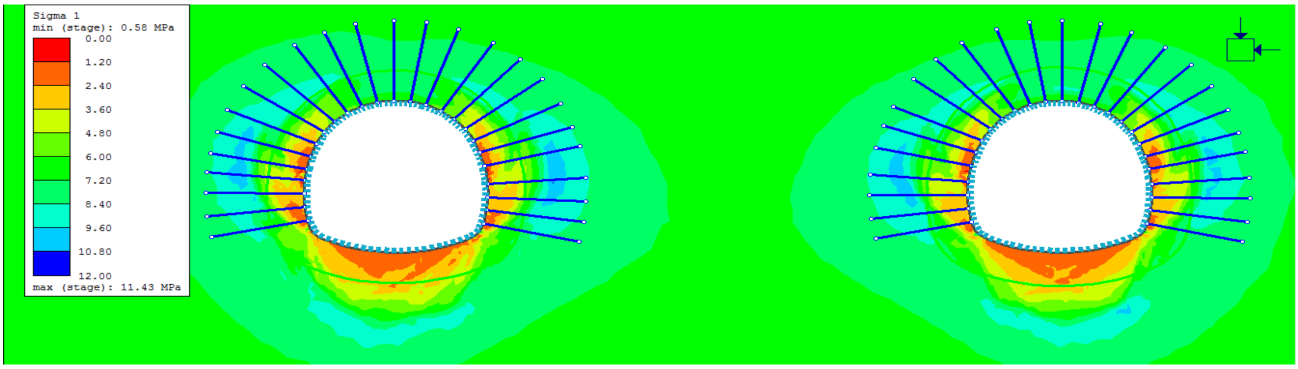


Figure 40: Major Principal Stress Contours for Rock Class IV

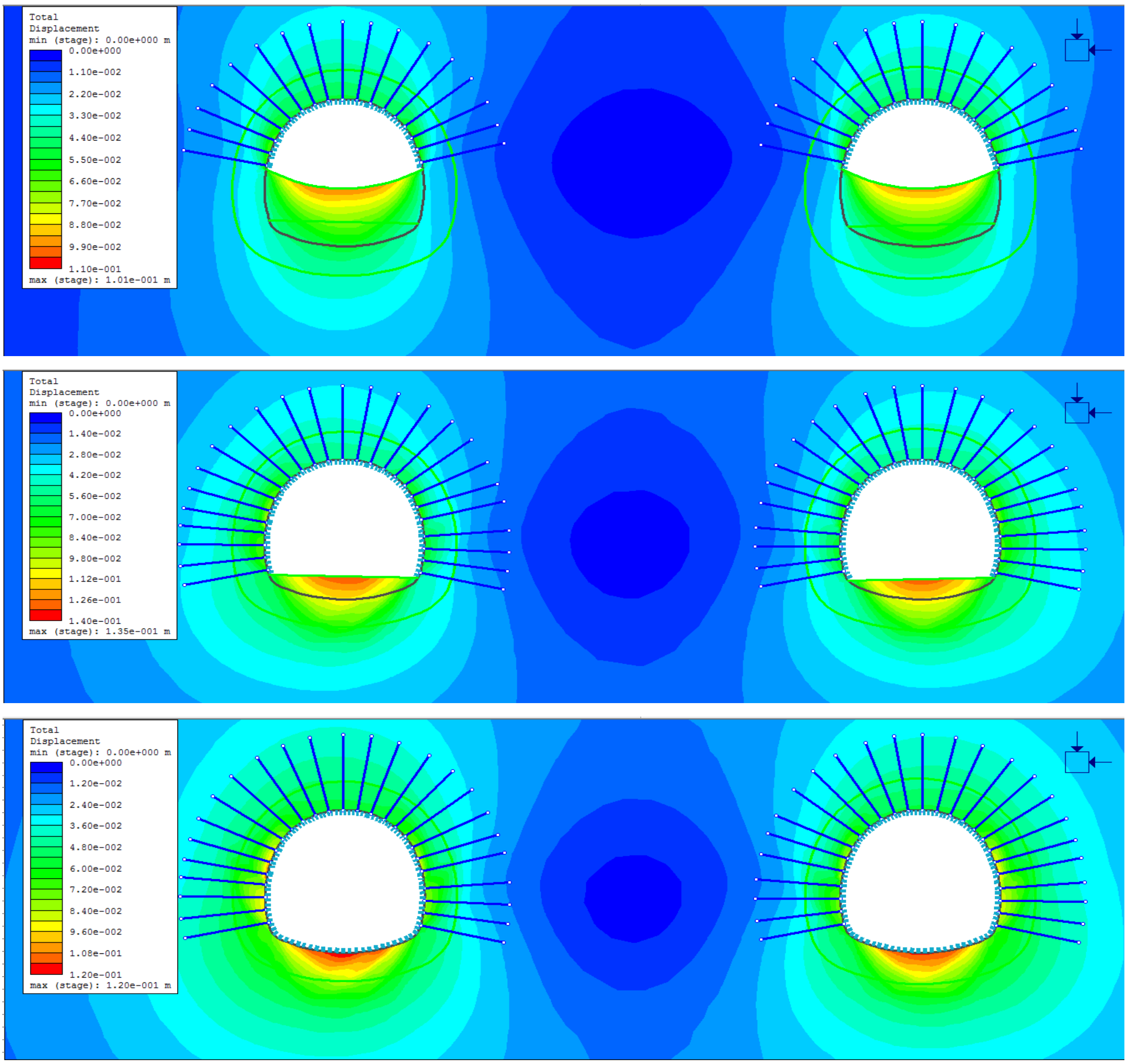


Figure 41: Total Displacement Contours for Rock Class IV (Stages 1 to 3)

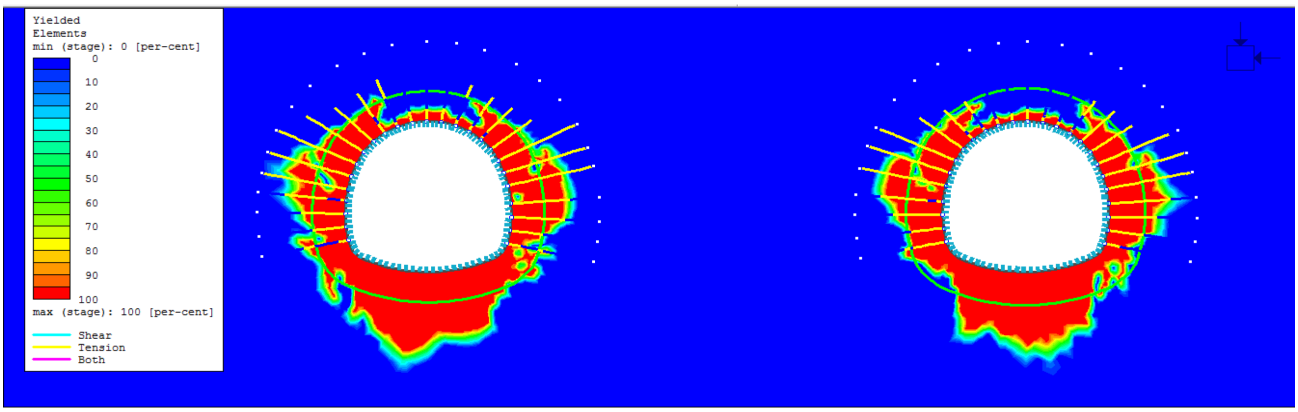


Figure 42: Yielded Zones and Strength Factor for Rock Class IV

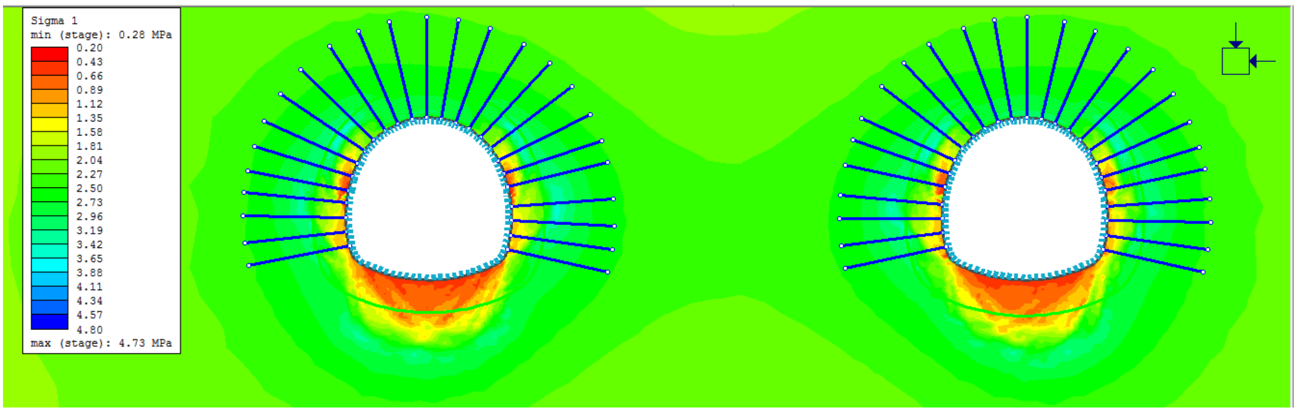


Figure 43: Major Principal Stress Contours for Rock Class V

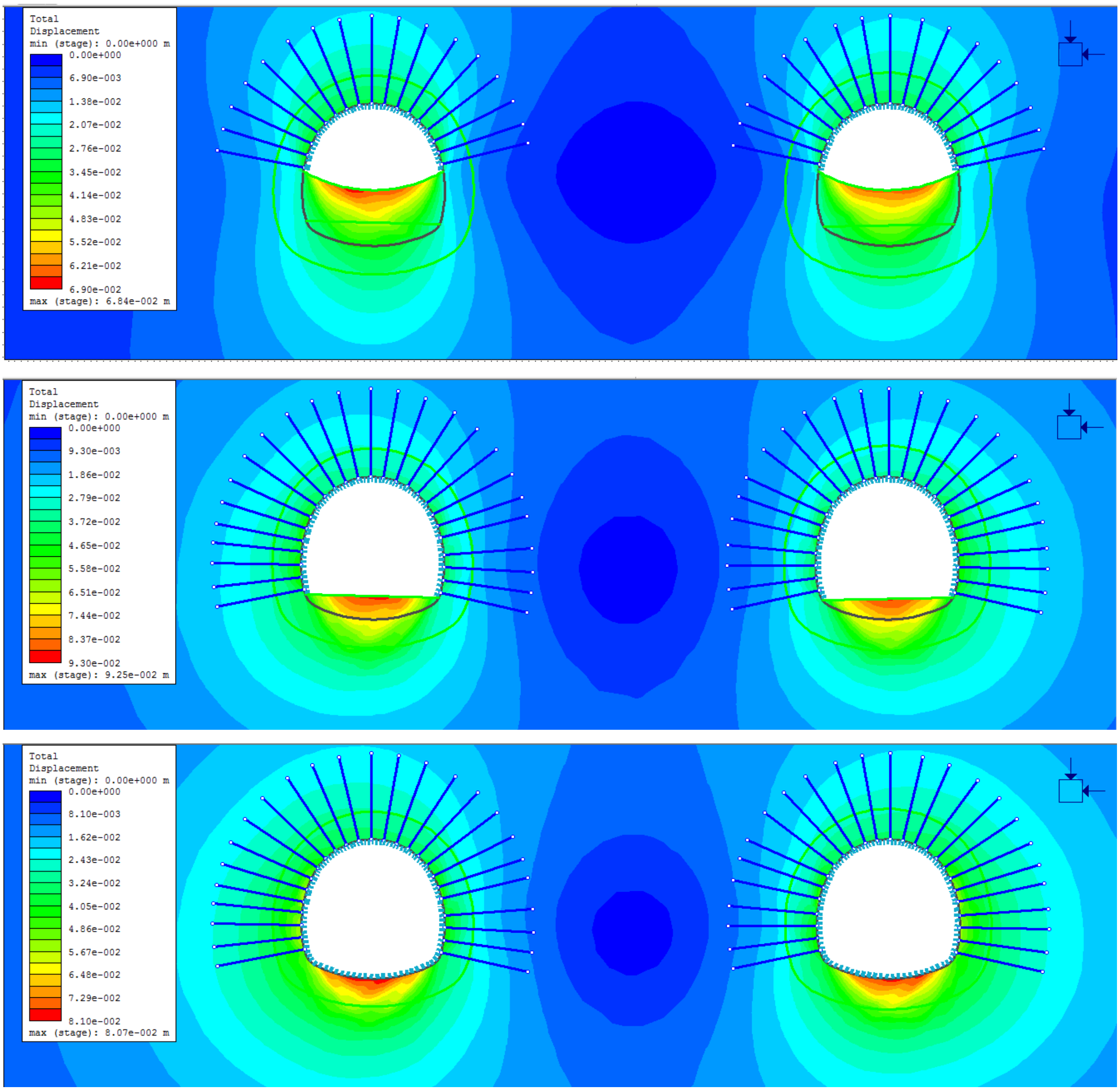


Figure 44: Total Displacement Contours for Rock Class V (Stages 1 to 3)

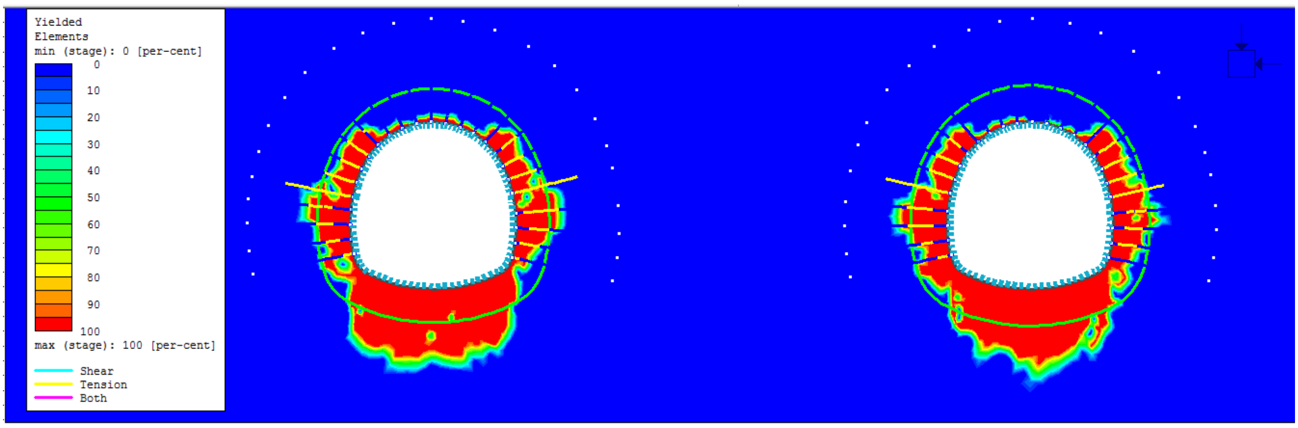


Figure 45: Yielded Zones and Strength Factor for Rock Class V

From Figures 19 to 45, it is seen that for the tunnel, the maximum deformations around the tunnel varies from 3.82 mm to 120 mm (From Rock Classes I to V) are well within the permissible limit. The major principal stresses vary from 2.5 MPa to 34 MPa. The yield zones are well contained by the support system. Hence the provided support system is safe.

4.6.4 Recommended Support System for Tunnel

Based on the above Phase2 analysis, the support system recommended for the tunnel is, as shown in Table 10.

