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The Administration of the Union Territory of Ladakh
PWD (R&B)

सत्यमेव जयते

Project:

Detailed Project Report (DPR) for preparation of various Road/Tunnel projects of Public Works (R&B) Department, UT of Ladakh - Highway tunnel across Fotu La Pass (1.7 Km approx.) along with its approaches on Zojila - Leh - Kargil Road

Subject:

FOTULA TUNNEL STRUCTURAL DESIGN REPORT- TUNNELS VOLUME-2B

Prepared by:

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Revision History

Rev.	Date	Long Description

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1 THE PROJECT

1.1 INTRODUCTION

Major Parts of the highways in Leh-Ladakh crossing high elevation mountain passes gets blocked every year by heavy snowfall and avalanches resulting in disruption of connectivity across various places. This makes them non-motorable for some duration of the year. It is envisaged that to serve the national interest, there should be an all-weather motorable road which in turn will enable round the clock connectivity to the most important strategic locations of the country.

In order to serve the above purpose, RITES Limited, a 'Navratna' Government of India Enterprise, has been entrusted with the assignment of preparation of Detailed Project Report (DPR) of various Road/Tunnel projects by Public Works (R&B) Department, Union territory of Ladakh vide letter No. CE/PW/R&B//Leh/97-99 dated 13.04.2022 in terms of Rule-133(3) (i) of GFR -2017

The total project work comprises of the following packages.

i. **Package-1**: Highway tunnel across KhardungLa Pass (5.5 Km approx.) along with its approaches on Leh –Khalsar road

ii. **Package-2**: Highway tunnel across Namik La Pass (2.5 Km approx.) along with its approaches on Zojila - Leh - Kargil Road

iii. **Package-3**: Highway tunnel across Fotu La Pass (1.7 Km ap-prox.) along with its approaches on Zojila - Leh - Kargil Road

iv. **Package-4:** Construction of Basgo - Nia La - Hunder Road to NH double lane specifications, inter valley connectivity between Indus (Sham) and Nubra/ Shyok Valleys

This report pertains to the preparation of DPR for Package -3 "Highway tunnel across Fotu La Pass (1.7 Km ap-prox.) along with its approaches on Zojila - Leh - Kargil Road".

The current report covers the economic and financial analysis of the Fotu La tunnel project and deliveries.

The Fotu La pass having an altitude of 4108m (circa) above sea level is located between the districts of Leh and Kargil on NH-1 (Leh-Srinagar Highway). The top of FatuLa pass has the fa- mous Lamayuru Monastry approx. 15km to its east. See figure 1 below.

Figure 1: Project Location

The main objective of the consultancy service is to prepare detailed project report for Construction of Tunnel along with the approach roads, with the aim to construct/provide all weather road across Fotu La Pass. The approach roads would be of 4/2-lane plus paved shoulders configuration based on the approved tunnel alignment & configuration.

1.2 Project Background

Fotu La pass is the highest point on NH-1 (Leh-Srinagar Highway). It is one of the two high altitude obstructions between Len and Kargil district of UT of Ladakh, the other being NamikLa pass. Present at an altitude of 4108m (Circa) from mean sea level, it connects the only two districts of UT of Ladakh, one being Leh at the distance of 129km on its east and the other being the district of Kargil at a distance of 75km towards its west. This road (NH-1) also connects Srinagar on its extreme west via Kargil and NH-1 on its east via Leh which further connects Ladakh to Himachal Pradesh

Figure 2: Fotu La Pass

The maintenance of road at such a high altitude is very difficult yet Border Roads Organisation (BRO) is doing it relentlessly. The road has steep switchbacks/hairpin pin bends on both side of the pass where the gradient is rising sharply, and travellers have to travel through a high-altitude road section. Also, the accumulation of Snow near the top provide hindrance in the mobility of the passengers traveling on it.

Also, the snow accumulation in this stretch is considerable during winter season which results in the frequent closing of the road and arduous snow clearance subsequently.

It is envisaged that to serve the national interest the Leh-Kargil road should be improved to an all- weather motorable road. In this regard RITES is entrusted by PWD (R&B), UT of Ladakh to carry out detailed project report for construction of tunnel across Fotu La pass, to provide all weather connectivity across this axis alongwith providing better mobility between the two districts.

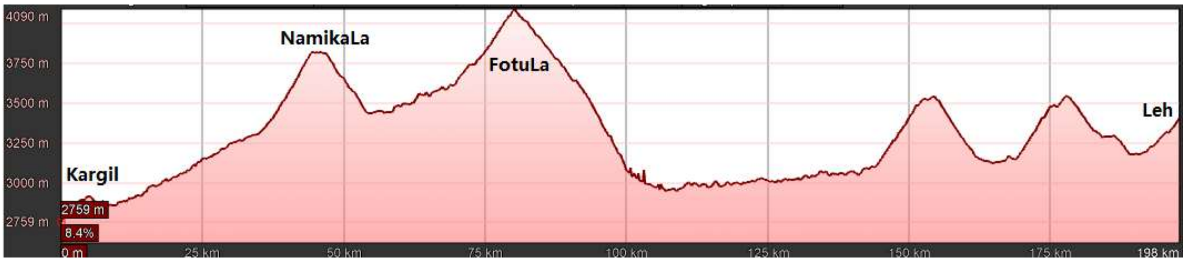


Figure 3: Elevation Profile of various mountain passes on Leh – Kargil highway (NH-1)

2 REFERENCES / DOCUMENTS MADE AVAILABLE

2.1 Documents made available

[1] Contract agreement for "Detailed Project Report (DPR) of various Road/Tunnel projects by Public Works (R&B) Department, Union territory of Ladakh" signed on 3rd June 2022.

[2] Traffic Survey report - 2022

2.2 Project Document

[3] RITES_00081_FOTULA_IR_Vol-1_R0, Inception report from RITES dated 5.07.2022

[4] RITES_00081_FOTULA_AR_R0, alignment report dated 11.11.2022

[5] RITES_00081_FOTULA_AR_R1, alignment report dated 31.07.2023

2.3 RITES_00081_FOTULA_AR_R1, alignment report dated 31.07.2023Standards

1. IRS-CBC -1997, Indian Railway Standard Code of Practice for Plain, Reinforced and Pre-stressed Concrete For General Bridge Construction

2. IS 1893 (Part 1) – 2002, Criteria for Earthquake Resistant Design

3. EN 1990 : Eurocode : Basis of structural design

4. EN 1991, Eurocode 1: Actions on structures

5. EN 1992, Eurocode 2: Design of concrete structures, Part 1-1: General rules and rules for buildings

6. IS 456:2000 Plain and Reinforced Concrete (Fourth Revision).

7. IS 1893(Part-1) : 2002 Criteria for earthquake resistant design of structures

8. IRC 6:2017: Standard specifications and code of practise for road bridges

9. IRC-SP-114-2018: Guidelines for Seismic designs of road bridges.

2.4 Software

1. STAAD Pro , programme for statically calculation for Plane frame 2D analysis.

2. Bekaert Software for Fibre reinforcement design.

3 CUT & COVER STRUCTURE GEOMETRY

The following cross section of Cut & Cover Structure has been used and the same is shown in figure 4.

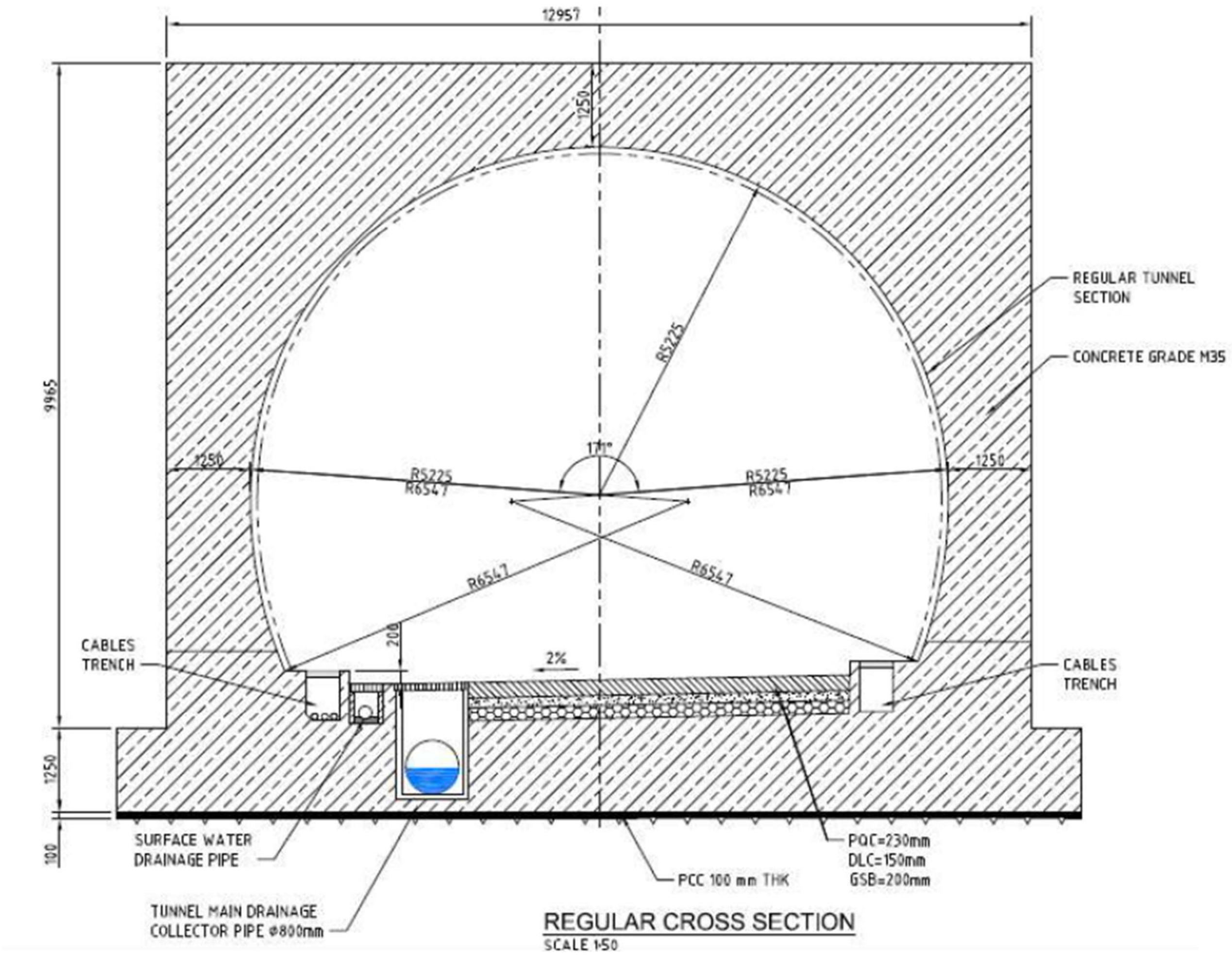


Figure 4: **Cut & Cover Cross Section**

4 GEOTECHNICAL CONDITIONS AND ROCK/SOIL PARAMETERS

4.1 Geological and geotechnical conditions

The Project area occurs in the Zanskar basin together with a part of the Spiti basin forms not only the largest succession of the Tethyan sequences in the Himalaya, but also exposes one of the best developed sections.

The Spiti Zanskar belt is NW-SE trending is tectonically bounded by the rocks of Indus Tectonic belt towards north and is juxtaposed against the rocks of Proterozoic in the south. The area of investigation exposes the rocks of Spiti Zanskar belt and shows best developed stratigraphic succession from Mesozoic to Recent age. The Mesozoic age of rocks comprises Undifferentiated Kuling-Lilang Group (Schuppean zone) and Undifferentiated Lilang Group, while Cenozoic age of rock comprises Sangeluma Group and Indus Group. Regional stratigraphic succession of the investigation area is given below.

Rocks of Undifferentiated Kuling-Lilang Group (Schuppen zone) comprise phyllitic limestone, calcareous shale, carbonaceous shale, Phyllitic limestones are creamish to greyish in colour.

Undifferentiated Lilang Group of rocks of Triassic-Jurassic age conformably overlies the Undifferentiated Kuling-Lilang Group of rocks of Permian-Jurassic age. It comprises phyllite, grey dolomitic limestone, shale, quartz arenite, shelly limestone with bivalves and coralline fossils. Undifferentiated Kuling-Lilang Group is bounded by Sanku Thrust in the south and Wakha Thrust in the north.

The greater portion of the Dras valley, as also the stretch between Kargil and Sanku along the Suru valley, are occupied by the volcanic suite of rocks associated with geosynclinal sediments of the volcanic belt. The rocks mainly are undifferentiated basalt-chert association and ultramafites (Dunite/Serpentinite-gabbro etc). It comprises greenish basic rocks with purple and chocolate colored ash beds.

4.1.1 Ground types

Five broad division of the rock mass types have been interpreted according to the combination of rock types (indicative) and their structure. The interpreted ground/ rock mass types and their mechanical evaluations are tabulated below in Table 1: General Ground types and their description from Tunnel area. below:

Table 1: General Ground types and their description from Tunnel area.

Ground Type	Lithology	Structure

GT1	**Reddish brown coloured to dark greyish coloured phyllitic limestone, limestonic phyllite**	**Bedded and closely but tightly jointed.**
GT2	**Light brownish to greyish coloured, moderately jointed, moderately to closely foliated, moderately strong phyllite/quartzitic phyllite**	**Stratified alternations with subordinate thinner bands of phyllites, often warped.**
GT3	**Highly folded, highly fractured, closely foliated, fine grained, light brownish grey coloured, quartzitic phyllite with quartzitic bands**	**Stratified in alternations with subordinate thinner bands of Phyllitic Quartzites/Quartizitic Phyllites/Phyllites, occasionally folded, visibly foliated.**
GT4	**Slope debris at portal area consisting of mainly heterogeneous matrix (sand, silt & clay) with angular to sub angular, boulder, cobble, pebble size fragments of Quartzite, Phyllite, Quartzitic-Phyllite and Slate**	**Inhomogeneous mixture of boulders in sandy soil matrix, Colluvium/ Talus material.**

4.2 Seismology

As per the Seismic zones of India Map IS:1893-2002, BIS and Seismotectonic Atlas of India and its Environs, GSI, the project area is in **Zone 4:** High Damage Risk Zone (MSK VIII) below mentioned table. The project area is in proximity to the Karakoram Fault and Thrusts around the Indus suture zone. Recent seismic records (since 2019), shows earthquake event sources close to the tunnel alignment at low focal depths and appears more proximally related to the Karakoram Fault. The project area of Fotu La Tunnel is situated in the seismically active mountain range of Himalaya and is influenced by active faulting associated with main tectonic features of the Himalayan mountain belt (e.g. Main Central Thrust, Main Boundary Thrust, Kishtwar Fault, etc.). According to seismic zoning map of India (IS-Code 1893:2022) the tunnel site is situated in Zone IV(Figure-5).

Seismic Zone	**Basic Horizontal Coefficient**	**Seismic Zone Factor**
I	0.08	0.40
II	0.05	0.25
III	0.04	0.20
IV	0.02	0.10
V	0.01	0.05

Table 2: Basic Horizontal Seismic Coefficients Values and Seismic Zone Factors in different zones.

