Project Specific Section

Example :

ROCKFALL PROTECTION ALONG SIDDHABABA SECTION OF SIDDHARTHA HIGHWAY

Ch. 28+200 km – Ch. 30+600 km

TABLE OF CONTENTS

1 INTRODUCTION

The Siddhababa stretch of Siddhartha Highway between Chainage 28+200 Km to 30+600 Km is a very hazardous road section due to the highly fractured rockfall site at the hillside of the road, characterized by an unfavorably discontinuity orientation with respect to the road alignment, and to high and steep slopes easily split by monsoon precipitation.

A relevant number of rockfall events has been registered during the time, therefore requiring the adoption of useful measures capable of minimizing the hazard of rock slope instability and debris flow by means of permanent structures for rockfall protections.

The project is aimed to avoid any risk related to rockfall and slope instability in the high hazard section for car traffic, but at the same time finding an attractive solution also for pedestrians.

A new tunnel only for cars will be executed along the whole high hazard section with a new alignment that departs from the existing road near the Siddha Baba Mandir and reconnect to it near the existing hydropower dam, for a total length of about 1120 m.

As for bicycles and pedestrian, they will keep on using existing road, but protected along the whole high hazard section by a rockshed, having a reduced width suitable to house only pedestrians and bicycles or, in case, emergency vehicles.

Local protection measures, such as rocknets, local installation of adherence wire meshes and local stabilization systems by shotcrete and rock bolts, are foreseen along medium risk areas.

2 DESIGN CRITERIA

2.1 References

2.1.1 Project references

- Ranjan Kumar Dahal and Shuichi Hasegwa (2008). Representative rainfall thresholds for landslides in the Nepal Himalaya. Geomorphology, Volume 100, Issues 3-4.
- Kayastha,P., Dhital,M.R. and De Smedt,F (2012). Application of the analytical hierarchy process (AHP) for landslide susceptibility mapping, A case study from Tinau watershed, west Nepal. Computer and Geosciencies.
- Kaushal Raj Gnyawali, Ranjit Shrestha, Anil Bhattarai, Pramod Rangu Magar, Anup Raj Dhungana, ImjalSukupayo, RaslaDumaru (2015). Rockfall Characterization and Structural Protection in the Siddhababa Section of Siddhartha Highway H10, Nepal. Journal of the Institute of Engineering.
- Calvetti F., di Prisco C. (2007). Guidelines for Rockshed Design. Starry Link Editor, Brescia, Italy.
- Terri Bannister (2016). Mapping Geohazards in the Churia Region of Nepal: An Application of Remote Sensing and Geographic Information Systems, MSc Thesis, University of Louisiana at Lafayette.

2.1.2 Project standards

- EN 1990:2002, Eurocode 0: Basis of structural design.
- EN 1991- all parts, Eurocode 1:Actions on structures. General actions. Densities, self-weight, imposed loads for buildings.
- EN 1992-1-1:2004, Eurocode 2: Design of concrete structures. General rules and rules Published for buildings.
- EN 1992-2:2005, Eurocode 2: Design of concrete structures - Part 2: Concrete bridges - Design and detailing rules
- EN 1997-1:2004,Eurocode 7: Geotechnical design. General rules.
- EN 1998-1:2004,Eurocode 8: Design of structures for earthquake resistance. General rules, seismic actions and rules for buildings.
- EN 1998-2:2005, Eurocode 8: Design of structures for earthquake resistance – Part 2: Bridges
- EN 1998-5:2004,Eurocode 8: Design of structures for earthquake resistance. Foundations, retaining structure and geotechnical aspects.
- Nepal Road Standard – 2070, 2013
- Nepal Pavement-Design-Guidelines-(Flexible-Pavement), 2013
- Nepal Safety Barrier, 1997
- Nepal Delineation Meausures, 1996
- Nepal Traffic Sign Manual, 1997
- ASTRA 12006 (2008), effects of stone chips on protective galleries.
- ASTRA 11001 (2017), guideline: normal profiles. Federal Roads Office.
- ASTRA 13001 (2008), guidelines: ventilation of the road tunnels.
- ASTRA technical manualOperating and safety equipment 23 001.
- ASTRA technical manual tunnel / geotechnics 24 001.
- SIA 197 (2004), project planning tunnel, basics.
- SIA 197/2 (2004), project planning tunnel, road tunnel.
- UNI EN 206:2016, Concrete – Specification, performance, production and conformity

- UNI EN 197-1:2011, Cement – Part 1: Composition, specifications and conformity criteria for common cement
- UNI EN 12620:2008, Aggregates for concrete
- UNI EN 1537– Execution of special geotechnical works - Ground anchors
- UNI EN ISO 22477-5:2018 - Geotechnical investigation and testing - Testing of geotechnical structures - Part 5: Testing of grouted anchors
- VSS 640 202 (2017) – Road geometrical normal profile.
- CEB N°187 - Comité-Euro-International du Béton (1988). Concrete Structures under Impact and Impulsive Load, Bulletin d'information N° 187, Draft TG V/14, Lausanne.
- EOTA (2012). ETAG 027 – Falling rock protection kits. Guideline for european technical approval.
- NBC 105:1994 Seismic design of buildings in Nepal

2.2 Design Working Life

Design Working Life of structures is defined as "the period of time during which the construction is assumed to be used for intended purposes, with anticipated maintenance, but without substantial repairs".

According to EN 1990 (Eurocode 0) the design working lives (Tunnel and Rock Shed) of Category 5 – Monumental building structures, bridges and other civil engineering structures – 100 years.

According to EN 1990 (Eurocode 0) the design working lives (Technical Building and Other Road structures) of Category 4 – Building structures and other common structures – 50 years.

This requirement has to be met by means of a design that includes an appropriate selection of the structural solutions and construction materials, a careful construction compliant with the design and a suitable inspection of the design, where appropriate. Construction and operation activities, together with an appropriate use and maintenance of the structures are as well of major importance to guarantee such requirement.

2.3 Design Approach

Structural and geotechnical design is carried out, as usually done in European countries, with reference to the semi-probabilistic method (limit state) according to various international standards (Eurocodes, SIA). Load Combinations, safety and partial factor coefficients, verifications and concrete check (both at USL and SLS) are defined according to Eurocodes.

2.3.1 Design conditions

When accomplishing the design situations that are important for the design check, all possible circumstances the structure have toface during its life should be taken into account.

As far as rockfall protective structures are concerned, the design situations to account for can be in general classified as:

- temporary situations, with reference to temporary conditions applicable to a structure, e.g. an executive phase or repair;
- persistent situations, which refer to normal service conditions;
- accidental or exceptional situations, which refer to exceptional conditions applicable to a structure, ex. rockfall, collisions, fires, explosions, ecc.;
- seismic situations, which refer to conditions applicable to the structure when subjected to seismic events.

The design situations to be taken into account in detailed verification are classified in the above mentioned categories. Note that each category requires a specific analysis of the time horizon in which it occurs; the design situations can occur throughout the design life of a structure or be limited to a specific executive phase or repair.

2.3.2 Design verifications

Ultimate limit states and serviceability limit state verifications are considered according to international standards such as Eurocode.

Safety checks are performed by means of the Partial Factors Method: for all relevant design situations, it is verified if the limit states are not exceeded when design values of the actions, material properties and geometric dates are introduced in structural and load models.

The non-exceedance limit check allows to state that the probability of reaching a certain limit situation is less than the value set by the standard during the structure lifeor during a timeframe of reference in case of execution/constructive phase.

The verifications shall ensure that:

- Assumed design actions do not cause the collapse of the structure or the ground (even in exceptional/accidental situations);
- Effects of the assumed design actions do not exceed the design strength of the structure at the ultimate limit state;
- Effects of the assumed actions do not exceed the functionality criteria for the service limit state.

Ultimate limit states connected both to the structure collapse (or the whole structure-ground) and to a partial failure are considered; Service ultimate states that match the conditions beyond which specific operational requirements connected to the structure or its elements are no longer met are taken into account.

Design dimensioning and verifications can be found in the relevant Calculation Reports.

3 UNDERGROUND WORKS

In the following, basic design principles and technical requirements of the new tunnel are presented, together with a description of design solutions and material properties. Design dimensioning and verifications can be found in the relevant Calculation Reports.

The tunnel design is performed in accordance to relevant guidelines and rules usually adopted during design and construction of road tunnels in Switzerland. Such guidelines are indeed the result of the experience gathered during design and construction of a number of road tunnels starting since more than a century ago and, hence, arehereby considered as the main reference.

3.1 Horizontal alignment

Having a total length of 1.126km, the tunnel extends between chainages 0+908.46 (south portal) and 2+034.52 (north portal).The position of the tunnel portals has been chosen considering a suitable site to minimize necessary excavation, hence entering the mountain almost perpendicularly to the slope, as well as to avoid the whole high hazard stretch.

At the south portal, the tunnel begins about40 m to the north of the existing «Siddhababa Mandir», having a curved alignment to the east direction (curve radius = 95m).

At the north portal, the tunnel begins about 40 m to the north of the existing «Ramapithecus Park» view point, near the Tinaauhydropower dam, having a straight alignment.

In the central part, assuming the north driving direction, the tunnel consists of a long curve to the west (curve radius = 150 m), followed by an almost straight stretch up tothe north portal. Due to such a curve, an enlarged section is necessary to guarantee visibility. Enlargement amounts 60 cm (according to Nepalese RoadStandard 2070) to the inside of the curve, between chainages 1+095.24 and 1+330.78.

Figure 1: Horizontal alignment of the tunnel

The U-shape of the horizontal alignment has been chosen in order to reach as soon as possible a sufficient depth (tunnel overburden) to minimize the tunnel excavation in low overburden areas, where weaker and altered rock can be foreseen, as well as larger water income.

3.2 Verticalalignment

According to swiss standards (SIA 197-2), the maximum longitudinal gradient shall not exceed 5% due to increased danger (accident frequency, spread of smoke). However, a maximum 4% longitudinal gradient was considered in accordance to the more stringent requirements of Nepalese Road Standard 2070.

In the present case, the requirement of 4% longitudinal gradient could be met considering the maximum height difference between south portal (about 200 m above sea level) and north portal (about 235 m above sea level) and, having the highest point about 44 m from the north portal (chainage 1+990.319). In the middle of the tunnel, between chainages 1+391.5 and 1+628.5, a reduced gradient equal toabout 0.5% is necessary, according to Nepalese Road Standard 2070 in order to avoid stretches with a constant longitudinal gradient longer than 600 m.

The chosen vertical alignment avoids the risk of water stagnation inside the tunnel, easing water discharge towards both ends of the tunnel, but mainly towards the south portal.

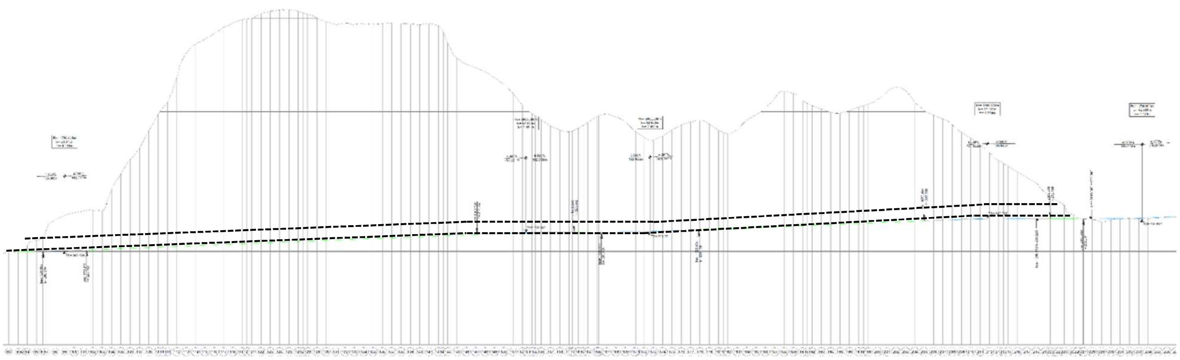


Figure 2: Vertical alignment of the tunnel

3.3 Definition of the inner space

The space above the carriageway is determined by the required usable space, as well as the constructional and technical execution requirements.

The usable space consists of the following elements:

- Usable space for traffic, consisting of:
  - clearance profile for passage through the tunnel;
  - space for walkways (service and emergency escape route);
  - space for equipment including any free space (safety margin).

- Usable space for constructional purposes, consisting of:
  - space for tolerances (a), which takes into account the deviations due to execution errors;
  - space for later constructional measures (b), which may be necessary during the service phase.

- Usable space for ventilation.

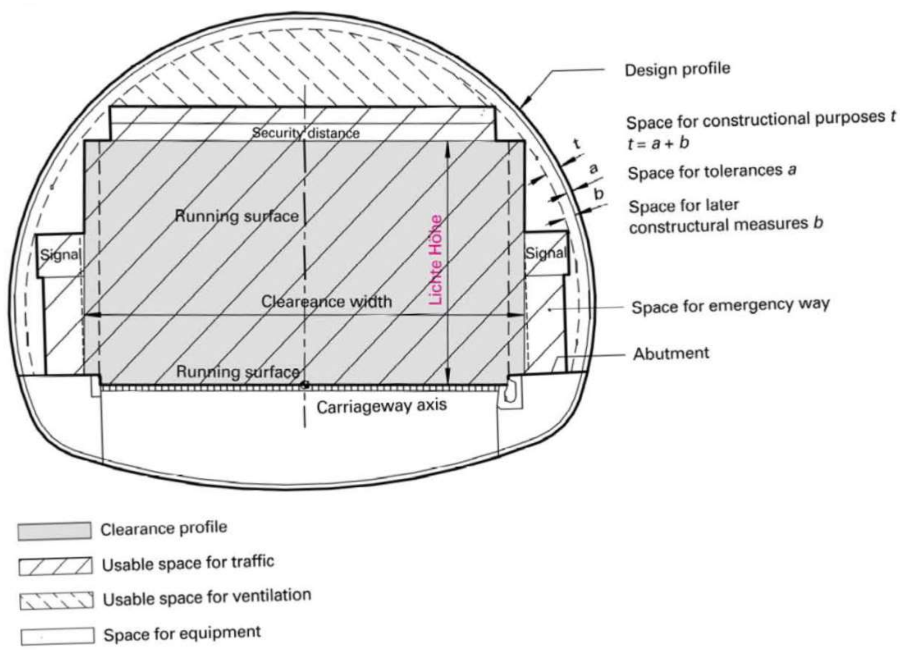


Figure 3: Definition of the usable space (road tunnels) according to SIA 197-2.

The minimum space requirements for traffic are defined according to Figure 4on the base of SIA197-2 and ASTRA 11001, where main dimensions are as follows:

- Walkways (to be used only in case of emergency) width ≥ 1 m;
- Available height on carriageway for traffic ≥ 4.5 m + 0.3 m (safety margin);
- Additional available height for signalling and equipment≥ 0.4 m.

The carriageway width is defined according to the requirements agreed with the Client and equivalent to the ones of DPR 2016, i.e. a carriagewaywidth equal to 7.5 m.Moreover an extra space equal to 0.25 m is considered on both sides. Thus, a total width of 8 m will be available.

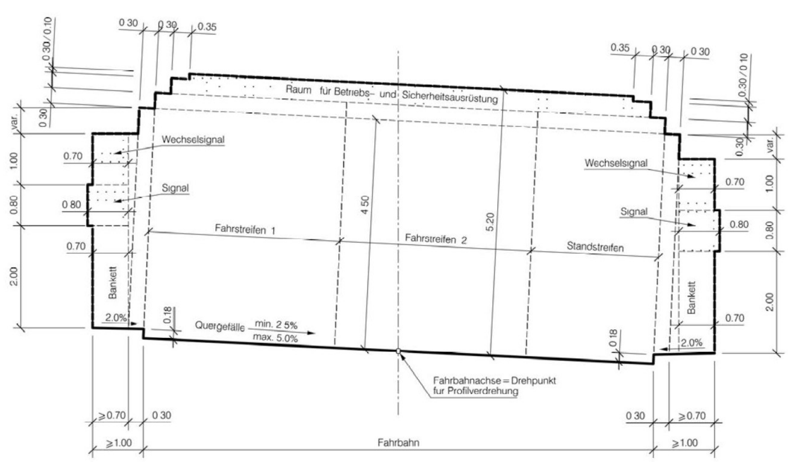


Figure 4: Operational envelope for traffic according to SIA 197-2

As far as the space for tolerances is concerned (a), nominal values for deviations according to *Table 1* taken from SIA 197 will be considered, whereas no space for later constructional measures is required in this project:

- space for tolerances (a) = 10 cm;
- space for later constructional measures (b) = 0 cm.

Method of excavation (see code SIA 198)	Recommended values in cm (measures as radius)	
	Excavation width ≤5 m	Excavation width > 5 m
Drill and blast	5	10
Mechanised excavation in rock	5	10
TBM – excavation in rock	15	15
Mechanised excavation in soil		
– without shield	10	15
– with shield	15	20
	Bypass	Main tunnel

Table 1:Space to accommodate execution inaccuracies

Thanks to the almost circular section, upon the operation traffic space, there is enough space for ventilation.

The space for ventilation equipment is considered into the ventilation design (see relevant E&M Report). In the present case, since the ventilation system consists of longitudinal ventilation, no smoke extraction is necessary, hence, no intermediate slab is required. The space for ventilation equipment is necessary to accommodate jet fans, having an impeller of 1120 mm.

For the minimum space requirements for emergency escape routes (bypass) see 3.4.2.

3.4 Construction measures for safety purposes

Th construction measures to ensure the safety of the tunnel user include:

- Lay-by bays;
- Emergency escape routes;
- SOS niches.

The spacing of the construction safety measures along the tunnel are based on a grid of 150 m.

3.4.1 Lay-by bays

Generally, lay-by bays shall be provided every 600 to 900 m. Two lay by bays are foreseen in the middle of the tunnel, one for each traffic direction:

- North direction: between chainages 1+453.45 and 1+495.00 (41.55 m);
- South direction: between chainages 1+561.55 and 1+520.00 (41.55 m).

In order to reduce difficulties during excavation and heavier safety measures, the two lay-by bays will be located staggered.

The additional emergency lane in the lay-by will be 3.00 m wide, having a transversal gradient equal to that of the main carriageway.