Table 10: Recommended Rock Support System for Tunnel

Rock Class	RMR	Rock Support			
		Shotcrete	Lattice Girders	Rock Bolts	Pipe Roofing
Class I	81-100	50mm thick SFRS	--	Spot bolting (where ever required) (25mmΦ, 5.0 m long fully grouted rock bolts)	--
Class II	61-80	100mm thick SFRS	--	25mmΦ, 5.0 m long fully grouted rock bolts @ 2.0 m c/c in crown in staggered pattern	--
Class III	41-60	150 mm thick SFRS	--	Systematic rock bolting, 25mmΦ, 5.0 m long fully grouted rock bolt @ 1.75 m c/c staggered at crown & wall	--
Class IV	21-40	250 mm thick SFRS	Lattice girder @ 0.5 m c/c	Systematic rock bolting, 25mmΦ, 7 m long fully	--

Rock Class	RMR	Rock Support			
		Shotcrete	Lattice Girders	Rock Bolts	Pipe Roofing
		in crown, wall & invert	as shown in drawings	grouted rock bolts @ 1.0 m c/c staggered at crown & wall	
Class V	0-20	250 mm thick SFRS in crown, wall & invert	Lattice girder @ 0.5 m c/c as shown in drawings	Systematic rock bolting, 25mmΦ, 7 m long fully grouted rock bolts @ 1.0 m c/c staggered at crown & wall	89 mm Φ (outer dia), 6 m long forepoling @ 400 mm c/c (circumferential spacing)

5. DESIGN OF CONCRETE LINING

5.1 Introduction

This report covers the design of concrete lining for the Khellani Tunnel and it is the part of Detail Project Report of Khellani Tunnel. The design of concrete lining has been carried out in such a way that it could sustain all the loads.

5.2 Input Parameters

5.2.1 Material Properties

- Grade of Concrete — M35
- Young Modulus of Concrete, E_c — 29580 MPa ($5000\sqrt{f_{ck}}$)
- Unit Wt. of Concrete — 25kN/m^3
- Grade of Steel — Fe500
- Yield Strength of steel — 500MPa
- Poisson's ratio — 0.20
- Clear Cover — 50mm

5.2.2 Rock Parameters

Table 11: Rock Parameters

Ground Type	Overburden (Max./Average) m	Q Index Selected	RMR Value Selected	Unit Wt. kN/m^3	RM Strength, σm Mpa	Poisson's Ratio, μ	Modulus, Erm Gpa	Internal Friction, Φ	Cohesion, Crm Mpa
3	831/413	11	42	26.38	4.7	0.25	10.80	36.6	2.71
4	456/323	0.05	22	26.59	2.2	0.26	5.20	35.4	1.29
5	432/291	0.007	10	26.31	1.2	0.26	1.90	34.8	1.10

5.2.3 Tunnel Geometry

Tunnel cross section with invert in rock class IV & V, cross section without invert in rock class III is taken for the analysis.

5.2.4 Loads

Following loads are considered in the design of concrete lining of tunnel.

Dead Load (G1)

Self-weight of the lining is considered as dead load. Dead load of concrete lining is calculated from concrete volumes taken off from physical dimensions of the tunnel.

Rock Load (G2)

Considering the plasticization around the cavity, the ground materials present different plasticized radius R_p depending on the time and magnitude of support applied, and on the geotechnical parameters of respective rock masses.

Concerning to rock load distribution in the final lining model ring, below it is shown a handmade scheme with the loads intervening on the model beams for the spring bedded model:

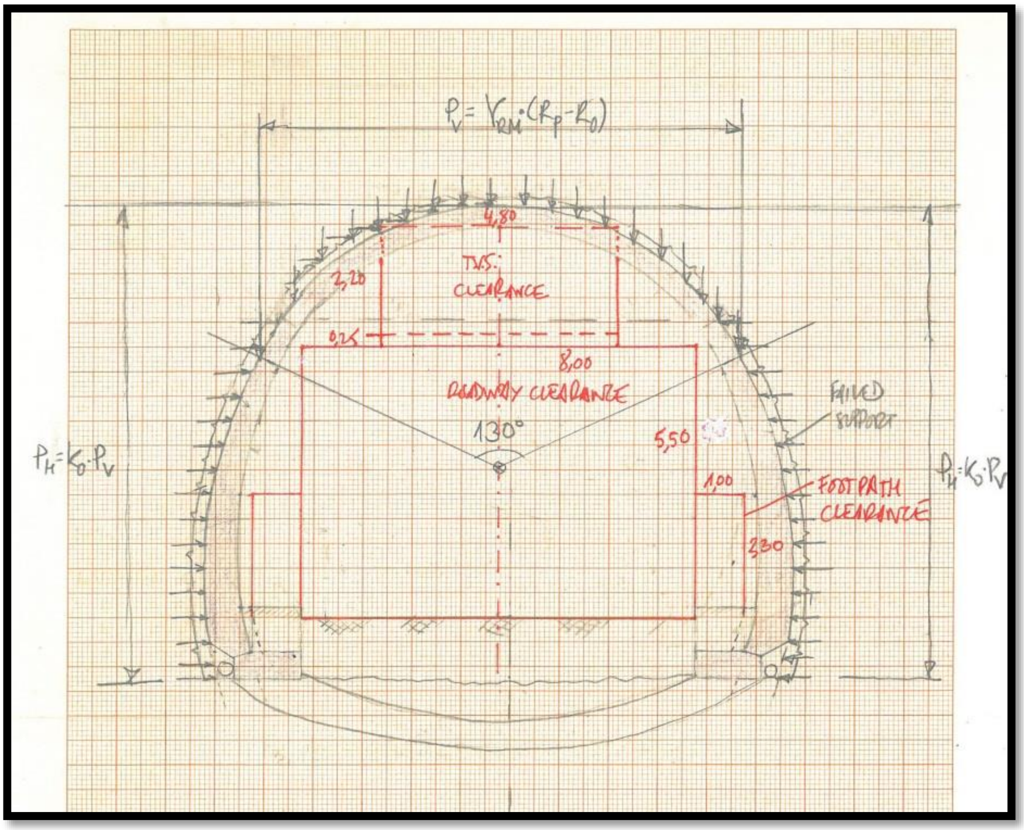


Figure 46: Rock Load distribution for final lining calculation in case of static loads

Vertical unit load is $P_v = \gamma_{RM} \cdot (Rp\text{-}R0)$, and acts on the 130º of crown umbrella, while horizontal unit load is $P_H = K_0 \cdot P_V$, where γ_{RM} is rock mass unit weight, and K_0 is the at rest earth pressure coefficient, which can be estimated as $K_0 = 1 - \sin\phi$ with ϕ as rock mass internal friction angle. Minimum K_0 is taken equal to 1.

Rock Loads considered in the analysis for different type of rock are given in below table.

Table 12: Rock Loads in Different Rock Classes

Excavation & Support Class	Plasticization Ring Width (Rp-R0), Adopted for Design (m)	Unit Wt. of Rock (kN/m³)	Rock Load on Crown, P_v (kN/m²)	Internal Friction, ϕ	Coefficient of Rock Pressure at Rest, K_o	Rock Load on Side Walls, P_H (kN/m²)
3	3.50	26.38	92.33	36.6	1.00	92.33
4	6.50	26.59	172.84	35.4	1.00	172.84
5	10.00	26.31	263.10	34.8	1.00	263.10

Load of Pavement (G1)

Pavement is consisting of PQC, dry lean concrete and granular sub base. The wt. of all these materials shall act on the invert of the tunnel. Considering average unit wt. of all these materials as 22kN/m3 and the corresponding total thickness, load is applied on the invert lining.

Temperature Load (Q1)

Temperate loads are generated due to the temperature differences between the atmosphere and inside the concrete lining. Since tunnel is an underground structure, so the temperature differences will be very less. Because of this, these loads are neglected in the design.

External Water Load

It is assumed that 50kPa water load can act as external pressure at the crown and it is linearly decreased up to nil towards the bottom. At the center of invert, 30kPa uplift force is taken which decreases up to nil towards both the sides.

Earthquake Force

In general, underground structures are subjected to much less stresses in earthquake than structures above the ground. These stresses reduce with increase in depth. Location of tunnel is underground where super-incumbent cover varies, due to this cover the effect of ground motion will reduce substantially. So, it can be assumed that earthquake induced stress in tunnel are much lower due to earthquakes. Due to this reason, seismic loads are not considered for the design of lining.

5.2.5 Load Combinations

Considering the limit state method following load combinations have been taken for the analysis,

I 1.5×G1

II 1.5×G1+1.50×G2

5.3 Design Approach & Methodology

A two-dimensional plane frame Analyses are performed using the computer program from STAAD Pro. Beam elements have been modeled to analyze the structure. The interface between lining and rock cannot withstand tension; therefore, interface elements may be used, or the springs deactivated when tensile stresses occur. Compression only surface spring is considered to generate the support condition. Springs have been generated by using STAAD command and reference can be made to STAAD manual for further details. Radial springs are applied at each node to simulate elastic interaction between the lining and the rock.

All loads have been applied on the lining and different possible loads combinations have been created and analyzed. Lining is designed for bending moment and shear forces taken from the STAAD pro output file.

5.4 Analysis

5.4.1 STAAD Model

Geometry of the tunnel cross section is taken from the AutoCAD software. A 3D view of the model created in the STAAD Pro is shown below.

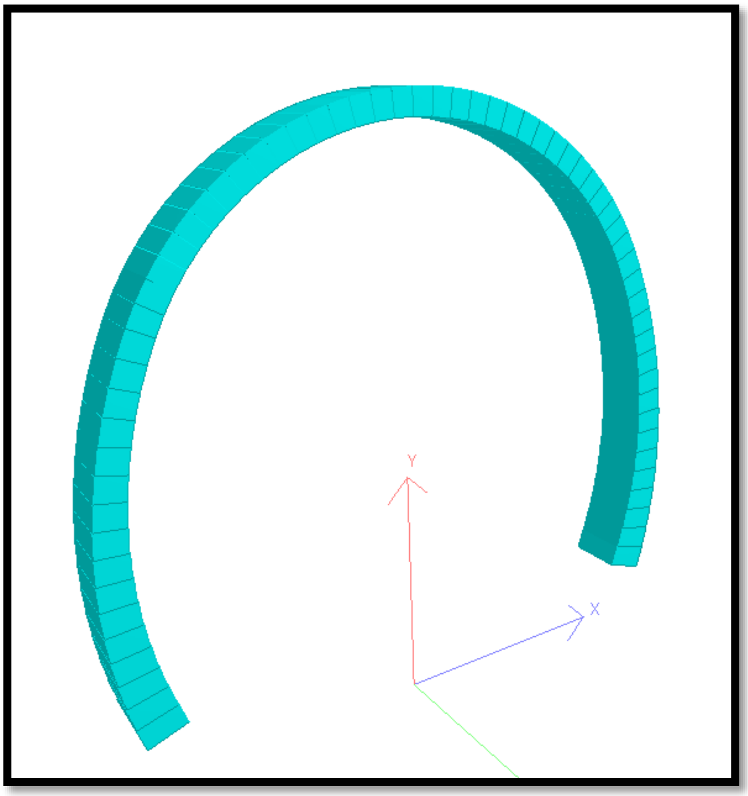


Figure 47: 3D View of STAAD Model (Section without Invert)

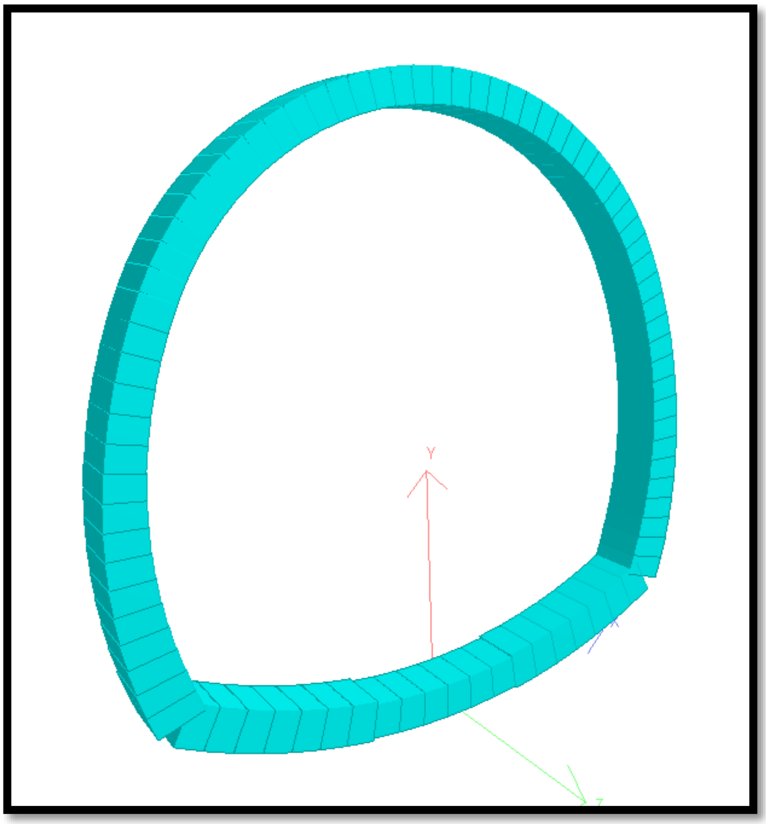


Figure 48: 3D View of STAAD Model (Section with Invert)

5.4.2 Spring Stiffness

Radial spring stiffness expressed in unit of force/displacement is calculated as per given formula,

K_r = $E_r\, b\, \theta / (1+\mu_r)$

K_T = $0.5K_r / (1+\mu_r)$

Where, K_r Radial Spring Stiffness

K_T Tangential Spring Stiffness

E_r Modulus of Deformation of Rock mass

b Length of tunnel element considered

θ Arc subtended by the beam element (radian)

μ_r Poison Ration of rock

A figure is shown below for the reference.