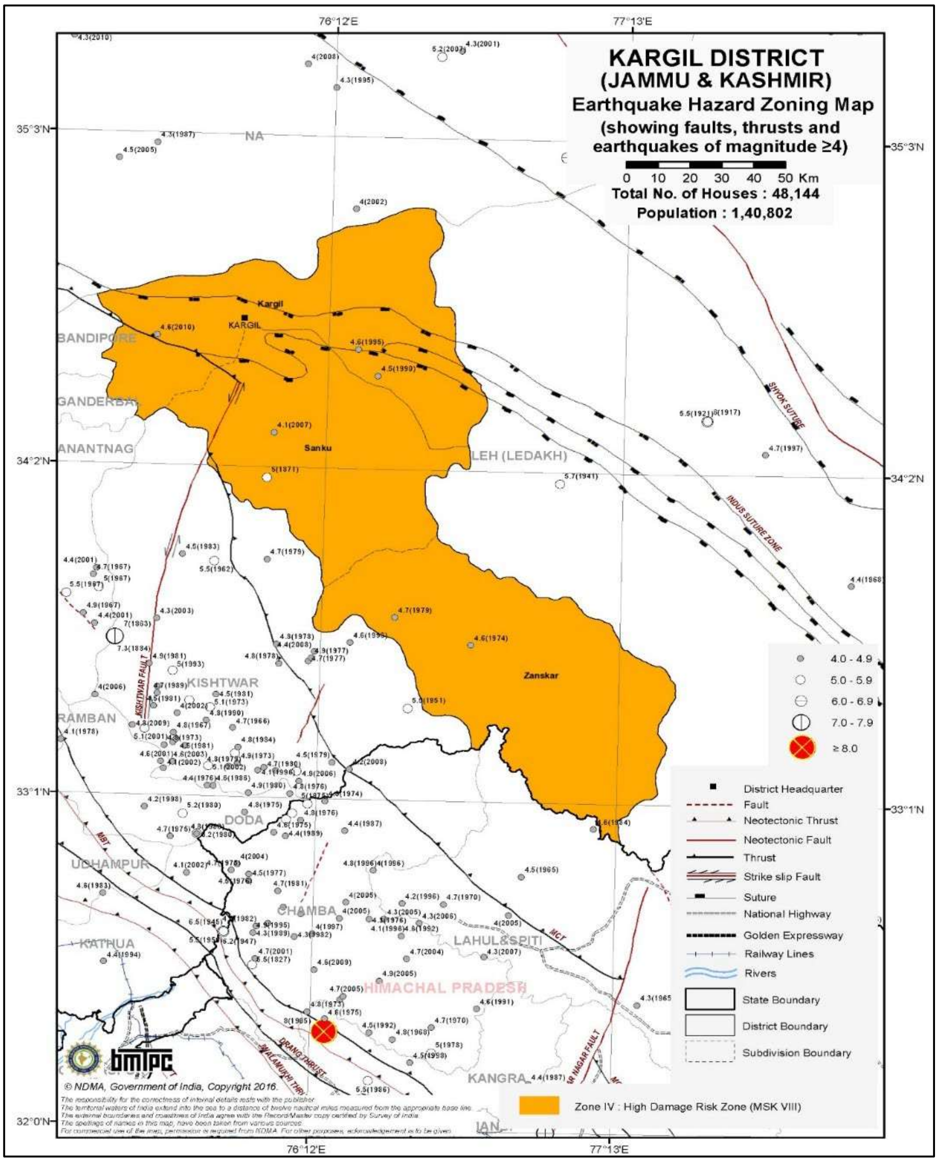


Figure 5 Seismic map of the Kargil

5 LOAD CASES

5.1 Permanent Loads [G]

5.1.1 Self-Weight [G1]

The volume used for calculation of self-weight of structures is based on the nominal dimensions of the structure. Self-weight of the reinforced concrete lining will be calculated with unit weight of concrete of =25kN/m3.

Self-Weight will be considered as dead load with partial load safety factor of 1.50.

5.1.2 Over Burden Pressure [G2]

With regard to earth pressure (vertical & horizontal load of filling to the lining), following loads are considered to be applied on lining:

For the design, maximum overburden of 9.28 m has been considered above the top slab of Cut and cover as shown in below figure along unit weight of Soil of =19 kN/m3. The effective lateral earth pressure is equal to the product of load due to weight of overburden and coefficient of lateral earth pressure Ko. For box type structures where earth fill is on both sides of the wall, earth pressure at rest condition exists and hence, the earth pressure coefficient has been calculated based on the ground type K_0=0.50.

Vertical earth pressure on the lining = γ*H

Earth pressure at rest in static condition, Pa = γ*H*Ko

Where γ, is unit weight of earth fill,

H- Height of earth fill

Ko- Earth pressure at rest coefficient.

Where: H is Height of overburden above crown.

Overburden pressure is considered with partial load safety factor of 1.5.

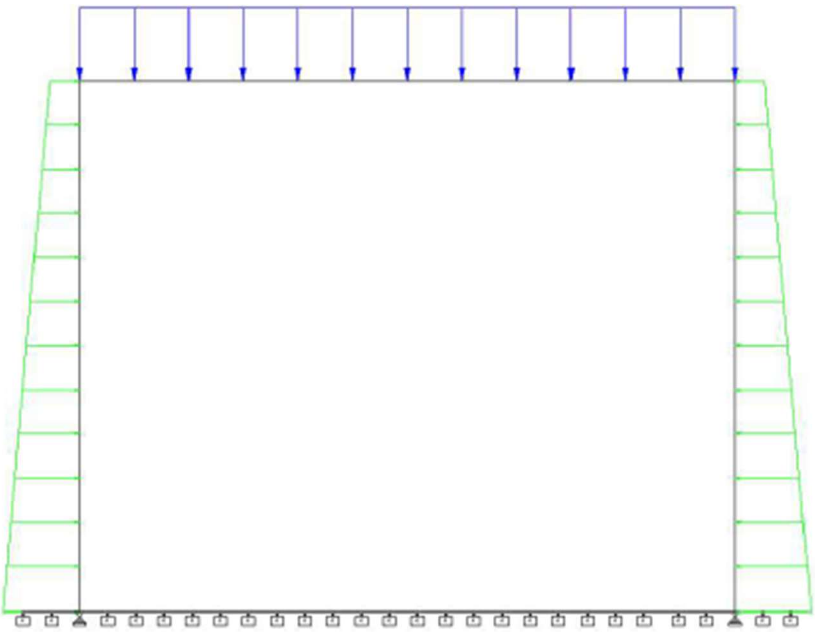


Figure 6: Vertical over burden Pressure and Lateral Earth Pressure

5.1.3 Surcharge Load [G4]

As per IRC 6, Live load surcharge equivalent to 1.2 m earth fill has been considered for the design. A uniform surcharge load is considered in the side wall of the cut & cover structure with partial load safety factor of 1.50.

5.1.4 Earthquake / Raking Force (EQ)

As per Indian Seismic Zoning Map IS 1893, the project site is located in seismic zone IV. Seismic coefficient has been calculated as per IRC 6

As per IS 1893, the design horizontal seismic coefficient (Ah) for a structure shall be determined by the following expression:

$A_h = Z/2$

The description and values of above variables as per IS 1893 are provided below:

Z: Zone Factor = 0.24 (for Seismic Zone IV)

Hence, the design horizontal seismic coefficient (Ah), using above value has been calculated as,

$A_h = 0.12$

Vertical seismic coefficient Av shall be 2/3rd of the Ah i.e Av = 0.08g

Dynamic Earth Pressure co-efficient (Ca) is calculated as per the provision of IRC 6 (2017) clause 214.1.1

Active dynamic earth pressure coefficient, Ka

$$\frac{(1\pm A_v)\cos^2(\phi-\lambda-\alpha)}{\cos\lambda\cos^2\alpha\ \cos(\delta+\alpha+\lambda)}\ x \left[\frac{1}{1+\left\{\frac{\sin(\phi+\delta)\sin(\phi-i-\lambda)}{\cos(\alpha-i)\cos(\delta+\alpha+\lambda)}\right\}^{\frac{1}{2}}}\right]^2$$

Where

φ = Angle of Internal friction of soil

α = Angle which earth face of the wall makes with vertical

β = Slope of Earth fill

δ= Angle of friction between the earth and earth fill should be equal to 2/3 of □

Subjected to a maximum of 22.5°

However, to be on conservative side, passive dynamic earth pressure has not been considered for the design.

5.1.5 Snow Load (SL)

For the design, snow load with a density of 0.8 g/cm3 and 5 m depth has been considered above the top slab of Cut and Cover.

Snow Load will be considered as dead load with partial load safety factor of 1.50.

6 COMBINATIONS OF ACTIONS

6.1 Applied load cases

The applied load cases are listed in the following:

- G1 Self weight

- G2 Overburden Pressure

- G3 Lateral Earth pressure

- G4 Surcharge Load

- E Earthquake

The general formats for combinations of loads for the ultimate and serviceability limit states are as given IS-456 Table 18.

The load combinations used for the analysis are listed in the following sections.

6.2 Ultimate Limit State (ULS)

Calculations of ultimate limit state consider the following load combinations:

6.2.1 ULS load combinations:

I =1.50×G1

II =1.50xG1+1.50×G2+1.50×G3

III =1.50×G1+1.50×G2+1.50×G3+1.50×G4

IV =1.20×G1+1.20×G2+1.20×G3+1.20×G4+1.2x E.L

6.2.2 Serviceability Limit State (SLS)

Calculations of serviceability limit state consider the following load combinations:

I =1. 0×G1

II =1.0XG1+1.0×G2+1.0×G3

III =1.0×G1+1.0×G2+1.0×G3+1.0×G4

IV =1.0×G1+1.0×G2+1.0×G3+1.0×G4+1.0x E.L

7 MATERIALS

The relevant materials which are concrete and reinforcement steel, confirms to the specifications given below.

7.1 Cast in place concrete

Specified characteristic compressive strength fck = **35 N/mm2** (Concrete Grade M35 according to IS 456:2000)

- Young's modulus: E = 29580 MPa
- Poisson's ratio: ѵ = 0.2
- Unit weight: ϒ = 25 kN/m3

7.2 Reinforcement steel

The steel for structural reinforcement shall correspond to Fe 500 according to IS 1786-2008:

Young's modulus E=200 GPa

Yield strength fyk=500 MPa

7.3 Concrete cover

The minimum concrete covers to all reinforcement (main and distribution reinforcing bars) considering the exposure conditions are adopted as follows:

- Concrete exposed to earth (external face) 60 mm
- Concrete not exposed to earth (internal face) 40 mm

7.4 Crack width

A maximum allowable crack width of 0.3 mm & 0.2 mm at Extrados and Intrados shall be considered respectively in accordance with IS 456-2000.

8 CALCULATION METHOD AND GENERAL ASSUMPTIONS

8.1 Calculation of Cross Section

According to the defined Cut & Cover Structures, geological conditions, overburden, etc the section as shown in Figure 1 is considered.

8.2 Calculation of Spring Constants

The lining is modelled as a beam bedded by springs. Multiple beam elements are created along centroidal axis of lining subtending angle of 50 to 100 representing linear 2D structure. Beam model spring constants are derived from modulus of sub grade reaction Ks, which is calculated from: $Ks = Er/(B(1-\mu^2))$, where:

B = Width of Cut and cover = around 13.45m

Poisson's ratio = 0.31

Er = 145 MPa

Modulus of subgrade reaction, Ks = 12338 KN/m3

The spring constant of a bedding spring representing a certain area A of sub grade is derived as:

The shear spring constants are set as 10% of the normal spring constants:

Kfy= 0.1× Kfx

The bending stiffness of the structural element is equal to Ec*Ig. The moment of inertia Ig is based on the modulus of inertia of gross concrete section about centroidal axis, neglecting reinforcement.

8.3 Analysis Method

A two-dimensional Plane Frame Analysis is performed using the computer program STAAD Pro. V8i SS5. A near realistic 2Dmodel using beams bedded by horizontal and vertical springs has been created and loads have been applied using STAAD command. Springs have been generated by using STAAD command and reference can be made to STAAD manual for further details.

After applying all the forces on the frame model in STAAD Pro as detailed in Section [5].The loads are combined as per the prescribed combination of actions in Section [6] for Ultimate Limit State (ULS) and Serviceability Limit State (SLS) and the Members are checked for theload combination for Ultimate Limit State (ULS) and Serviceability Limit State (SLS). The Normal force, bending moment and shear force for all members are taken from the STAAD.Pro and designed accordingly.

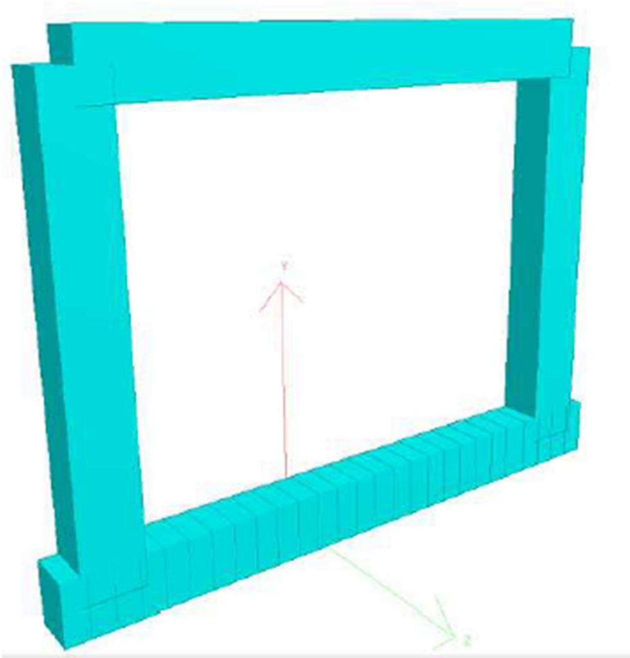


Figure 7: 3D Rendered View of Model

9 STRUCTURAL DESIGN

9.1 Structural Design Method

The structural design is carried out in accordance with IS 456. Load combinations for the Ultimate Limit States (ULS) and the Serviceability Limit States (SLS) are considered for the reinforcement design as described in section above.

Based on the results, the reinforcement requirements and details are as follows and the same has been incorporated in the drawings.

S No	Description	Reinforcement Details	
		Location	**Top & Bottom**
1.	Top Slab (1500mm thk)	Main Bar	32 dia @100mmc/c + 20 dia @100c/c
		Distribution Bar	16 dia @100mm c/c
2.	Side Walls (1500mm thk)	Main Bar	32 dia @100mmc/c + 20 dia @100c/c
		Distribution Bar	16 dia @100mm c/c
3.	Base Slab (1500mm thk)	Main Bar	32 dia @100mmc/c + 20 dia @100c/c
		Distribution Bar	16 dia @100mm c/c

10 MAIN TUNNEL PERMANENT LINING DESIGN

10.1 Lining Type and Geometry

Considering all the possible loads and ground conditions, the following cross sections of Inner Lining (flat and curved invert based on the ground conditions) have been considered and the Flat invert & Arch Invert section is shown in **Figure 8** & **Figure 9** respectively.