An emergency alarm cabin and a fire hydrant will be located at the end of each lay-by bay.

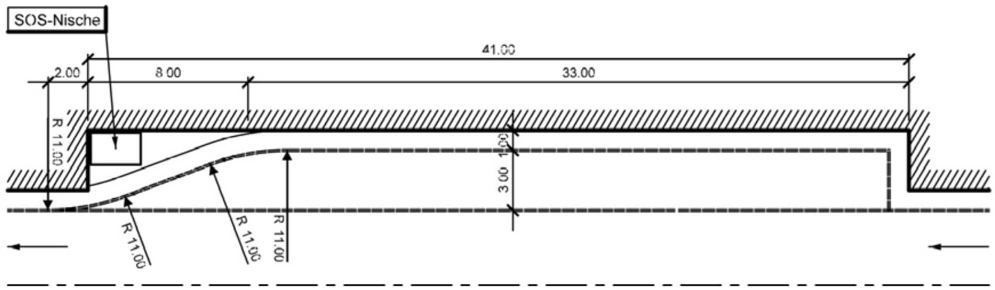


Figure 5: typical lay-by bay geometry according to SIA 197-2 (swiss traffic direction)

3.4.2 Emergency escape route (bypass)

The emergency escape routes will be placed at regular intervals along the river side of the tunnel. In case of emergency, escape routes allow the tunnel users to evacuate in the shortest possible time from the danger zone, leading directly to a safe space within the bypass tunnel itself and, from there, to the pedestrian rockshed along the existing road.

Three pedestrian bypasses will be provided along the tunnel, having a maximum spacing of 300 m. No emergency escape route for vehicular access is foreseen due to the length of the tunnel (< 1.2 km).

- Bypass 1 (ch. 1+145.00): about 155 m long, longitudinal gradient 2% towards the main tunnel (40.5 m) and 1% towards rockshed.
- Bypass 2 (ch. 1+445.00): about 145 m long, longitudinal gradient 2% towards the main tunnel (20 m) and 7.5% towards rockshed.
- Bypass 3 (ch. 1+745.00): about 131 m long, longitudinal gradient 2% towards the main tunnel (40.5 m) and 12.3% towards rockshed.

The requirements for the definition of the inner space of a pedestrian bypass are:

- a minimum free space 1.50 m wide and 2.20 m high;
- space for tolerances (a) = 5 cm, according to Table 1 (excavation width < 5 m);
- space for later constructional measures (b) = 0 cm.

On both sides of the bypass platform, water discharge channels 20 cm x 5 cm will be provided. A transversal discharge channel with a grid will be placed at both ends of the bypass and connected to the sewage discharge system.

A fire resistant sliding door is foreseen at the beginning of the bypassas well as proper painting and marking in order to clarify its position to drivers in case of emergency (see example in Figure 6); moreover, two additional doorsare foreseen at the other end of the bypass ("air lock" section, see chapter 3.11), so that a proper ventilation system can be installed in order to guarantee an overpressure within the emergency escape route compared to the road tunnel, in order to make it a safe place as no smoke can enter in case of fire. The safety concept of the provided escape routes is described in Figure 7. Additional information and details could be found in the tunnel ventilation report (see relevant E&M technical report).

Bypass door shall fulfil the following requirements:

- Pressure resistance — between -2'000 Pa and +2'000 Pa in 0.3 seconds
- Fire resistance — REI 120
- Tightness — max. 0.15 m^3/s with $\Delta P = 50$ Pa
- Opening force — max. 120 N with $\Delta P = 400$ Pa
- Closure system — automatic
- Materials — min. stainless steel 1.4571
- Anchors and components — min. stainless steel 1.4529
- Design life — ≥ 30 years
- Door opening system — sliding door from left to right
- Door dimensions (once open) — min. width 120 cm, height 210 cm
- Final painting — RAL 6029 (green) on both sides.

Figure 6: Example of emergency escape route with sliding fire resistant door and proper marking

Figure 7: Emergency escape route adopted system

3.4.3 SOS niches

SOS niches will be provided every 150 m, alternatively on the two sides of the tunnel.

Minimum dimensions of the niches are:

- Depth 2.10 m (between door and bottom wall)
- Width 1.80 m
- Height 2.40 m (between pavement and ceiling)

Inside each SOS niche, an alarm cabinet will be provided and installed on a concrete footing, connected to the cable shaft in front of the niche by electrical pipes (see 3.7).

The SOS niches pavement will be made of concrete (same concrete of the adjacent walkway), with a transversal gradient equal to 2% towards the carriageway.

SOS niches are not intended as safety rooms, i.e. no ventilation of the niches is provided.

SOS niches door shall fulfil the following requirements:

- Pressure resistance between -2'000 Pa and +2'000 Pa in 0.3 seconds
- Fire resistance no requirement
- Tightness max. 0.15 m^3/s with ΔP = 50 Pa
- Closure system automatic
- Materials min. stainless steel 1.4571
- Anchors and components min. stainless steel 1.4529
- Design life ≥ 30 years
- Door opening system swing door, to the inside
- Door dimensions width 80 cm, height 210 cm
- Door window width 30 cm, height 170 cm
- Final painting RAL 2004 (orange) on both sides.

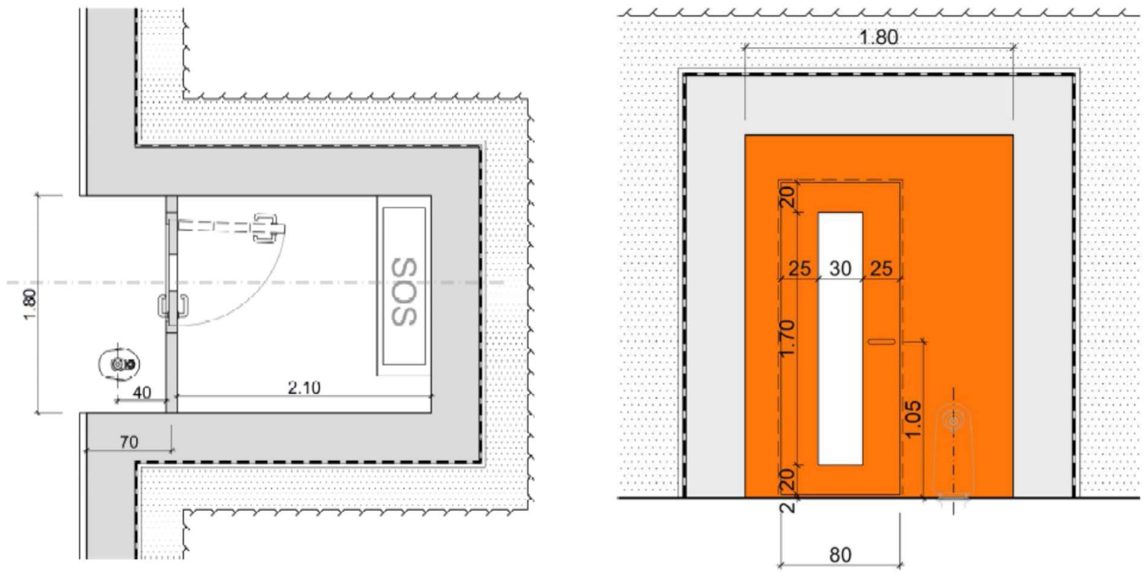


Figure 8: Typical SOS Niche

3.5 Carriageway

The super elevation of the carriageway in tunnel is variable, according to the road design. It shall not exceed a maximum value of 5% in curved stretches.

Whenever in a straight stretch, a minimum transversal gradient of 2.5% shall be guaranteed.

The super elevation is necessary to allow waters coming from the outside during rainfall, waters coming from tunnel washing operations or liquids leaking during an incident to drain away quickly.

The tunnel platform rotates around the design axis and affects the total height of the walkways at both sides of the carriageway.

The following bituminouscourses will be provided:

- Wearing course 5 cm BM 80/100 bitumen
- Binder course 5 cm BM 60/70 bitumen
- Base layer 20 cm Unbound granular mix (crusher-run macadam, according to grading II, table 12.8 of Standard Specifications for Road and Bridge Works).
- Filling gravel 0/45 (minimum compaction grade 100 MN/m^2)

Road markings of the tunnel carriageway consist of:

- Lateral continuous white line (width 25 cm);
- Central double and continuous white line (width 20 cm, free space 15 cm);
- "Cat's eye" retroreflective safety devices in the middle of the road between continuous lines (longitudinal step 6.5 m).

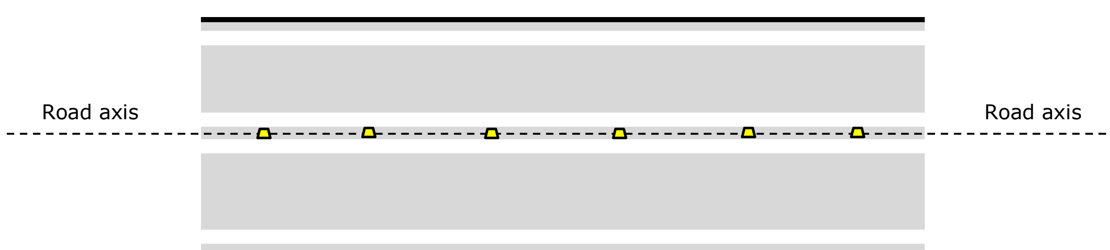


Figure 9: Main tunnel road markings

3.6 Walkways

Walkways are used as escape routes in case of incident inside the tunnel. They permit to reach SOS niches, bypass or tunnel portals in case of emergency. They also accommodate cable ducts, cable shafts and water supply pipe.

The minimum walkway width shall be 1 m, including the kerb. Transversal gradient shall be at least 2% towards the carriageway, whereas the step height will be 18 cm.

The walkways limits on the carriageway side can be:

- Kerbs (precast polymer concrete or natural stone elements such as granite or gneiss – see Figure 10);
- Linear road drainage channel (precast polymer concrete halogen free– at the minimum points of the road gradient – see Figure 11).

Both kerbs and drainage channels must be placed on a concrete foundation (min. 200 mm, C25/30, XC4, XF1).

Linear road drainage channel must have a minimum drainage capacity of 100 l/s.

According to Figure 4, the free space above the walkways is equal to at least 2 m. Moreover, the space requirement for traffic signals located against the tunnel walls consists of a squared area 80 x 80 cm, that must be kept free on both sides of the tunnel above the walkway.

A 3 cm thick bituminous layer MA 8 N or similar will be provided on the walkways surface.

In order toimprove visibility and traffic management, LED "cat's eye" devices will be installed above the kerb on both walkways (see E&M Technical Report).

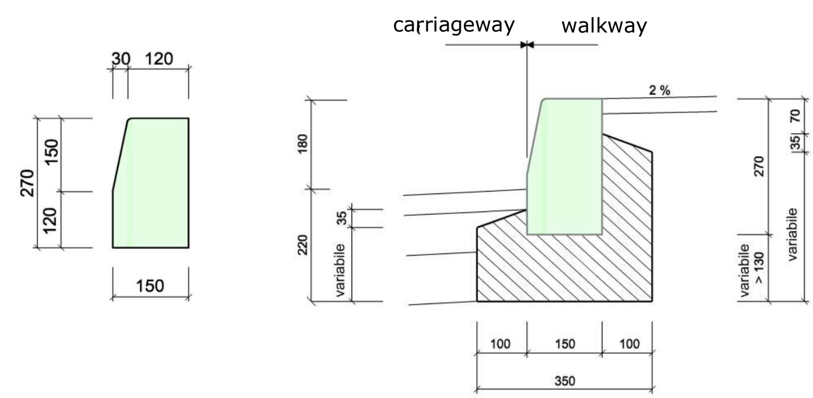


Figure 10: Walkways kerb (ASTRA 24 001-10402)

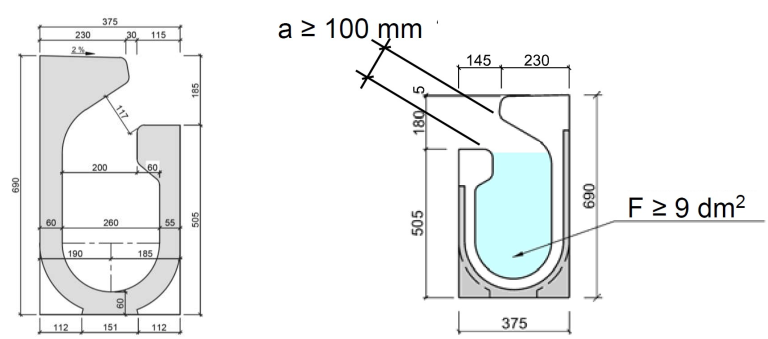


Figure 11: Linear road drainage channel, typical according to ASTRA 24 001-10602

3.7 Cable pipes and cable shafts

Cable pipes will be accommodated under both walkways, embedded in concrete. The following pipes for each walkway will be provided, having a minimum net distance between each other of 5 cm and a minimum distance from the walkway surface of 10 cm.

- 4x HDPE electrical pipes DN 120 (inside diameter 120 mm, outside diameter 132 mm), in a 2x2 pattern. No PVC pipes are allowed;
- 2x HDPE electrical pipes DN 150 (inside diameter 148 mm, outside diameter 163 mm), in a 2x1 pattern, at the bottom of the pipes group. No PVC pipes are allowed.

At regular intervals (see Tunnel Layout plan), cable shafts will be provided inside the walkways, having the following minimum dimensions in tunnel:

- Shaft type A2 (45 cm wide, 185 cm long), according to ASTRA 23 001-14300;
- Shaft type A3 (45 cm wide, 279 cm long), according to ASTRA 23 001-14300;
- Bypass pits (45 cm wide, 45 cm long).

Suitable sleeves must be used at the interface between electrical pipes ends and cable shaft walls,in order topermit a favourable installation of cables form inside the shafts.

Manholes covers will be suitable for vehicles (minimum load class C 250, according to ASTRA 23 001-14300) and sealed so as to prevent flammable liquids from entering the shafts. Besides, a drainage pipe (diameter 60 mm) at the bottom of the shafts will permit condensation water to drain away into the gravel filling under the carriageway.

Along the tunnel, electrical cable connections will be provided (see Tunnel Layout plan for more details):

- Connections to a SOS niche.
  3x HDPE electrical pipes DN 80 (inside diameter 80 mm, outside diameter 92 mm) will connect the cable shaft in front of a SOS niche and the foundation of the alarm cabin inside the niche.

- Connections to the technical buildings.
  10x HDPE electrical pipes DN 120 will connect the cable shaft in front of the technical building and the low voltage room.
  2x HDPE electrical pipes DN 120 will connect the cable shaft in front of the technical building and the medium voltage room.

- Connections to/along a bypass
  2x HDPE electrical pipes DN 120 (inside diameter 120 mm, outside diameter 132 mm) will connect the cable shaft in front of a bypass and the bypass electrical pit.

- Connections to the vault.
  A minimum of 5x HDPE electrical pipes DN 80 (inside diameter 80 mm, outside diameter 92 mm) will connect the cable shaft with suitable openings inside the vault at a height of 4.5 m from the walkways. Openings minimum dimensions are as follows: height 30 cm, depth into the vault 25 cm, longitudinal length according to the number of electrical pipes, having a 5 cm space between them. The minimum concrete cover of the pipes is 7 cm.

- Connections to the bypass vault.
  2x HDPE electrical pipes DN 80 (inside diameter 80 mm, outside diameter 92 mm) will connect the bypass pit with the bypass vault at a height of 3.0 m.

Electrical pipes and relevant shafts will be extended to the north and to the south of the tunnel portals (at least 200 m), along the road stretches approaching the tunnel.

3.8 Groundwater management

Water collection along the tunnel is based on the so called "separate" water management system. It pursues the separation between clean groundwater, collected outside the tunnel lining perimeter, and polluted waters, collected inside the tunnel lining perimeter.

3.8.1 Tunnel waterproofing

Groundwater, coming from the surrounding rock mass, is collected at the foot of the tunnel vault, thanks to the drainage and waterproofing layers around the tunnel. The tunnel waterproofing system consists of the following package of layers (in setting sequence, from top to bottom):

- Geocomposite drainage layer (Enkadrain or similar);
- Waterproofing PVC membrane (SIKAPLAN WP 2110-21HL or similar), thickness ≥ 2 mm;
- Waterproofing protection sheet (SIKAPLAN WP Protection Sheet 20H or similar).

Before setting of the geocomposite layer, the surface of the shotcrete primary lining must be accurately checked and, wherever necessary, regularized and smoothed. Waterproofing membrane shall be continuous; hence, any connection between adjacent strips of membrane shall be welded together by a double line of welds and continuous welding shall be guaranteed and tested by proper pressure tests.

At the north and south portal, where cut and cover stretches are foreseen, the following system will be provided (in setting sequence, from bottom to top):

- Waterproofing PVC membrane (SIKAPLAN WP 2110-21HL or similar), thickness ≥ 2 mm, hot-glued over the entire surface of the concrete lining (smooth and clean);
- Waterproofing protection sheet (SIKAPLAN WP Protection Sheet 20H or similar)
- Cement mortar (10 cm) reinforced with a wire mesh (ϕ6 mm 10x10 cm) as a final protection layer, with respect to subsequent filling and compaction.

The tunnel waterproofing system will be applied to the whole vault. No waterproofing layer is foreseen around an invert, wherever and whenever provided according to local geological conditions.

3.8.2 Drainage system

At the base of the vault, on both sides of the main tunnel and bypasses, HDPE slotted drainage pipes with an internal diameter equal to 200 mm will be provided and wrapped with filtering gravel 16/32 mm.

Drainage pipes allow groundwater to flow into flushing niches. Once in the niches, waters are collected by the seepage pipe (HDPE pipe connecting all the flushing niches, with an internal diameter equal to 300 mm).