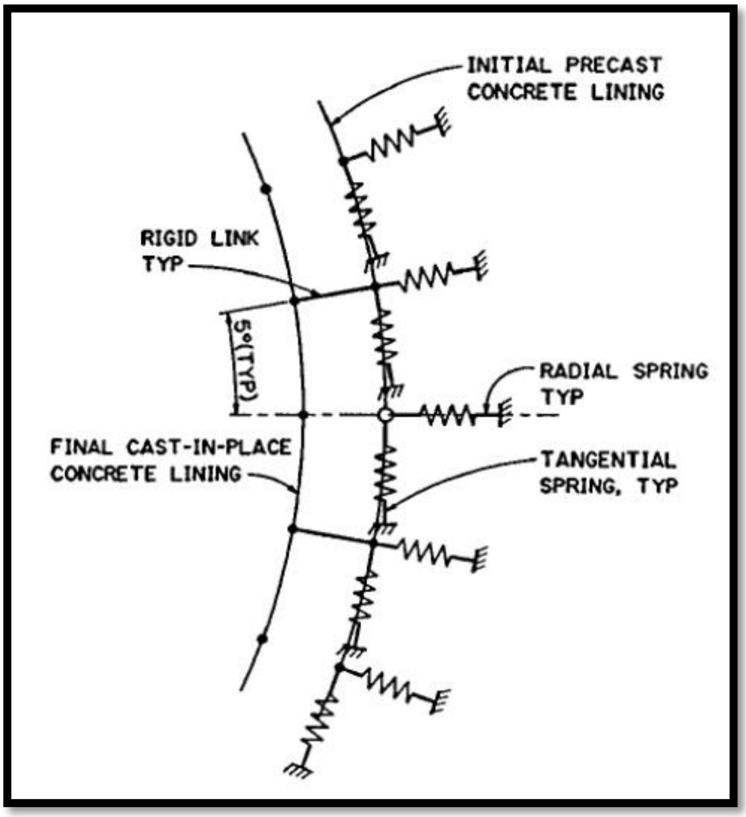


Figure 49: Beam Spring Model

Calculations are shown in below tables,

Table 13: Class Wise Calculations (Radial Spring Stiffness)

Class- 3						
#	**Radial Spring Stiffness**	**K_r**	**$E_r.b.\Phi/(1+\mu_r)$**			**Unit**
	Where		Walls	Crown	Invert	
1	Modulus of Deformation of Rock Mass	Er	10800	10800	10800	N/mm²
2	Width of Element under consideration	b	1000	1000	1000	mm
3	Average Length of member		0.410	0.355	0.500	m
4	Radius of lining		8.36	5	10.06	m
5	Angle subtended by element	$\Phi = l/r$	0.049	0.071	0.050	Radians
6	Poisson Ratio of Rock		0.25	0.25	0.25	
7	Radial Spring Stiffness	K_r	423732	613440	429423	kN/m
8	Tangential Spring Stiffness	K_T	169493	245376	171769	kN/m
Class- 4						
#	**Radial Spring Stiffness**	**K_r**	**$E_r.b.\Phi/(1+\mu_r)$**			**Unit**
	Where		Walls	Crown	Invert	
1	Modulus of Deformation of Rock Mass	Er	5200	5200	5200	N/mm²
2	Width of Element under consideration	b	1000	1000	1000	mm
3	Average Length of member		0.410	0.355	0.500	m
4	Radius of lining		8.36	5	10.06	m
5	Angle subtended by element	$\Phi = l/r$	0.049	0.071	0.050	Radians
6	Poisson Ratio of Rock		0.26	0.26	0.26	
7	Radial Spring Stiffness	K_r	202400	293016	205118	kN/m
8	Tangential Spring Stiffness	K_T	80317	116276	81396	kN/m
Class- 5						
#	**Radial Spring Stiffness**	**K_r**	**$E_r.b.\Phi/(1+\mu_r)$**			**Unit**
	Where		Walls	Crown	Invert	
1	Modulus of Deformation of Rock Mass	Er	1900	1900	1900	N/mm²
2	Width of Element under consideration	b	1000	1000	1000	mm
3	Average Length of member		0.410	0.355	0.500	m
4	Radius of lining		8.36	5	10.06	m
5	Angle subtended by element	$\Phi = l/r$	0.049	0.071	0.050	Radians
6	Poisson Ratio of Rock		0.26	0.26	0.26	
7	Radial Spring Stiffness	K_r	73954	107063	74947	kN/m
8	Tangential Spring Stiffness	K_T	29347	42486	29741	kN/m

STAAD model with the applied support as spring is shown below,

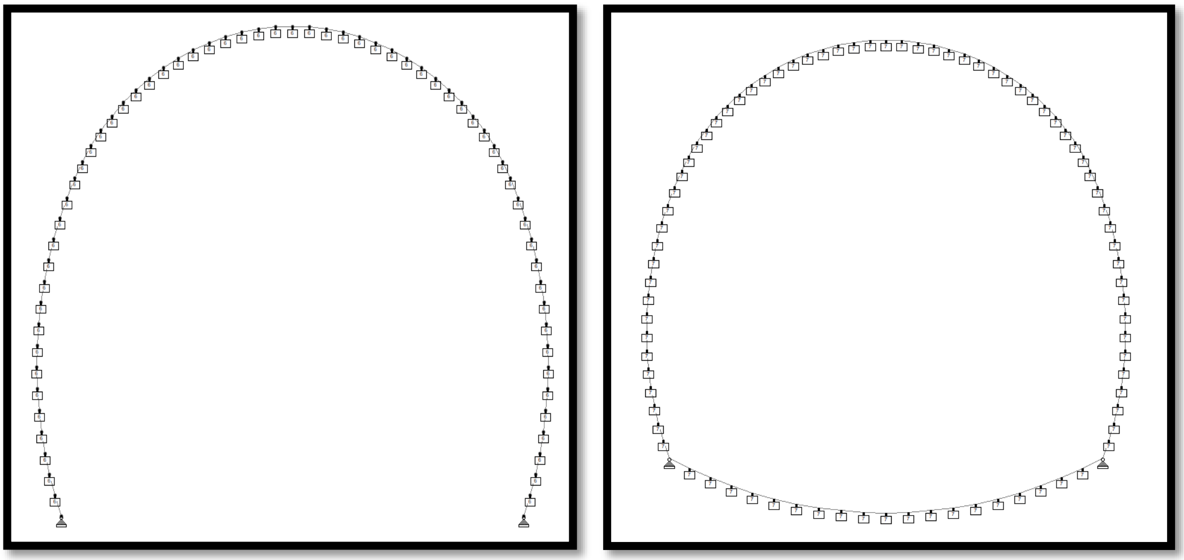


Figure 50: STAAD Model with Applied Supports

5.4.3 Applied Loads

Self wt. of the lining and rock loads have been applied on the structure. STAAD model with the applied rock load is shown below,

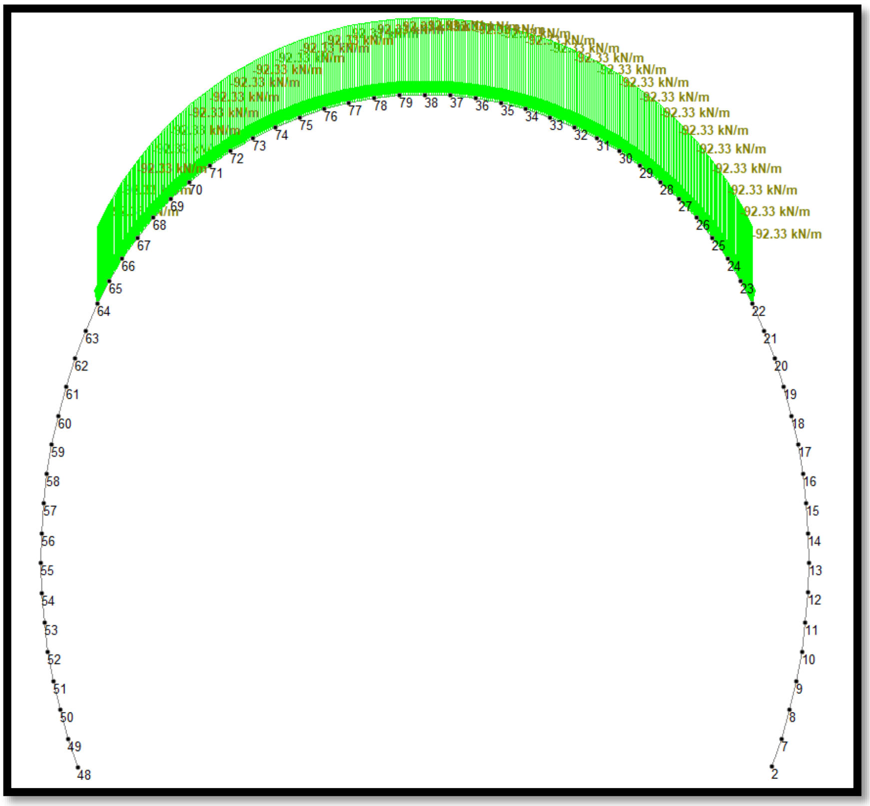


Figure 51: Rock load at Crown (Class-3)

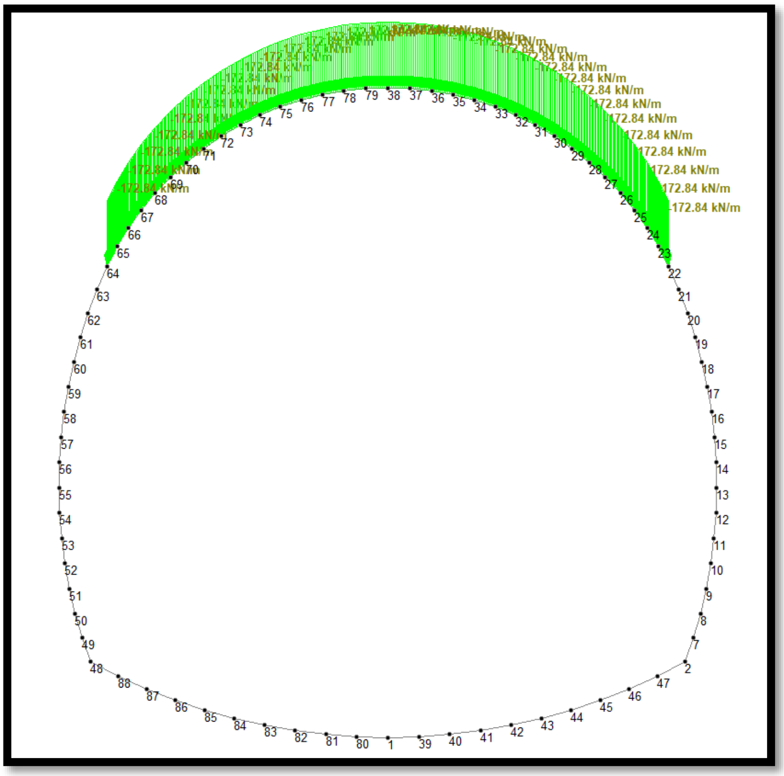


Figure 52: Rock load at Crown (Class-4)

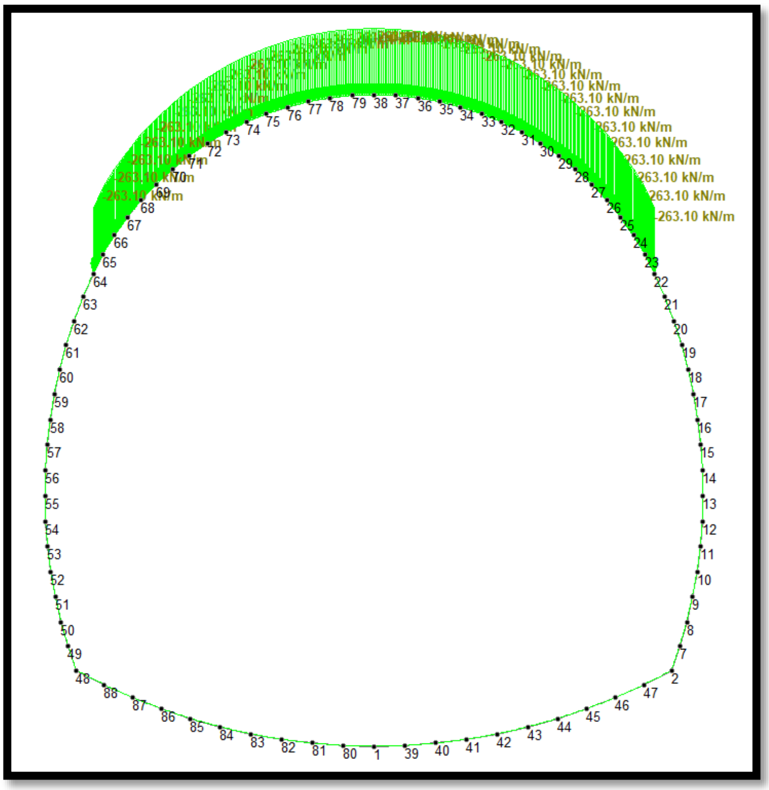


Figure 53: Rock load at Crown (Class-5)

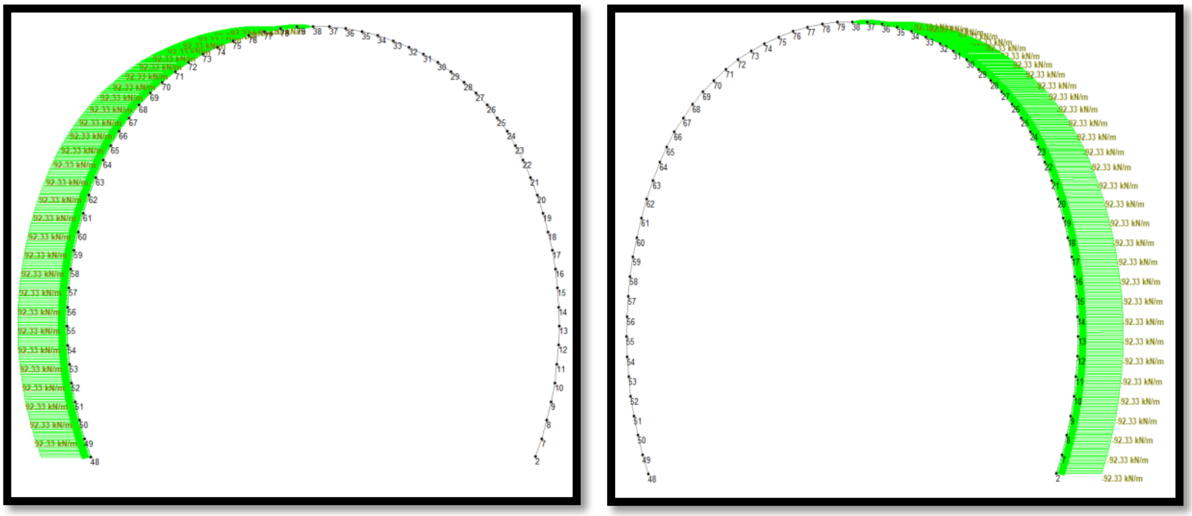


Figure 54: Rock load at Walls (Class-3)

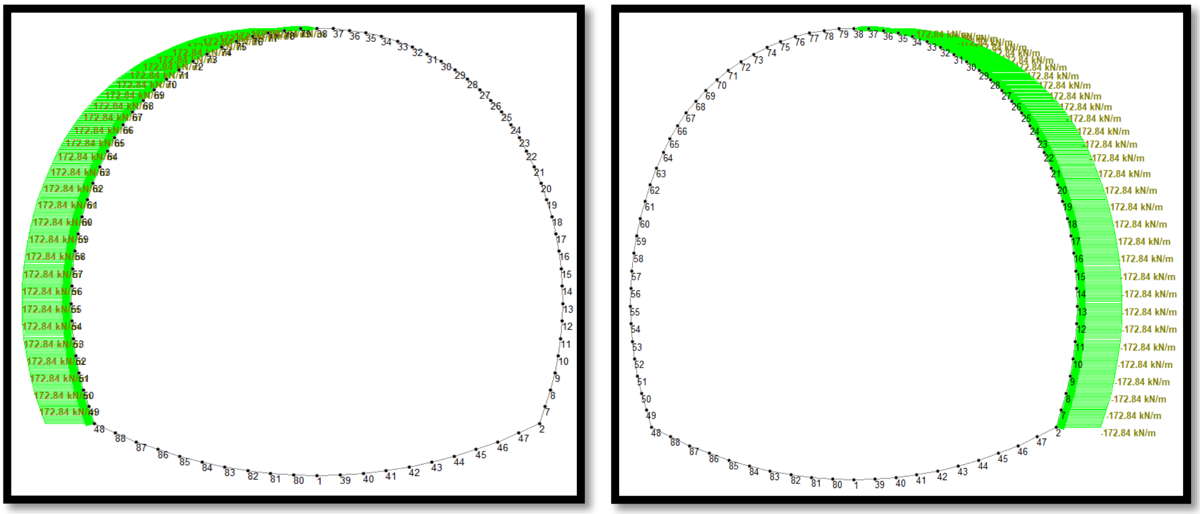


Figure 55: Rock load at Walls (Class-4)