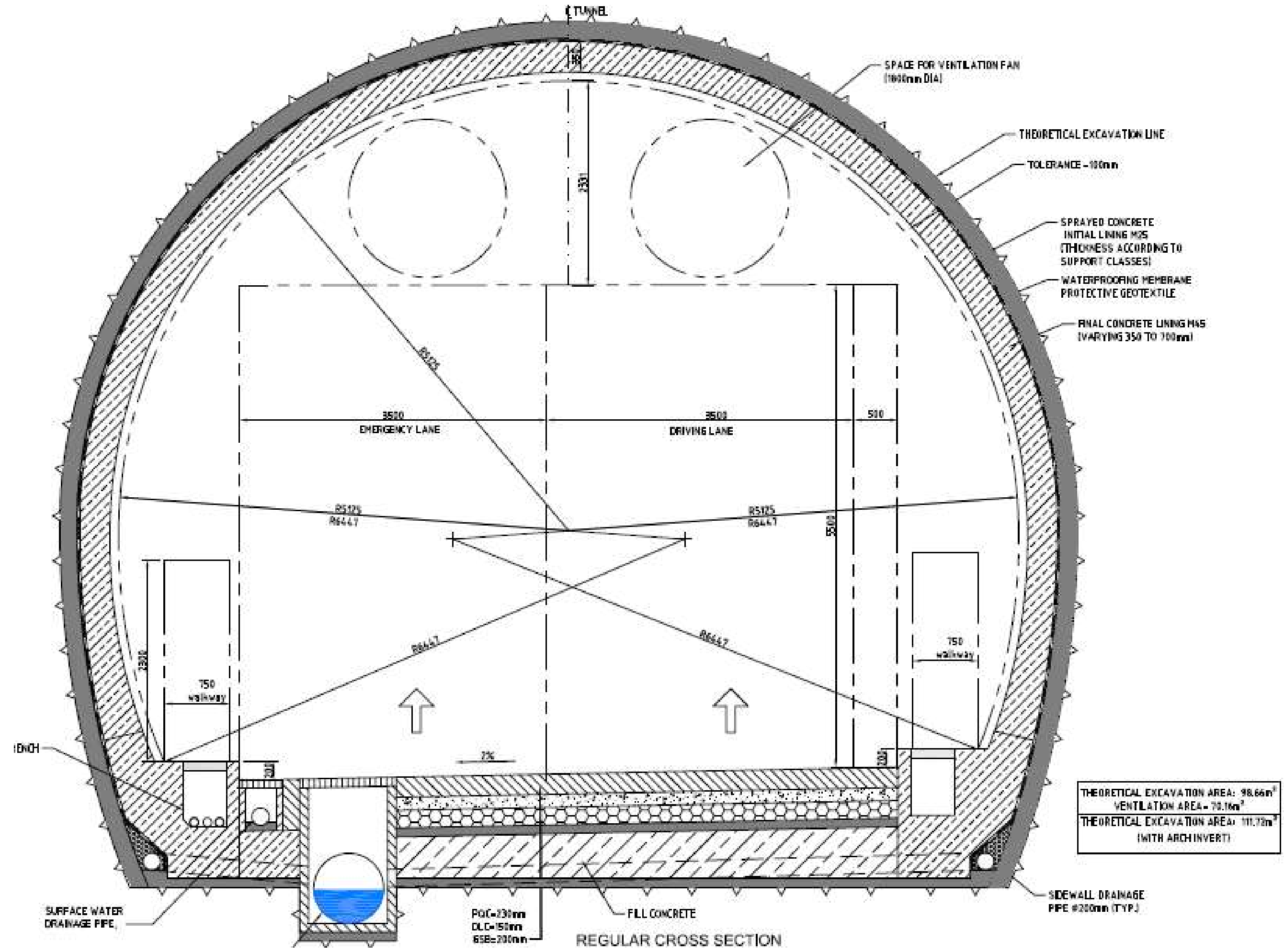


Figure 8: Typical Flat Invert Tunnel Cross Section - Inner Lining geometry

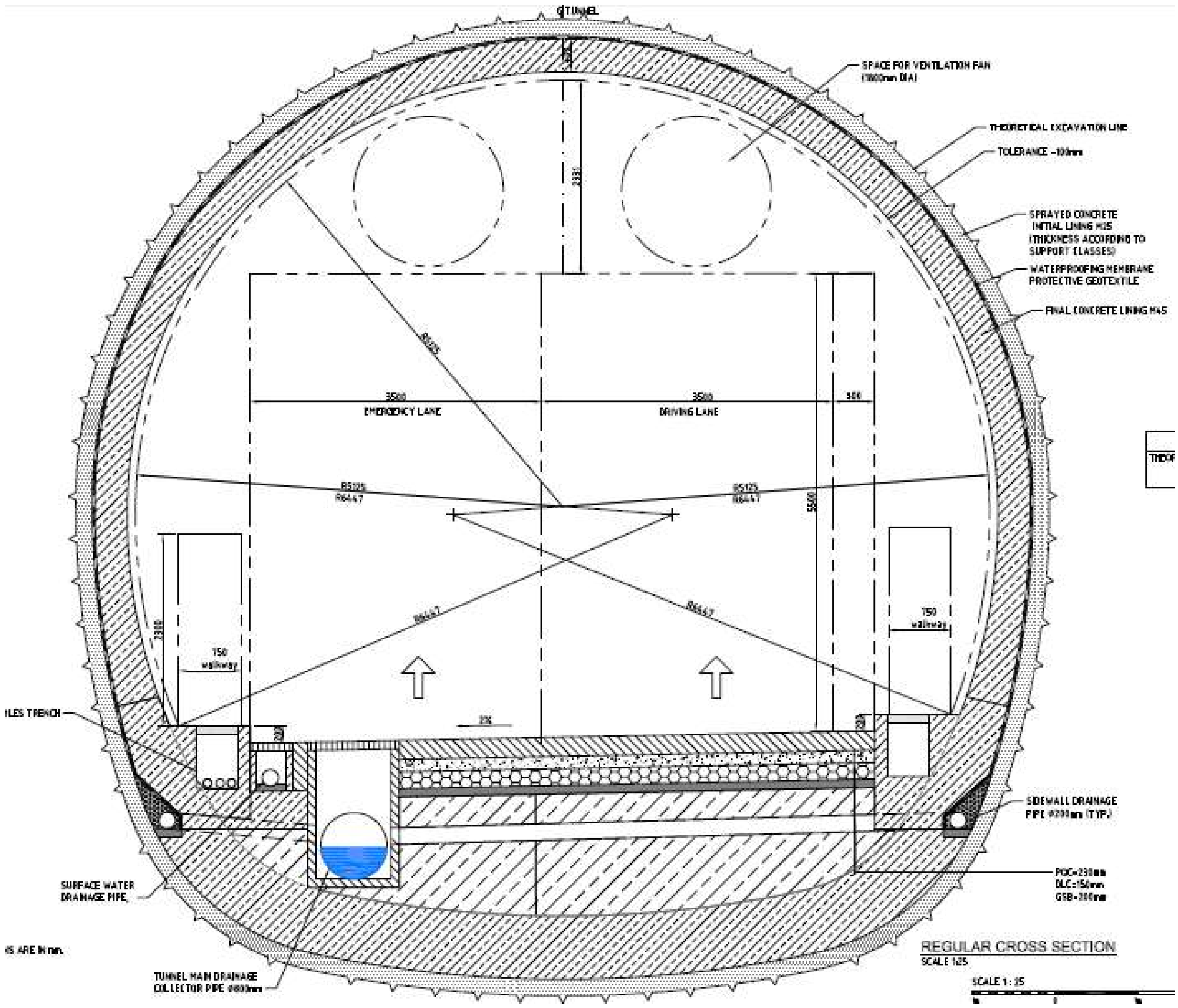


Figure 9: Typical Arch Invert Tunnel Cross Section - Inner Lining geometry

11 GEOTECHNICAL CONDITIONS AND SOIL PARAMETERS

The geotechnical parameters for the analysis of tunnel lining have been considered as per**Table 3** and the same is mentioned below for ready reference.

Table 3: Geotechnical Parameters

S.No.	Ground Type	Range	Deformation Modulus in MPa	Poisson's Ratio	Density	Remarks
1	GT-1	Low	4000	.24	26	Reddish brown coloured to dark greyish coloured phyllitic limestone
2	GT-1	High	13200	.25	28	
3	GT-2	Low	1200	.28	26	Moderately strong phyllite/quartzitic phylliye
4	GT-2	High	1300	.30	28	
5	GT-3	Low	750	.30	24	Quartzitic phyllite with quartzitic bands
6	GT-3	High	900	.30	25	
7	GT-4	Low	145	.30	19	Slope debris (mainly heterogenous matrix)
8	GT-4	High	150	.31	21	

12 LOAD CASES CONSIDERED FOR ANALYSIS & DESIGN OF LINING WITH INVERT OF THE MAIN TUNNEL

12.1 Permanent Loads [G]

12.1.1 Self-Weight [G1]

The volume used for calculation of self-weight of structures is based on the nominal dimensions of the structure. Self-weight of the reinforced concrete lining will be calculated with unit weight of concrete of γ_{con}=25kN/m^3.

Self-Weight will be considered as dead load with partial load safety factor of 1.50.

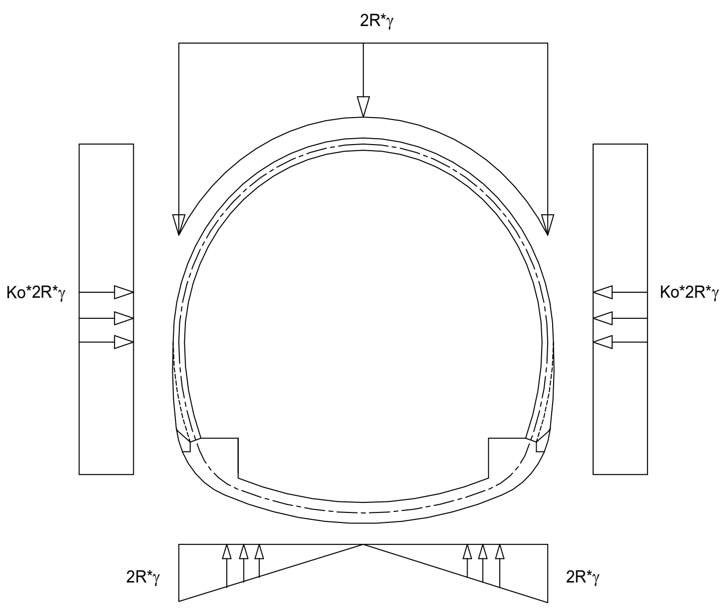
12.1.2 Invert Fill [G1]

Self-weight of invert fill (fill concrete & gravels) if any, is considered for the load combinations for the service condition. As the invert backfill is acting favourable on the tunnel invert, this load is not considered in the analysis.

12.1.3 Earth Pressure [G2]

With regard to vertical earth pressure (vertical load of overburden to the lining), following loads are considered to be applied on the lining.

where: H is overburden above crown, R is tunnel radius.



- **H ≥ 2R: Rock ground condition**: Loads of overburden in excess of 2R can be neglected.
- **H ≥ 2R: soil**: Loads of overburden in excess of 4R can be neglected.

Based on the GT information, the overburden depth has been considered differently for the below locations:

1. An overburden depth of **11 meters** has been considered.

The effective lateral earth pressure is equal to the product of load due to weight of overburden and coefficient of lateral earth pressure K_0 is calculated based on Geotechnical Parameters. Earth pressure is considered with partial load safety factor of 1.50.

12.1.4 Shrinkage [G3]

The self-tension of the tunnel bearing elements due to concrete shrinkage is simulated as uniform cooling of the lining. The amount of lining deformation is calculated according to IS 456: 2000 and converted into uniform cooling temperature difference of -15°C.

The load factor for the effects of shrinkage, where relevant, shall be taken as 1.25.

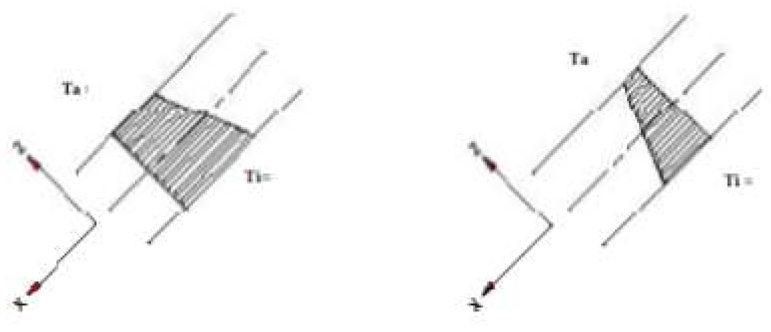
12.1.5 Water Pressure [G4]

The water pressure has not been considered for the design of primary lining as no water has been found during the preliminary investigation. Additionally, water proofing membrane connected with side drains has been considered for final lining if any water pressure develops during the service life of tunnel.

12.2 Live Loads [Q]

12.2.1 Temperature Load [Q1]

The temperature loads are applied only onto the tunnel arch above the construction joint. An average temperature during construction equal to tm=+10° is assumed and active temperature differences acting on the tunnel lining are taken as follows:



SUMMER **WINTER**

Since the internal forces due to temperature differences result from constraint deformation the partial load safety factor according is adopted equal to 1.15 for ULS and 0.80 for SLS.

12.3 Fire load (F)

As required by the European Guideline, the structural fire resistance is to be given - especially in areas where a local collapse can have catastrophic consequences. This condition arises in stretches where the ground is weak (soil, decomposed rock) and where the loss of the support system is causing global instability.

The permanent lining is designed to cater the for fire load of 50MW with the European code using the fire curves (HC curves/ISO 834).

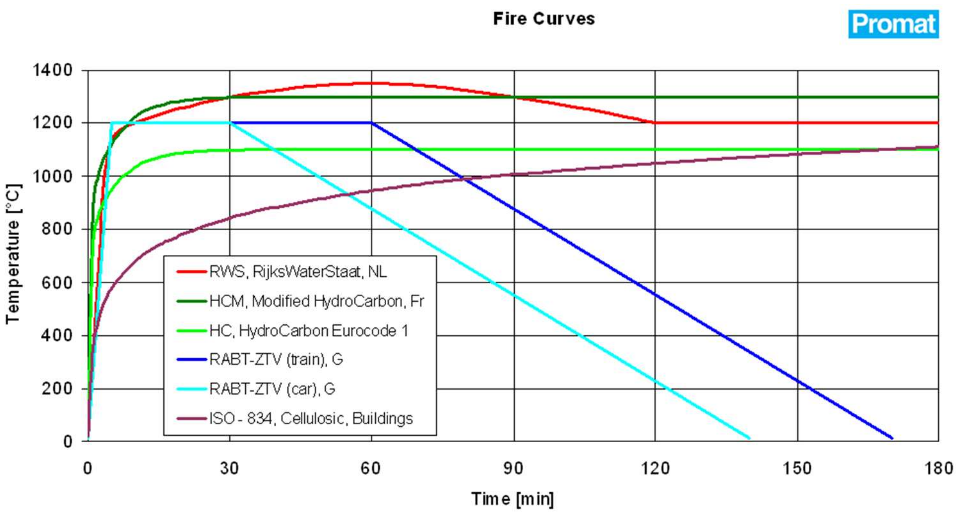


Figure 10:Typical Fire curves from different national annexures

12.4 Earthquake

In general, subsurface structures are subjected to much less forces in earthquake than buildings/structures above ground. These forces reduce with increase in depth. So, it can be assumed that earthquake induced stress in tunnel are much lower due to earthquakes. As a rule, tunnels are not designed for earthquake forces. (Pl refer “Guide 853.9120 to 853.2001 DB directive”, concerning paragraph 16).

Hence, the effect of earthquake force is not considered for structural design of tunnel inner lining. Further, to verify this assumption, effect of seismic load on tunnel (maximum and minimum E value i.e GT1 & GT5) is evaluated as described in literature “***Seismic design and analysis of underground structures***” by YMA Hashhash, JJ Hook, Birger Schmidt and John I-Chiang Yao (ref Tunnelling and Underground Space Technology 16 (2001) 247-293) and with the reduced factor of 1.2 with seismic, the static loads are governing the design.

13 MATERIALS

The relevant construction materials which are concrete and reinforcement steel, confirms to the specifications given below.

13.1 Cast in place concrete

- Specified characteristic compressive strength f_{ck} = **45** N/mm^2 (Concrete Grade M45 according to IS 456:2000)
- Young's modulus: E = 33541 MPa
- Poisson's ratio: ν = 0.2
- Unit weight: γ = 25 kN/m^3

13.2 Reinforcement steel

The steel for structural reinforcement shall correspond to Fe 500 according to IS 1786: 2008:

Young's modulus E=200 GPa

Yield strength f_{yk}=500 MPa

13.3 Steel Fibre

Steel fibers are used as a reinforcement in cast in-situ lining of the tunnel. The aspect ratio (Length/Diameter) of the fiber is considered 65. The specifications shall confirm to EN 14889-1

Nominal Fiber tensile strength: > 2300 MPa

Average wire ductility= 6%

13.4 Concrete cover

The minimum concrete covers to all additional reinforcement considering the exposure conditions are adopted as follows:

- Concrete exposed to earth (external face) 60 mm
- Concrete not exposed to earth (internal face) 40 mm

14 ANALYSIS AND DESIGN OF THE LINING OF MAIN TUNNEL

14.1 Cross Section of Lining

According to the geological conditions, overburden, etc the section as shown in **Figure 8**, **Figure 9** are considered for the analysis and design of lining.