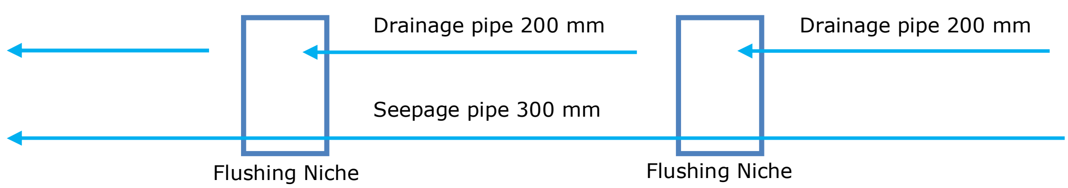


Figure 12: Typical groundwater drainage system

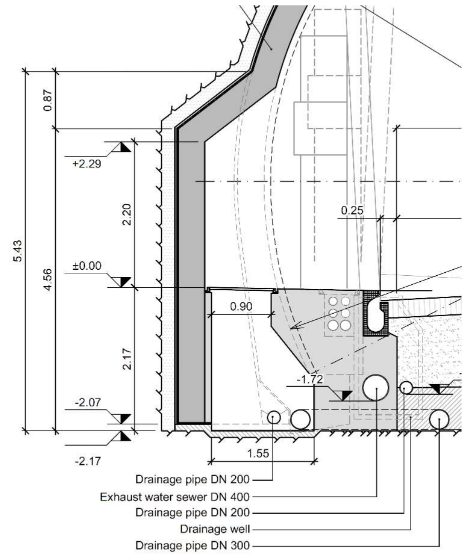
3.8.3 Flushing Niches

Flushing niches collect groundwaters and allow maintenance (regular flushing) of both drainage and seepage pipes.

Niches will be provided on both sides of the main tunnel, with a longitudinal step equal to 75 m and a minimum longitudinal length equal to 120 cm.

In the bypasses, two flushing shafts are foreseen at a distance of 75 m from the bypass end (river side).

For additional details see "Main tunnel layout" drawing D-A-C-D-002-C00.



3.8.4 Discharge at the portals

At the south portal, groundwaters coming from the drainage system will be discharged directly into the river. In the first drainage stretch at the north portal (between external shafts and the first flushing niche at km 2+005, see "main tunnel layout" D-A-C-D-002-C00), drainage pipelines shall be installed so that a longitudinal gradient can lead waters towards south.

3.9 Dirty and polluted water management

According to the so called "separate" water management system, dirty and polluted waters will be collected by a separate system and never mixed with the groundwater.

3.9.1 Sewage system

Dirty and polluted waters coming from in the inner tunnel space are:

- Carriageway waters which are carried inside the tunnel by vehicles in case of rain;
- Polluted liquids or fuel in case of accident or leaking;
- Firefighting waters in case of fire;
- Waters used during tunnel walls cleaning operations.

These kinds of water are collected by the linear drainage channel, thanks to the transversal gradient of the carriageway (see 3.6) and transported to the first chamber of the syphoned wells, every 50 m.

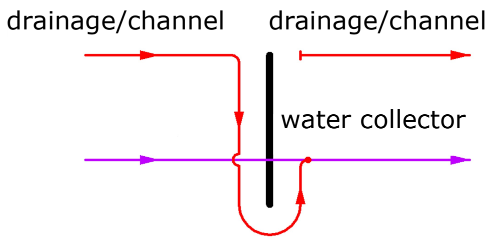
Some waters could also leak under the carriageway and seep through the filling gravel. They will be collected by a dedicated HDPE slotted drainage pipe with an internal diameter equal to 200 mm, connected to the first chamber of the siphoned wells.

3.9.2 Syphoned wells and water collector

A HDPE water collector pipe with an inner diameter equal to 400 mm connects all the syphoned wells and transports polluted waters through the tunnel to the south portal.

Every 50 m, special polymer concrete double chamber syphoned wells will be provided. They allow to avoid direct communication between the inner space of the tunnel and the main water collector and, hence, avoid propagation of fire liquids along the tunnel in case of accidents/fire.

Syphoned wells consist of two separate chambers, connected at the bottom by an opening into the separation wall, which is always under water:



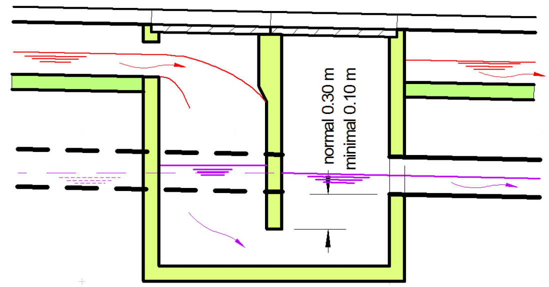


Figure 14: Syphoned wells functioning scheme according to ASTRA guidelines

- The first chamber (to the north) collects all the waters transported by the linear drainage channel and the drainage pipe under the carriageway. The main water collector does not communicate with the first chamber.
  - Pipes in: linear channel, carriageway drainage pipe;
  - Pipes out: none;
  - Pipes passing through: main water collector.
- The second chamber (to the south) collects waters transported by the main water collector, so that a minimum level of water is always present into the syphoned wells.
  - Pipes in: main water collector;
  - Pipes out: main water collector;
  - Pipes passing through: none.

3.9.3 Discharge at the portals

At the south portal, dirty waters will be discharged into a water basin, located outside the carriageway. A water basin volume, equal to 150 m^3, allows to collect waters and, whenever necessary, to avoid the direct discharge into the local sewage systems. In normal operation situation, waters coming from the tunnel water management system can be directly discharged into the local sewage net. In special cases, such as a fireor an accident inside the tunnel or duringtunnel washing operations, the basin volume shall be used to gather waters coming from:

- Firefighting (estimated 120 m^3 according to ASTRA guidelines) and accident liquids (estimated 50 m^3 according to ASTRA guidelines);
- Tunnel walls cleaning operations (estimated 100 m^3 according to ASTRA guidelines).

In these cases, the water basin connection to the local sewage system will be temporarily interrupted and gathered waters can be pumped out afterwards.

At the north portal, dirty waters will be discharged into a similar water basin, located outside the carriageway, with a reduced volume, equal to 50 m^3. It will be connected to the road water management system.

3.10 Fire management

3.10.1 Water supply system

A water supply system is foreseen in order to provide firefighting water in case of accident.

The main water supply pipe (ductile cast iron with PUR internal coating or similar), with an inner diameter equal to 200 mm, will be installed under the mountain side walkway and wrapped by sand. It will be always full of water under pressure.

Fire hydrants shall be located on both sides of the tunnel every 150 m.

Minimum service requirements at the hydrants are:

- Minimum dynamic pressure 3.5 bar
- Minimum hydrostatic pressure 6 bar
- Minimum water flow rate
  - 1 hydrant used 40 l/s

- 2 hydrants used at the same time 30 l/s each
- 3 hydrants used at the same time 25 l/s each

Hence, the minimum water flow rate in the water supply pipe shall be at least equal to 75 l/s.

Hydrants shall comply with the following minimum requirements (type Von Roll 5000S or similar):

- 1x Storz connector (75 mm);
- Stainless materials;
- Internal and external anticorrosive coating (epoxy layer or similar);
- Red colour finishing (RAL 3000).

3.10.2 Hydrant niches

Hydrants will be located ineach SOS niche and, on the opposite side, in a dedicated hydrant niche.

In combined SOS/hydrants niches, hydrants shall respect a minimum 40 cm distance from the niches' door.

A proper water discharge will be provided at the bottom of the 60 x 60 cm pit, right in front of the hydrants, by means of a HDPE 100 mm pipe, connected to the carriageway drainage pipe.

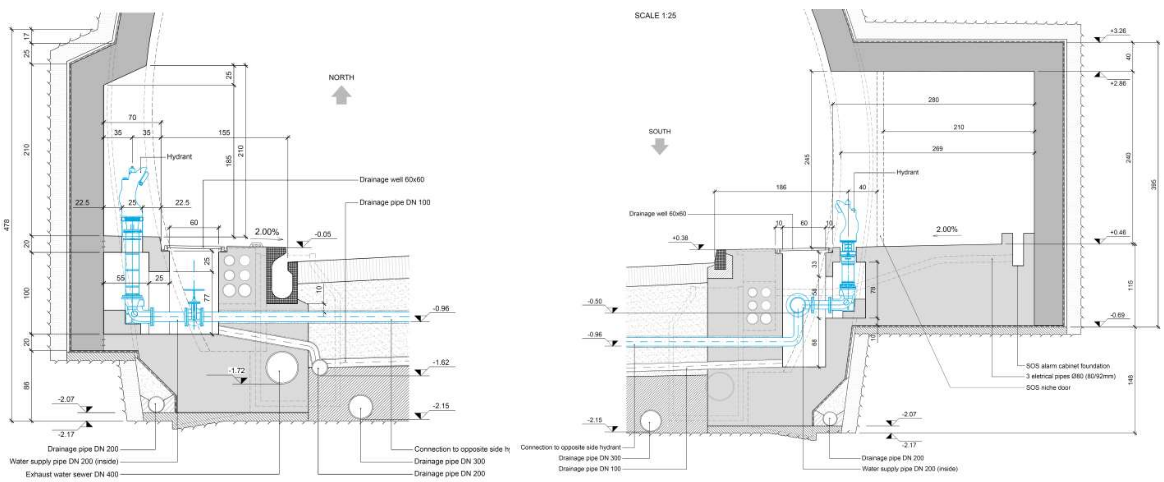


Figure 15: Hydrant niches and combined SOS/hydrant niches

3.10.3 Water supply reservoir

A 250 m^{3}water reservoir is foreseen at the underground level of the north technical building (see also the relevant chapter 4.3.2).Actually, 6 tanks of about 50 m^3 are foreseen in order to allow tanks maintenance, one by one in turn, without interrupting the availability of a minimum of 250 m^3 of water for the tunnel firefighting system.

Water withdrawal will be done at the river level (about -54 m down the portal level), in the existing "Tinaau" hydropower dam area, by means of two 100 mm pipelines (one is for safety in case of malfunctioning of the first one)and two alternating pumps (10.4 l/s).

The following actions must be taken by the Contractor:

- to design the most suitable withdrawal system and pipeline alignment, according to the local conditions and possibilities;
- to get all the necessary authorizations by all Authorities concerning the hydropower dam site and «Ramapithecus Park»;
- to provide measures such as signage and fencing, to prevent people from bathing in the withdrawal point area;
- to define how to access the withdrawal site for maintenance operations;
- to check the stability of the river bed and riverside as well as maximum and minimum water levels upstream and downstream of the dam;
- to adopt countermeasures to avoid clogging of the pipelines and to provide systems in order to allow sedimentation (such as a sedimentation/setting basin);

- to provide a water basin control and alarm system, with sensors that provide alarm to the tunnel control room in case of malfunctioning of the intake pumping system, or water levels in every tanks lower than expected or malfunctioning of the pumping station.

The following requirements must be then fulfilled at any time by the system:

- water volume — 300 m^3 (min. 250 m^3 in case of one tank maintenance);
- maximum filling time — 8 hours;
- water flow rate during filling — 10.4 l/s;
- reservoir emptying time — 1.1 hours (in case of the use of 3 hydrants – tot. 75 l/s).

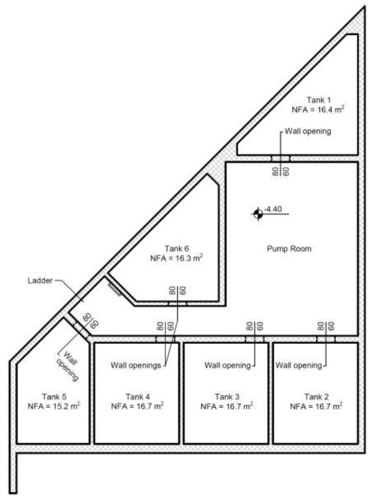


Figure 16: Water supply reservoir layout

3.10.4 Pumping station

The pumping room is located at the underground level of the technical building north, together with water reservoir tanks.

Pumping of water into the tunnel firefighting pipeline will be provided by at least 5 pumps (min. 20 l/s), working in parallel, to satisfy the following needs:

- Minimum dynamic pressure — 3.5 bar
- Minimum hydrostatic pressure — 6 bar
- Minimum water flow rate
  - 1 hydrant used — 40 l/s
  - 2 hydrants used at the same time — 30+30 l/s
  - 3 hydrants used at the same time — 25+25+25 l/s

3.10.5 Pressure tests

The Contractor must check the firefighting system by means of suitable pressure tests according to EN 805, SVGW W4and local standards.

3.11 Tunnel ventilation

The tunnel ventilation system, by means of jet fans, smoke sensors and other specific devices, is described in the relevant annex of the E&M report. Couples of jet fans will be installed in the upper free space of the tunnel vault.

Bypasses will be nevertheless ventilated in order to maintain air overpressure along the escape routes in case of fire. In this case, a special enlarged section (called "Air Lock" section) will be provided in proximity of the bypass portals, on the rockshed side.The air lock section will be 5 m long and characterized by the following elements:

- Two slinding doors (see details in 3.4.2);

- 3 square openings 1m x 1m in the upper part of the separation walls, having a 35 cm minimum distance from the sliding door structure and the tunnel vault profile.

3.12 Standard design sections

According to the space requirements described in 3.3, the following standard design sections are provided:

- Typical cross section

  This section fulfils all the minimum requirements for the inner space.

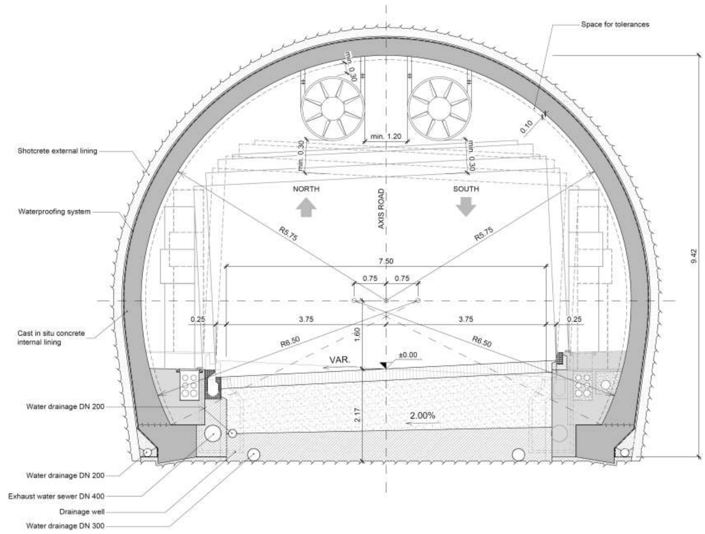


Figure 17: Main tunnel, typical cross section

- Widened typical cross section

  This section takes into account the widening requirements (60 cm) for visibility in the curved stretch of the tunnel.
  Basically, the geometry of the inner profile (arches, radii) is the same as that of the typical cross section, but a 60 cm straight segment at the vault key is added.

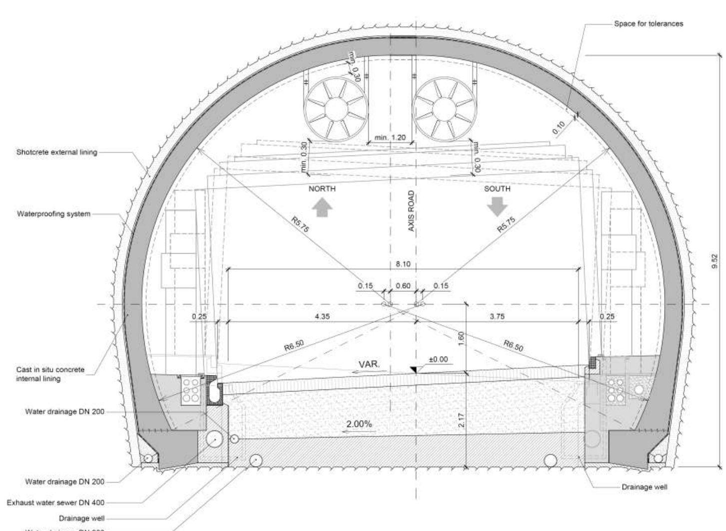


Figure 18: Main tunnel, widened typical cross section

- Lay by typical cross section

This section is representative of the lay-by bays in the central part of the tunnel. The geometry of the tunnel walls is equal to that of the typical cross section, whereas the vault radius is longer.

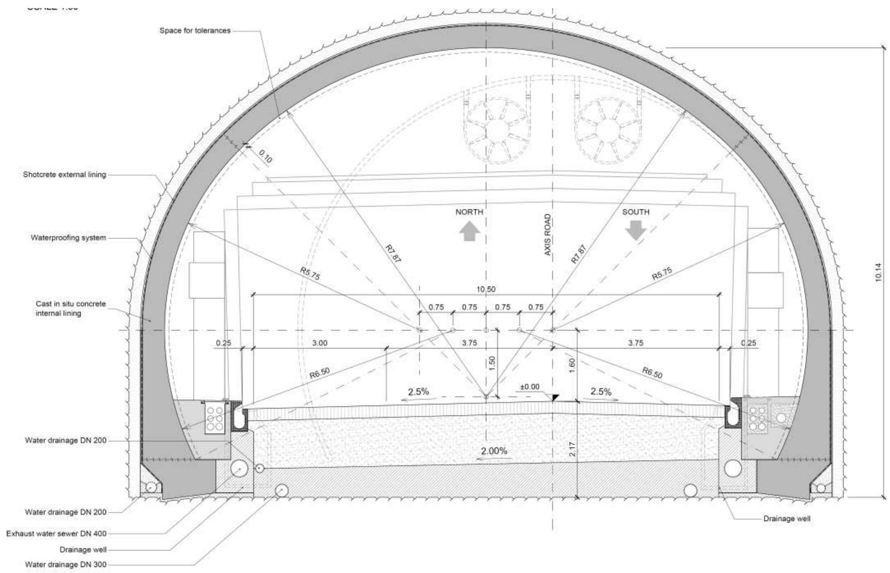


Figure 19: Main tunnel, lay by typical cross section

- Bypass typical cross section

This section fulfils the minimum requirements for the inner space of the bypass. Moreover, it takes into account the necessary space for the sliding door frame.