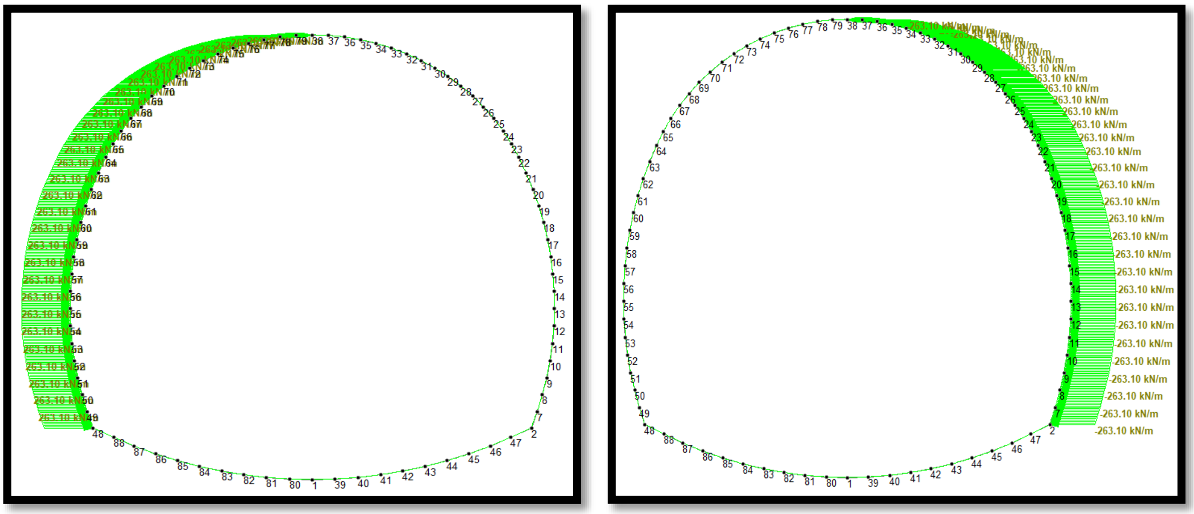


Figure 56: Rock load at Walls (Class-5)

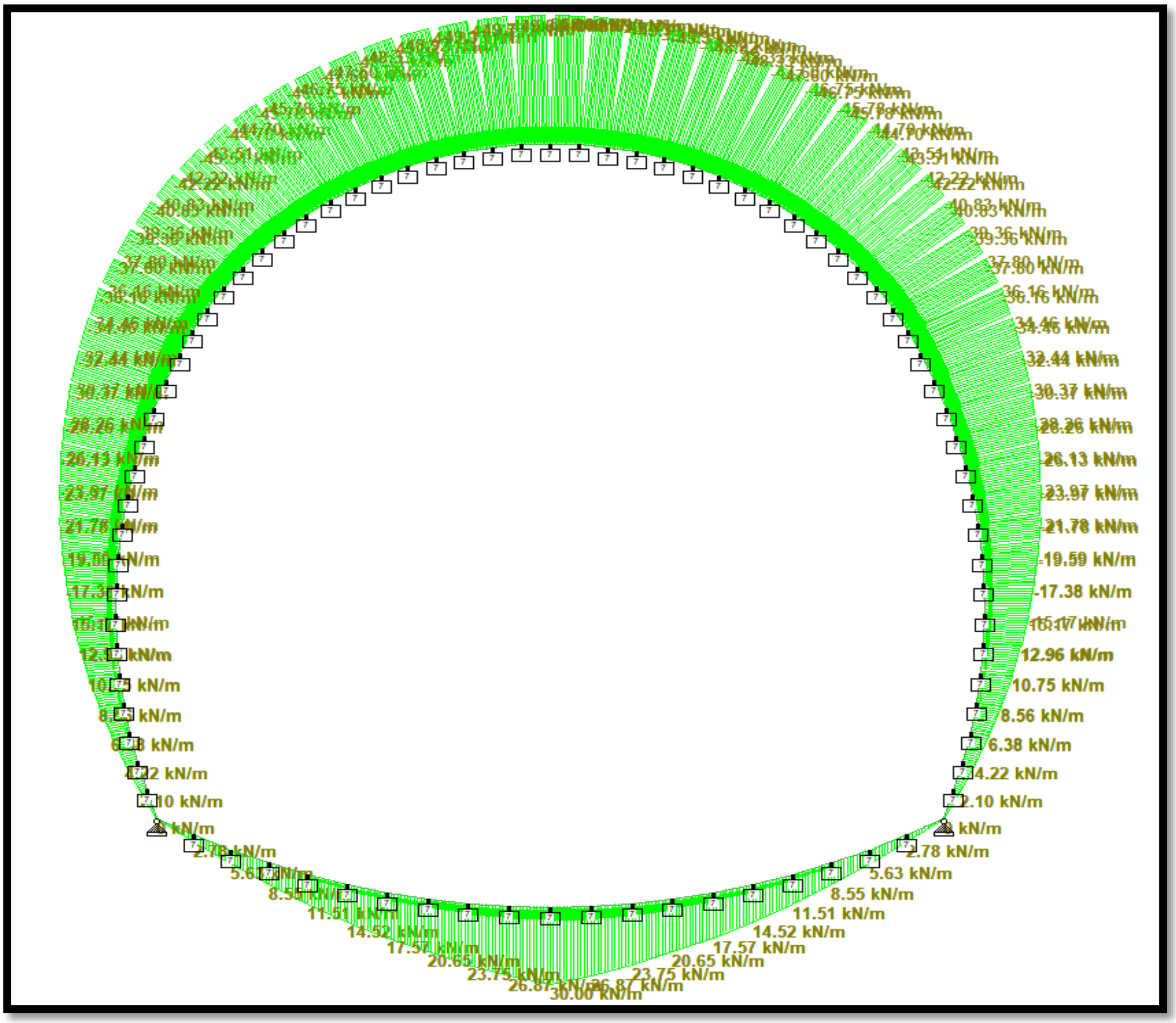


Figure 57: External Water Load (All Class)

5.5 Result and Discussion

Analysis has been performed for the all the applied loads and their possible combination. After analysis of the model, the bending moment and shear forces have been taken from the output file. Required thickness of concrete lining and required reinforcement has been calculated for the critical moments and shear forces. Results are shown for critical loading combinations in below figures.

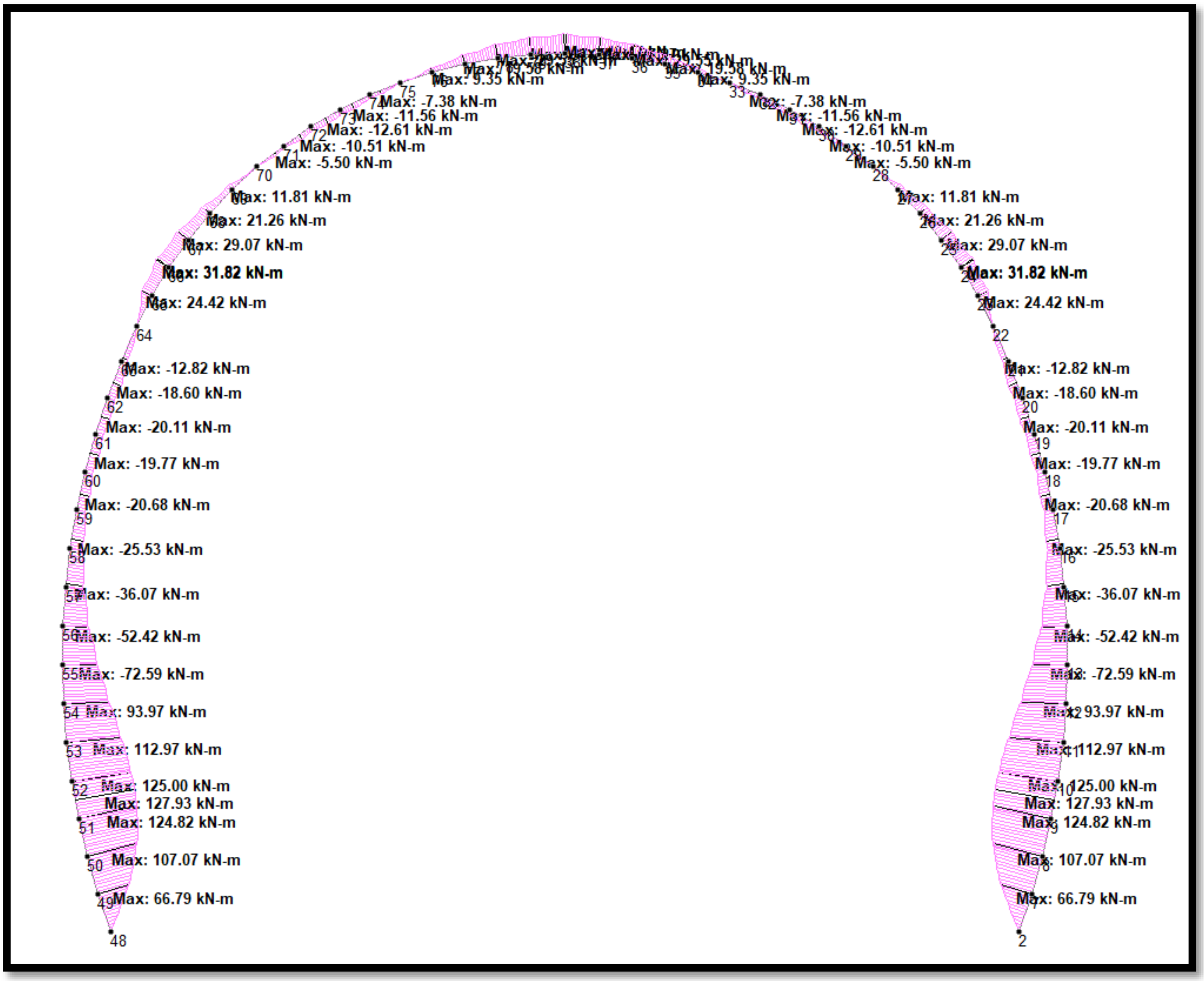


Figure 58: Bending Moment Diagram (Class III)

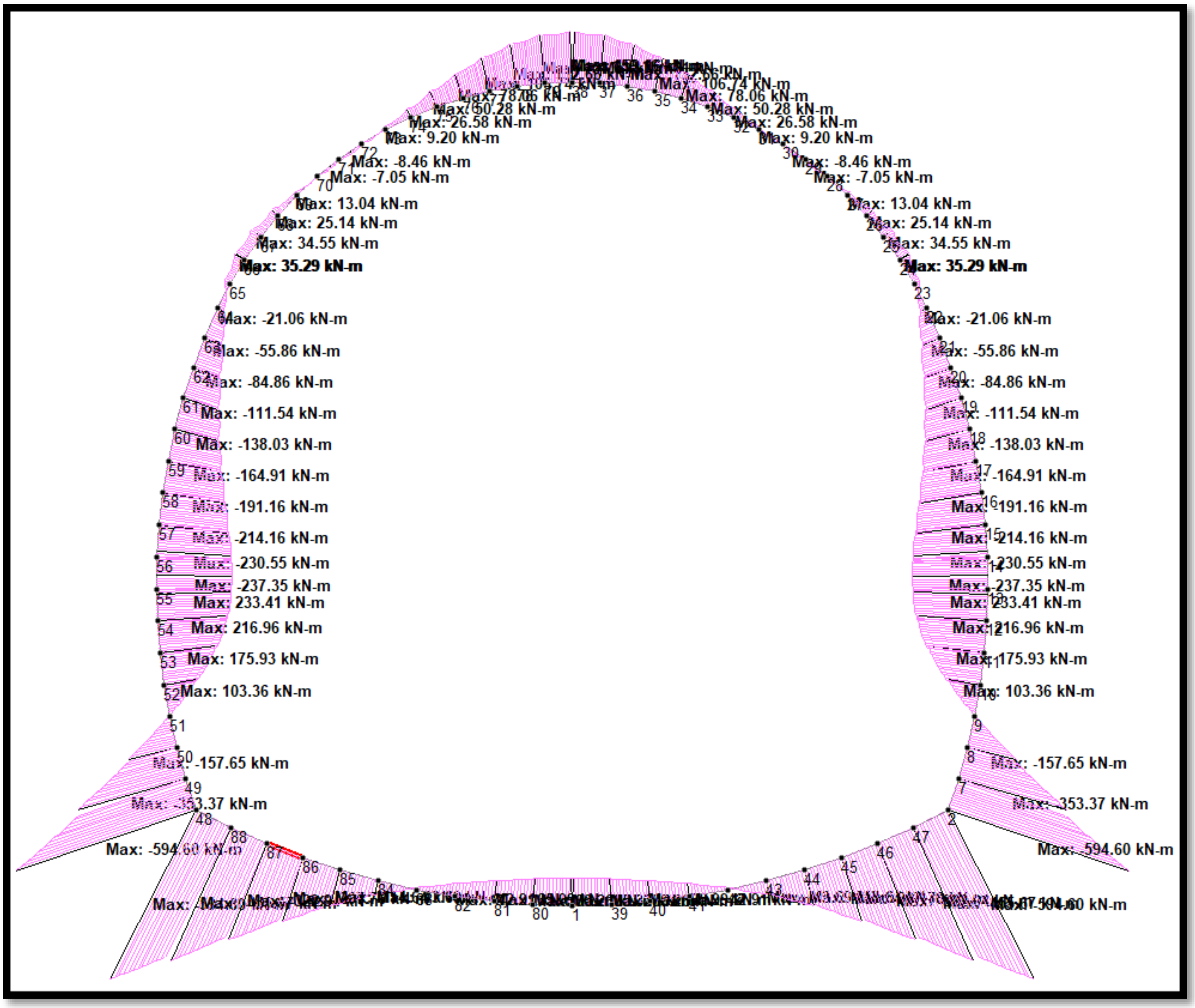


Figure 59: Bending Moment Diagram (Class IV)