14.2 Calculation of Spring Constants

The lining is modelled as a beam bedded by springs. Multiple beam elements are created along centroidal axis of lining subtending angle of 5^0 to 10^0 representing linear 2D structure.

Beam model spring constants are derived from modulus of sub grade reaction Ks, which is calculated from: $K_S = \frac{E}{(1+\nu)\times R}$, where:

E… Young's Modulus of soil/rock mass

ν… Poisson's Ratio of soil/rock mass

R…. Radius of Tunnel (with R ≤ 7 m)

The spring constant of a bedding spring representing a certain area A of sub grade is derived as: $C_r = K_S \times A$

The tangential spring constants are set as 1% of normal (radial) spring constants:

Kt = 0.01× Ks

The bending stiffness of the structural element is equal to E_c*I_g. The moment of inertia I_g is based on the modulus of inertia of gross concrete section about centroidal axis, neglecting reinforcement.

14.2.1 Analysis Method

A two-dimensional Plane Frame Analyses are performed using the computer program from STAAD Pro. V8i SS5. A near realistic 2D model using beams bedded by radial and tangential springs has been created and loads have been applied using STAAD command. Springs have been generated by using STAAD command and for further details, reference can be made to STAAD manual.

The bedding is modelled in such a way that the parts of the cross-sections where inward deformation occurs, i.e., where the springs would be subject to tensions, are neglected. The material behaviour of ground and lining is generally assumed as being elastic.

After applying all the forces on the frame model in STAAD Pro as detailed in Section 12, the loads are combined as per the prescribed combination of action given in section 15 for Ultimate Limit State (ULS) & Serviceability Limit State (SLS) and the Members are checked for the load combination for Ultimate Limit State (ULS) & Serviceability Limit State (SLS).

The normal force, bending moment and shear force for all members are taken from the STAAD Analysis results and designed PCC lining as per Euro code EN1992-1-1:2004(E).

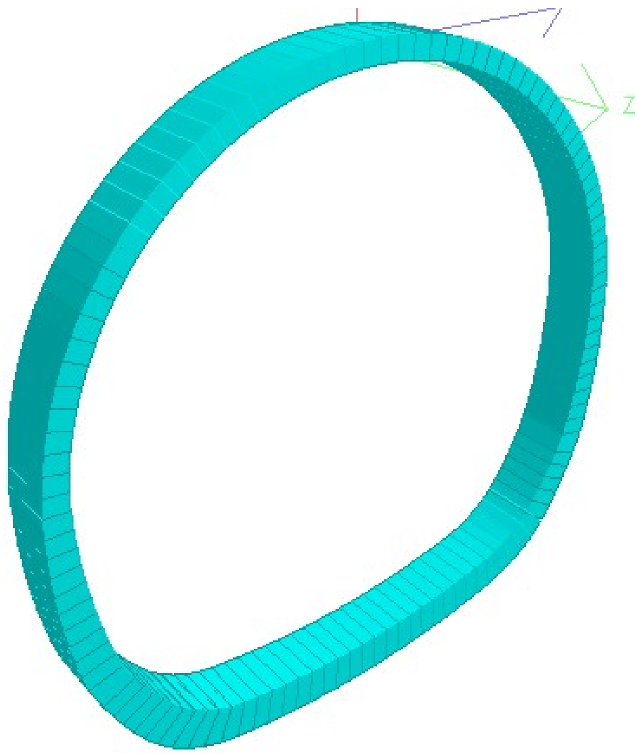


Figure 11: 3D Rendered View of Model for Arch Invert

Figure 12: 3D Rendered View of Model for Without Invert

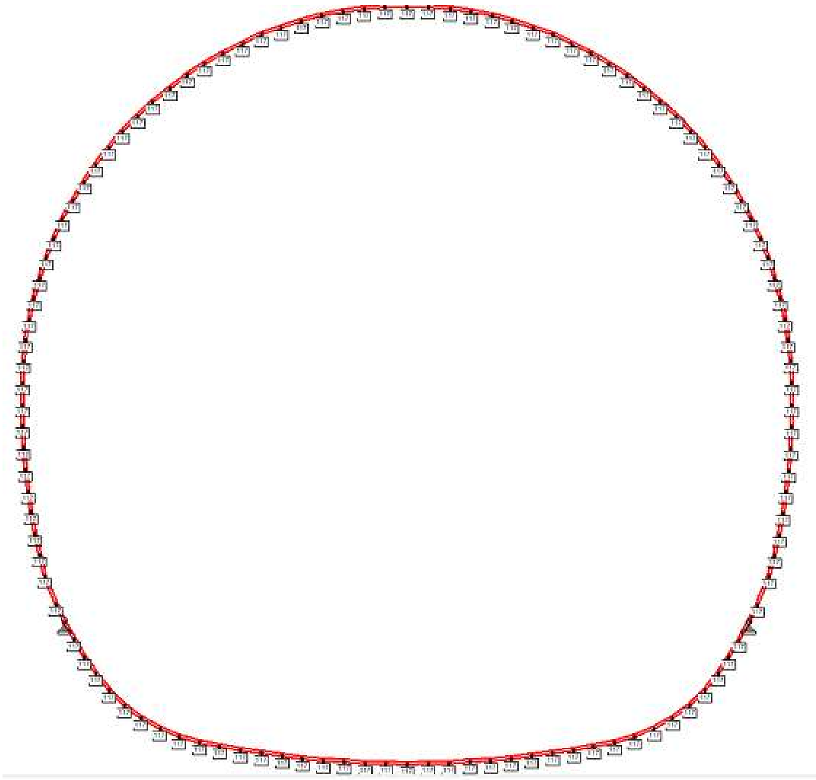


Figure 13: Idealized Model with Supports (Arch Invert)

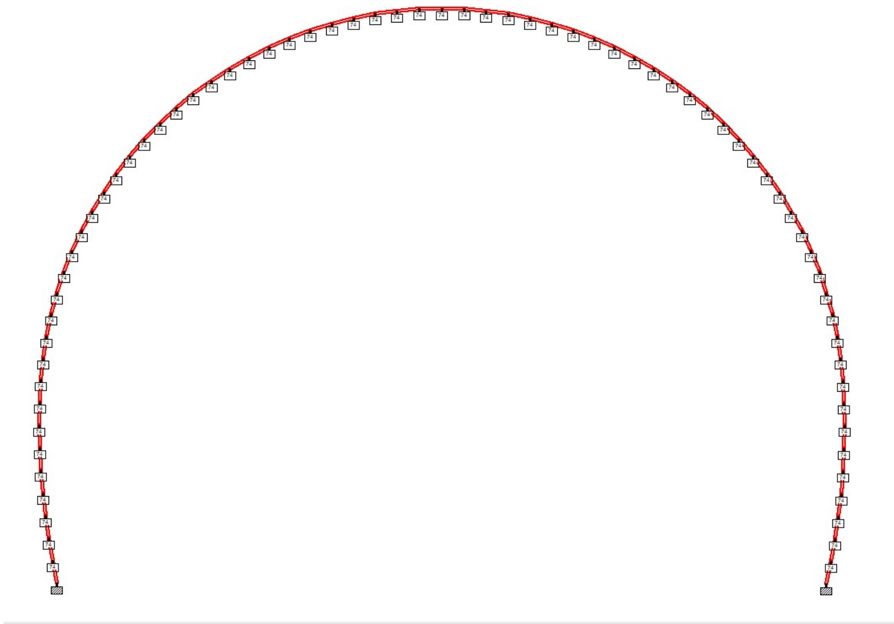


Figure 14: Idealized Model with Supports (Flat Invert) – for kicker beam design

15 LOAD COMBINATIONS

15.1 Applied load cases

The applied load cases are listed in the following:

- G_1 Self weight
- G_2 Earth pressure
- G_3 Hydrostatic Pressure
- G_4 Shrinkage
- Q_1 Temperature loads (winter and summer)

The general formats for combinations of actions for the ultimate and serviceability limit states are given as below.

The load combinations used for the calculation are listed in the following tables.

15.2 Ultimate Limit State (ULS)

Calculations of ultimate limit state consider the following load combinations:

I $=1.5\times G_1$
II $=1.5\times G_1+1.50\times G_2+1.50\times G_3$
III $=1.5\times G_1+1.50\times G_2+1.50\times G_3+1.25\times G_4$
IV $=1.5\times G_1+1.50\times G_2+1.50\times G_3+1.250\times G_4+1.15\times Q_{1,summer}$
V $=1.5\times G_1+1.50\times G_2+1.50\times G_3+1.250\times G_4 +1.15\times Q_{1,winter}$

15.3 Serviceability Limit State (SLS)

Calculations of serviceability limit state consider the following load combinations:

I $=1.0\times G_1$
II $=1.0\times G_1+1.0\times G_2$
III $=1.0\times G_1+1.0\times G_2+1.0\times G_3$
IV $=1.0\times G_1+1.0\times G_2+1.0\times G_3+1.0\times G_4$
V $=1.0\times G_1+1.0\times G_2+1.0\times G_3+1.0\times G_4+0.8\times Q_{1,summer}$
VI $=1.0\times G_1+1.0\times G_2+1.0\times G_3+1.0\times G_4+0.8\times Q_{1,winter}$

15.3.1 Structural Design

15.3.1.1 Structural Design method

Load combinations for the Ultimate Limit States (ULS) and the Serviceability Limit States (SLS) are considered for the design as described in section 15 above.

Partial safety factors for materials for ultimate limit states are adopted according to Indian codes IS 456: 2000.

Table 4: Partial factors for materials for ULS

Concrete	*Reinforcement Steel*
1.5	1.15

15.3.2 Design Results

Based on the calculation results, the reinforcement / fibre reinforcement requirement are given in the below table.

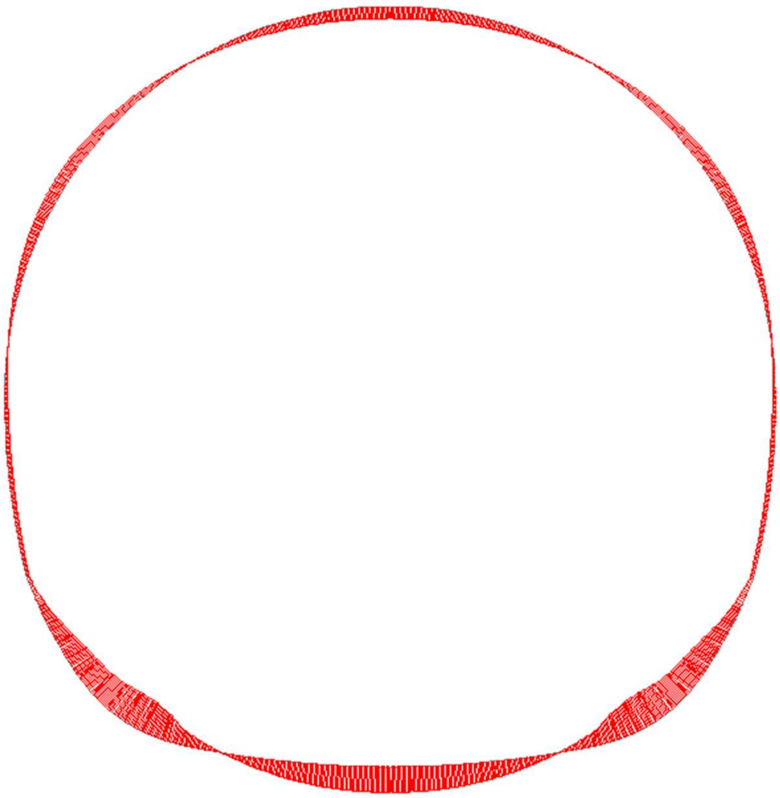


Figure 15: 3D The bending Moment of the Main Tunnel with Invert section

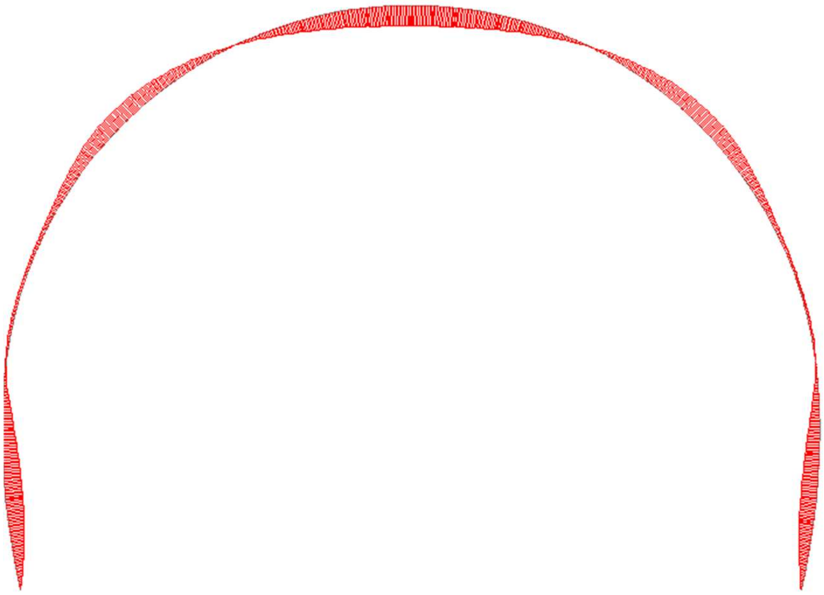


Figure 16: 3D The bending Moment of the Main Tunnel without Invert section

Sr No.	Main Tunnel Lining Reinforcement Details for Ground Type (GT1 TO GT2)			
	Description	**Lining thickness**	**SFRC Concrete Grade**	**Lining Reinforcement**
1	GT1 – E_{rm} – 13200MPa	Overt - 350mm Sidewall varying 350mm to 700mm	M45	Only Fiber*
	GT1 – E_{rm} – 4000MPa			
2	GT2 – E_{rm} – 1300MPa			
	GT2 – E_{rm} – 1200MPa			
	Important note			
	* Microfibers of 1 kg/m3 are recommended for fire resistance (anti-spalling)			
	**25kg/m^3 4D 80/60/BGP fiber or similar fibers to be used with microfibers			

	MT Tunnel Lining Reinforcement Details for Ground Type (GT3 TO GT4)			
Sr No.	**Description**	**SFRC Concrete Grade**	**Lining thickness**	**Lining Reinforcement**
1	GT3 – E_{rm} -900 Mpa	M45	Overt - 400mm Sidewall varying 400mm to 700mm	Overt above springing line - 16 dia 125 c/c - Each Face + fibers* Side wall 16 dia 125 c/c - Each Face + fibers* Invert - 12 dia 125 c/c - Each Face + fibers*
	GT3 – E_{rm} -750 Mpa			
2	GT4 – E_{rm} - 150MPa			
	Important note			
	*Microfibers of 1 kg/m3 are recommended for fire resistance (anti-spalling)			

	MT Tunnel Lining Reinforcement Details for Ground Type (GT3 TO GT4)			
Sr No.	**Description**	**SFRC Concrete Grade**	**Lining thickness**	**Lining Reinforcement**
	**25kg/m^3 4D 80/60/BGP fiber or similar fibers to be used with microfibers			

Note - Technical support from Dramix has been taken to do some design verification of this report however any material meeting the technical specification can be used by the contractor without any obligation to Dramix.