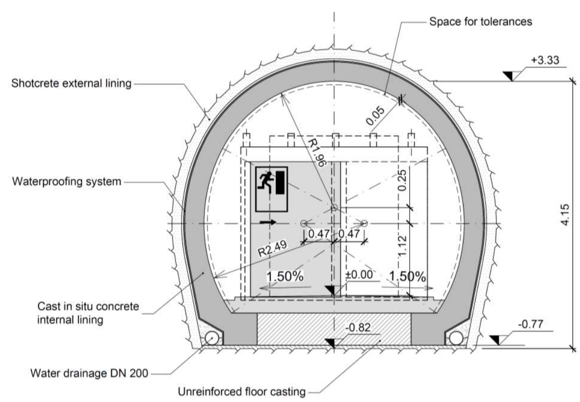


Figure 20: Bypass, typical cross section

- Bypass "air lock" cross section

This section fulfils the minimum ventilation requirements for the inner space of the "air lock" section of the bypass. Moreover, it takes into account the necessary space for the sliding door frame, ventilation openings and command cabin.

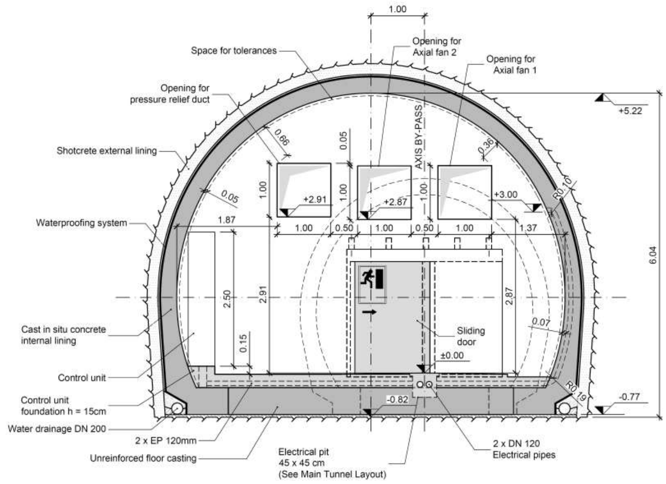


Figure 21: Bypass "Air Lock", typical cross section

3.13 Excavation and tunnel support

3.13.1 Excavation system

Considering the length of the tunnel, the foreseen geological conditions and the accessibility of the site, it is foreseen to excavate the tunnel by conventional tunnelling method. The use of a mechanized tunnelling method (i.e. using a TBM or similar) is considered not suitable mainly for two basic reasons: first of all, the length of the tunnel does not justify the cost for transport and supplying of a TBM; moreover the small available space at the portals makes complex the logistic during construction.

Conventional tunnelling consists of a cyclic execution process of repeated steps of excavation followed by the application of relevant primary support, which depends on existing ground/rock conditions and behaviour.

Considering predictable rock conditions in the present case, it is foreseen the use of drill and blast for most of the tunnel in compact rock, whereas ripper and hydraulic breaker are foreseen near the portals where weaker and weathered rock could be present. An experienced team of tunnel workers, assisted by special equipment, shall execute each individual cycle of tunnel construction.

By the use of special equipment and allowing access to the tunnel excavation face at almost any time, the conventional tunnelling method is very flexible in situations that require a change in the structural analysis and/or in the design of support measures. A standard set of equipment consists of the following items:

- Drilling jumbo: to drill holes for blasting (in medium to hard rock), rock bolting, water and pressure release;
- Road header or excavator, mainly where rock blasting is not possible (weak rock);
- Lifting platform allowing the miners to reach each part of the tunnel crown and face;
- Loader or excavator for loading excavated material onto dump trucks;
- Dump trucks for hauling excavated material;
- Set of shotcrete manipulators for application of wet shotcrete.

The assumed tunnel standard cross-section (about 110 m^2) is suitable to foresee a full face excavation: thanks to the high degree of mechanisation of the works and to the use of large, high performance equipment, full face excavation can be achieved even in difficult rock conditions, where face stability and support will be given paramount consideration.

3.13.2 Hazard scenarios and observational design approach

The recognition and the assessment of potential hazards as well as the planning of appropriate mitigation measures are fundamental to the design of underground structures. Hazards consist of events that have the potential to impact on matters relating to the project, which could give rise to consequences associated with health and safety, the environment, the design, the construction schedule and costs.

A preliminary evaluation of the geological-geotechnical scenario and relevant hazards have been identified and evaluated. The main expected hazards are (see also the geological and geomechanical profiles):

- stones falling from the crown;
- unstable blocks on the excavation contour;
- detachment of slabs;
- loosening of rock mass around the tunnel;
- plastic deformation of the rock mass;
- instability of the tunnel face;
- water income (effects on springs and surface waters).

The aforementioned hazards, individually or in combination, constitute possible hazard scenarios to be considered to define tunnel support measures.

Moreover, when tunnelling in a sedimentary rock, variable local rock conditions shall be expected and, hence, a flexible design and construction approach shall be adopted. Considering such expected conditions, the observational design approach is adopted, based on the concept to foresee, during design, different rock reinforcement and temporary support systems, to be applied along the tunnel depending on local rock behaviour measured during construction. Adopting the aforementioned design approach, the design shall include different fundamental instruments:

- based on geological investigation, the range of variability of rock mass characteristics shall be estimated and defined for each homogeneous section (from a geological point of view) along the tunnel;
- within the defined range of variability, a number of different hazard scenarios shall be identified;
- for each hazard scenario, the most suitable rock reinforcement and temporary support system shall be designed in order to guarantee safety and, in the meantime, optimize costs and construction time;
- A guideline that provides the range of rock conditions (for instance, described by well-known geological parameters such as GSI, RMR or Q) and of rock behaviour (for instance, described by level of deformation of the tunnel face or profile) for which each rock reinforcement and temporary support system is suitable;
- A geotechnical monitoring plan that define monitoring instruments to be installed and adopted during construction to assess local rock conditions and, hence, the applicability of the different support systems foreseen in the design;
- A longitudinal profile which provides, for each geologically homogeneous section, the foreseen alternative rock reinforcement and support systems and, for each of them, the probability of use, in order to obtain an estimation of construction time and costs.

The purpose of the primary/temporary support is to stabilize the underground excavation profile until the final lining is installed. Several elements are applied individually or in combination with different types of support, depending on the assessment of ground conditions.

According to the ground conditions, sub-horizontal drain pipes shall be installed at the tunnel face to avoid the risk of unexpected and sudden water inflow, in particular near the portals, where more fractured and weathered rock is expected.

3.13.3 Tunnel support class 0

Tunnel support class 0 is representative of the best geological rock mass conditions along the tunnel, where the main predictable hazard is the falling of stones from the vault.

The following supports are in sequence foreseen (every 3 m - advance shift):

- 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- Swellex rock bolts (Ftk ≥ 240 kN, L=4 m), if necessary;
- 5 cm C25/30 shotcrete layer (0/8 mm aggregates).

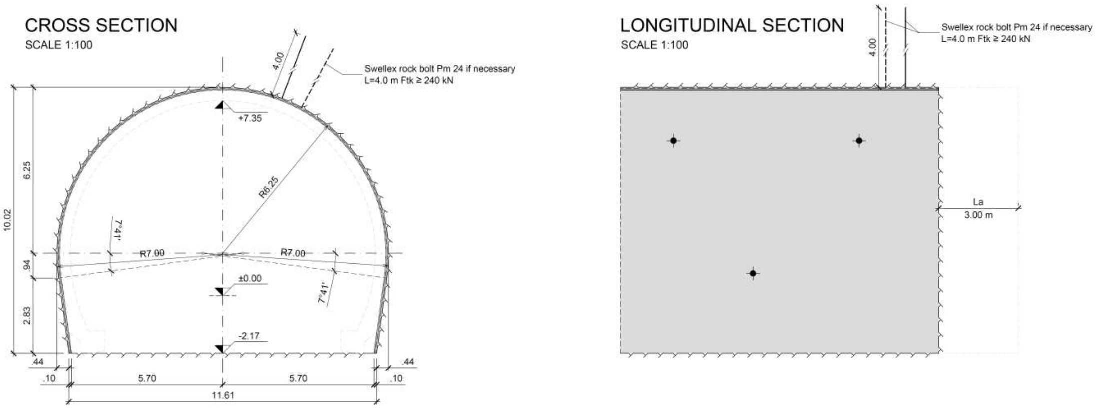


Figure 22: Tunnel support class 0, standard section

3.13.4 Tunnel support class 1

Tunnel support class 1 is foreseen to mitigate the following main hazards:

- stones falling from the crown;
- unstable blocks on the excavation contour;
- detachment of slabs.

The following supports are in sequence foreseen (every 2/3 m- advance shift, according to the encountered geological conditions) in standard/widened/bypass sections and every 2 m in lay-by bay section:

- 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- Swellex rock bolts:
  - Standard/Widened section: swellex rock bolts (Ftk ≥ 240 kN, L=4 m), with a 1.5 m (transversal) x 1.5/2.0 m (longitudinal) pattern (longitudinal step can be adapted according to the encountered geological conditions);
  - Bypass section: swellex rock bolts (Ftk ≥ 160kN, L=3 m), with a 1.5 m (transversal) x 2.0 m (longitudinal) pattern;
  - Lay-by Bay section: swellex rock bolts (Ftk ≥ 240 kN, L=5 m), with a 1.5 m (transversal) x 1.5 m (longitudinal) pattern;
- 10 cm C25/30 shotcrete layer (0/8 mm aggregates);
- Excavation face stabilization, by means of 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres.

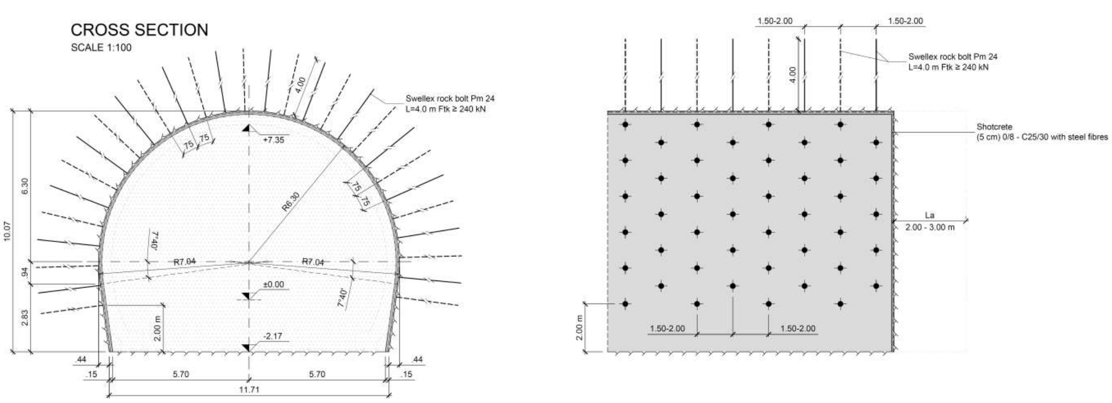


Figure 23: Tunnel support class 1, standard section

3.13.5 Tunnel support class 2

Tunnel support class 2 is foreseen to mitigate the following main hazards:

- stones falling from the crown;
- unstable blocks on the excavation contour;
- detachment of slabs;
- low to medium loosening of rock mass around the tunnel (GSI >45).

The following supports are in sequence foreseen (every 1.5/2 m - advance shift, according to the encountered geological conditions):

- 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- 10 cm C25/30 shotcrete layer (0/8 mm aggregates);
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- Cemented rock bolts:
  - Standard/widened/lay-by section: cemented rock bolts (Ftk ≥ 350 kN, L=7 m), with a 1.5 m (transversal) x 1.5 m (longitudinal) pattern;
  - Bypass section: cemented rock bolts (Ftk ≥ 250 kN, L=4.5 m), with a 1.5 m (transversal) x 1.5 m (longitudinal) pattern;
- 5 cm C25/30 shotcrete layer (0/8 mm aggregates);
- Excavation face stabilization, by means of 5/10 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres, and fiberglass or cemented anchors if necessary.

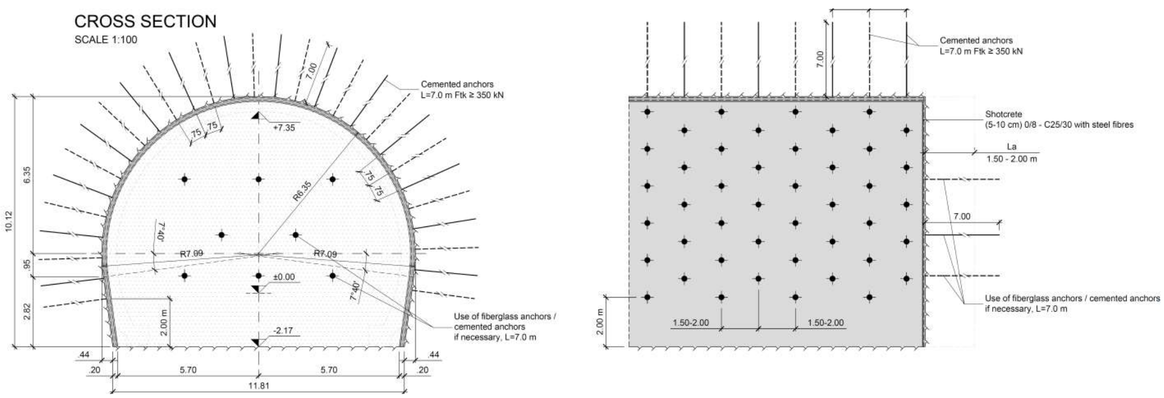


Figure 24: Tunnel support class 2, standard section

3.13.6 Tunnel support class 3

Tunnel support class 3 is foreseen to mitigate the following main hazards:

- stones falling from the crown;
- unstable blocks on the excavation contour;
- detachment of slabs;
- medium to high loosening of rock mass around the tunnel (GSI < 40).

The following supports are in sequence foreseen (every 1 m - advance shift):

- 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- Sub-horizontal spiles (forepoles) (Ftk ≥ 550 kN, L=3 m), with a 0.375 m (transversal) x 1.0 m (longitudinal) pattern, distributed at the vault with an angle of 120°. The bottom side of the forepoles (excavation side) lays on lattice girders;
- Lattice girders (longitudinal spacing 1.0 m):
  - Standard/widened section: lattice girders type 3G-70/26/34 or similar;
  - Lay-by bay section: lattice girders type 3G-130/20/30 or similar;
  - Bypass section: lattice girders type 3G-70/18/26 or similar;
- C25/30 shotcrete layer (0/8 mm aggregates);
  - Standard/widened section: 13 cm;
  - Lay-by bay section: 18 cm;
  - Bypass section: 11 cm;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- C25/30 shotcrete layer (0/8 mm aggregates);

  - Standard/widened section: 7 cm;
  - Lay-by bay section: 7 cm;
  - Bypass section: 4 cm;
- Excavation face stabilization, by means of 5/10 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres, and fiberglass or cemented anchors if necessary.

The primary lining foot shall have a thickness of at least 350 mm (standard/widened section) and 400 mm (lay-by section).

At the bottom of the tunnel walls of the standard/widened section, 1 m above the vaults' foot, cemented rock bolts (Ftk ≥ 350 kN, L=5 m), with a 1 m longitudinal spacing and a 250 x 250 x 20 mm steel anchor plate, will be provided to stabilize the tunnel paraments.

Whereas during spilesinstalltion water income is recorded or if water income is recorded at the tunnel face, at least n.2 slotted sub-horizontal drainage pipes at the tunnel face shall be installed, using slotted PVC pipes (or equivalent) with diameter 2", 15 m long, to be repeated every 10 m (advance length), till water income are nomore recorded. Drainage pipes shall be installed with 5° inclination upward, one on the left half and one at the right half of the tunnel face, starting at a height around 2/3 of the tunnel height.

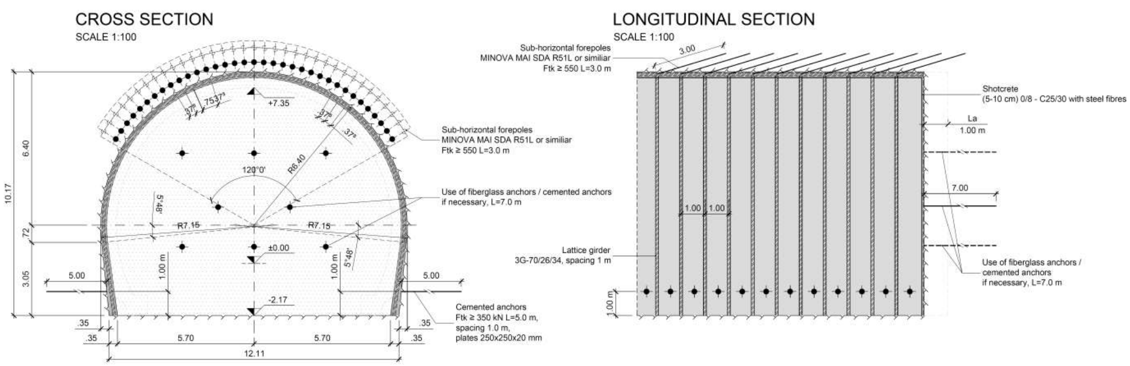


Figure 25: Tunnel support class 3, standard section

3.13.7 Tunnel support class 4

Tunnel support class 4 is foreseen to mitigate the following main hazards:

- stones falling from the crown;
- unstable blocks on the excavation contour;
- detachment of slabs;
- medium to high loosening of rock mass around the tunnel (GSI < 40) with low overburden (< 30 m), typically at the north and south portals;
- instability of the tunnel face.

The following supports are in sequence foreseen (every 1 m - advance shift):

- Execution of a steel tubes forepoling umbrella (steel grade S355) every 10 m (advance length). Diameter min. 114.3 mm, thickness min. 16 mm, drilling diameter min. 150 mm, transversal spacing 0.4 m, length 15 m, gradient 6% with reference to the tunnel axis;
- 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- HEB 180 steel ribs (steel grade S355) with a longitudinal spacing equal to 1.0 m;
- C25/30 shotcrete layer (0/8 mm aggregates): 18 cm;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- C25/30 shotcrete layer (0/8 mm aggregates): 7 cm(wherever necessary, shotcrete completion by filling the gap between primary lining and final lining, before final lining and waterproofing execution);
- Excavation face stabilization, by means of 5/10 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres, and 18 fiberglass anchors (Ftk ≥ 800kN, drilling diameter min. 100 mm, length = 16 m, overlapping = 8m, execution every 8 m).

The primary lining foot shall have a thickness of at least 450 mm.