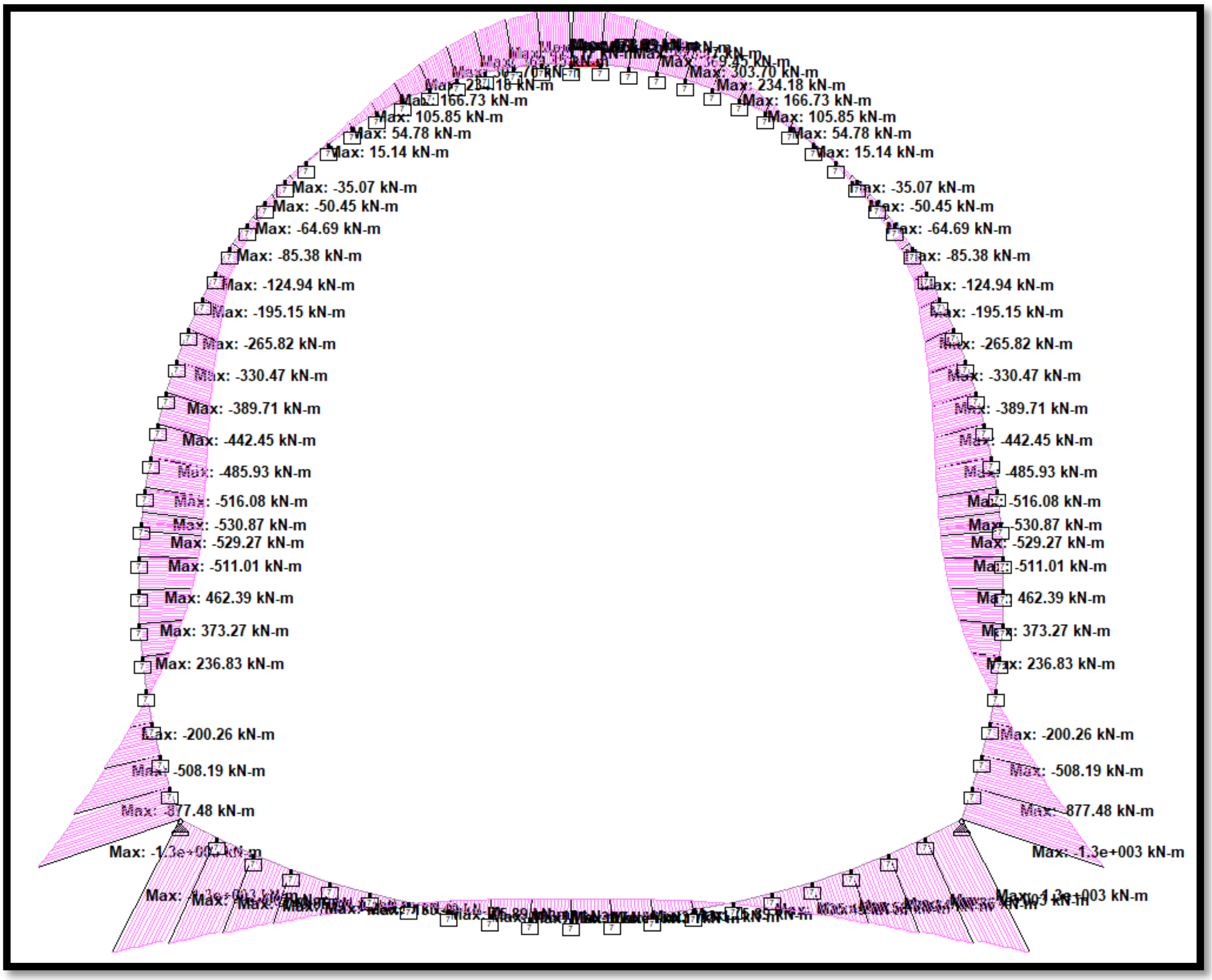


Figure 60: Bending Moment Diagram (Class V)

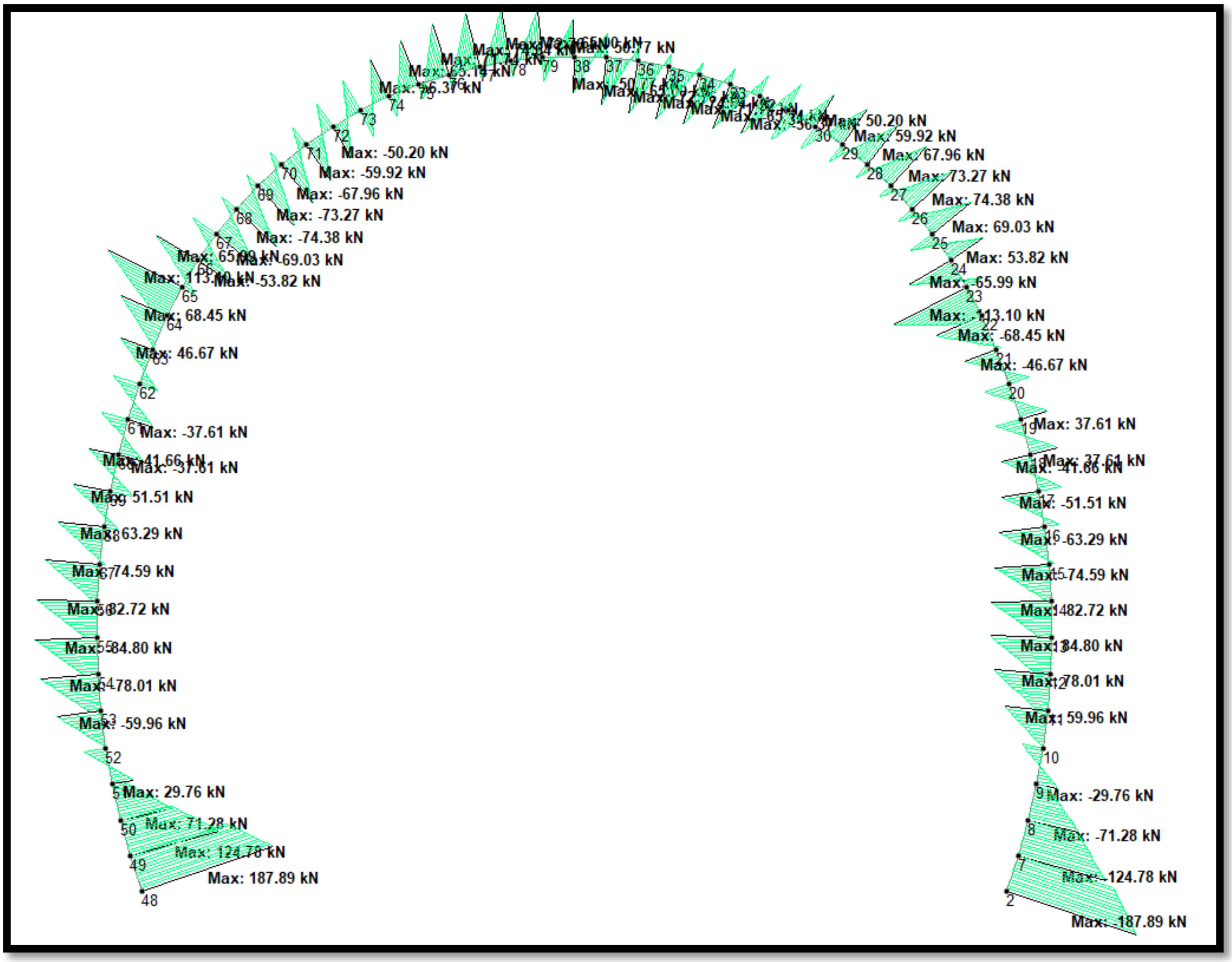


Figure 61: Shear Force Diagram Class III

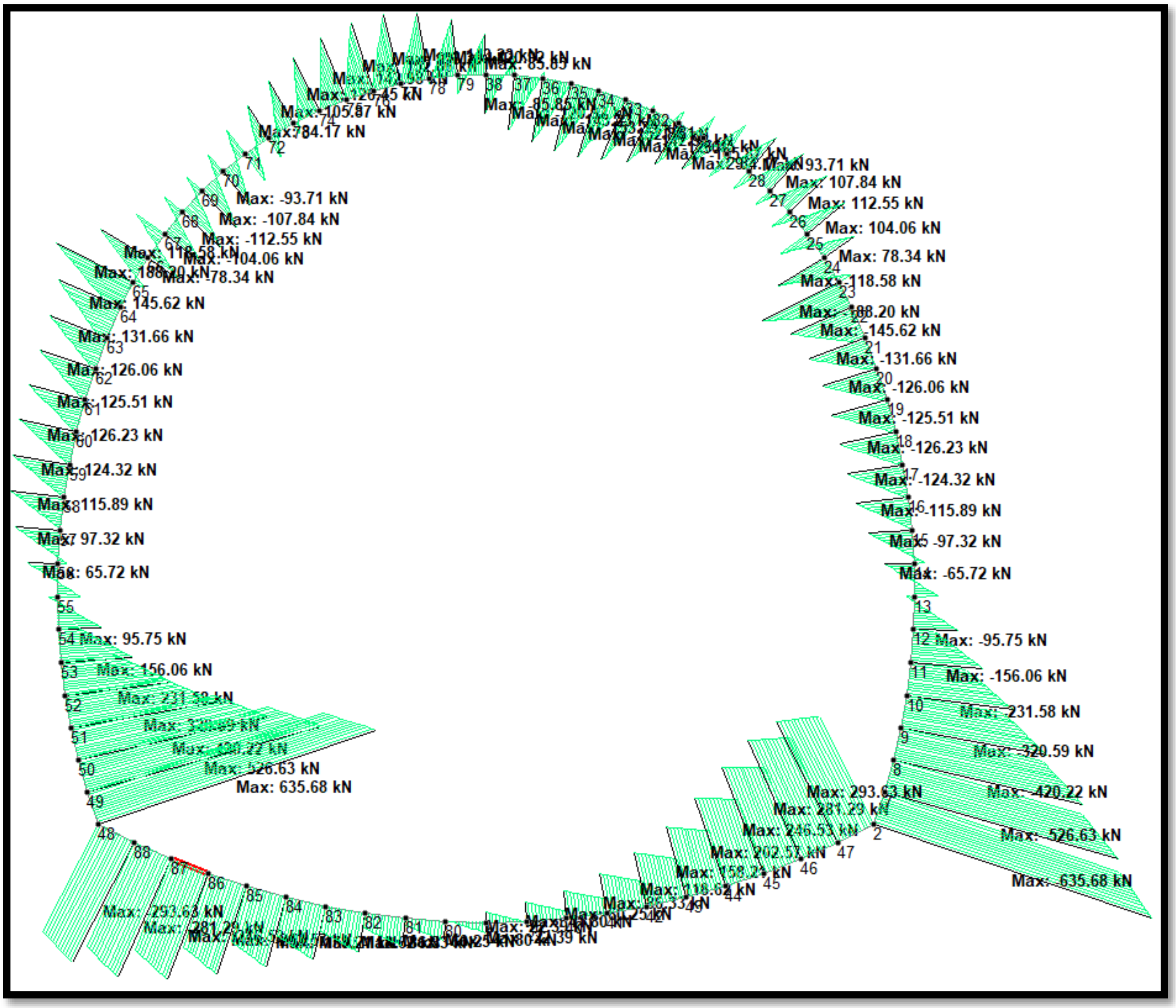


Figure 62: Shear Force Diagram (Class IV)

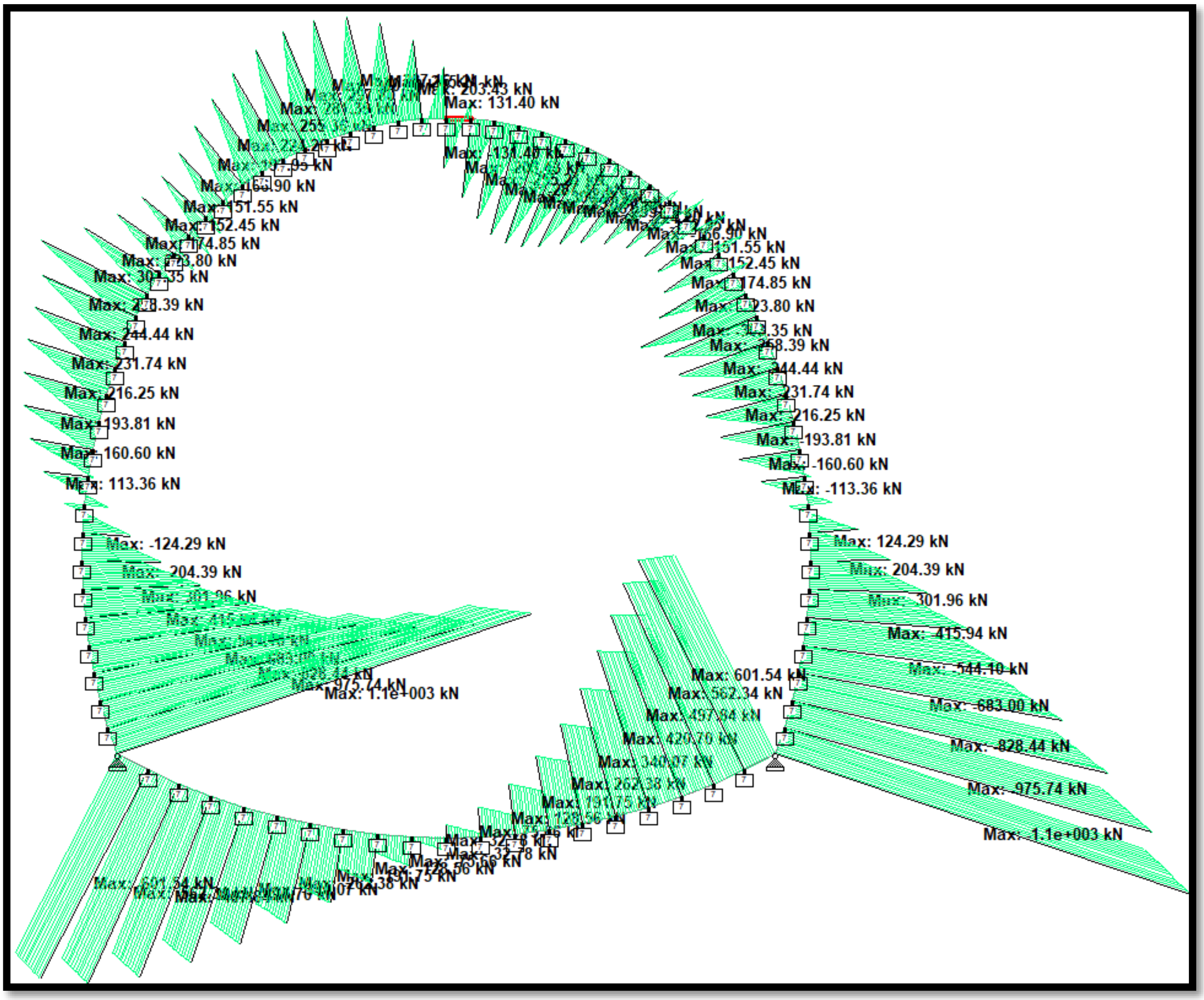


Figure 63: Shear Force Diagram (Class V)

As per the analysis, it is observed that the sections in class-4 & 5 are required RCC lining. In section of class-3, moments, shear forces and corresponding tensile stresses are well below the tensile strength of grade M35 concrete. So, RCC lining is not required in rock class-3 and above.

As per the moment and shear force diagram, maximum moment and shear occurs at the bottom corners of the wall and invert. To counter these moments and shear, thickness of lining is increased at both the corners. Reinforcement and thickness of lining are calculated for wall, invert and crown locations of tunnel.

Summary of the results is shown in below table.