16 LOAD CASES CONSIDERED FOR ANALYSIS & DESIGN OF CROSS PASSAGES

16.1 Permanent Loads [G]

16.1.1 Self-Weight [G1]

The volume used for calculation of self-weight of structures is based on the nominal dimensions of the structure. Self-weight of the reinforced concrete lining will be calculated with unit weight of concrete of γ_{con}=25kN/m^3.

Self-Weight will be considered as dead load with partial load safety factor of 1.50.

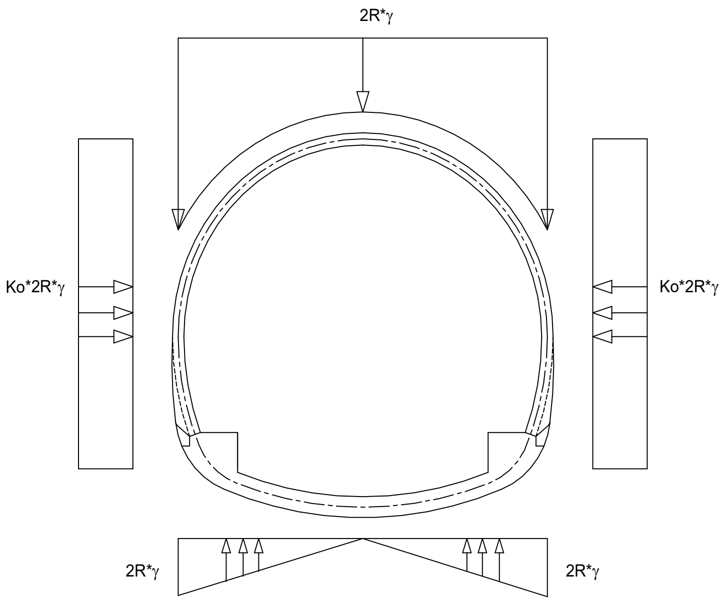
16.1.2 Invert Fill [G1]

Self-weight of invert fill (fill concrete & gravels) if any, is considered for the load combinations for the service condition. As the invert backfill is acting favourable on the tunnel invert, this load is not considered in the analysis.

16.1.3 Earth Pressure [G2]

With regard to vertical earth pressure (vertical load of overburden to the lining), following loads are considered to be applied on the lining.

where: H is overburden above crown, R is tunnel radius.



- **H ≥ 2R: Rock ground condition**: Loads of overburden in excess of 2R can be neglected.
- **H ≥ 2R: soil**: Loads of overburden in excess of 4R can be neglected.

Hence, for the preliminary design of lining, over burden depth of 8m has been considered. The effective lateral earth pressure is equal to the product of load due to weight of overburden and coefficient of lateral earth pressure K_0. Earth pressure is considered with partial load safety factor of 1.50.

16.1.4 Shrinkage [G3]

The self-tension of the tunnel bearing elements due to concrete shrinkage is simulated as uniform cooling of the lining. The amount of lining deformation is calculated according to IS 456: 2000 and converted into uniform cooling temperature difference of -15°C.

The load factor for the effects of shrinkage, where relevant, shall be taken as 1.25.

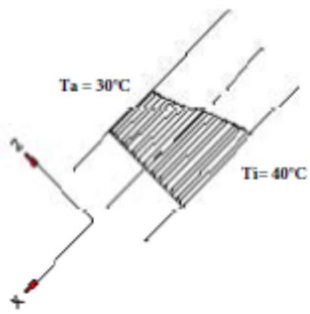
16.1.5 Water Pressure [G4]

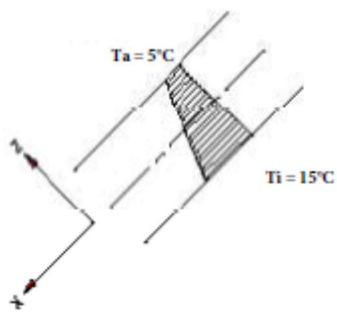
The water pressure has not been considered for the design of primary lining as no water has been found during the preliminary investigation. Additionally, water proofing membrane connected with side drains has been considered for final lining if any water pressure develops during the service life of tunnel.

16.2 Live Loads [Q]

16.2.1 Temperature Load [Q1]

The temperature loads are applied only onto the tunnel arch above the construction joint. An average temperature during construction equal to tm=+10° is assumed and active temperature differences acting on the tunnel lining are taken as follows:





SUMMER **WINTER**

Since the internal forces due to temperature differences result from constraint deformation the partial load safety factor according is adopted equal to 1.15 for ULS and 0.80 for SLS.

16.3 Fire load (F)

As required by the European Guideline, the structural fire resistance is to be given - especially in areas where a local collapse can have catastrophic consequences. This condition arises in stretches where the ground is weak (soil, decomposed rock) and where the loss of the support system is causing global instability.

The permanent lining is designed to cater the for fire load of 50MW with the European code using the fire curves (HC curves/ISO 834).

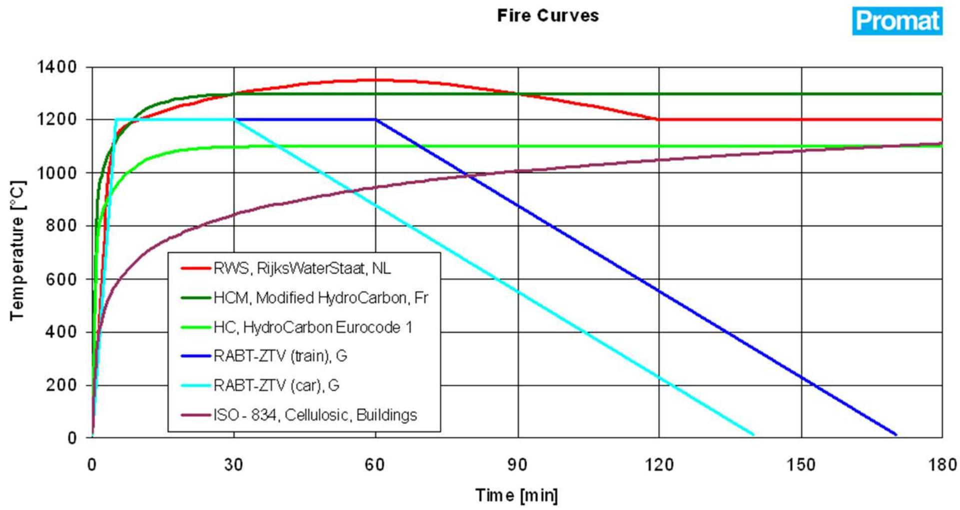


Figure 17: Typical Fire curves from different national annexure

16.4 Earthquake

In general, subsurface structures are subjected to much less forces in earthquake than buildings/structures above ground. These forces reduce with increase in depth. So, it can be assumed that earthquake induced stress in tunnel are much lower due to earthquakes. As a rule, tunnels are not designed for earthquake forces. (Pl refer “Guide 853.9120 to 853.2001 DB directive”, concerning paragraph 16).

Hence, the effect of earthquake force is not considered for structural design of tunnel inner lining. Further, to verify this assumption, effect of seismic load on tunnel is evaluated as described in literature “***Seismic design and analysis of underground structures***” by YMA Hashhash, JJ Hook, Birger Schmidt and John I-Chiang Yao (ref Tunnelling and Underground Space Technology 16 (2001) 247-293). Based on the main tunnel lining results, it is concluded that static forces are governing the design.

17 MATERIALS

The relevant construction materials which are concrete and reinforcement steel, confirms to the specifications given below.

17.1 Cast in place concrete

- Specified characteristic compressive strength f_{ck} = 45 N/mm^2 (Concrete Grade M45 according to IS 456:2000)
- Young's modulus: E = 33540 MPa
- Poisson's ratio: ν = 0.2
- Unit weight: γ = 25 kN/m^3

17.2 Reinforcement steel

The steel for structural reinforcement shall correspond to Fe 500 according to IS 1786: 2008:

Young's modulus E=200 GPa

Yield strength f_{yk}=500 MPa

17.3 Steel Fibre

Steel fibres are used as reinforcement in cast in-situ lining of the tunnel. The aspect ratio (Length/Diameter) of the fibre is considered 65. The specifications shall confirm to EN 14889-1

Nominal Fibre tensile strength: > 2300 MPa

Average wire ductility= 6%

18 ANALYSIS AND DESIGN OF THE LINING FOR FLAT INVERT OF CROSS PASSAGE

18.1 Cross Section of Lining

According to the geological conditions, overburden, etc the section shown in Figure **18** is considered for the analysis and design of lining.

18.2 Calculation of Spring Constants

The lining is modelled as a beam bedded by springs. Multiple beam elements are created along centroidal axis of lining subtending angle of 5^0 to 10^0 representing linear 2D structure.

Beam model spring constants are derived from modulus of sub grade reaction Ks, which is calculated from: $K_S = \frac{E}{(1+\nu)\times R}$, where:

E… Young's Modulus of soil/rock mass

ν… Poisson's Ratio of soil/rock mass

R…. Radius of Tunnel (with R ≤ 7 m)

The spring constant of a bedding spring representing a certain area A of sub grade is derived as: $C_r = K_S \times A$

The tangential spring constants are set as 1% of normal (radial) spring constants:

Kt = 0.01× Ks

The bending stiffness of the structural element is equal to E_c*I_g. The moment of inertia I_g is based on the modulus of inertia of gross concrete section about centroidal axis, neglecting reinforcement.

18.2.1 Analysis Method

A two-dimensional Plane Frame Analyses are performed using the computer program from STAAD Pro. V8i SS5. A near realistic 2D model using beams bedded by radial and tangential springs has been created and loads have been applied using STAAD command. Springs have been generated by using STAAD command and for further details, reference can be made to STAAD manual.

The bedding is modelled in such a way that the parts of the cross-sections where inward deformation occurs, i.e. where the springs would be subject to tensions, are neglected. The material behaviour of ground and lining is generally assumed as being elastic.

After applying all the forces on the frame model in STAAD Pro as detailed in Section 16, the loads are combined as per the prescribed combination of action given in section 19 for Ultimate Limit

State (ULS) & Serviceability Limit State (SLS) and the Members are checked for the load combination for Ultimate Limit State (ULS) & Serviceability Limit State (SLS).

The normal force, bending moment and shear force for all members are taken from the STAAD Analysis results and designed PCC lining as per Euro code EN1992-1-1:2004(E).

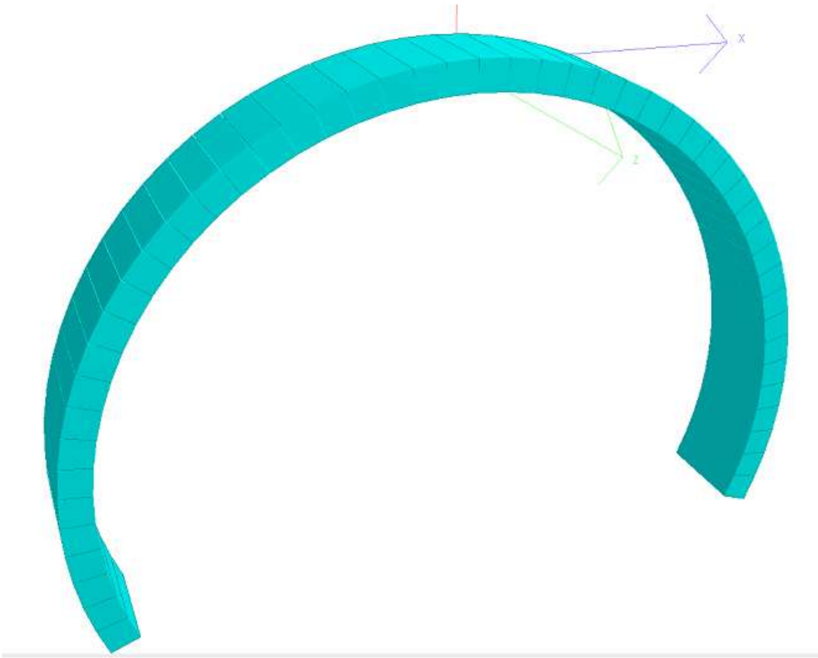


Figure 18: 3D Rendered View of Model Without Invert

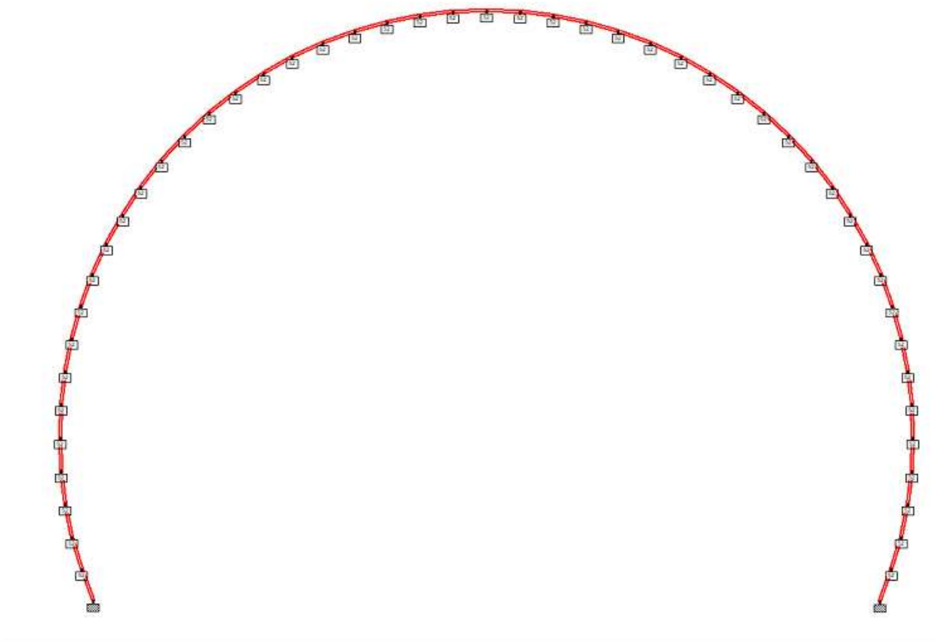


Figure 19: Idealized Model with Without Invert

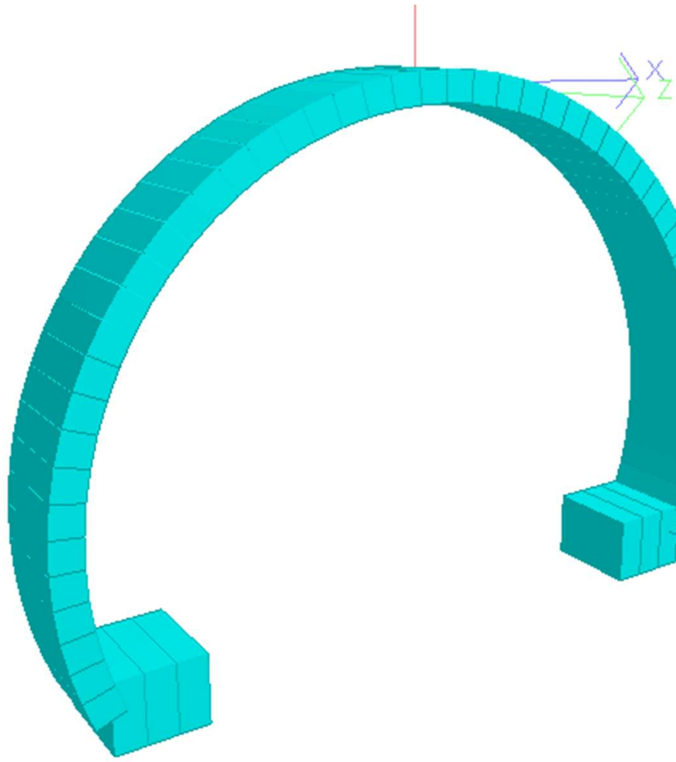


Figure 20: 3D Rendered View of Model for Flat Invert

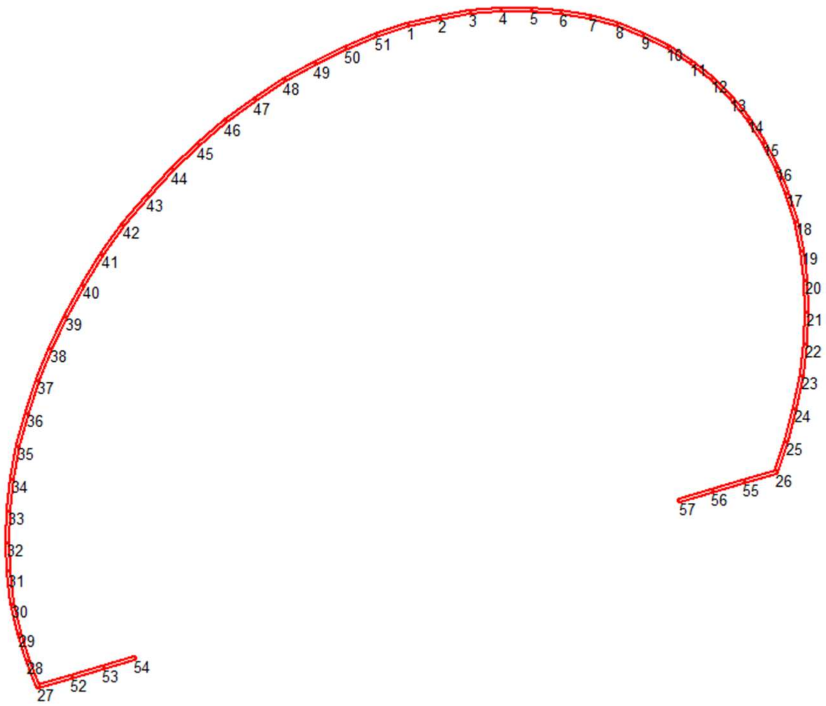


Figure 21: 3D Idealized Model for Flat Invert

19 LOAD COMBINATIONS

19.1 Applied load cases

The applied load cases are listed in the following:

- G_1 Self weight
- G_2 Earth pressure
- G_3 Hydrostatic Pressure
- G_4 Shrinkage
- Q_1 Temperature loads (winter and summer)

The general formats for combinations of actions for the ultimate and serviceability limit states are given as below.