At the bottom of the tunnel walls of the standard section, 1 m above the vaults' foot, cemented rock bolts (Ftk ≥ 460 kN, L=5.5 m), with a 1 m longitudinal spacing and a 250 x 250 x 20 mm steel anchor plate, will be provided to stabilize the tunnel paraments.Whereas during drilling steel pipe of forepoling umbrella, water income is recorded, at least n.2 slotted sub-horizontal drainage pipes at the tunnel face shall be installed, using slotted PVC pipes (or equivalent) with diameter 2", 15 m long, to be repeated every 10 m (advance length), till water income are nomore recorded. Drainage pipes shall be installed with 5° inclination upward, one on the left half and one at the right half of the tunnel face, starting at a height around 2/3 of the tunnel height.

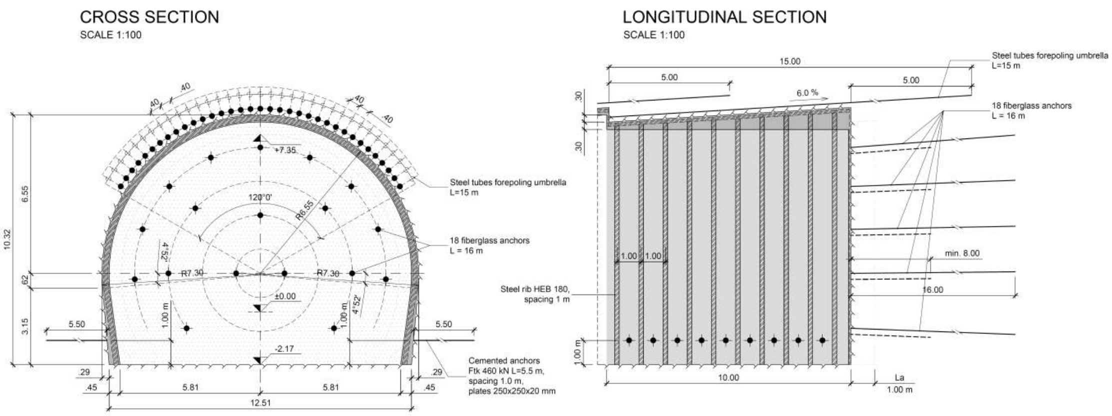


Figure 26: Tunnel support class 4, standard section

3.13.8 Tunnel support class 5

Tunnel support class 5 is foreseen to mitigate the following main hazards:

- stones falling from the crown;
- unstable blocks on the excavation contour;
- detachment of slabs;
- plastic deformation of the rock mass;
- instability of the tunnel face.

A tunnel invert is foreseen in order to face rock pressures due to the plasticization of the surrounding rock mass.

The following supports are in sequence foreseen (every 1 m - advance shift):

- Vault excavation and support

- 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- HEB 180 steel ribs (steel grade S355) with a longitudinal spacing equal to 1.0 m;
- C25/30 shotcrete layer (0/8 mm aggregates): 18 cm;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- C25/30 shotcrete layer (0/8 mm aggregates): 12 cm;
- Stabilization/Reinforcement of both the excavation face and the tunnel contour, by means of 5/10 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres, and 60 fiberglass anchors (Ftk ≥800kN, drilling diameter min. 100 mm, length = 18 m, overlapping = 9 m, execution every 9 m).

- Invert excavation and support (distance from the tunnel excavation face = 2 m)

- 5 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with steel fibres;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- HEB 180 steel ribs (steel grade S355) with a longitudinal spacing equal to 1.0 m;
- C25/30 shotcrete layer (0/8 mm aggregates): 18 cm;
- Steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- C25/30 shotcrete layer (0/8 mm aggregates): 12 cm.

Whereas during fiberglass anchor at the tunnel face, water income is recorded, at least n.2 slotted sub-horizontal drainage pipes at the tunnel face shall be installed, using slotted PVC pipes (or equivalent) with diameter 2", 15 m long, to be repeated every 10 m (advance length), till water income are nomore recorded. Drainage pipes shall be installed with 5° inclination upward, one on the left half and one at the right half of the tunnel face, starting at a height around 2/3 of the tunnel height.

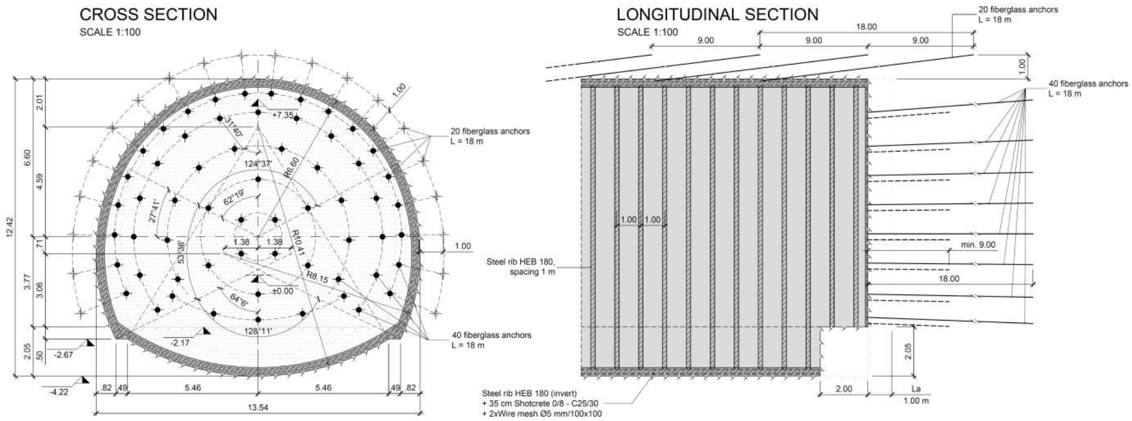
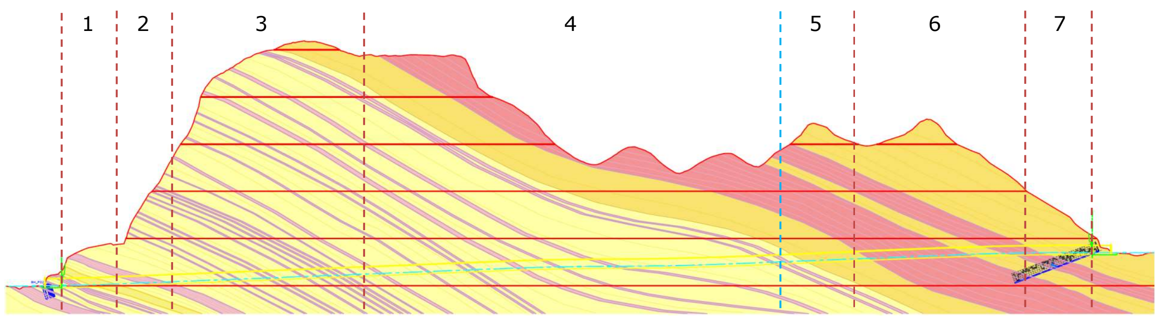


Figure 27: Tunnel support class 5, standard section

3.13.9 Classes distribution along the tunnel

In the geomechanicallongitudinal profile, suitable homogeneous sections have been identified, on the basis of expected geology and hazards (from 1 to 7 in Figure 28). Excavation support classes have been accordingly distributed along the tunnel.



	1	2	3	4+5	6	7
	km 0+925 - 0+982	km 0+982 - 1+036	km 1+036 - 1+256	km 1+256 - 1+765	km 1+765 - 1+941	km 1+941 - 2+012
CLASS 0	-	-	10%	20%	-	-
CLASS 1	-	-	30%	50%	-	-
CLASS 2	-	10%	40%	20%	10%	-
CLASS 3	20%	40%	20%	10%	20%	20%
CLASS 4	70%	-	-	-	-	70%
CLASS 5	10%	50%	-	-	70%	10%

Figure 28: Tunnel support classes distribution along the main tunnel

3.13.10 Classes distribution along the bypasses

As far as escape routes are concerned, excavation support classes have been distributed along the each bypass:

- Bypass 1 (south)

- 7 m portal section — 100% Class 3
- Air lock section — 100% Class 3
- Middle section — 10% Class 0 / 30% Class 1 / 40% Class 2 / 20% Class 3

- 10 m connection section 100% Class 3

- Bypass 2 (intermediate)

- 7 m portal section 100% Class 3
- Air lock section 100% Class 3
- Middle section 20% Class 0 / 50% Class 1 / 20% Class 2 / 10% Class 3
- 10 m connection section 100% Class 3

- Bypass 3 (north)

- 7 m portal section 100% Class 3
- Air lock section 100% Class 3
- Middle section 10% Class 0 / 30% Class 1 / 40% Class 2 / 20% Class 3
- 10 m connection section 100% Class 3

3.13.11 Water income management and grouting

In any support class, whenever necessary based on water income during the systematic horizontal survey drilling to be done at the front face (see monitoring concept at 3.15), sub horizontal drainage pipes shall be used ahead of the excavation facein order to manage water income. Slotted drainage PVC pipes with a diameter of at least 100 mm or equivalent seystems shall be used. If necessary, they will be covered with a sleeve of geotextile (not woven) to prevent clogging. The length (min. 10 m) and the position of drainage pipes should be evaluated during advancement operations, according to local conditions.

When excavating upward (from south to North) a proper water collection system shall be realized in order to bring water at the portal and avoiding water stagnation near the tunnel face and at the foots or the temporary ling. When excavating downward (from North to South), a proper pumping system shall be also provided by the Contractor and continuously kept in service in order to avoid also risk of foin order to avoid tunnel flooding.

As during design survey, sudden water incomes were experienced during borehole coring, expecially during advancement from North, possible narrow sections with high water income are expected. In order to be able to face such local conditions without reducing too much the advancement rateand in order to reduce total water income during service of the tunnel, the Contractor shall be ready and demonstrate to be able to perform local intervention with chemical grouting, in order to locally reduce rock permeability around the tunnel and shall produce a concept to perform such additional grouting work. In the following picture, just as example, it is shown a concept of chemical grouting work aimed to reduce rock permeability around the tunnel.

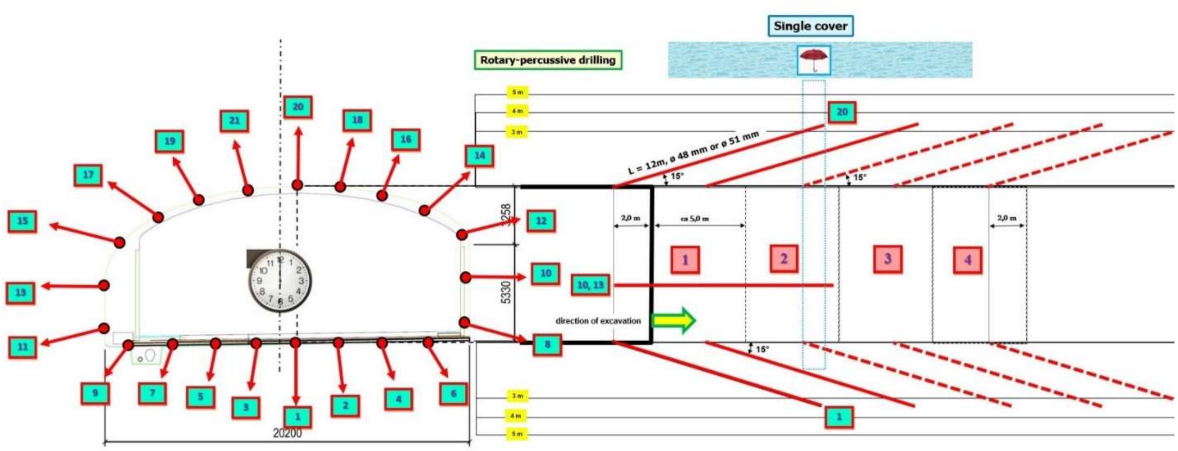


Figure 29: Example of chemical grouting work to reduce rock permeability around the tunnel

3.13.12 Anchors onsite tests

In order toverify that rock bolts and anchors meet the design requirements, suitable pull out tests shall be provided at least in the following situations:

- before tunnel excavation;
- during excavation, whenever a change in the geological formation is encountered;
- during excavation, whenever an unexpected geological formation is encountered.

In each homogeneous rock formation or ground condition, at least 3 pull out tests shall be provided for each designed anchor type (swellex rock bolts, cemented rock bolts, fiber glass elements). The design of the tests (location, pulling and contrast system, etc.) shall be provided by the Contractor according to Eurocodes. In the following, minimum requirements for the anchors resistance, in terms of characteristic friction between anchor and rock, are summarized according to the present design:

- Swellex rock bolts 80kN/m;
- Cemented rock bolts 94 kN/m.

Fiberglass reinforcements shall be verified by means of pull-out tests at a minimum test load equal to 760 kN.

3.13.13 False tunnel at the portals

In order to safely excavate the tunnel at the two portals, a false tunnel will be provided, at least 2 m long. The false tunnel will be made of shotcrete and reinforced with HEB 180 steel ribs and wire meshes (see relevant plan for details).

3.14 Expected rock mass parameters

In the following table, expected rock mass parameters are summarized. More details could be found in the geological report.

Rock mass parameters				TO (tunnel homogeneous section)								
				1 - Portal South		2	3	4	5	6	7 - Portal north	
				Sandstone	Mudstone						Sandstone	Mudstone
ROCK	RQD	min - max	[%]	0 - 100	65 - 80	50 - 100	50 - 100	50 -100	40 -100	0 - 100	0 - 100	65 - 80
	GSI	min - max	-	25 -85	25 - 60	30 - 80	40 - 80	40 - 80	30 - 80	30 - 80	30 - 80	25 - 60
	σc	min - max	[MPa]	14 - 51	5 - 35	5 -35	15 - 50	15 - 50	15 - 50	5 - 35	14 - 51	5 - 35
	Bulk density	min - max	[g/cm3]	2.37 - 2.66								
	Hoek-Brown	D		0.7								
		mi		13	7	7	7 - 13	7 - 13	7 - 13	7	13	7
		φ	[°]	38 - 57	21 - 46	19 - 40	30 - 47	33 - 49	29 - 51	18 - 38	38 - 57	21 - 46
		c	[kPa]	64 - 960	26 - 430	90 - 520	390 - 1360	310 - 1240	205 - 1160	105 - 560	70 - 810	26 - 430
		UCS	[MPa]	1.5 - 7	0.02 - 2.3	0.05 - 2.3	0.3 - 7	0.3 - 9.7	0.1 - 9.7	0.05 -2.3	0.12 - 5.8	0.02 - 2.3
		v		0.2	0.25	0.25	0.2	0.2	0.2	0.25	0.2	0.25
		E	[GPa]	0.8 - 20	0.34 - 11.5	0.6 - 11.5	2 - 20	2 - 20	1.12 - 20	0.6 - 11.5	1.02 - 18.2	0.34 - 11.5
Joints	fi	min - max	[°]	15.95 - 18.26								
	c	min - max	[kPa]	108 - 158								
Permeability k		min - max	[m/s]	1.9x10-3 - 2.5x10-4		<1.0x10-4	2.5x10-4 - 1.0x10-4	2.5x10-4 - 1.0x10-4	2.5x10-4 - 1.0x10-4	<1.0x10-4	1.9x10-3 - 2.5x10-4	

Table 2:Expected rock mass parameters

3.15 Tunnel monitoring

During excavation, deformation response of the surrounding rock mass and, hence, displacements of the primary lining shall be monitored during all the tunnel construction.

The monitoring phase begins when the excavation work starts and a proper monitoring system must be installed and activated as soon as the construction begins. Monitoring is aimed:

- to be able to verify design assumptions and to calibrate them during excavation (intensity and distribution of support measures);

- to check the conditions and response of the tunnel over time (long term behaviour).

An adequate tunnel monitoring program shall be provided by the Contractor. Hereby, the minimum requirements are summarised:

- continuous geological/geomechanical check of the excavation face during excavation and description of the lithology and discontinuities;
  - quick check in homogeneous or constant ground situations (at least every 10 m);
  - detailed check and descriptions in case of change of lithology and discontinuities;

- one horizontal drilling from the tunnel face, 30 m long, to be done every 20 m advancement and recording drilling parameters (so-called DAC-test), to be used to identify in advance rock quality changes;

- convergence measurements by means of mini prisms, fixed to the shotcrete primary lining right behind the excavation face (topographical monitoring section);

- topographical monitoring sections every 25 m;

- at least 5 mini prisms for each topographic section, located at the tunnel abutments, walls and vault key (see Figure 30).

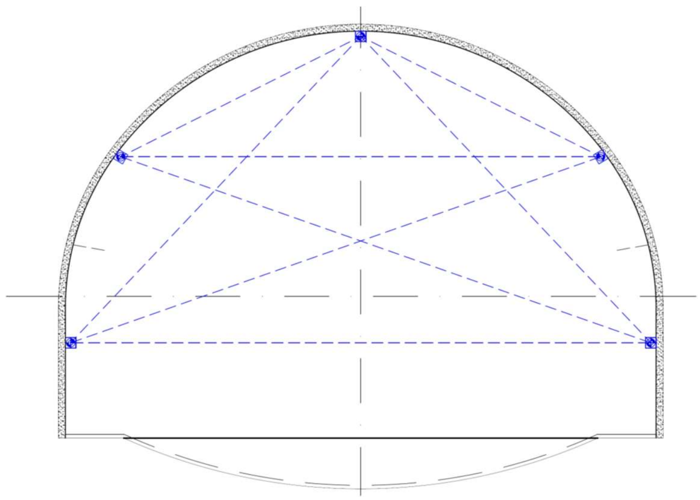


Figure 30: Example of convergence monitoring section

3.15.1 Frequency

Data acquisition frequency:

- daily, having a distance from the tunnel excavation face < 25 m;
- two times a week, having a distance from the tunnel excavation face > 25 m.

3.15.2 Thresholds

Convergence thresholds / Tunnel support Class 0-1-2-3:

- Expected maximum vertical displacement 6 mm - 10 mm (lay-by) - 1 mm (bypass);
- Alert threshold, vertical displacement 10 mm;
- Alarm threshold, vertical displacement 15 mm;

- Expected maximum horizontal displacement 2 mm;
- Alert threshold, horizontal displacement 5 mm;
- Alarm threshold, horizontal displacement 10 mm.