Table 14: Results - Analysis (Class 5-With Invert)

S. No.	Description	Bending Moment kN-m	Shear Force kN
1	Invert	741	498
2	Bottom Corner	1307	1120
3	Side walls	531	976
4	Crown	479	304

Table 15: Results - Analysis (Class 4-With Invert)

S. No.	Description	Bending Moment kN-m	Shear Force kN
1	Invert	323	247
2	Bottom Corner	595	636
3	Side walls	238	527
4	Crown	160	188

5.6 Design of Concrete Lining

Concrete lining has been designed using the limit state method. Lining thickness at the different locations (invert, crown, walls and bottom corners) has been checked. Calculations have been shown at Annexure A1 & A2. Outcome of the design is tabled below,

Table 16: Outcome of the Design (Concrete lining)

<table>
<tr><th rowspan="2">Description</th><th rowspan="2">Grade of Concrete Lining</th><th colspan="3">Lining Thickness (mm)</th></tr>
<tr><th>At crown</th><th>At Invert</th><th>At Wall</th></tr>
<tr><td>Section with Invert</td><td rowspan="2">M35</td><td>500</td><td>590 (at mid)
Increasing towards the corner</td><td>Varying from 500 to 760</td></tr>
<tr><td>Section without invert</td><td>400</td><td>-</td><td>Varying from 400 to 660</td></tr>
</table>

Annexure - A1

Design of Concrete Lining (Class-5)

Input Data

1	Grade of Concrete	M	35		
2	Grade of Steel	Fe	500		
3	Compressive strength of concrete	f_{ck}	35	N/mm^2	
4	Length considered in analysis	b	1000	mm	
5	Clear Cover		50	mm	

			Wall	Bottom Corner	Invert	Crown	Unit
9	Moment as per STAAD	M_u	531	1307	741	479	kNm
10	Shear Force as per STAAD	F_u	976	1120	498	304	kN
Thickness Calculation							
11	Required effective thickness		338	530	399	321	mm
12	Total Thickness required		400	592	461	383	mm
13	Thickness provided (Considering 200mm shotcrete)			**930**	**780**	**500**	mm
	At the location of max. moment		**587**				mm
	At the location of max. Shear		**762**				mm
14	Effective Thickness,	d	515	858	708	428	mm
			690				mm
Calculation of Main Reinforcement							
15	R	$R = Mu/bd^2$	2.01	1.78	1.48	2.62	
16	Required area of steel	$A_{st} = \frac{0.5 f_{ck}}{f_y}\left[1-\sqrt{1-\frac{4.6R}{f_{ck}}}\right]bd$	2555	3738	2539	2848	mm^2
			0.50%	0.44%	0.30%	0.67%	
17	Minimum area of steel,	A_{st}= 0.12% bd	617	1029	1203	727	mm^2
18	Required Spacing of bar						
		No. of layers	1	1	1	1	
		Dia of bar	25	25	25	25	
	1 dia	bar @	192	131	193	172	mm c/c spaicng
	2	Diff. Dia Bars @	158	108	159	141	mm c/c spaicng
19	**Lets provide**	25 ϕ, bar @	***300***	**200**	**200**		***mm c/c spaicng***
		20 ϕ, bar @	***300***	**200**	**200**	**100**	***mm c/c spaicng***
20	Provided Reinforcement		2683	4025	4025	3142	mm^2
			0.39%	0.47%	0.57%	0.73%	
Check in Shear							
21	Nominal Shear Stress	τ_v	1.42	1.31	0.70	0.71	N/mm^2
22	Design Shear Strength	τ_c	0.44	0.48	0.53	0.58	N/mm^2
23	Design Shear Force		303	412	375	248	kN
			Unsafe	*Unsafe*	*Unsafe*	*Unsafe*	
24	Dia of stirrup/ link bar		10	10	10	10	mm
25	No. of legs/bars along the length		6	6	4	4	Nos
26	Area of Shear Reinforcement,	A_{sv}	471	471	314	314	mm^2
27	Design Shear force	$(\tau_v-\tau_c)bd$	672620	708400	123025	56050	N
28	Spacing of Shear Reinforcement		174	206	652	865	mm
29	Min. Spacing of Shear Reinforcement		425	425	284	284	mm
30	Let's provide		**150**	**150**	**150**	**280**	**mm, c/c spacing**

Distribution Reinforcement

31	Thickness considered		500	mm
32	Required reinforcement	0.12%	600	mm^2
			600	mm^2 (on each face)
33	Required Spacing of bar			
		12 mm dia of bar @	188	mm c/c spaicng
	Lets provide		***175***	***mm c/c spaicng***

Annexure - A2

Design of Concrete Lining (Class-4)

Input Data

1	Grade of Concrete	M	35	
2	Grade of Steel	Fe	500	
3	Compressive strength of concrete	f_{ck}	35	N/mm^2
4	Length considered in analysis	b	1000	mm
5	Clear Cover		50	mm

No.	Description	Symbol	Wall	Bottom Corner	Invert	Crown	Unit
9	Moment as per STAAD	M_u	238	595	323	160	kNm
10	Shear Force as per STAAD	F_u	527	636	247	188	kN
	Thickness Calculation						
11	Required effective thickness		226	358	263	185	mm
12	Total Thickness required		286	418	323	245	mm
13	Thickness provided (Considering 200mm shotcrete)			**930**	**780**	**500**	mm
	At the location of max. moment		**587**				mm
	At the location of max. Shear		**762**				mm
14	Effective Thickness,	d	517	860	710	430	mm
			692				mm
	Calculation of Main Reinforcement						
15	R	$R = Mu/bd^2$	0.89	0.80	0.64	0.87	
16	Required area of steel $A_{st} = \frac{0.5f_{ck}}{f_y}\left[1-\sqrt{1-\frac{4.6R}{f_{ck}}}\right]bd$		1092	1636	1069	882	mm^2
			0.21%	0.19%	0.12%	0.21%	
17	Minimum area of steel,	A_{st}= 0.12% bd	620	1032	1207	731	mm^2
18	Required Spacing of bar						
	No. of layers		1	1	1	1	
	Dia of single bar		20	20	20	20	
	1 dia	bar @	288	192	260	356	mm c/c spaicng
	2	Diff. Dia Bars @	236	157	241	292	mm c/c spaicng
19	**Lets provide**	20	**300**	**300**	**200**	**150**	*mm c/c spaicng*
		16	**300**	**300**	**200**		
20	Provided Reinforcement		1717	1717	2576	2094	mm^2
			0.25%	0.20%	0.36%	0.49%	
	Check in Shear						
21	Nominal Shear Stress	τ_v	0.76	0.74	0.35	0.44	N/mm^2
22	Design Shear Strength	τ_c	0.37	0.33	0.36	0.49	N/mm^2
23	Design Shear Force		256	284	256	211	kN
			Unsafe	*Unsafe*	*Safe*	*Safe*	
24	Dia of stirrup/ link bar		10	10	10	10	mm
25	No. of legs/bars along the length		4	4	4	4	Nos
26	Area of Shear Reinforcement,	A_{sv}	314	314	314	314	mm^2
27	Design Shear force	$(\tau_v-\tau_c)bd$	270960	352200	No Shear	No Shear	N
28	Spacing of Shear Reinforcement		290	277	#VALUE!	#VALUE!	mm
29	Min. Spacing of Shear Reinforcement		284	284	284	284	mm
30	Let's provide		**250**	**250**			mm, c/c spacing

Distribution Reinforcement

31	Thickness considered		500	mm
32	Required reinforcement	0.12%	600	mm^2
			600	mm^2 (on each face)
33	Required Spacing of bar			
	12	mm dia of bar @	188	mm c/c spaicng
	Lets provide		***175***	***mm c/c spaicng***

5.7 Reference

5.7.1 Codes and Standards

1) USACE EM 1110-2-2901 Engineering and Design - Tunnels and Shafts in rock
2) IS 456:2000 Plain and Reinforced Concrete
3) IS 1893 (Part 1) – 2002, Criteria for Earthquake Resistant Design

6. TUNNEL E&M DESIGN AND METHODOLOGY

6.1 Power Supply and Technical Rooms

6.1.1 Technical Rooms Distribution

In order to provide enough space for the electrical power and control equipment of the tunnels, a series of technical buildings have been planned in the following locations, according to what is reflected in the corresponding drawings:

- Outdoor technical buildings (2), next to both portals of Khellani tunnel, composed of an electrical substation, a low voltage room, a diesel generator room and a communications room.
- Communication niches in all cross – passages for PLCs and communications racks.

In addition, the Main Control Centre will house the major control and monitoring equipment of the different subsystems.

6.1.2 Power Supply System

6.1.2.1 Design

The power supply shall be provided from two independent power sources – two independent HV transmission lines brought to each end of the tunnel system from two VHV networks. Transformer stations shall be connected to both transmission lines, sequentially, with automatic switching in case of failure on the main line. HV power transmission lines to both portals are not considered to be part of the tunnel power supply system.

If only one transmission line was finally installed, all the HV/LV transformers would be loop connected (one cable for each tube) with automatic switching to ensure connectivity in case of maintenance or failure of one side of the ring.

HV/LV transformer stations shall be executed at both tunnel portals in outdoor technical rooms.

2 transformers (1 duty + 1 standby) shall be installed in all transformer stations.

It shall be necessary to install emergency power sources to ensure required level of power supply in case of failure of the main power source(s). And also it shall be necessary to provide a fuel tank in order to achieve 48 hours of fuel capacity available at full load.

LV system shall be designed in the way that LV control rooms shall be located at tunnel cross passages in detached fire segregated spaces. They shall be connected to the closest HV/LV transformer. Individual equipment in the tunnel shall be connected to the closest LV control rooms.

To ensure uninterruptible power supply of individual essential equipments there shall be installed on-line 10 minutes UPS in LV control rooms. These essential equipments are:

- Emergency and evacuation lighting
- Tunnel closure and traffic control
- Exit signs
- Emergency communication
- Tunnel drainage
- Fire alarm and detection
- CCTV
- SCADA and control systems

The control rooms of power supply networks shall be executed as separate fire segregated spaces. Cabling for all the emergency systems shall be fire-resistant, with a minimal fire rating of 2 hours. The cables used in the tunnel shall be Low Smoke Zero Halogen (LSZH).

Earthing system will be preferentially designed as buried ground electrodes embedded in concrete layer of the tunnel foundation. The value of tunnel earthing resistance shall be less than 1 Ohm. All the electrical equipment of the tunnel will be connected to the tunnel earthing system.

All components shall be resistant to the environmental conditions of the installation place. Fire resistance according to standards (typical 2-hour rating) and resistance against corrosion shall be taken into account (humidity, salt, exhaust emissions, pollution, power water, etc.). Required degree of protection of electrical equipment in the tunnel shall be IP 65, and support structures (e.g. cables trays) have to be made from stainless steel of the type AISI316TI.

Civil works design shall be as defined at the drawings of this DPR.

6.1.2.2 Basic Specifications:

- Voltage systems:
  - HV – 3AC 50 Hz 22 kV
  - LV – 3PEN AC 50 Hz 400V / TN-S

Short circuit relations have to be complemented on basis of electro distributor's data.

- Protection against casualty:
  - HV – 3 AC 50Hz 22 kV
    - Living parts – by insulation, constraints, locality
    - Non Living parts – by earthing in network where the source node is not grounded, potential consolidation.
    - Complementary protection in HV control rooms: dielectric carpet.
  - LV – 3 PEN AC 50 Hz 400V / TN-S
    - Living parts – by insulation, constraints, locality
    - Non Living parts – by earthing in network where the source node is not grounded, potential consolidation.

6.1.3 Cable Ducting and Channelling

The connection between the outdoor technical rooms and the tunnel access portals will be done by means of buried ducts with pull boxes that will be arranged for the wiring, both electrical and control.

Inside the tunnels, the distribution of wiring will be done along the duct banks under the sidewalks, and also through the cable trays located on the walls of the tunnel.

The derivation from the duct banks or the cable trays to each individual equipment will be carried out under a protective steel or polycarbonate tube.

6.2 Ventilation System

6.2.1 Ventilation System in Tunnel

A longitudinal ventilation system has been proposed for Khellani Tunnel.

The design of the ventilation system has been performed according to two different criteria:

- Pollutants concentration below threshold limits for sanitary ventilation
- Critical velocity (V_C) achieved for emergency ventilation

6.2.1.1 Jet-Fan and Tunnel Characteristics

The system is based on the installation of jet-fan pairs along the tunnel, preferably near the transformer rooms due to electrical limitations (entrances or centre of tunnel).

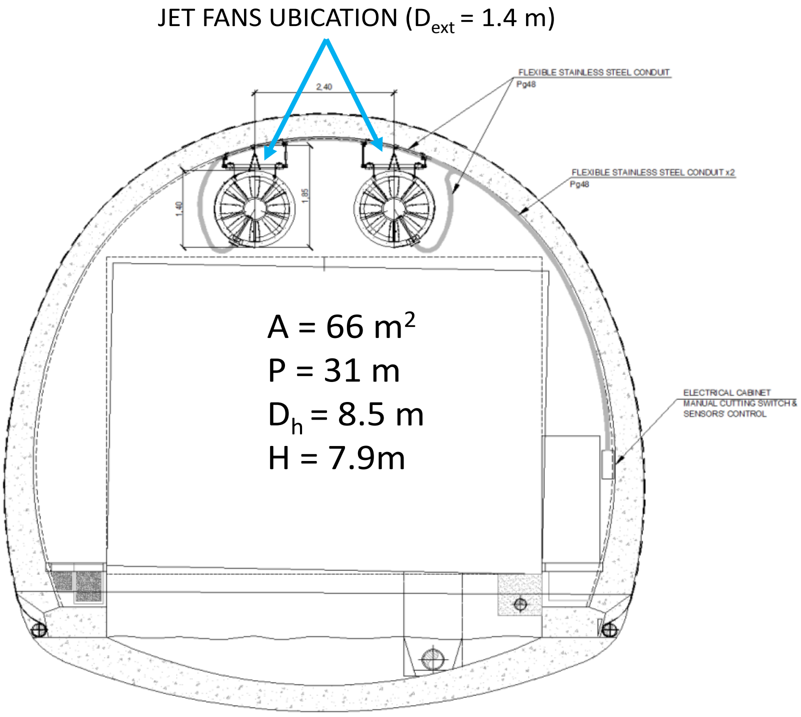


Figure 64: Jet-Fan Position

The characteristics of the jet-fans proposed are included in the following table:

Internal Diameter (mm)	Air Flow (m^3/s)	Jet Velocity (m/s)	Thrust (N)	Installed Power (kW)
1200	37.5	33.2	1441	37.0

Figure 65: Jet Fan Characteristics

6.2.1.3 Meteorological Data

The following general considerations have been used for the design of the system:

- Pressure at tunnel portals have an important effect on the ventilation velocity
- In very long tunnels the most important effect is the pressure difference between portals induced by a difference of ambient conditions at each side of the mountain
- The pressure induced by the wind can be neglected compared with the effect mentioned above
- Pressure difference is analysed using data obtained from the meteoblue web site (www.meteoblue.com)

6.2.1.4 System Design

6.2.1.4.1 Emergency ventilation

- **Dimensioning study**

The following conditions are used for the design:

- 30 MW fire (equivalent to HGV fire, this fire size has been defined assuming that tankers will not be allowed to travel along the tunnel. These tankers shall travel along the existing road.
  - Enough jet fans pairs would be installed to achieve a ventilation velocity over the critical velocity according to NFPA 502 (2017)
  - An extra jet fan pair will be installed for redundancy (failure or maintenance)

A sensitivity analysis is made in order to find the most unfavourable fire position for each tunnel/tube.

Considering the extra pair needed for redundancy, the number of jet-fans at each tunnel is:

Table 17: Number of Jet-Fans at Each Tunnel

TUNNEL	NUMBER OF JET FAN PAIRS
Khellani Tunnel – TUBE 1	6
Khellani Tunnel – TUBE 2	2

HRR sensitivity analysis

The systems have been designed for a Heat Release Rate (HRR) of 30 MW, equivalent to a HGV fire according to PIARC and typical design value for tunnel ventilation, with an important safety margin though. But a road tunnel fire could eventually reach higher values of HRR, depending on the kind and number of vehicles involved.