The load combinations used for the calculation are listed in the following tables.

19.2 Ultimate Limit State (ULS)

Calculations of ultimate limit state consider the following load combinations:

I $=1.5\times G_1$
II $=1.5\times G_1+1.50\times G_2+1.50\times G_3$
III $=1.5\times G_1+1.50\times G_2+1.50\times G_3+1.25\times G_4$
IV $=1.5\times G_1+1.50\times G_2+1.50\times G_3+1.250\times G_4+1.15\times Q_{1,summer}$
V $=1.5\times G_1+1.50\times G_2+1.50\times G_3+1.250\times G_4+1.15\times Q_{1,winter}$

19.3 Serviceability Limit State (SLS)

Calculations of serviceability limit state consider the following load combinations:

I $=1.0\times G_1$
II $=1.0\times G_1+1.0\times G_2$
III $=1.0\times G_1+1.0\times G_2+1.0\times G_3$
IV $=1.0\times G_1+1.0\times G_2+1.0\times G_3+1.0\times G_4$
V $=1.0\times G_1+1.0\times G_2+1.0\times G_3+1.0\times G_4+0.8\times Q_{1,summer}$
VI $=1.0\times G_1+1.0\times G_2+1.0\times G_3+1.0\times G_4+0.8\times Q_{1,winter}$

19.3.1 Structural Design

19.3.1.1 Structural design method

Load combinations for the Ultimate Limit States (ULS) and the Serviceability Limit States (SLS) are considered for the reinforcement design as described in section 19 above.

Partial safety factors for materials for ultimate limit states are adopted according to Indian codes IS 456: 2000.

Table 5: Partial factors for materials for ULS

Concrete	*Reinforcement Steel*
1.5	1.15

19.3.2 Design Results

Based on the calculation results, the reinforcement / fibre reinforcement requirement are given in the below table.

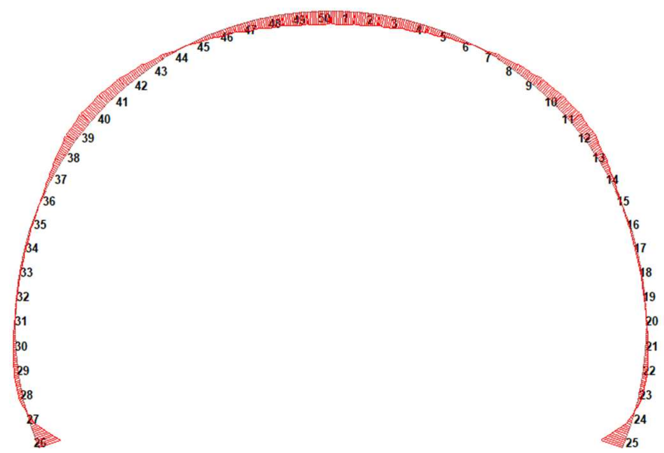


Figure 22: 3D The bending Moment of the CP without Invert section

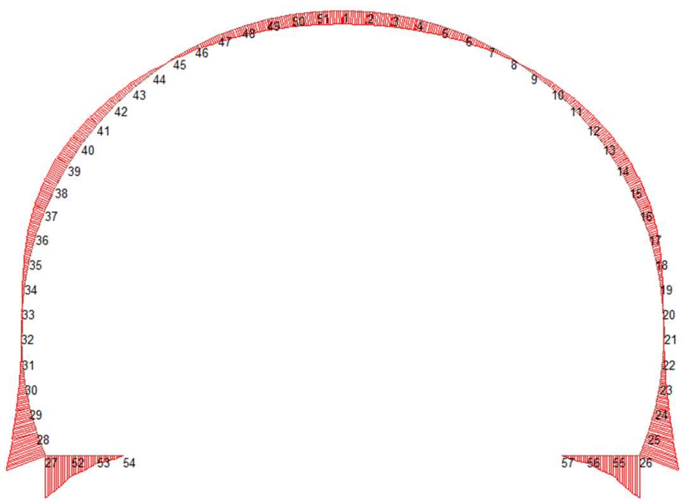


Figure 23: 3D The bending Moment of the CP with Flat Invert

<table>
<tr><th colspan="8">Tunnel Lining Reinforcement Details for different Ground Type</th></tr>
<tr><th>Sr No.</th><th>Type</th><th>Support Class</th><th>Section</th><th>SFRC Concrete Grade</th><th>Lining Thickness</th><th>Fiber Type</th><th>Fiber Dosage (kg/m3)</th></tr>
<tr><td rowspan="2">1</td><td rowspan="8">Cross Passage</td><td rowspan="2">E13200</td><td>Crown</td><td>M45</td><td rowspan="8">Overt 300 mm

Side wall 350 mm</td><td>4D 80/60/BGP</td><td>Only Fiber*</td></tr>
<tr><td>Side Wall</td><td>M45</td><td>4D 80/60/BGP</td><td>Only Fiber*</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">E1300</td><td>Crown</td><td>M45</td><td>4D 80/60/BGP</td><td rowspan="3">Only Fiber*</td></tr>
<tr><td>Top Side wall</td><td>M45</td><td>4D 80/60/BGP</td></tr>
<tr><td>Top Bottom wall</td><td>M45</td><td>4D 80/60/BGP</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">E750</td><td>Crown</td><td>M45</td><td>4D 80/60/BGP</td><td rowspan="3">Only Fiber*</td></tr>
<tr><td>Top Side wall</td><td>M45</td><td>4D 80/60/BGP</td></tr>
<tr><td>Top Bottom wall</td><td>M45</td><td>4D 80/60/BGP</td></tr>
<tr><td></td><td></td><td colspan="5">Important Note:</td><td></td></tr>
<tr><td></td><td></td><td colspan="5">Mandatory: - Microfibers of 1 kg/m3 are recommended for fire resistance (anti-spalling)</td><td></td></tr>
<tr><td></td><td></td><td colspan="5">* 25 kg/m3 of Dramix 4D 65/60GG fibers with microfibers</td><td></td></tr>
</table>

*Note - Technical support from Dramix has been taken to do some design verification of this report however any material meeting the technical specification can be used by the contractor without any obligation to Dramix.

RITES THE INFRASTRUCTURE PEOPLE	SECONDARY LINING DESIGN CHECK (E=145 N/mm2)	Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH
		Project No.	RT510-00-081
Calculation Title		Prepared by:	Rishabh/Pravar — Date 5-Aug-25
		Checked by:	RS Dhull — Date 5-Aug-25

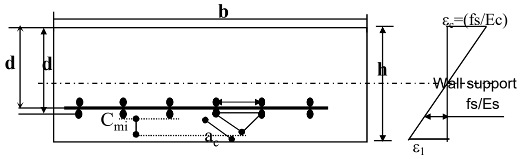
GENERAL BM TREND (ULS)

Grade of Concrete	f_{ck}	=	**45**	N/mm^2
Grade of steel	f_Y	=	**500**	N/mm^2
Min. clear cover to any reinf.		=	**50**	mm
Max. permissible shear stress	$\tau_{c,max}$	=	**4**	N/mm^2

	Zone	OVERT		SIDE WALLS		INVERT	
		soil	exc	soil	exc	soil	exc
Width b	mm	**1000**	**1000**	**1000**	**1000**	**1000**	**1000**
Depth D	mm	**400**	**400**	**420**	**550**	**700**	**700**
Ultimate B.M. M_u	kN.m	**13**	**202**	**160**	**240**	**69**	**166**
Effective depth d	mm	332	332	354	484	636	636
M_u / bd^2		0.12	1.83	1.28	1.02	0.17	0.41
$M_{u,Lim} / bd^2$ = 0.133 * fck		5.99	5.99	5.99	5.99	5.99	5.99
Singly / Doubly reinforced	?	Singly	Singly	Singly	Singly	Singly	Singly
$P_{t,lim}$ (Limiting reinf.)	%						
P_{t2} (Additional tensile reinf.)	%						
$P_t = P_{t,lim} + P_{t2}$	%						
$A_{st,required}$	mm^2	90	**1472**	**1076**	**1172**	251	607
$A_{st,min.reqd}$ 0.12%	mm^2	**480**	480	504	660	**840**	**840**
Dia of rebars	mm	**16**	**16**	**16**	**16**	**12**	**12**
Spacing of bars	mm	**125**	**125**	**125**	**125**	**125**	**125**
Diameter of Spacer Bar	mm	32	32	32	32	32	32
Dia of additional rebars	mm	**0**	**0**	**0**	**0**	**0**	**0**
Spacing of additional rebar	mm	**125**	**100**	**100**	**100**	**100**	**100**
Diameter of Spacer Bar	mm	0	0	0	0	0	0
Dia of additional rebars	mm	**0**	**0**	**0**	**0**	**0**	**0**
Spacing of additional rebar	mm	**125**	**125**	**125**	**125**	**125**	**125**
No. of layers	Nos.	1	1	1	1	1	1
$A_{st,provided}$	mm^2	1608	1608	1608	1608	905	905
		OK	OK	OK	OK	OK	OK
$A_{sc,required}$ $P_{t2}[0.87f_y/(f_{sc}-f_{cc})]$	mm^2						
Dia of rebars	mm						
No. of rebars	Nos.						
No. of layers	Nos.						
$A_{sc,provided}$	mm^2						
Shear Force	kN	**280**	**280**	**330**	**330**	**201**	**201**
Actual shear stress τ_v	MPa	0.84	0.84	0.93	0.68	0.00	0.32
$A_{st,provided}$	%	0.48	0.48	0.45	0.33	0.14	0.14
Perm. shear stress τ_c	MPa	0.51	0.51	0.49	0.43	0.29	0.29
S.F. taken by concrete	kN	168	168	174	207	185	185
Remaining S.F.	kN	**112**	112	**156**	123	**16**	16
Dia of stirrups	mm	**10**	**10**	**8**	**8**	**8**	**8**
No. of Legs	Nos.	**2**	**2**	**2**	**2**	**2**	**2**
Spacing of stirrups	mm	**100**	**100**	**100**	**100**	**200**	**200**
Shear capacity of stirrups	kN	**227**	**227**	**155**	**212**	**139**	**139**
		OK	OK	Revise	OK	OK	OK

RITES THE INFRASTRUCTURE PEOPLE	SECONDARY LINING DESIGN CHECK (E=145 N/mm2)	Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH	
		Project No.	RT510-00-081	
Calculation Title		Prepared by:	Rishabh/Pravar	Date 5-Aug-25
		Checked by:	RS Dhull	Date 5-Aug-25

Calculation of Flexural Crack Width - IS 456 : 2000 : Clause 35.3.2 & 43.1



Strain Diagram

			OVERT		SIDE WALLS		INVERT	
			soil	exc	soil	exc	soil	exc
Serviciability State Moment, Mmax unfactored	M_s	=	9	135	107	160	46	111
Serviciability State Axial Force	P	=	1	1	1200	1	1	1
C/C bar Spacing of Tension Reinforcement	s	=	125	125	125	125	125	125
Diameter of Tension Reinforcement Bars 1st Layer	ϕ_1	=	16	16	16	16	12	12
Diameter of Spacer Bar	ϕ_s	=	32	32	32	32	32	0
Diameter of Tension Reinforcement Bars 2nd Layer	ϕ_2	=	0	0	0	0	0	0
Diameter of Spacer Bar	ϕ_s	=	0	0	0	0	0	0
Diameter of Tension Reinforcement Bars 3rd Layer	ϕ_2	=	0	0	0	0	0	0
Nominal Cover to 1st layer of reinforcement	n_c	=	50	50	50	50	50	50
Diameter of Link Bar	L_{bar}		10	10	8	8	8	8
Width of Section	b	=	1000	1000	1000	1000	1000	1000
Total depth of member	h	=	400	400	420	550	700	700
Dist' from comp' face to the point at which the crack is being cal'd, Usually 'h' if crack on tension face	a	=	380	380	400	530	680	680
Minimum clear cover to tension reinforcement	c_{min}	=	40	40	40	40	40	40
Width of section at centroid of tension reinforcement	b_t	=	1000	1000	1000	1000	1000	1000
Characteristic strength of concrete, 28 day cube strengt	$f_{ck,28}$	=	45	45	45	45	45	40
Characteristic strength of reinforcement bar	f_y	=	500	500	500	500	500	500
Concrete modulus (28 day), IS 456 : CL : 6.2.3.1 $E_{c,28}$ = 5(	$E_{c,28}$	=	33541.02	33541.02	33541.02	33541	33541.02	33541.02
Steel modulus	E_s	=	210000	210000	210000	210000	210000	210000
Area of Tension Reinforcement	A_s	=	1608	1608	1608	1608	905	905
Tension reinforcement proportion *i.e.*	p	=	0.0048	0.0048	0.0045	0.0033	0.0014	0.0014
Eff. Depth of Tension Reinforcement, d=h-nc-ϕ_1/2 **OR** d=	d	=	332.0	332.0	354.0	484.0	636.0	636.0
Creep coefficient IS 4	θ	=	1.10	1.10	1.10	1.10	1.10	1.10
Eff. Modulus of the concrete, E_{eff}= E	E_{eff}	=	15972	15972	15972	15972	15972	15972
Modular ratio, for cracked section m	m	=	13.15	13.15	13.15	13.15	13.15	13.15
therefore	m*p	=	0.0637	0.0637	0.0597	0.0437	0.0187	0.0187
Ratio of Neutral axis depth to Eff. Depth x/d=√[p²m²+2(mp	k = x/d	=	0.299	0.299	0.291	0.255	0.176	0.176
Depth to neutral axis ;	x	=	99.2	99.2	103.0	123.5	111.7	111.7
Lever arm z =	z	=	298.9	298.9	319.7	442.8	598.8	598.8
Stress in tension steel f_s=[M_s / (A_s*z)] should be < 0	f_s	=	18.0	280.1	207.5	224.6	84.9	204.3
Compressive Stress in concrete f_{cb}=2M_s/(z*b*x) should be<(	f_{cb}		0.6	9.1	6.5	5.9	1.4	3.3
Strain at the level considered, calculated ignoring the stiffening effect of concrete in the tension zone, IS 456 : ANNEX F ε_1=(f_s/E_s	ε_1	=	0.00010	0.00161	0.00117	0.00121	0.00044	0.00105
Strain at the level considered, calculated considering the stiffening effect of concrete due to Axial load, ε_2=((P/b*h) /E_{eff})	ε_2	=	0.00000	0.00000	0.00018	0.00000	0.00000	0.00000
Net effective Strain ε'_1 $\varepsilon'_1 = \varepsilon_1 - \varepsilon_2$	ε'_1	=	0.00010	0.00161	0.00099	0.00121	0.00044	0.00105
Distance from critical crack position to surface of rebar max' crack width occurs midway between the bars on t	a_{cr}	=	70.8	70.8	70.8	70.8	71.6	71.6
Average strain at level where crack is considered	ε_m	=	-0.00025	0.00125	0.00062	0.00073	-0.00068	-0.00006