Convergence thresholds / Tunnel support Class 4:

- Expected maximum vertical displacement 8 mm;
- Alert threshold, vertical displacement 10 mm;
- Alarm threshold, vertical displacement 15 mm;

- Expected maximum horizontal displacement 2 mm;
- Alert threshold, horizontal displacement 5 mm;
- Alarm threshold, horizontal displacement 10 mm.

Convergence thresholds / Tunnel support Class 5:

- Expected maximum vertical displacement 8 mm;
- Alert threshold, vertical displacement 10 mm;
- Alarm threshold, vertical displacement 15 mm;

- Expected maximum horizontal displacement 6.5 mm;
- Alert threshold, horizontal displacement 10 mm;
- Alarm threshold, horizontal displacement 15 mm.

3.16 Inner lining

The lining concept to be applied shall be a double-shell lining, where the external lining shall support rock load during construction and inner lining loads in the long term; a proper waterproofing system is needed to guarantee serviceability of the tunnel (see 3.8.1).

The final lining shall be in plain or reinforced concrete, C30/37. A working Life of 50yearshas been foreseen.

In order to guarantee sufficient durability, the concrete shall be suitable for exposure classes XC4, XD1 and XF1, accordingly to EC2 and SIA 262; moreover shall be resistant to alkali-aggregates reaction.

A minimum 50 mm concrete cover must be guaranteed.

Before casting the inner lining, the waterproofing system shall be installed, having previously regularized the surface of temporary lining, in order to avoid the risk of damage of the waterproofing system (no steel element protruding from the shotcrete surface and no cavity/irregularities in the shotcrete surface that prevent the waterproofing membrane to fully rest on the shotcrete surface). Then, reinforcement, where foreseen, is installed by using a mobile scaffolding and adopting proper plastic element to guarantee a proper cover to reinforcement. Finally the concrete is poured usually in tunnel sections between 10 and 12 m long. No discontinuities on the waterproofing membrane are allowed, i.e. no structural elements through it that cause holes in it.

The following minimum design thicknessesare foreseen:

- Standard tunnel section

- Support Classes 0-1	unreinforced concrete	40 cm
- Support Classes 2-3	reinforced concrete	40 cm
- Support Classes 4-5	reinforced concrete	50 cm
- Invert (Class 5)	reinforced concrete	50 cm

- Widened tunnel section

- Support Classes 0-1	unreinforced concrete	40 cm
- Support Classes 2-3	reinforced concrete	40 cm

- Lay-by bay section

- Support Classes 0-1-2-3	reinforced concrete	50 cm

- Bypass section/Air Lock section

- Support Classes 0-1	unreinforced concrete	30 cm
- Support Classes 2-3	reinforced concrete	30 cm

3.17 Tunnel painting

Tunnel walls will be painted (Tosadur 2K coating or similar) with a RAL 9010 (white) colour up to +4.00 m above the walkways.

Before painting the walls, the following activities must be executed in order to adequately prepare the concrete surface (up to +4.00 m above the walkways):

- High pressure tunnel wall washing (min. 300 bar, pressure to be calibrated);
- Coating with a cement mortar base product 2-3 mm (tear strength >1.5 MPa, StoCrete TF or similar);
- Hydrophobic coating (SikaGard 706 Thixo or similar).

3.17.1 Painting: SOS Niches

In the SOS niches surrounding surface (1 m around the niche's profile), tunnel walls will be painted with a RAL 2004 (orange) colour (Tosadur 2K coating or similar, see Figure 31).

3.17.2 Painting: escape routes accesses (bypass)

In the escape route surrounding surface (3 m to the north and to the south of the bypass access profile and up to +4.00 m above the walkways), tunnel walls will be painted with a RAL 6029 (green) colour (Tosadur 2K coating or similar, see Figure 31).

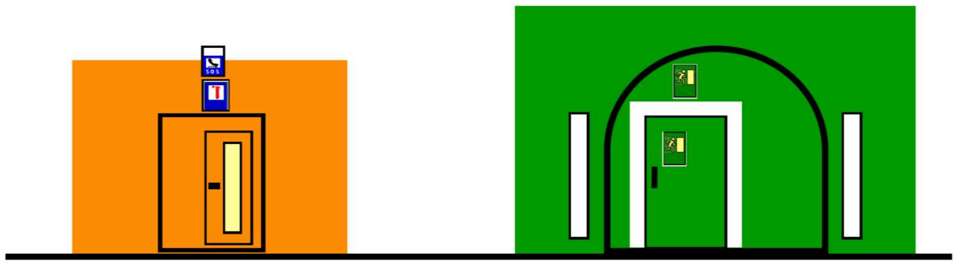


Figure 31: Typical painting patterns of SOS niches (left) and bypass accesses (right)

3.18 Summary of execution phases

In the following, general execution phases of the underground tunnel are described:

- Phase 0 – Tunnel Face support/pre-confinement

- Excavation face support by means of a shotcrete layer reinforced with steel fibres and fiberglass anchors/cemented anchors where necessary.
- Wherever foreseen, face reinforcement/pre-confinement by means of fiberglass anchors or fiberglass structural elements according to the design geometry and overlapping lengths.
- In tunnel support class 4, execution of a steel tubes forepoling umbrella at the excavation contour, according to design geometry and design overlapping length.
- Drilling and installation of drainage pipes will be provided if necessary.

- Phase 1 – Tunnel Advance

- Full face excavation with an advance length according to the applied tunnel support class.

- Phase 2 – Tunnel support

- Placing of a first fibre reinforced shotcrete layer on the tunnel excavation profile and, if necessary, on the excavation face.
- Placing of the first wire mesh steel reinforcement.
- Drilling and installation of radial rock bolts or sub horizontal forepoles.
- Where pertinent, placement of steel ribs/lattice girders according to the applied tunnel support class.
- After placing of steel ribs, connection of the ribs to each other by means of connecting steel bars.
- Placing of a second shotcrete layer and wire mesh according to the applied tunnel support class.
- Completion of the preliminary shotcrete lining. In tunnel support class 5, the last layer of shotcrete will be completed once the invert support is also executed.

- Phase 2b – Tunnel invert

- In tunnel support class 5, excavation of the invert at a 2 m distance from the excavation face.
- Preliminary lining of the invert by means of shotcrete, wire mesh and steel ribs.

- Connection of the invert steel ribs to the vault steel ribs and completion of the preliminary shotcrete lining.

• Phase 3 – Cast of the tunnel invert

- In tunnel support class 5, placement of the steel bars and cast of the concrete invert, having a maximum distance from the excavation face to be defined according to the monitoring results.

• Phase 4 – Waterproofing

- Placement of tunnel vault drainage pipes and filtering gravel package.
- Placement of the tunnel vault waterproofing system.

• Phase 5 – Cast of the final lining

- Cast of the tunnel final lining according to the design layout.

• Phase 6 – Carriageway, walkways and cable ducts

- Placement of cable ducts, shafts, drainages, pipes and hydrants.
- Cast of the walkways.
- Completion of the carriageway and niches.
- Technical installations (operating and safety equipment).

3.19 Operating and safety equipment

Accordingly to SIA 197/2, the following plants and equipment shall be designed and provided in order to guarantee proper operation of the tunnel and safety conditions:

- Lighting;
- Ventilation;
- Traffic management equipment (traffic signals and road markings);
- Surveillance system;
- Control system and communication network;

Moreover, the following is necessary for the operation of the above facilities:

- Energy supply;
- Cabling system;
- Auxiliary systems;
- Control room.

For additional details, see the relevant E&M technical report.

3.20 Construction phases

The construction of the tunnel is foreseen to be performed by the following main construction phases:

- Excavation of the main tunnel
- Excavation of the transversal tunnels;
- Construction of the tunnel lining;
- Construction of internal finishing
- Construction of technical buildings
- Installation of equipments.

Excavation of the main tunnel is foreseen to be performed by both portals, after excavation of the portal trenches itself; two tunnel advancement are performed in the mean time. During tunnel advancament from North to South, a pumping system shall be always made available at the tunnel face to avoid risk of tunnel flooring in case of sudden water income.

As during excavation of both portal trenches and first part of the tunnel from both sides, the road near the portals will be in srvice and the buildings near the portals will be operated (as weel as the temple near the South Portal), proper protection measures to avoid rock projection during excavation as well as proper mitigation measures to clearly separate the construction area from the road and pedestrian areas and reduce noise pollution shall be applied by the Contractor.

Excavation of the 3 transversal tunnels is foreseen one by one, after accomplishing main tunnel excavation and during tunnel linig construction. Excavation of transversal tunnels will be performed mainly from inside the tunnel in order to minimize disturbance to road traffic. Only last 7 m of excavation can be performed form the existing road, reducing the road width to one half and adopting intermediate traffic on the two dirction.

Tunnel lining construction is foreseen by use of only one movable formwork to be installed at the south portal and dismantled at the North Portal, moving from South to North; the formwork shall be able to cast the whole lining (except for the invert, where foreseen, and a small abutment as support) in one piece, in order to guarantee proper quality and finishing of the internal surface (i.e. continuous surface without longitudinal joints from the pedestrian pavement up to the crown. After casting, a proper protection of the hardening concrete shall be adopted in order to avoid thermal shock and to reduce shrinkage so to meet cracking requirmeents in accordance to relevant Eurocodes and design requirements: a proper concrete treatment protection concept shall be studied by the Contractor and presented to the Owner for acceptance.

Internal finishing will be installed and casted following inner lining at a proper distance to guarantee.

In parallel to tunnel lining construction, once excavation of the tunnel will be finished and, hence, installation areas at the portals shall be reduced, the technical buildings will be built at the two portals.

Once technical buildings shall be finished, equipments installation shall start from the buildings themselves and will continue in the tunnel once civil works will be completed.

4 CUT&COVER AND PORTALS

4.1 Excavation of north and south portals

The aim of this chapter is to provide an overview on the excavation works for the execution of the new road tunnel. The image below highlights North and South portal area:

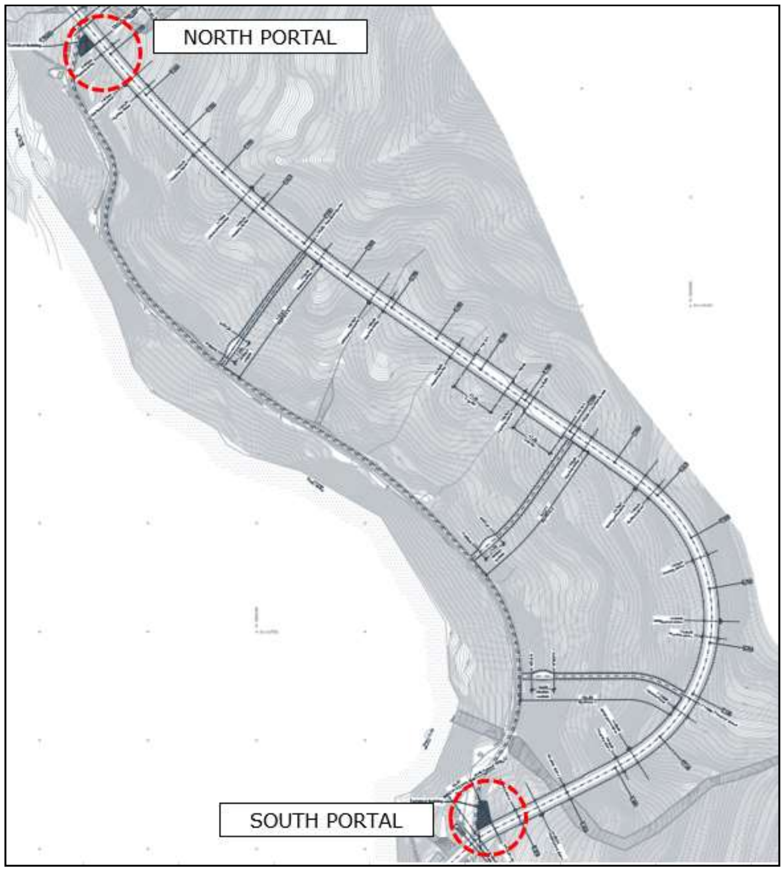


Figure 32 - General Tunnel Key plan

Figure 33 - North Portal Area

Figure 34 - South Portal Area

The proposed project of the Siddhababa tunnel road belongs to the rocks of the Siwaliks (Sub-Himalaya), Western Nepal. In Western Nepal, the rocks of the Siwaliks are subdivided into the Lower, Middle and Upper Siwaliks based on increasing grain size and lithological variation.

Figure 35 - Rock exposed on hill side

In general, soil parameters for each portal excavation design are reported below:

North Portal	γ [kN/m3]	φ'[°]	c' [kPa]	Poisson coeff. [-]	Elastic Modulus [GPa]
Sandstone_North_disturbance factor = 0.7	26	38	110	0.2	1.18
Sandstone_North_disturbance factor = 0.2	26	45	150	0.2	1.18

South Portal	γ [kN/m3]	φ'[°]	c' [kPa]	Poisson coeff. [-]	Elastic Modulus [GPa]
Sandstone_South_High Fracturated	26	38	110	0.2	1.18
Sandstone_South_disturbance factor = 0.7	26	41	125	0.2	1.55
Sandstone_South_disturbance factor = 0.2	26	47	165	0.2	1.55

4.1.1 Excavationprocess

Execution phases are reported below:

- **PHASE 1**

EXCAVATION UP TO -0.5 METERS BELOW FIRST LEVEL OF ROCK BOLTS;

- **PHASE 2**

PLACEMENT OF A LAYER OF SHOTCRETE REINFORCED WITH STEEL WIRE MESH;

- **PHASE 3**

EXECUTION OF THE FIRST LEVEL OF ROCK BOLTS;

- **PHASE 4**

EXECUTION OF THE DRAINAGES;

- **PHASE 5**

REPLICATION OF THE PREVIOUS STEPS UP TO THE FIRST LEVEL OF ANCHORS;

- **PHASE 6**

EXCAVATION UP TO -0.5 METERS BELOW ANCHORS, CAST OF THE RC BEAM AND EXECUTION OF THE ANCHORS.

4.1.1.1 Drilling

Drilling necessary disturbs the ground, methods should be chosen relative to the ground condition to cause either the minimum disturbance.

Holes for ground anchorages should be drilled to the position shown on the design drawings within a tolerance od +- 75mm.

For a specified alignment at entry point, the hole should be drilled to an angle of tolerance of +- 2.5°.

Tendons should be handled and protected prior to homing in such a manner as to avoid corrosion and physical damage.

To ensure proper central position and spacing of the tendon in the borehole, appropriate centralizer/spacer should be employed. Over the bond length, bar tendons should be centralized in the borehole to ensure a minimum grout cover to the tendon of 5 mm between centralizer location and 10mm at centralizer locations.

Centralizer are devices made of polyvinyl chloride (PVC) or other synthetic materials that are installed at various locations along the length of each bar to ensure that a minimum thickness of grout completely covers the nail bar. Centralizers shall be installed at regular intervals, typically not exceeding 2.5m, along the length of the nail

The stressing head and bearing plate should be assembly concentrically with the tendon within an accurancy of +-10mm and should be positioned not more than 5° form the tendon axis.

During the drilling operation, all changes in ground type should be recorded together with the notes on water levels encountered, drilling rates, flushing losses or stoppages.

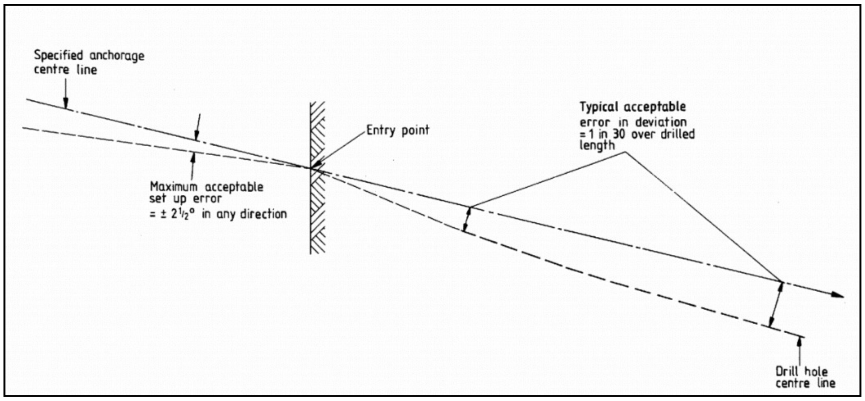


Figure 36 - Drill hole Deviation

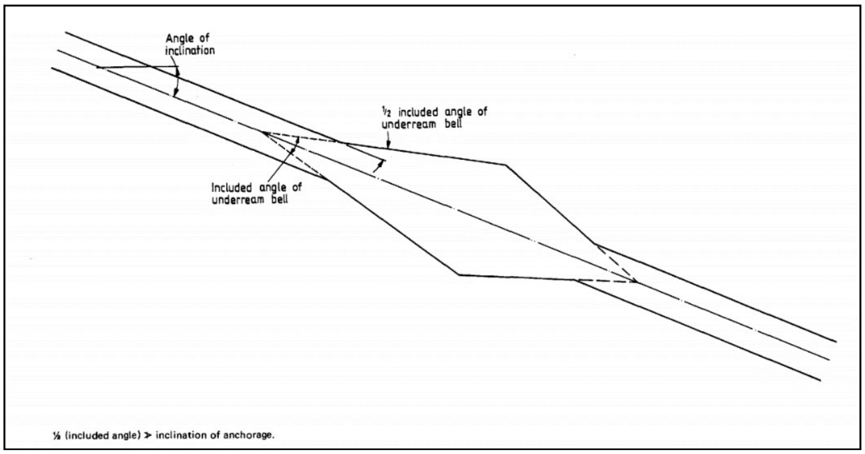


Figure 37 - Limiting Inclination for anchors

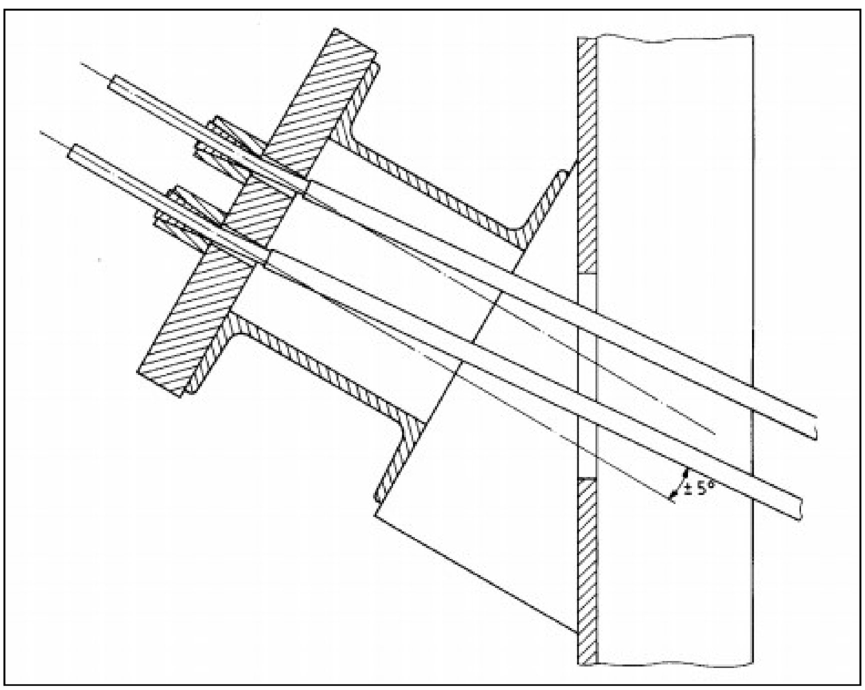


Figure 38 - Limiting angular tolerance at anchor head

4.1.1.2 Grouting

Grouting performs the following functions:

- To form the fixed anchors in order that the applied load may be transferred from the tendon to the surrounding ground;
- To increase the protection of the tendon against corrosion;

- To strengthen the ground immediately adjacent to fixed anchor in order to enhance anchorage capacity;
- To seal the ground immediately adjacent to the fixed anchor in order to limit loss of grout.