6.2.1.5 Ventilation control

Ventilation shall be automatically controlled from the Control Centre, activating the necessary jet-fan pairs according to the information from the ambient control devices.

The system shall control continuously the wind direction in tunnel to ensure that there is never a counter-flow against traffic and start ventilation accordingly to achieve at least a ventilation velocity of 1 m/s if necessary. This situation may only arise at night (with low piston effect because of the reduced traffic) and with adverse weather conditions (higher pressure at exit portal than at the entrance).

Jetfans shall always work in pairs, starting both jetfans of the couple at the same time to ensure that the system will work correctly.

Each jetfan shall be activated by means of a soft-starter or frequency-variable drive. No intermediate states are expected to be necessary, just 'on' or 'off'. To avoid excessive consumption at start-up of ventilation and over-dimensioning of the electrical system, jetfans are expected to be activated sequentially in pairs, leaving 1 minute between the activation of one pair and the following.

- Emergency Ventilation

In case of fire (either detected by the fire detection systems, AID or launched by manual alarm at tunnel or Control Centre) the system will check ventilation velocity according to the tunnel anemometer data upstream from the fire. In case that the ventilation velocity falls below 1.5-2 m/s in the traffic direction the system will start additional jet-fan pairs (first the ones furthest away from the fire) sequentially.

The intention of this ventilation procedure for the first minutes is to achieve a safe evacuation environment at both sides of the fire, primarily upstream, were most vehicles are expected to have stopped.

Once the evacuation process has concluded the system will increase the ventilation velocity by starting sequentially the necessary jetfans until reaching critical velocity (around 3-4 m/s), in order to achieve a safe path for the emergency services intervention while trying to maintain smoke stratification downstream of the fire, in case there are people still trapped in the tunnel at that side.

The proposed ventilation procedure shall be approved by AHJ (Authority Having Jurisdiction) in any case.

- Sanitary Ventilation

The Control System will check continuously the values obtained from the environment control sensors (NOx, CO, opacity), starting jetfan pairs sequentially if the sensor reach a certain minimum threshold value. The following table shows the proposed values according to PIARC Technical Committee C4 – Road Tunnels: Vehicle Emissions and Air Demand for Ventilation (2011) for normal operation and for closing the tunnel:

Table 18: Design and threshold values for CO and visibility. Source: PIARC

Traffic situation		coefficient K	(beam length: 100 m)
	ppm	10^{-3} m^{-1}	%
Free flowing peak traffic 50 – 100 km/h	70	5	60
Daily congested traffic, stopped on all lanes	70	7	50
Exceptional congested traffic, stopped on all lanes	100	9	40
Planned maintenance work in a tunnel under traffic*	20	3	75
Threshold values for closing the tunnel**	200	12	30

* National workplace guidelines have to be considered
** The values given here are for tunnel operation only and not for determining ventilation capacities.

Maximum air velocity at the tunnel shall be 10 m/s to avoid annoyances to motorists and bikers.

If pollutant concentration reach a certain value the tunnel shall be closed. The proposed values for closing tunnel are included in the following table:

Table 19: Pollutant Design Limits for Tunnel Closing

Pollutant	Limit	Value
CO	Peak value	200 ppm
NO2	Tunnel average	4 ppm
Particulate matter	Peak value	0.012 m^{-1}

For the system to be prepared for emergency ventilation, it is advisable to ensure that the air is permanently going in the traffic direction. The system shall activate the necessary jetfan pairs to achieve this forward ventilation if the piston effect of the traffic is not enough to cope with adverse meteorological conditions, according to the tunnel anemometer data.

6.3 Fire Detection and Firefighting Systems

6.3.1 Fire Detection and Alarm System (FDAS)

6.3.1.1 Fire Detection in Tunnels

A linear fire detection system will be installed in tunnel, being able to detect a fire source, its magnitude and evolution. The alarm signal can occur for one of the following reasons:

- Exceeding a pre-set temperature
- Fast increase in temperature
- Exceeding the average tunnel temperature by 15ºC (adjustable)

The control units will be distributed in the different technical rooms, inside and outside the tunnels, and they will be able to control the condition of all the tubes.

The control of the detector cable will be performed from the evaluation units installed in the corresponding technical rooms. With these evaluation units, it will be possible to transmit all the information about the fire detection system so that, in case of fire, it will be possible to act safely on the maximum number of elements (ventilation, lighting, signalling, public address system, etc.).

Besides, for safety reasons, alarm buttons will be added in the fire hydrant niches, so that users can advise of an incident inside the tunnel.

6.3.1.2 Fire Detection in Technical Rooms

It has been planned to install a conventional fire detection system by means of thermal and thermovelocimetric detectors. In addition, fire buttons and alarms will be added in order to increase security in case of fire.

Moreover, in the technical rooms located inside the tunnels, there will be an automatic fire-fighting system by inert gas. This system will be designed on account of the risk that could cause to the circulation a fire in an interior technical room.

6.3.2 Firefighting System

6.3.2.1 Criteria Design

Water pipe

A water pipe of ductile cast iron will be installed under the right sidewalk in the driving direction of the road, with transverse connections between both tunnel tubes, providing and “ring” configuration. This pipe will connect the tunnel with the Fire Pumping Station. The underground main pipe will have a diameter of 8”, whereas the diameter of the derivation to the fire hydrants will be 4” and the derivations to the hose connections will be 2 ½”. All the piping will be made of ductile cast iron but the pipes and manifolds of the Fire Pumping Station which will be of black still.

The derivations of each hydrant will be equipped with a cut-off valve, which will be always opened unless there is a leak in one of the hydrants. In its case, the valve will be manually closed. Furthermore, a series of gate valve stems will be installed at both sides of every cross - connection inside the tunnel for assuring the different sections of the extinction network in case of leak or maintenance work in any of the stretches.

There will be water pipes under the road crossing every vehicle cross - passage in order to enable the closure of the circuit. Besides, every cross-connection will have a shut-off valve for regulating in case of failure.

Hydrants

There will be fire hydrants of 4” diameter installed every 250 meters. Each hydrant will be equipped with 2 connection types, one of 2 x 2 ½” and the second of 4”.

Fire hose - coil

There will be hose connections of 2 ½” every 83.33 meters between fire hydrants.

Water Supply

Due to the location of the tunnel, far from any water distribution network, the water supply tank will be fulfilled by a tanker truck.

Fire Pumping Station

The Fire Pumping Station will supply the water to the hydrants in order to be able to provide water for 1 hour with a flow of 946 l/min in 2 hydrants simultaneously. For fulfilling this requirement, the reservoir will have a capacity of 120 m^3. This tank will be divided into two symmetric volumes in order to enable maintenance operations and availability of 50 % of the capacity in any circumstance.

In the adjacent room the pumping system will be installed, with an altitude slightly inferior to the water reservoir so that the pumps are always in “load” state.

The water tank room will have little grills for assuring its correct ventilation.

For Khellani tunnel only one fire pumping station is required which will be installed in the upper portal in order to reduce the necessary pumping pressure.

Pumping System

The pipe for fulfilling the reservoir will be installed from the outside till the pumping room where it will be connected to a general manifold. Independent water supplies will leave from the collector to provide water to the different areas of the Fire Pumping Station controlled by a solenoid valve with by-pass and the corresponding valves for controlling the plant.

Different level sensors will be installed for controlling the level of water in the reservoir, with the following procedure:

- Overflow alarm
- Filling closing
- Filling opening
- Minimum level alarm

This system will be complemented with a continuous indicator of the water level of the tank.

According to the NFPA, the pumping system and the water supply will be designed for the simultaneous operation of the two most unfavourable firefighting equipment with a flow of 946 l/min each and a minimum residual pressure of 6.9 bar. The whole system is sized for assuring one hour of supply of two hose connections of 2 ½" (system Class I), therefore, it is necessary a water reservoir of 120 m^3 (2 fire hose - coil x 946 l/min x 60 min), according to the NFPA 502.

Hand – Operated Fire Extinguishers

The firefighting system will be complemented by hand – operated fire extinguishers installed in a cabinet every 83, 33 meters in the right side along the tunnel, in combination with the hose connections, hydrants or emergency station, depending on the position.

Each egress passageway will have an emergency station composed by two fire extinguishers.

All the fire extinguishers will be type ABC dry powder extinguisher of 13 lb (6 kg).

In addition, all the different rooms will have fire extinguishers (Technical Rooms, Fire Pumping Station). The electrical rooms will be provided by ABC dry powder extinguisher of 10 lb (4,5 kg) as well as by dioxide extinguisher (CO_2) of 10 lb (4,5 kg), more appropriate for fires caused by electrical problems.

6.4 Lighting and Signage systems

6.4.1 Lighting System

6.4.1.1 Main Tunnel Lighting

The design of the main tunnel lighting will consist of the determination of the night road lighting of the tunnel access roads in from of the tunnel portals, the controlled lighting of the accommodation and transit sections inside the tubes and the necessary illumination in the cross - passages.

The lighting system shall be calculated regarding the Guide for Lighting Road Tunnels and Underpasses CIE 88/2004. Also, the Guidelines for Road Tunnels IRC:SP:91-2010 will be taken into account.

According to the IRC, motorist vision must get adapted to the lighting environment of the tunnel. This adaptation takes a short time, and it has to be smooth. Such transition can be only produced by well-designed lighting conditions at the entry and exit areas of the tunnel and in the tunnel itself.

The time that a motorist needs to get adapted to the tunnel lighting environment is generally considered as about 4 seconds. Nevertheless, considering the CIE 88/2004, the distance that is used as a reference to divide the zones is the stopping distance, which is different in each tube, since it depends on the slope among other factors.

It has been decided to follow the CIE 88/2004 as it is the most recognized standard worldwide in relation to tunnel lighting design, and regarding the security aspect, it shows just slightly more restrictive values than the IRC for the tunnel entrance area.

Table 20: Stopping Distance and Zone Length

Tube	CIE 88/2004	IRC:SP:91-2010
	Stopping Distance in the Entrances (m)	Zones Length (m)
Khellani Tunnel - Tube 1	106	89
Khellani Tunnel - Tube 2	92	89

It must be taken into account that, although the speed limit in the tunnel is 50 kmph, for the tunnel lighting design, a higher speed has been used (80 kmph) in order to minimize the risk in the case of some vehicles exceeding the speed limit. This decision can be considered safe, as the layout of the road is favourable.

The characteristics of each one of the zones are described below:

- Access Road Sections: The access sections of the different tubes will start 200 m before the portals and will finish in the portals.
- Threshold Zone: This zone will have a different length in each tunnel as it is shown in the following table:

Table 21: Threshold Zone Length

Tube	Length (m)
Khellani Tunnel - Tube 1	106
Khellani Tunnel - Tube 2	92

The threshold zone of each tube will be divided into two different parts, so that there are two jumps between the luminance of the access zone and the luminance of the transition zone.

- Transition Zone: Each zone will be divided into four parts. In this way, the luminance will vary from 45 cd/m^2 to 8 cd/m^2 progressively.
- Interior zone: The interior zone of each tube will be composed by two parts. The

first one will serve as an intermediate jump between the last part of the transition zone and the interior zone that will cover most of the tube.

In this zone, the IRC recommends using a luminance between 15 and 20 cd/Sq.m. However, as the IRC indicates values for the luminance in the interior zone that are significantly higher than the usual designs and that overcome what the main international recommendations indicate, in order to obtain a better energy efficiency, the criterion stablished by the CIE for the interior zone has been considered. Nevertheless, the CIE criterion has been slightly upgraded considering a higher-class road. The considered luminance for the interior zone is 3 cd/m^2

- Exit zone: According to the CIE 88/2004, it is important to have a zone in the tunnel that allows the adaptation of the driver to the exterior light. In this manner, the exit zone length of each tube will depend on the stopping distance in the exit part.

After studying the different luminances required in each section in order to facilitate the adaptation of the motorists to the variation of lighting inside the tunnel, the following adaptation curve has been obtained, in which it is possible to see changes in lighting from the moment the vehicles enter the tunnel until they reach the interior zone of the tunnel.

6.4.1.2 Outdoor lighting

During the night, the tunnel lighting will only consist of permanent lighting, that is, there will be a luminance of 3 cd/m^2. In order to adapt the sight of the drivers to this interior lighting level, the entrance and exit routes of the tubes will also be illuminated. The lighting fixtures, 210 W LED, will be distributed from the entrance of the tube to a distance of 320 m, the same will happen in the exit of the tube. The arrangement will be staggered, with the fixtures located at a height of 12 meters and separated 80 meters on the same side of the road (40 m on opposite sides). In this way, there will be four fixtures on each side, with eight luminaires in each entrance/exit.

In addition, the access roads to the technical rooms will be illuminated, using the same fixtures (210 W LED), at 12 meters, with a staggered arrangement. On the other hand, luminaires of 70 W LED at a height of 6 meters will be used to illuminate the surroundings of the outdoor technical rooms.

6.4.1.3 Emergency Tunnel Lighting

All those lighting luminaires that must be working even if a failure occurs in the power source will compose the emergency lighting.

This emergency lighting will be used for emergency exits and tunnel sidewalks. Moreover, the emergency configuration of the tunnel lighting system could be a selection from all the lighting fixtures of the system, forming linear and symmetric lighting series, fed by the Uninterruptible Power Supply.

Below, the zones of the tunnel that will have extra lighting and the characteristics of the extra lighting are shown:

- **Sidewalk Lighting:** The lighting in the sidewalks will be composed of LED lighting fixtures of 12 W, located every 10 m at a height of 1 m; this will ensure enough visibility to reach the emergency exits if necessary. The lighting fixtures shall not light to the upper half-plane.
- **Cross - Passages Lighting:** The lighting in the cross passages will be different for pedestrian cross passages and vehicular cross passages. This lighting system will have 2x28 W LED lighting fixtures, located every 5 m in the pedestrian cross passages and every 3.33 m in the vehicular cross passages.

6.4.1.4 Technical Rooms Lighting

In addition to the lighting system installed in the different zones of the tunnel, the technical rooms will be provided with the sufficient lighting level to guarantee the correct execution of the different activities that will be developed in each of those rooms.

6.4.2 Signage System

The emergency signage included in the Khellani Tunnel is composed by all those signals indicating the presence of emergency equipment and evacuation routes that shall be used in the event of an incident in the tunnel.

Two different types of signals will be used, luminous and reflective traffic signs, depending on the equipment or the area of the tunnel that must be located by the users.

6.4.2.1 Reflective Traffic Signs (RTS)

The reflective traffic signs will be used to indicate the distance to the closest cross - passage shall be located inside the tunnel, indicating the escape exists in both directions. The maximum allowed distance between these signals is 25 meters, so that in case of emergency users can easily find a reference to reach the closest exit. In this case, the signals have been placed every 22 meters in both sides, in order to match the total distance between emergency exits.

6.4.2.2 Luminous Traffic Signs (LTS)

On the other hand, to indicate the cross - passages and some emergency equipment, luminous traffic signs with their own backup battery will be used, in order to ensure that users can easily locate emergency items whenever necessary.