$\varepsilon_m = \varepsilon'_1$ - [b_t(h-x)(a-x)/(3$E_s$$A_s$(d-x))]

SURFACE CRACK WIDTH w = (3$a_{cr}$$\varepsilon_m$)/(1+2(($a_{cr}$ - c_{min})/(	**Wcr =**	**no crack**	**0.220**	**0.110**	**0.136**	**no crack**	**no crack**
		OK	**< 0.3 mm OK**	**< 0.2 mm OK**	**< 0.3 mm OK**	**OK**	**OK**

Calculation Title	SECONDARY LINING DESIGN CHECK (E=750 N/mm2)	Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH		
		Project No.	RT510-00-081		
		Prepared by:	Rishabh/Pravar	Date	5-Aug-25
		Checked by:	RS Dhull	Date	5-Aug-25

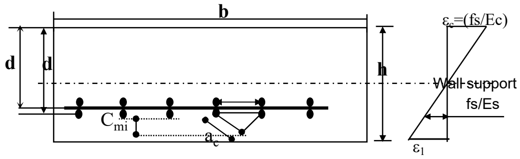
GENERAL BM TREND (ULS)

Grade of Concrete	f_{ck}	=	45	N/mm^2
Grade of steel	f_Y	=	500	N/mm^2
Min. clear cover to any reinf.		=	50	mm
Max. permissible shear stress	$\tau_{c,max}$	=	4	N/mm^2

	Zone	OVERT		SIDE WALLS		INVERT	
		soil	exc	soil	exc	soil	exc
Width b	mm	1000	1000	1000	1000	1000	1000
Depth D	mm	350	350	420	550	700	700
Ultimate B.M. M_u	kN.m	103	159	141	181	48	11
Effective depth d	mm	284	284	354	484	636	636
M_u / bd^2		1.28	1.97	1.13	0.77	0.12	0.03
$M_{u,Lim} / bd^2$ = 0.133 * fck		5.99	5.99	5.99	5.99	5.99	5.99
Singly / Doubly reinforced	?	Singly	Singly	Singly	Singly	Singly	Singly
$P_{t,lim}$ (Limiting reinf.)	%						
P_{t2} (Additional tensile reinf.)	%						
$P_t = P_{t,lim} + P_{t2}$	%						
$A_{st,required}$	mm^2	863	1360	944	878	174	40
$A_{st,min.reqd}$ 0.12%	mm^2	420	420	504	660	840	840
Dia of rebars	mm	16	16	16	16	12	12
Spacing of bars	mm	125	125	125	125	125	125
Diameter of Spacer Bar	mm	32	32	32	32	32	32
Dia of additional rebars	mm	0	0	0	0	0	0
Spacing of additional rebar	mm	125	100	100	100	100	100
Diameter of Spacer Bar	mm	0	0	0	0	0	0
Dia of additional rebars	mm	0	0	0	0	0	0
Spacing of additional rebar	mm	125	125	125	125	125	125
No. of layers	Nos.	1	1	1	1	1	1
$A_{st,provided}$	mm^2	1608	1608	1608	1608	905	905
		OK	OK	OK	OK	OK	OK
$A_{sc,required}$ $P_{t2}[0.87f_y/(f_{sc}-f_{cc})]$	mm^2						
Dia of rebars	mm						
No. of rebars	Nos.						
No. of layers	Nos.						
$A_{sc,provided}$	mm^2						
Shear Force	kN	220	220	300	300	130	130
Actual shear stress τ_v	MPa	0.77	0.77	0.85	0.62	0.00	0.20
$A_{st,provided}$	%	0.57	0.57	0.45	0.33	0.14	0.14
Perm. shear stress τ_c	MPa	0.54	0.54	0.49	0.43	0.29	0.29
S.F. taken by concrete	kN	154	154	174	207	185	185
Remaining S.F.	kN	66	66	126	93	0	0
Dia of stirrups	mm	8	8	8	8	8	8
No. of Legs	Nos.	2	2	2	2	2	2
Spacing of stirrups	mm	100	100	100	100	200	200
Shear capacity of stirrups	kN	124	124	155	212	139	139
		OK	OK	OK	OK	OK	OK

RITES THE INFRASTRUCTURE PEOPLE	SECONDARY LINING DESIGN CHECK (E=750 N/mm2)	Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH	
Calculation Title		Project No.	RT510-00-081	
		Prepared by:	Rishabh/Pravar	Date: 5-Aug-25
		Checked by:	RS Dhull	Date: 5-Aug-25

Calculation of Flexural Crack Width - IS 456 : 2000 : Clause 35.3.2 & 43.1

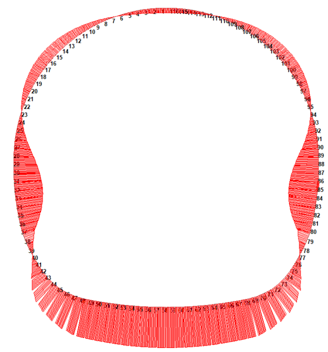


Strain Diagram

			OVERT		SIDE WALLS		INVERT	
			soil	exc	soil	exc	soil	exc
Serviciability State Moment, Mmax unfactored	M_s	=	69	106	94	121	32	7
Serviciability State Axial Force	P	=	1	1	1206	1	1	1
C/C bar Spacing of Tension Reinforcement	s	=	125	125	125	125	125	125
Diameter of Tension Reinforcement Bars 1st Layer	ϕ_1	=	16	16	16	16	12	12
Diameter of Spacer Bar	ϕ_s	=	32	32	32	32	32	32
Diameter of Tension Reinforcement Bars 2nd Layer	ϕ_2	=	0	0	0	0	0	0
Diameter of Spacer Bar	ϕ_s	=	0	0	0	0	0	0
Diameter of Tension Reinforcement Bars 3rd Layer	ϕ_2	=	0	0	0	0	0	0
Nominal Cover to 1st layer of reinforcement	n_c	=	50	50	50	50	50	50
Diameter of Link Bar	L_{bar}		8	8	8	8	8	8
Width of Section	b	=	1000	1000	1000	1000	1000	1000
Total depth of member	h	=	350	350	420	550	700	700
Dist' from comp' face to the point at which the crack is being cal'd, Usually 'h' if crack on tension face	a	=	332	332	402	532	682	682
Minimum clear cover to tension reinforcement	c_{min}	=	40	40	40	40	40	40
Width of section at centroid of tension reinforcement	b_t	=	1000	1000	1000	1000	1000	1000
Characteristic strength of concrete, 28 day cube strengt	$f_{ck,28}$	=	45	45	45	45	45	40
Characteristic strength of reinforcement bar	f_y	=	500	500	500	500	500	500
Concrete modulus (28 day), IS 456 : CL : 6.2.3.1 $E_{c,28}$ = 5	$E_{c,28}$	=	33541.02	33541.02	33541.02	33541	33541.02	33541.02
Steel modulus	E_s	=	210000	210000	210000	210000	210000	210000
Area of Tension Reinforcement	A_s	=	1608	1608	1608	1608	905	905
Tension reinforcement proportion *i.e.*	p	=	0.0057	0.0057	0.0045	0.0033	0.0014	0.0014
Eff. Depth of Tension Reinforcement, d=h-nc-ϕ_1/2 **OR** d=	d	=	284.0	284.0	354.0	484.0	636.0	636.0
Creep coefficient IS 4	θ	=	1.10	1.10	1.10	1.10	1.10	1.10
Eff. Modulus of the concrete, E_{eff}= E	E_{eff}	=	15972	15972	15972	15972	15972	15972
Modular ratio, for cracked section m	m	=	13.15	13.15	13.15	13.15	13.15	13.15
therefore	m*p	=	0.0745	0.0745	0.0597	0.0437	0.0187	0.0187
Ratio of Neutral axis depth to Eff. Depth x/d=√[p²m²+2(m	k = x/d	=	0.319	0.319	0.291	0.255	0.176	0.176
Depth to neutral axis	x	=	90.5	90.5	103.0	123.5	111.7	111.7
Lever arm z =	z	=	253.8	253.8	319.7	442.8	598.8	598.8
Stress in tension steel f_s=[M_s / (A_s*z)] should be < 0	f_s	=	168.2	259.6	182.8	169.4	59.1	13.5
Compressive Stress in concrete f_{cb}=2M_s/(z*b*x) should be<	f_{cb}		6.0	9.2	5.7	4.4	1.0	0.2
Strain at the level considered, calculated ignoring the stiffening effect of concrete in the tension zone, IS 456 : ANNEX F ε_1=(f_s/E_s	ε_1	=	0.00100	0.00154	0.00104	0.00091	0.00031	0.00007
Strain at the level considered, calculated considering the stiffening effect of concrete due to Axial load, ε_2 =((P/b*h) /E_{eff})	ε_2	=	0.00000	0.00000	0.00018	0.00000	0.00000	0.00000
Net effective Strain ε'_1 $\varepsilon'_1 = \varepsilon_1 - \varepsilon_2$	ε'_1	=	0.00100	0.00154	0.00086	0.00091	0.00031	0.00007
Distance from critical crack position to surface of rebar max' crack width occurs midway between the bars on t	a_{cr}	=	70.8	70.8	70.8	70.8	71.6	71.6
Average strain at level where crack is considered $\varepsilon_m = \varepsilon'_1$ - [b_t(h-x)(a-x)/(3$E_s$$A_s$(d-x))]	ε_m	=	0.00068	0.00122	0.00048	0.00044	-0.00082	-0.00105
SURFACE CRACK WIDTH w = (3$a_{cr}\varepsilon_m$)/(1+2((a_{cr} - c_{min})/(	**Wcr =**		**0.117**	**0.210**	**0.086**	**0.081**	**no crack**	**no crack**
			< 0.2 mm OK	**< 0.3 mm OK**	**< 0.2 mm OK**	**< 0.3 mm OK**	**OK**	**OK**

RITES THE INFRASTRUCTURE PEOPLE	SECONDARY LINING DESIGN CHECK (E=1200 N/mm2)	Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH	
		Project No.	RT510-00-081	
Calculation Title		Prepared by:	Rishabh/Pravar	Date: 25-Feb-25
		Checked by:	RS Dhull	Date: 25-Feb-25

GENERAL BM TREND (ULS)

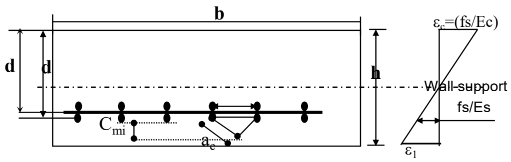


Grade of Concrete	f_{ck}	=	45	N/mm^2
Grade of steel	f_Y	=	500	N/mm^2
Min. clear cover to any reinf.		=	50	mm
Max. permissible shear stress	$\tau_{c,max}$	=	4	N/mm^2

	Zone	OVERT		SIDE WALLS		INVERT	
		soil	exc	soil	exc	soil	exc
Width b	mm	1000	1000	1000	1000	1000	1000
Depth D	mm	350	350	420	550	700	700
Ultimate B.M. M_u	kN.m	233	371	344	430	112	24
Effective depth d	mm	282	280	352	482	636	636
M_u / bd^2		2.93	4.75	2.78	1.85	0.28	0.06
$M_{u,Lim}$ / bd^2 = 0.133 * fck		5.99	5.99	5.99	5.99	5.99	5.99
Singly / Doubly reinforced	?	Singly	Singly	Singly	Singly	Singly	Singly
$P_{t,lim}$ (Limiting reinf.)	%						
P_{t2} (Additional tensile reinf.)	%						
$P_t = P_{t,lim} + P_{t2}$	%						
$A_{st,required}$	mm^2	2069	3555	2435	2159	408	87
$A_{st,min.reqd}$ 0.12%	mm^2	420	420	504	660	840	840
Dia of rebars	mm	20	25	20	20	12	12
Spacing of bars	mm	100	100	100	100	125	125
Diameter of Spacer Bar	mm	32	32	32	32	32	32
Dia of additional rebars	mm	0	0	0	0	0	0
Spacing of additional rebars	mm	100	100	100	100	100	100
Diameter of Spacer Bar	mm	0	0	0	0	0	0
Dia of additional rebars	mm	0	0	0	0	0	0
Spacing of additional rebars	mm	100	100	100	100	100	100
No. of layers	Nos.	1	1	1	1	1	1
$A_{st,provided}$	mm^2	3142	4909	3142	3142	905	905
		OK	OK	OK	OK	OK	OK
$A_{sc,required}$ $P_{t2}[0.87f_y/(f_{sc}-f_{cc})]$	mm^2						
Dia of rebars	mm						
No. of rebars	Nos.						
No. of layers	Nos.						
$A_{sc,provided}$	mm^2						
Shear Force	kN	214	214	284	284	111	111
Actual shear stress τ_v	MPa	0.76	0.77	0.81	0.59	0.00	0.17
$A_{st,provided}$	%	1.11	1.76	0.89	0.65	0.14	0.14
Perm. shear stress τ_c	MPa	0.72	0.85	0.65	0.57	0.29	0.29
S.F. taken by concrete	kN	202	238	230	277	185	185
Remaining S.F.	kN	12	0	54	7	0	0
Dia of stirrups	mm	8	8	8	8	8	8
No. of Legs	Nos.	2	2	2	2	2	2
Spacing of stirrups	mm	100	100	100	100	200	200
Shear capacity of stirrups	kN	123	122	154	211	139	139
		OK	OK	OK	OK	OK	OK

RITES THE INFRASTRUCTURE PEOPLE	SECONDARY LINING DESIGN CHECK (E=1200 N/mm2)	Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH	
		Project No.	RT510-00-081	
Calculation Title		Prepared by:	Rishabh/Pravar	Date 25-Feb-25
		Checked by:	RS Dhull	Date 25-Feb-25