Each stage of injection should be performed in one continuous operation. At all time during injection, the end of the tremie pipe should remain submerged in grout.

For downward inclined holes, the grout should be injected through grout tubes into the lowest part of the hole.

Grout is commonly a neat cement grout and the injection pressure is equal to 20 kPa per meter depth of ground.

The cutting of the tendon after final grouting should be done by a disc-cutter.

4.1.1.3 Stressing

Stressing is required to fulfil the following two functions and the equipment and procedures should be designed accordingly:

- To tension the tendon and to anchor it as its secure load;
- To record the behaviour of the anchorage so that it can be compared with the behaviour of control anchorages.

For cementitious grouts, stressing should not commence until the primary grout forming the fixed anchors has attained a crushing strength of at least 30MPa, as verified from test on 100mm cubes.

No tendon part of temporary works should be stressed at any time beyond 80% of the characteristic strength. Corrosion protection

The design solution is defining a double corrosion protection (DCP), implying two physical barriers against corrosion. The purpose of the outer second barrier is to protect the inner barrier against the possibility of damage during tendon handling and placement.

Protection is achieved generally for free length of tendons by injection of solidifying fluids to enclose the tendon or by pre-applied coatings.

The bond length requires the same degree of protection as the free length. In addition the protective elements have all to be capable of transmitting high tendon stresses to the ground.

The essence of the anchor head protection is to provide an effective overlap with the free length protection, to protect the short exposed length of tendon below the plate and to isolate the short section of exposed tendon passing through the plate.

4.1.2 North portal excavation

Main relevant sections, highlighted in the key plan below, have been considered for the design of the north portal excavation:

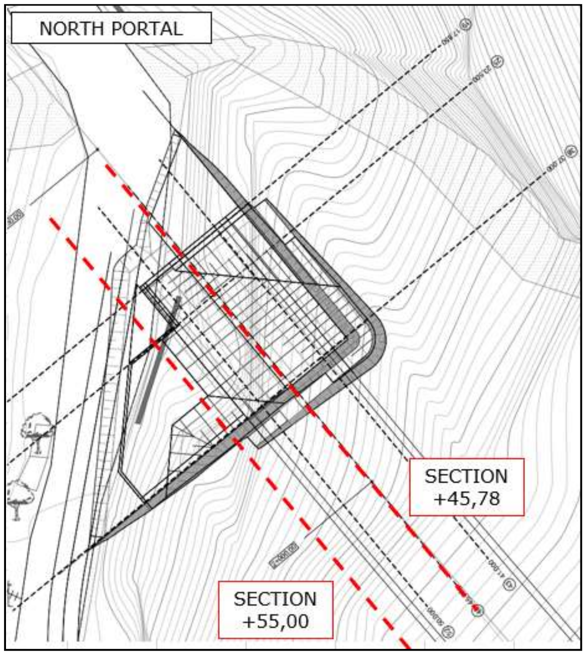


Figure 39 - Keyplan North Portal

Sections have been design according to UNI EN 1997 through Design Approach 1, considering both static and seismic load case. Refer to "Tunnel Calculation Report" for further details.

- Section +45.78, H excavation = 23m

  ✓ Rockboltsdiam. 32mm, L=15m, spacing 2.0m(horiz) x 2.0m(vert.)
  ✓ Rockboltsdiam. 43mm, L=15m, spacing 2.0m(horiz) x 2.0m(vert.)
  ✓ Pre-tensioned anchorage; n strand =5, Ai =140mm^2, L free length= 10m, L grouted length= 10m, spacing 2.0m(horiz.), P0 =360kN
  ✓ Shotcrete reinforced with wire steel mesh, th. 200mm, Φ12/14, mesh (150x150)mm

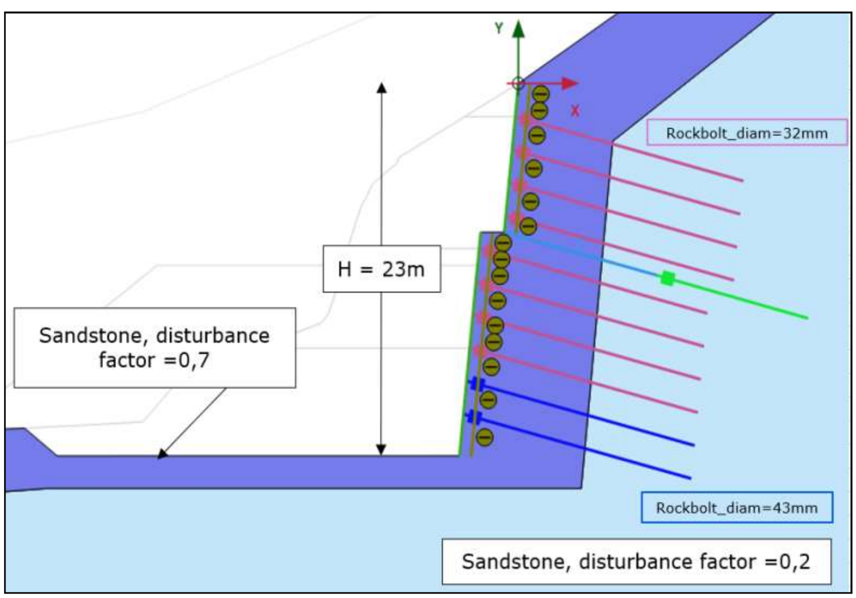


Figure 40 - Plaxis 2D Model Layout - North Section +45.78

- Section +55.00, H excavation = 20m

  - ✓ Rockboltsdiam. 32mm, L=15m, spacing 2.0m(horiz) x 2.0m(vert.)
  - ✓ Rockboltsdiam. 43mm, L=15m, spacing 2.0m(horiz) x 2.0m(vert.)
  - ✓ Pre-tensioned anchorage; n strand =5, Ai =140mm^2, L free length= 10m, L grouted length= 10m, spacing 2.0m(horiz.), P0 =360kN
  - ✓ Shotcrete reinforced with wire steel mesh, th. 200mm, Φ12/14, mesh (150x150)mm

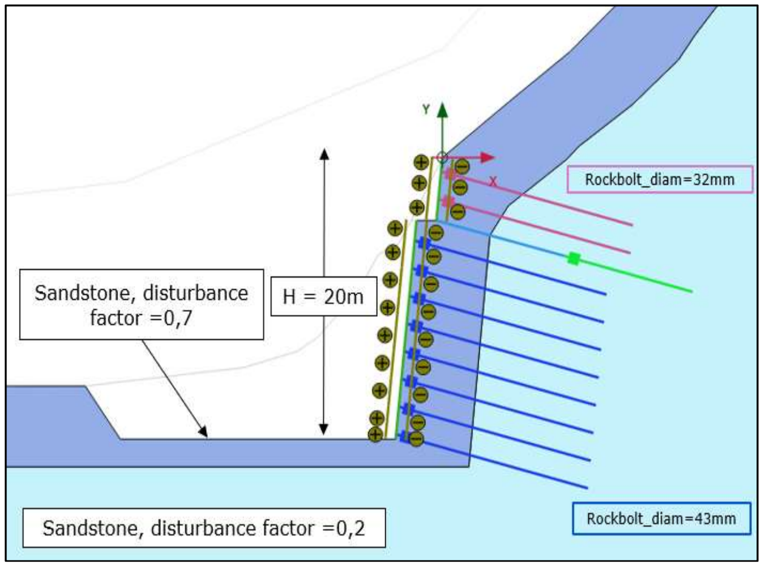


Figure 41 - Plaxis 2D Model Layout - North Section +55.00

4.1.3 South portal excavation

Main relevant sections, highlighted in the key plan below, have been considered for the design of the south portal excavation:

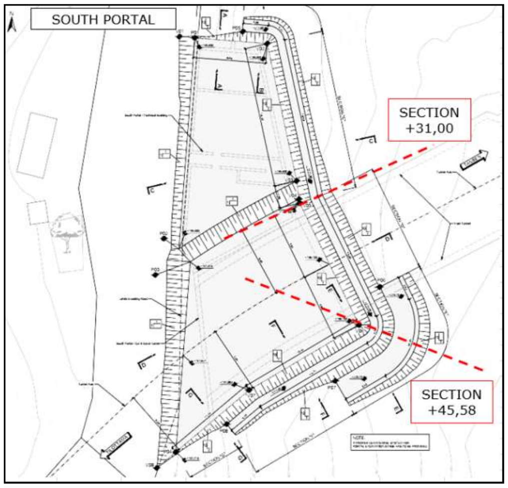


Figure 42 - Keyplan South Portal

Sections have been designed according to UNI EN 1997 through Design Approach 1, considering both static and seismic load case. Refer to "Tunnel Calculation Report" for further details.

- Section +45.58, H excavation = 35m
  - ✓ Rockboltsdiam. 32mm, L=15m, spacing 2.0m(horiz) x 2.0m(vert.)
  - ✓ Rockboltsdiam. 43mm, L=15m, spacing 2.0m(horiz) x 2.0m(vert.)
  - ✓ Pre-tensioned anchorage; n strand =5, Ai =140mm^2, L free length= 10m, L grouted length= 10m, spacing 2.0m(horiz.), P0 =360kN
  - ✓ Shotcrete reinforced with wire steel mesh, th. 200mm, Φ12, mesh (150x150)mm

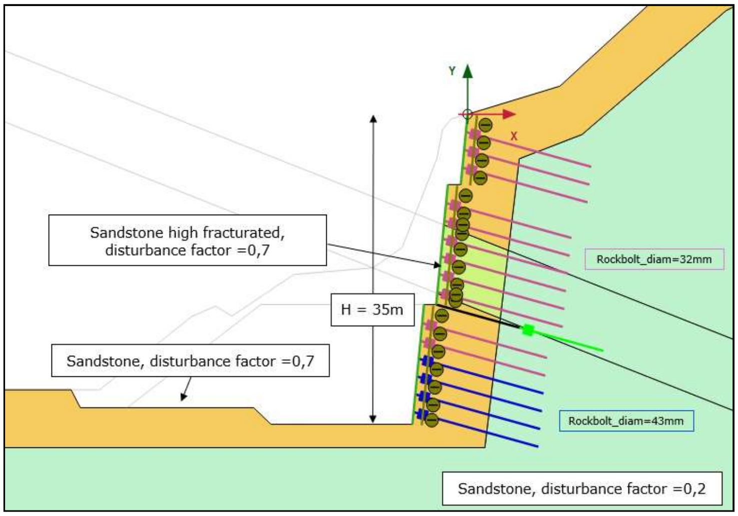


Figure 43 - Plaxis 2D - Model Layout - South Section +45.58

- Section +31.00, H excavation = 25m
  - ✓ Rockboltsdiam. 32mm, L=15m, spacing 2.0m(horiz) x 2.0m(vert.)
  - ✓ Pre-tensioned anchorage; n strand =5, Ai =140mm^2, L free length= 10m, L grouted length= 10m, spacing 2.0m(horiz.), P0 =360kN
  - ✓ Shotcrete reinforced with wire steel mesh, th. 200mm, Φ12, mesh (150x150)mm

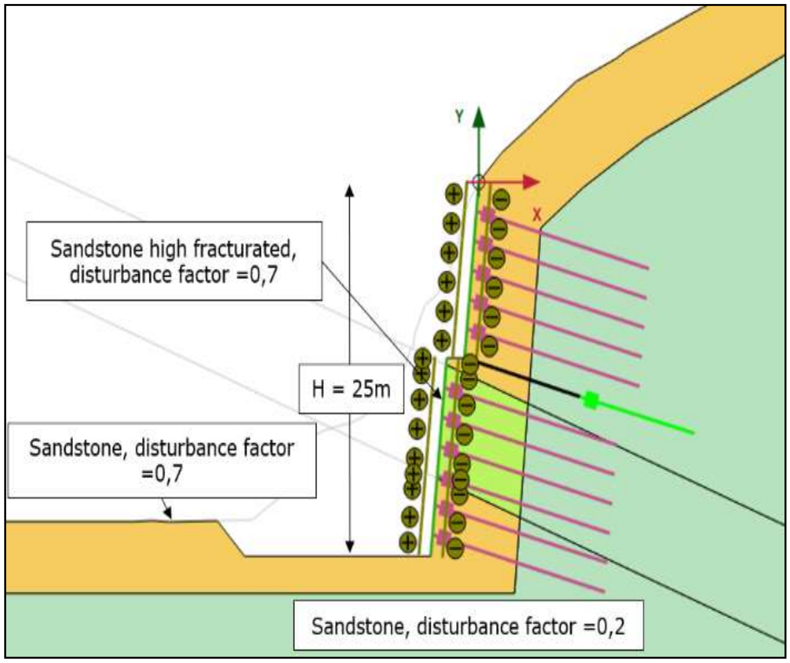


Figure 44 - Plaxis 2D - Model Layout - South Section +31.00

4.1.4 Excavationdetails

In the following figures, details related the permanent grouted rockbolts and to the pre-stressed anchors adopted for the stabilization of the excvations at the north and south portals are reported.

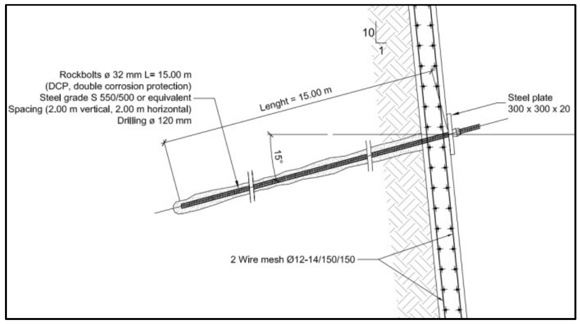


Figure 45 - Rockbolt Detail

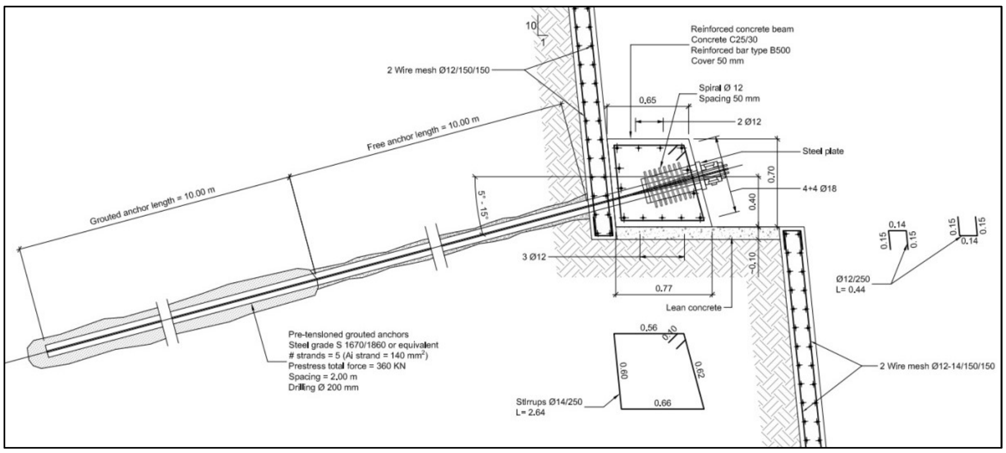


Figure 46 - Anchorage Detail

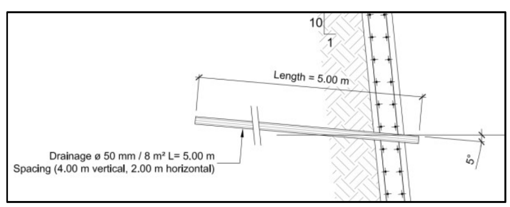


Figure 47 - Drainage Detail

4.1.5 Onsite tests

Field pull-out testing of nails shall be conducted to verify that the nail design loads can be carried without excessive movements and with an adequate safety factor for the service life of the structure, and to verify the adequacy of the contractor's drilling, installation, and grouting operations prior to and during construction of nails.

A representative sample of all rock bolts has to be subjected to acceptance tests, according to UNI EN 1997-1:

- Total number of rock bolts for each portal= 500
- Total number of rock bolts to be tested for each portal= 10

Test locations have to be chosen in order to guarantee an adequate sampling of rock condition in the project area.

In order to verify the design bond resistance value (q_S) , a pull-out test is prescribed to be executed to rock bolts sample of 5m length (3m bond length).

Considering a q_S base value for fractured rocks equal to 500 kPa, the diameter of the bar to be tested has been dimensioned limiting FS=1.25.