Three different luminous panels will be used in order to indicate the distinct combinations of emergency equipment. First of all, there will be a luminous panel indicating the existence of SOS boxes (emergency phones) with individual extinguishers next to a hydrant. Another panel indicating the existence of an only hydrant will be placed at the entrance of tubes 1 of Khellani tunnel. Finally, luminous panels with the pictogram of an extinguisher and a hydrant will be installed in order to indicate the existence of an individual fire extinguisher next to a hydrant. The three luminous panels that will be distributed along the tunnels can be seen below:

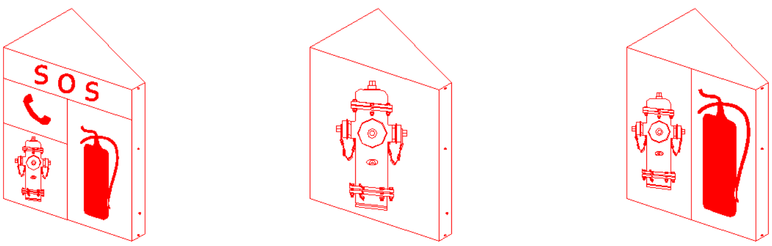


Figure 66: Luminous Panels

Also luminous signals indicating the presence of cross - passages will be placed over each one of the emergency doors.

Finally, one out of every four reflective panels that show the distance to the closest emergency exit will be replaced by a luminous signal with the same indication and backup battery.

6.5 Traffic Control System

The equipment that will be necessary to implement the traffic control system is listed below:

- Traffic Lights - Three Coloured (R-A-G)
- Traffic Lights - Amber (A-A)
- Variable Message Signs (VMS)
- Tunnel Variable Lane Signs (TVLS)
- Speed Limit Variable Sign (SLVS)

6.5.1 Variable Message Signs (VMS)

The installation of Variable Message Signs (VMS) outside the tunnels has been designed. The VMS will be located between 200 and 300 meters before the tubes entrances, so that drivers have enough time to read and react to the transmitted message. In addition, Variable Message Signs will be installed inside the tunnel every 1300 m. These VMS will allow to indicate the opening of the cross - passages in case they must be used to guarantee users safety. Other messages may also be indicated depending on the situation.

Also, Tunnel Variable Lane Signs (TVLS), with “Red Cross” and “Green Arrow”, will be installed inside the tunnel every 250 m so that it can be indicated when a lane is closed. Besides, TVLS with “Red Cross”, “Green Arrow”, “Crossover Yellow Arrow” and “Entryway prohibited” shall be installed in the tunnel entrances in order to stop the entrance to the tunnel or indicate the need to use the emergency lane if necessary. One Speed Limit Variable Sign (SLVS), that indicates the speed limit in case the established limit in the road varies for safety reasons, will accompany each TVLS, also in the entrances.

6.5.2 Traffic Signals

Many things can create an emergency situation that leads to closing the access to the tunnel, such as a fire, a failure of power supply or an accident, among others. Therefore, traffic lights three coloured (TLTC) will be installed, in both sidewalls, at the entrances of the tubes, which must be used to close the tunnel traffic if necessary. The amber light of the TLTC shall serve also as flashing warning signal in exceptional traffic situations. Moreover, Traffic Lights Two Coloured shall be placed inside the tunnel just by the TVLS and the SLVS to highlight the caution indication. These traffic lights will be only located on the left sidewall of the tubes, since on the right side the emergency doors will be located.

6.5.3 Entrance Height Excessive Vehicle Control System (EHD)

Mechanical and electronic height excessive vehicle control systems will be installed to avoid incidents due to the arrival of too high vehicles to the tunnel.

The system will be composed by:

- Fixed signal to inform about the maximum height allowed in the tunnel.
- A 6 meters high structure over the road with a bar located at 5.6 m high and an infrared barrier at 5.5 meters high.
- An electromagnetic loop for the detection of the presence of vehicles and to reduce the incidence of false detections.
- Variable message sign to inform about height excess.

The location of the different equipment composing the system will be of utmost importance to ensure that vehicles that do not meet the maximum height requirements can be deflected to another route or turn around.

The structure will have an optic sensor (transmitter-receiver) located at 5.5 meters over the ground with some electromagnetic loops on the road surface that can detect if a vehicle travels over them. Once an object (vehicle) interrupts the luminous beam between the transmitter and the receiver and the loops detect the presence of a vehicle, a signal will be transmitted to a panel located around 100 meters forward. At this moment, the panel will show a message to inform about the excessive vehicle height so that the vehicle can leave the road immediately.

6.5.4 Traffic Counting System (TCS)

A traffic counting system will be installed in tunnel in order to control the traffic travelling in this road. The system will be composed of double electromagnetic loops for the data gathering in both tunnels. The loops will be located at least at the entrance and exit of each tube, so that the traffic in all the tubes can be controlled. The data will be transmitted to the Control Centre through the control network.

6.5.5 Mechanical Barriers

A tunnel-closing system has been included in the design through the installation of mechanical barriers at the entrances of the two tubes. These barriers will be double, located on both sides of the road, about 30 meters from the entrance of the tubes. In this way, it will be possible to control the closure of the tunnels along with other equipment that will be located in the vicinity of the tunnel entrances.

The electric supply of this system will be performed so that it will be possible to ensure the operation of the barriers in the event of an incident. Each pair of barriers will be connected to the closest technical room, and all of them will be controlled from the Control Centre.

6.6 Communications Systems

6.6.1 CCTV/AID System

6.6.1.1 External Video Surveillance System

This system enables the surveillance of the tunnel portals as well as the continuous monitoring of the road and its surroundings by four revolving cameras located in front of the entrances of the tunnel.

The revolving cameras will be placed on specific rigid poles. The revolving range of the cameras will be 360º horizontally and 90º vertically. The variable zoom objective of the cameras shall enable wide overview of the road traffic as well as detailed vehicle and people identification in relative wide scale of distances.

The cameras exact location will need to be studied in the Detailed Design phase, but for budgeting purposes they are assumed to be 15 meters high and located 60 meters before the entrance to the tubes.

Further two outdoor cameras will be installed in order to ensure the control of the buildings where the technical rooms are located. There will be one camera near each building, placed on specific rigid poles, and they shall have a revolving range of 360º horizontally and 90º vertically.

Besides an interior camera will be included in each building; these cameras will be placed in the distribution area of the building in order to control access to the technical rooms. The cameras shall be installed in the ceiling, and they will have a revolving range of 360º in the horizontal plane and 90º in the vertical plane.

6.6.1.2 Traffic Video Surveillance System

The design of the CCTV of the tunnel has been made taking into account the different geometric and layout characteristics of the tunnel. All the tubes are equipped with cameras for monitoring entrances to the tunnels.

The design of the interior CCTV system is based on the location of cameras at appropriate distances, considering a maximum of 90 m to obtain a correct supervision of their area of influence and ensure the proper operation of the Automatic Incident Detection System (AID) integrated into the camera itself. The system sends the information in order to develop the visualization and analysis in the Control Center. In addition, with the maximum distance established (90 m), it is possible to make sure that there will always be a camera with visibility to the connection between the tube and the cross - passages. There will be 40 cameras in both the tubes of Khellani tunnel.

The cameras will be located at an approximate height of 5 meter, and they will be installed in the right or left sidewall, depending on the road layout, in order to obtain appropriate tunnel images for the proper AID system operation. In this case, the cameras will be located in the left side of the tubes with respect to the lane direction.

The cameras will have long focal distance and coloured picture presentation, and its housing degree of protection will be IP 66.

The camera adjusting system will be composed by a moving metal camera fixation joint that enables the adjustment of a stationary traffic camera. The camera adjustment should be 30º in the horizontal direction and 45º in the vertical direction.

Due to the position of the cameras inside the tunnels, it can be guaranteed that there will always be a correct view of the emergency elements such as the SOS boxes, the laybyes, the firefighting equipment, etc. In this way, it will not be necessary to include a specific video monitoring system for these particular areas of the tunnel.

The operating network of the CCTV system will be the IP network. The communications system includes industrial PoE switches, installed next to the SOS boxes. The cameras will be connected to the PoE industrial switches with 4-twisted pair network cable, to the VLAN access ports, always connecting the camera to the closest switch in order to keep the distance below 90 m. In this way, the video transmission and the camera supply are performed from an only network cable.

The cable will go through the tube. In the Control Center the signals will be connected to the digital video recorder of the system, which can record all the images captured by the cameras for at least 21 days.

6.6.1.3 Cross – Passages Video Surveillance System

One camera will be installed in each cross - passage, so that it is possible to monitor the situation in these passageway when an incident occurs in the tunnel. The installation will be developed through revolving cameras, whose revolving range is 360º in horizontal direction and 90º in vertical direction, located on the ceiling of the cross - passage over the middle of the lane. The housing degree of protection of these cameras shall be IP 66.

6.6.1.4 AID System

The Automatic Incident Detection System consists of the implantation of an AID card for each camera, which performs the video analytics. These AID cards will be installed in the CCTV and AID Rack in the Control Center.

The cameras will send an entrance signal to the detection unit (AID card). When the camera or the video image processing modules are adjusted, the detection zones are superimposed on the video image.

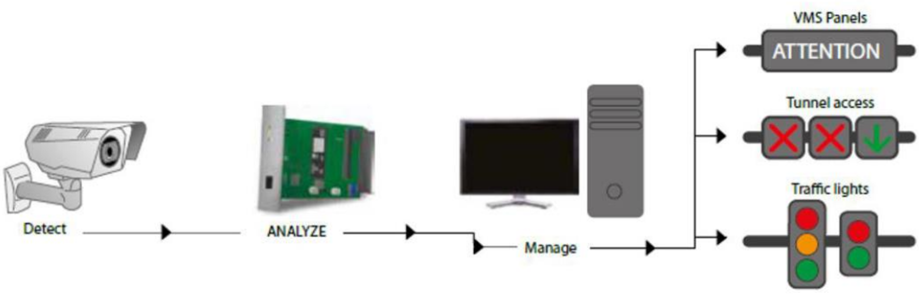


Figure 67: AID System

When a user enters in the detection zone, the detection system is activated. The specific algorithms generate several types of traffic information: presence and data related to incidents, data for statistical processing and data for the analysis before and after the incidents.

The AID system will be integrated in the Control Center, including the programming and the licenses incorporation to the system.

6.6.2 VA/PA System

A Public Address system has been planned in order to allow the broadcast of messages in case of an emergency, this is why the sound pressure must be enough to overcome the existing noise levels and obtain a correct degree of intelligibility of the message.

The system is composed by a uniform distribution of 30 W exponential loudspeakers, which are installed in the sidewalls or hanging from the electric trays. The distance between the loudspeakers in the tunnel will be 33.5 meters.

The public address central unit will be placed in the Control Center, while the amplifiers will be distributed in the different cross - passages, depending on the location of the loudspeakers they must supply.

The loudspeakers will be connected in parallel, thus, the public address (PA) system in the Khellani tunnel will be divided into several sections with the purpose of transmitting different messages in each zone of the tunnel, being able to indicate the procedure that must be followed in case of an emergency depending on the location of each user.

On the other hand, each cross - passage will be a different zone with two speakers connected to one amplifier that will be located in the cross - passage itself.

The connection between the public address system and the amplifiers will be made using the tunnel's general communications infrastructure. Therefore, the public address system will operate with TCP/IP protocol, so that the amplifiers shall be directly connected to the switches of the technical rooms. This connection will allow bringing the audio signal of the messages and the control contacts to the different emission zones.

The public address wiring will be protected in a tube for the general line and under a polycarbonate LSZH tube until reaching each loudspeaker.

There will be several pre-recorded messages that will be automatically broadcasted depending on the received alarm. These messages will be transmitted in English and local languages.

The amplifiers power supply will be made from the nearest low-voltage distribution board.

Some of the speakers will be located in the lay-bys to make sure that, in case there are people waiting, they receive the emergency messages.

6.6.3 Radio Rebroadcast System

The tunnel will have a Radio Rebroadcast System for the emergency services. This system will consist of main racks with antennas in the outdoor Technical Rooms. These main racks will be connected between them and with the signal amplifiers, installed in the Technical Rooms, by single – mode fiber optic in order to transmit the data and state of the equipment of the tunnel.

Furthermore, these main racks will be communicated by radiant cable, installed along the tunnel at both sides, to all the signal amplifiers. The connection between the main rack and the radiant cable will be done by a coaxial cable. The amplifiers will communicate between them by radiant cable.

The single – mode fiber optic will go along the tubes of the tunnels making a ring. This fiber allows the connection of the main racks with the Control Center.

The tunnel will have also a radio frequency for emergency communications with the users of the tunnel. The radio frequency will be specified at the entrance of the tunnel. The communications of the radio channel will be by radiant cable and connecting the signal amplifiers and main racks, as described above.

6.7 Access Control and Alarms

The installation of an access control system allows restricting access to the tunnel and its dependencies, so that only authorized personnel can access. This will result in avoiding intrusions, sabotage and accidents.

The system will be composed of presence detection, CCTV and access control subsystems, which will be constituted of several equipment such as electromagnetic contacts to open the passage doors, volumetric detectors, proximity card readers, electric locks, exit button and cameras, among others.

There will be different equipment in the access zones to the emergency exits and the technical rooms, including the cabinets that house the security equipment. All the detectors will be connected to the corresponding alarms control units, which will allow their unequivocal identification in case of activation.

The intrusion detection system will be connected to the Control Center and it will be integrated into its centralized management system.

The CCTV subsystem will provide relevant images to the Control Center in order to obtain a correct visual control of possible incidents that can take place in the tunnel. There will also be a recording and visualizing system.

Lastly, the installation of anti-intrusion and access control system will provide an access control of the individuals to the restricted areas with the purpose of controlling the entrances, the staying time and the exit of authorized personal in some areas.

6.8 Control Network

The Control Network will be monitored by the Main Control Center. The system will consist of a Redundant Server installed at the Control Center and Remote Terminal Units (R.T.U.) and Data Acquisition Stations (D.A.S.) fixed in the Technical Rooms. The communication among them will be by 16 strands fiber cable.

These Remote Terminal Units will communicate with the Data Acquisition Stations (D.A.S.), installed in every technical rooms, for collecting all the information and send it to the Server. These D.A.S. will have modules of digital and analog input and output, as well as the automatisms of all the equipment existing in the tunnel, in order to gather all the information provided by the equipment of the tunnel and to transmit it to the R.T.U.

The R.T.U. will be in charge of managing the tunnel in real time. These Remote Terminal Units will communicate between them and with the Control Center by a communication network of 1 Gigabit Ethernet of fiber optic.

Furthermore, in order to integrate all the signals coming from the equipment of the tunnel, there will be switches fixed in the technical rooms connected to the D.A.S., which will gather all the information by audio, video and data network connected to the different switches and Programmable Logic Controller (PLC) installed along the tunnel.

The different installations that will exist in the tunnel, such as, emergency stations, ventilation, PA, CCTV, etc., will be connected to the switches installed at the position of the emergency stations (every 166,67 meters), which at the same time, will connect by the network to the PLC fixed at every cross – passage.

6.8.1 Control Centre

The Main Control Centre of the tunnel systems will presumably be located at the western portal of Khellani tunnel, although the final location may vary due to geotechnical limitations of the terrain, difficulty of earth movements, etc. The main requirement for the final location is to have a reliable fiber optic network to connect the Control Centre to the communications equipment of the tunnel.

A location near the access to the tunnel would only facilitate the unification of the tasks of maintenance of the tunnels and rapid attention of incidents with the control tasks in the same complex of buildings.

The Main Control centre will house the operator stations for 24 hr. surveillance of the tunnels, the main control servers, the image viewing and recording equipment and the control equipment of all the rest of subsystems. It will also have a rest area, administration office, toilets, and a crisis room in which the tunnel control officers would meet with the emergency services in case of major incident in the tunnel, for decision making.