Test load:

P0 = 500kPa x 0.12m x ∏ x 3m = **565 kN**

Drlling diameter = 0.12m

Bond length = 3m

Bond resistance = 500 kPa

Bar diameter

D = √(4A / ∏) = 42.4 mm = **43mm**

A = 565000 N / 400 MPa = 1412.5 mm^2

fyk = 500 MPa /1.25= 400 MPa

The extraction of the bar at reaching the full load test, guarantees a respect of partial factor on materials as the qs value used in the modelling has been choose equal to 300KPa.

Once the pull-out test on rockbolts have been finalized, procedure for anchor tests has to be detailed based on results reached, considering 3 anchor samples for each tunnel portal, according to "*UNI EN ISO 22477-5:2018 - Geotechnical investigation and testing - Testing of geotechnical structures - Part 5: Testing of grouted anchors".*

Following completion of all on-site proving test the results should be available from the anchorage contractor in the form of a report before any working anchorage is installed.

4.1.6 Monitoring Plan

Failure of an anchorage may take three forms, namely breakage, relaxation of pre-stress or overtensioning above the design figure. The effect of each on the structure should be considered

Breakages will generally be due to corrosion or accidental mechanical damage and may occur at any point between the end of the fixed anchor and the anchor head.

Relaxation of tension may be due to several causes: the breakage of some of the wires in a tendon, movement of the fixed anchor or compression of the ground between the fixed anchor and the anchor head due to stress change.

Over tensioning may occur through the movement within rock formations or excavations.

Monitoring procedures should be designed to pinpoint the mode of failure and to determine the cause. It's recommended as the behaviour of anchorages (5% of working anchorages) can be safely by monitoring the behaviour of the structure as whole (by precision surveying of movements or by measurement of stress levels within the structure). In addition the malfunctioning of anchorages could endanger the structure and cause it to become an hazard to life.

As the anchorage will be part of a temporary work, rock bolts has to be monitored on design life base by installed monitoring sight:

- 6 topographical monitoring sections will be selected as the most representative for each portal area.
- 2 mini prisms, fixed to the shotcrete, will be place on each excavation height between berms.

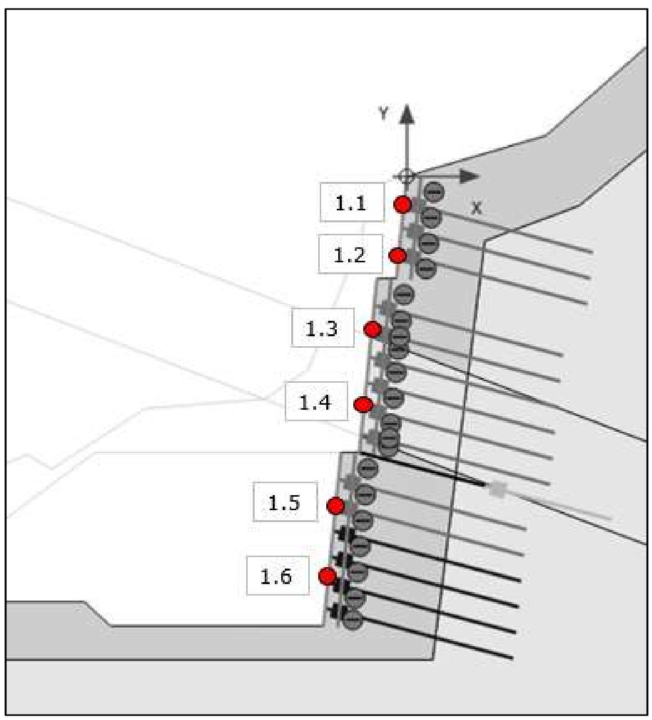


Figure 48 –Example of monitoring section

For detection of ground movements, procedure should be designed to record the pattern of the movements and should continue until they become negligible. In general test should initially be at short intervals of 3 months to 6 months, with later test at longer intervals depending on results.

4.2 Cut & Cover tunnel sections

At the portals, cut & cover sections of the tunnel will be executed after excavation of the portal trenches.

Each C&C section will be about 20 m long and the concrete lining will have a minimum concrete thickness equal to 70 cm. Waterproofing of the lining is described in chapter 3.8.1.

On one side, the C&C sections will be cast directly against the technical buildings.

The filling of the C&C sections, up to a maximum overburden of 9 m over the tunnel vault's key, will be provided by means of a suitable filling granular material, set stratum by stratum (max 50 cm) and compacted (minimum compaction modulus Me > 40 MN/m^2). Before starting filling above the tunnel, the adjacent building shall be finished, as it is part of the lateral supporting system of the tunnel.

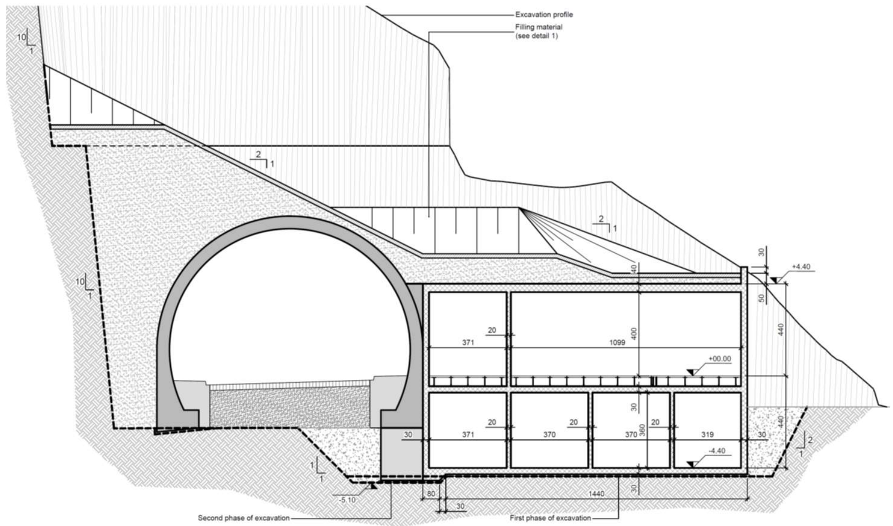


Figure 49: Cut & Cover section and interface with the technical building north

4.3 Technical buildings

At both the north and the south portal, technical buildings are necessary to accommodate operating and safety equipment, as well as maintenance rooms and living spaces for the tunnel personnel.

The filling of the technical buildings, with a minimum overburden equal to 50 cm will be provided by means of a suitable filling granular material, set stratum by stratum (max 50 cm) and compacted (minimum compaction modulus Me > 40 MN/m^2).

The Contractor is responsible for the design and dimensioning of the heating, ventilation and air conditioning plant of the buildings, according to the functional layout described below and relevant Nepalese laws. Moreover he is responsible for the design of all holes, cable shafts, pipe crossings, sanitary fitting, furnishing, fire emergency and extinguishing devices (according to Nepalese standards), lighting etc.

Additional requirements can be found in the E&M technical report.

4.3.1 Technical building south

The technical building at the south portal will accommodate the following rooms and equipment as a minimum requirement (additional details can be found in the E&M technical report):

- Ground floor

- Medium voltageroom (MVR), min. 35 m^2
  - direct access from the outside;
  - separation wall between MVR and other spaces;
  - reinforced concrete floor and crawl space for cables;
  - electrical pipelines connection to an external cable pit, outside the building, for electrical pipelines coming from the tunnel;
  - connection to an external cable pit, outside the building, for medium voltage cable lines (see E&M technical report).
- Low voltage room (LVR) , min. 65 m^2

- direct access from the outside;
- floating technical floor, min. height 50 cm, load capacity ≥15 kN/m^2 (other requirements according to ASTRA guidelines 23 001-11870);
- connection to an external cable pit, outside the building.

- Garage/Storage/Workshop, min. 100 m^2
  - direct access from the outside of a maintenance vehicle*;
  - water supply pointinside the room;
  - water supply point outside the room (outside the building);
  * a suitable space to park the maintenance vehicle directly outside the building must be reserved and fenced.
- Main entrance and stairs.
- Expected minimum heating development by electrical equipment 70 kW.

- First floor

- Electromechanical room, min. 70 m^2
  - trap door on the floor 1.5 m x 1.5 m;
  - 1 ton hoist for technical equipment lifting.
- HVAC (heating, ventilation and air conditioning) room, min. 30 m^2.
- Living spaces for tunnel personnel
  - Kitchen and dining room, min. 20 m^2.
  - Office, min. 20 m^2.
  - Meeting room, min. 15 m^2.
  - Control room, min. 35 m^2.
  - WC room, min. 9 m^2.
  - Corridor and stairs.

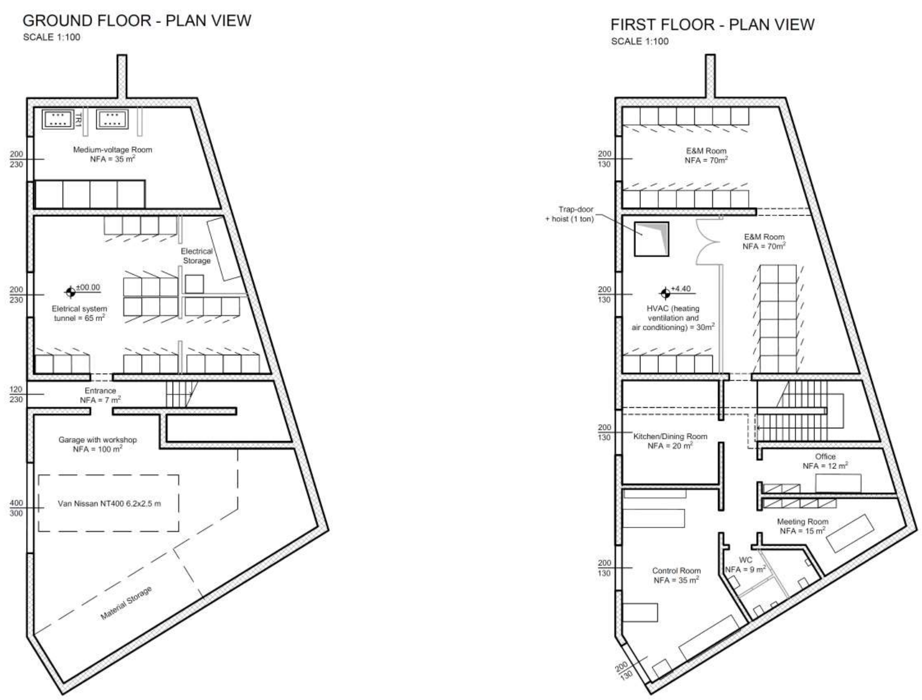


Figure 50: Technical building south, functional layout

4.3.2 Technical building north

The technical building at the south portal will accommodate the following rooms and equipment as a minimum requirement (additional details can be found in the E&M technical report):

- Ground floor

- Medium voltageroom (MVR), min. 35 m^2
  - direct access from the outside;
  - separation wall between MVR and other spaces;
  - reinforced concrete floor and crawl space for cables;

- 2x HDPE DN 120 electrical pipes connection to the cable shaft in the tunnel walkway adjacent to the building.
- Low voltage room (LVR) , min. 50 m^2
  - floating technical floor, min. height 50 cm, load capacity ≥15 kN/m^2 (other requirements according to ASTRA guidelines 23 001-11870);
  - 10x HDPE DN 120 electrical pipes connection to the cable shaft in the tunnel walkway adjacent to the building.
- Electrical storage room, min. 10 m^2.
- Warehouse, min. 15 m^2.
- Main entrance and trap door on the floor, including steel ladder to access underground floor and 1 ton hoist for technical equipment lifting.
- HVAC (heating, ventilation and air conditioning) room, min. 20 m^2.
- Expected minimum heating development by electrical equipment 45 kW.

- Underground floor

- Water supply reservoir
  - Pump room to accommodate 5x min. 20 l/s (min. power 22 kW) pumps, working in parallel and min. 2x 10.4 l/s (min. power 12 kW) alternating pumps.
  - 6x 50 m^3 water tanks with wall openings for inspection (80x60 cm), located at a distance of 20 cm from the ceiling.

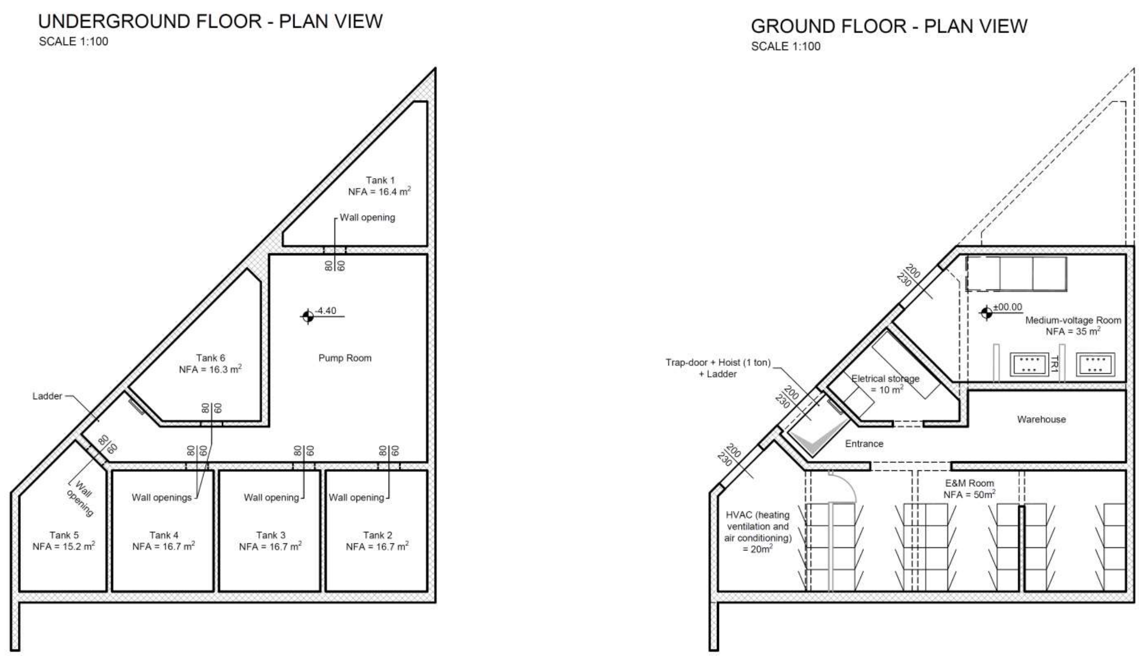


Figure 51: Technical building north, functional layout

4.4 Bypass portals

4.4.1 Excavation

The bypass portals will be executed by means of a limited excavation of the natural rocky slope along the existing road. Before excavation begins, preliminary safety measures shall be provided by means of shotcrete and cemented anchors on the surrounding rock of the bypass excavation contour. The following phases describe the construction sequence and technical requirements:

- Phase 0 – Scaling of unstable stones at least 5 m above the bypass excavation contour;

- Phase 1 – Preliminarysafetymeasures

- Safety measures shall be provided on a slope surface measuring at least 5 m above and on each side of the bypass excavation contour;

- Execution of a 15 cm C25/30 shotcrete layer (0/8 mm aggregates), reinforced with a steel wire mesh (steel grade B500 A or similar) ϕ 5mm/10x10 cm;
- Cemented rock bolts (Gewi 20 mm or similar, B500 B steel grade), with a 2 x 2 m pattern, 4/5 m long, having a drilling diameter > 100 mm.

- Phase 2 – Bypass class 3 sub-horizontal forepoles execution (first forepoles umbrella).
- Phase 3 – Bypass excavation and supports according to the foreseen tunnel support classes and their distribution along the bypass axis.

4.4.2 Connection to rockshed structure

After waterproofing and casting of the inner lining of the bypass, the connection to the rockshed will be provided by casting a box shape concrete structure, having a minimum thickness of 60 cm.

Waterproofing layers of rockshed and bypass shall be welded together.

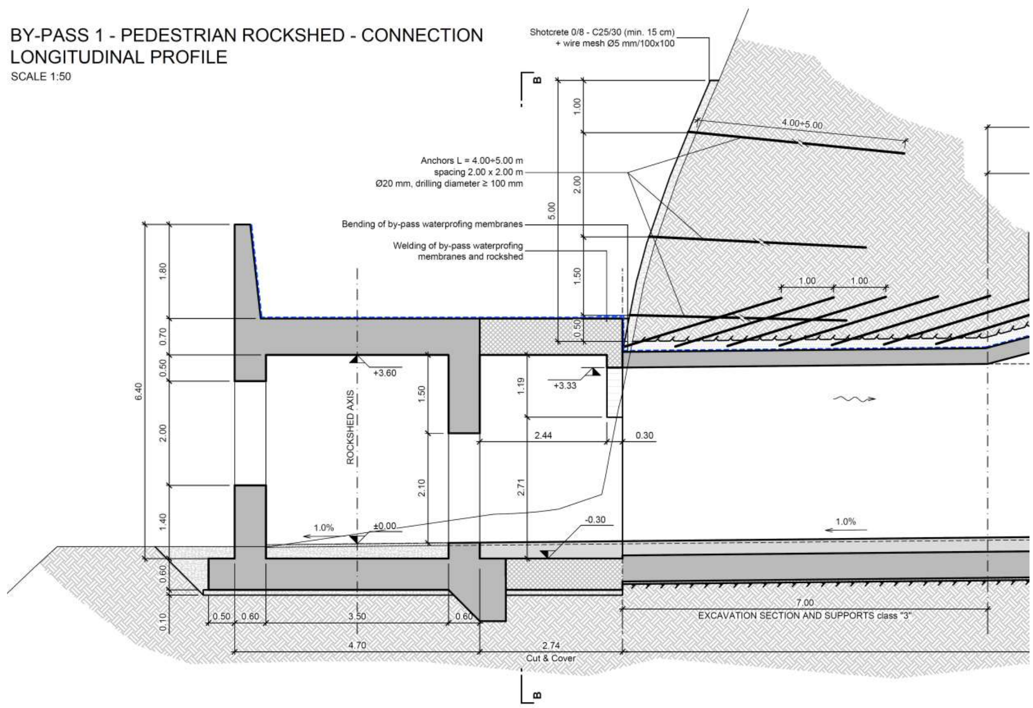


Figure 52: Typical bypass portal and connection to rockshed