Calculation of Flexural Crack Width - IS 456 : 2000 : Clause 35.3.2 & 43.1



Strain Diagram

			OVERT		SIDE WALLS		INVERT	
			soil	exc	soil	exc	soil	exc
Serviceability State Moment, Mmax unfactored	M_s	=	9	134	107	160	46	44
Serviceability State Axial Force	P	=	1	1	1180	1	1	1
C/C bar Spacing of Tension Reinforcement	s	=	125	125	125	125	150	150
Diameter of Tension Reinforcement Bars 1st Layer	ϕ_1	=	25	25	32	32	25	25
Diameter of Spacer Bar	ϕ_s	=	32	32	32	32	32	0
Diameter of Tension Reinforcement Bars 2nd Layer	ϕ_2	=	0	0	0	0	0	0
Diameter of Spacer Bar	ϕ_s	=	0	0	0	0	0	0
Diameter of Tension Reinforcement Bars 3rd Layer	ϕ_2	=	0	0	0	0	0	0
Nominal Cover to 1st layer of reinforcement	n_c	=	50	50	50	50	50	50
Diameter of Link Bar	L_{bar}		10	10	8	8	8	8
Width of Section	b	=	1000	1000	1000	1000	1000	1000
Total depth of member	h	=	400	400	420	550	700	700
Dist' from comp' face to the point at which the crack is being cal'd, Usually 'h' if crack on tension face	a	=	380	380	400	530	680	680
Minimum clear cover to tension reinforcement	c_{min}	=	40	40	40	40	40	40
Width of section at centroid of tension reinforcement	b_t	=	1000	1000	1000	1000	1000	1000
Characteristic strength of concrete, 28 day cube streng	$f_{ck,28}$	=	40	40	40	40	40	40
Characteristic strength of reinforcement bar	f_y	=	500	500	500	500	500	500
Concrete modulus (28 day), IS 456 : CL : 6.2.3.1 $E_{c,28}$ = 5C	$E_{c,28}$	=	31622.78	31622.78	31622.78	31623	31622.78	31622.78
Steel modulus	E_s	=	210000	210000	210000	210000	210000	210000
Area of Tension Reinforcement	A_s	=	3927	3927	6434	6434	3272	3272
Tension reinforcement proportion *i.e.*	p	=	0.0120	0.0120	0.0186	0.0135	0.0052	0.0052
Eff. Depth of Tension Reinforcement, d=h-nc-ϕ_1/2 **OR** d=h	d	=	327.5	327.5	346.0	476.0	629.5	629.5
Creep coefficient IS 4	θ	=	1.10	1.10	1.10	1.10	1.10	1.10
Eff. Modulus of the concrete, E_{eff}= E	E_{eff}	=	15058	15058	15058	15058	15058	15058
Modular ratio, for cracked section m :	m	=	13.95	13.95	13.95	13.95	13.95	13.95
therefore	m*p	=	0.1672	0.1672	0.2593	0.1885	0.0725	0.0725
Ratio of Neutral axis depth to Eff. Depth x/d=√[p^2m^2+2(mp	k = x/d	=	0.435	0.435	0.506	0.454	0.315	0.315
Depth to neutral axis	x	=	142.4	142.4	175.1	216.0	198.4	198.4
Lever arm z =	z	=	280.0	280.0	287.6	404.0	563.4	563.4
Stress in tension steel f_s=[M_s / (A_s*z)] should be < 0.	f_s	=	7.9	122.2	57.6	61.6	24.9	24.0
Compressive Stress in concrete f_{cb}=2M_s/(z*b*x) should be<0.	f_{cb}		0.4	6.7	4.2	3.7	0.8	0.8
Strain at the level considered, calculated ignoring the stiffening effect of concrete in the tension zone, IS 456 : ANNEX F ε_1=(f_s/E_s)	ε_1	=	0.00005	0.00075	0.00036	0.00035	0.00013	0.00013
Strain at the level considered, calculated considering the stiffening effect of concrete due to Axial load, ε_2=((P/b*h) /E_{eff})	ε_2	=	0.00000	0.00000	0.00019	0.00000	0.00000	0.00000
Net effective Strain ε'_1 $\varepsilon'_1 = \varepsilon_1 - \varepsilon_2$	ε'_1	=	0.00005	0.00075	0.00017	0.00035	0.00013	0.00013
Distance from critical crack position to surface of rebar max' crack width occurs midway between the bars on	a_{cr}	=	69.1	69.1	67.9	67.9	79.0	79.0
Average strain at level where crack is considered	ε_m	=	-0.00009	0.00061	0.00010	0.00025	-0.00014	-0.00014
$\varepsilon_m = \varepsilon'_1$ - [b_t(h-x)(a-x)/(3$E_s$$A_s$(d-x))]								
SURFACE CRACK WIDTH w = (3$a_{cr}$$\varepsilon_m$)/(1+2(($a_{cr}$ - c_{min})/(	**Wcr =**		**no crack**	**0.104**	**0.016**	**0.044**	**no crack**	**no crack**
			OK	**< 0.3 mm OK**	**< 0.2 mm OK**	**< 0.3 mm OK**	**OK**	**OK**

RITES		Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH		
	SECONDARY LINING DESIGN CHECK (E=4000 N/mm2)	Project No.	RT510-00-081		
Calculation Title		Prepared by:	Rishabh/Pravar	Date	25-Feb-25
		Checked by:	RS Dhull	Date	25-Feb-25

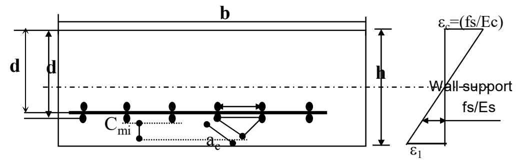
GENERAL BM TREND (ULS)

Grade of Concrete	f_{ck}	=	45	N/mm^2
Grade of steel	f_Y	=	500	N/mm^2
Min. clear cover to any reinf.		=	50	mm
Max. permissible shear stress	$\tau_{c,max}$	=	4	N/mm^2

	Zone	OVERT		SIDE WALLS		INVERT	
		soil	exc	soil	exc	soil	exc
Width b	mm	1000	1000	1000	1000	1000	1000
Depth D	mm	350	350	420	550	700	700
Ultimate B.M. M_u	kN.m	159	273	259	277	112	24
Effective depth d	mm	284	282	354	484	636	636
M_u / bd^2		1.97	3.43	2.07	1.18	0.28	0.06
$M_{u,Lim}$ / bd^2 = 0.133 * fck		5.99	5.99	5.99	5.99	5.99	5.99
Singly / Doubly reinforced	?	Singly	Singly	Singly	Singly	Singly	Singly
$P_{t,lim}$ (Limiting reinf.)	%						
P_{t2} (Additional tensile reinf.)	%						
$P_t = P_{t,lim} + P_{t2}$	%						
$A_{st,required}$	mm^2	1360	2466	1782	1359	408	87
$A_{st,min.reqd}$ 0.12%	mm^2	420	420	504	660	840	840
Dia of rebars	mm	16	20	16	16	12	12
Spacing of bars	mm	100	100	100	100	125	125
Diameter of Spacer Bar	mm	32	32	32	32	32	32
Dia of additional rebars	mm	0	0	0	0	0	0
Spacing of additional rebars	mm	100	100	100	100	100	100
Diameter of Spacer Bar	mm	0	0	0	0	0	0
Dia of additional rebars	mm	0	0	0	0	0	0
Spacing of additional rebars	mm	100	100	100	100	100	100
No. of layers	Nos.	1	1	1	1	1	1
$A_{st,provided}$	mm^2	2011	3142	2011	2011	905	905
		OK	OK	OK	OK	OK	OK
$A_{sc,required}$ $P_{t2}[0.87f_y/(f_{sc}-f_{cc})]$	mm^2						
Dia of rebars	mm						
No. of rebars	Nos.						
No. of layers	Nos.						
$A_{sc,provided}$	mm^2						
Shear Force	kN	170	170	284	284	97	97
Actual shear stress τ_v	MPa	0.60	0.60	0.80	0.59	0.00	0.15
$A_{st,provided}$	%	0.71	1.11	0.57	0.42	0.14	0.14
Perm. shear stress τ_c	MPa	0.59	0.72	0.54	0.47	0.29	0.29
S.F. taken by concrete	kN	169	202	192	229	185	185
Remaining S.F.	kN	1	0	92	55	0	0
Dia of stirrups	mm	8	8	8	8	8	8
No. of Legs	Nos.	2	2	2	2	2	2
Spacing of stirrups	mm	100	100	100	100	200	200
Shear capacity of stirrups	kN	124	123	155	212	139	139
		OK	OK	OK	OK	OK	OK

RITES THE INFRASTRUCTURE PEOPLE	SECONDARY LINING DESIGN CHECK (E=4000 N/mm2)	Project Title:	DESIGN OF FOTULA TUNNEL,UT LADAKH		
		Project No.	RT510-00-081		
Calculation Title		Prepared by:	Rishabh/Pravar	Date	25-Feb-25
		Checked by:	RS Dhull	Date	25-Feb-25

Calculation of Flexural Crack Width - IS 456 : 2000 : Clause 35.3.2 & 43.1



Strain Diagram

			OVERT		SIDE WALLS		INVERT	
			soil	exc	soil	exc	soil	exc
Serviciability State Moment, Mmax unfactored	M_s	=	9	134	107	160	46	44
Serviciability State Axial Force	P	=	1	1	1180	1	1	1
C/C bar Spacing of Tension Reinforcement	s	=	125	125	125	125	150	150
Diameter of Tension Reinforcement Bars 1st Layer	ϕ_1	=	25	25	32	32	25	25
Diameter of Spacer Bar	ϕ_s	=	32	32	32	32	32	0
Diameter of Tension Reinforcement Bars 2nd Layer	ϕ_2	=	0	0	0	0	0	0
Diameter of Spacer Bar	ϕ_s	=	0	0	0	0	0	0
Diameter of Tension Reinforcement Bars 3rd Layer	ϕ_2	=	0	0	0	0	0	0
Nominal Cover to 1st layer of reinforcement	n_c	=	50	50	50	50	50	50
Diameter of Link Bar	L_{bar}		10	10	8	8	8	8
Width of Section	b	=	1000	1000	1000	1000	1000	1000
Total depth of member	h	=	400	400	420	550	700	700
Dist' from comp' face to the point at which the crack is being cal'd, Usually 'h' if crack on tension face	a	=	380	380	400	530	680	680
Minimum clear cover to tension reinforcement	c_{min}	=	40	40	40	40	40	40
Width of section at centroid of tension reinforcement	b_t	=	1000	1000	1000	1000	1000	1000
Characteristic strength of concrete, 28 day cube streng	$f_{ck,28}$	=	40	40	40	40	40	40
Characteristic strength of reinforcement bar	f_y	=	500	500	500	500	500	500
Concrete modulus (28 day), IS 456 : CL : 6.2.3.1 $E_{c,28}$ = 5C	$E_{c,28}$	=	31622.78	31622.78	31622.78	31623	31622.78	31622.78
Steel modulus	E_s	=	210000	210000	210000	210000	210000	210000
Area of Tension Reinforcement	A_s	=	3927	3927	6434	6434	3272	3272
Tension reinforcement proportion *i.e.*	p	=	0.0120	0.0120	0.0186	0.0135	0.0052	0.0052
Eff. Depth of Tension Reinforcement, $d=h-nc-\phi_1/2$ **OR** d=h	d	=	327.5	327.5	346.0	476.0	629.5	629.5
Creep coefficient IS 4	θ	=	1.10	1.10	1.10	1.10	1.10	1.10
Eff. Modulus of the concrete, E_{eff}= E	E_{eff}	=	15058	15058	15058	15058	15058	15058
Modular ratio, for cracked section m :	m	=	13.95	13.95	13.95	13.95	13.95	13.95
therefore	m*p	=	0.1672	0.1672	0.2593	0.1885	0.0725	0.0725
Ratio of Neutral axis depth to Eff. Depth $x/d=\sqrt{[p^2m^2+2(mp}$	k = x/d	=	0.435	0.435	0.506	0.454	0.315	0.315
Depth to neutral axis	x	=	142.4	142.4	175.1	216.0	198.4	198.4
Lever arm z =	z	=	280.0	280.0	287.6	404.0	563.4	563.4
Stress in tension steel $f_s=[M_s / (A_s*z)]$ should be < 0.	f_s	=	7.9	122.2	57.6	61.6	24.9	24.0
Compressive Stress in concrete $f_{cb}=2M_s/(z*b*x)$ should be<0.	f_{cb}		0.4	6.7	4.2	3.7	0.8	0.8
Strain at the level considered, calculated ignoring the stiffening effect of concrete in the tension zone, IS 456 : ANNEX F $\varepsilon_1=(f_s/E_s)$	ε_1	=	0.00005	0.00075	0.00036	0.00035	0.00013	0.00013
Strain at the level considered, calculated considering the stiffening effect of concrete due to Axial load, $\varepsilon_2=((P/b*h)/E_{eff})$	ε_2	=	0.00000	0.00000	0.00019	0.00000	0.00000	0.00000
Net effective Strain ε'_1 $\varepsilon'_1=\varepsilon_1-\varepsilon_2$	ε'_1	=	0.00005	0.00075	0.00017	0.00035	0.00013	0.00013
Distance from critical crack position to surface of rebar max' crack width occurs midway between the bars on	a_{cr}	=	69.1	69.1	67.9	67.9	79.0	79.0
Average strain at level where crack is considered $\varepsilon_m=\varepsilon'_1-[b_t(h-x)(a-x)/(3E_sA_s(d-x))]$	ε_m	=	-0.00009	0.00061	0.00010	0.00025	-0.00014	-0.00014
SURFACE CRACK WIDTH $w=(3a_{cr}\varepsilon_m)/(1+2((a_{cr}-c_{min})/($	**Wcr =**		**no crack**	**0.104**	**0.016**	**0.044**	**no crack**	**no crack**
			OK	**< 0.3 mm OK**	**< 0.2 mm OK**	**< 0.3 mm OK**	**OK**	**OK**

Moment Capacity for Dramix® Steel Fiber Reinforced Concrete in User Defined ULS for CIP

Detailed Design Note and Basic Theory

This calculation must be used within the context of an overall design.

This calculation is only valid for Dramix® steel fibres.
Using fibers of any other kind is strictly prohibited and Bekaert will refuse any liability or warranty.

This calculation must not be applied to any other application or project than what is being mentioned below.

Project	**Fotu La Tunnel**
object	E750
street	Cross Passage
location	Side wall Bottom
remark	Hybrid

Customer	**Rites**
street	-
location	-
e-mail	-
phone	INPUT
contact	INPUT
internet	INPUT

date	25-2-2025

This report was prepared by:

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Moment Capacity 4.0.2

Terms and Definitions

α_{cc}	is the coefficient taking account of long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied.
α_{char}	is the coefficient taking account of the variation of the material properties for the selected application
α_{sys}	is the coefficient taking account of effects due to fibre orientation, size and load redistribution for the selected application (if applicable)
$\alpha_{R,c}$	is a coefficient for the calculation of the resulting compressive force
$A_{s,1}$	is the cross sectional area of the bending reinforcement
b	is the width of the cross section, for panel-type sections it is 1000 mm/m
c_{nom}	is the nominal concrete cover of the reinforcing bars (if any)
d	is the effective depth of a cross-section, with d = h for "fibers only" and d = d for combined reinforcement
d_s	is the bar diameter
ε_c	is the actual compressive strain in the concrete
ε_{cu}	is the ultimate compressive strain in the concrete
ε^f_{ct}	is the actual tensile strain in the steel fiber concrete
$\varepsilon^f_{ct,max}$	is the ultimate tensile strain in the steel fiber concrete
E_s	is the design value of the modulus of elasticity of the reinforcing steel
ε_{s1}	is the actual tensile strain in the reinforcing steel
ε_{su}	is the ultimate tensile strain in the reinforcing steel
f_{cd}	is the design value of the concrete compressive strength
f_{ck}	is the characteristic value of the concrete compressive strength
F_{cd}	is the design value of the force in the compression zone
F^f_{ct}	is the design value of the force in the tension zone due to the steel fiber concrete
$f_{R1,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 0.5 mm
$f_{R3/4,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 2.5 / 3.5 mm
$F_{s1,d}$	is the design value of the force in the tension zone due to the reinforcing bars
f_{yd}	is the design yield strength of the reinforcement
f_{yk}	is the characteristic yield strength of the reinforcement
γ_c	is the partial factor for concrete in compression
γ^f_{ct}	is the partial factor for steel fiber concrete in tension
γ_s	is the partial factor for reinforcing steel
h	is the overall depth of a cross-section
k_a	is a coefficient for the calculation of lever arm of the resulting compressive force
κ_h	is a coefficient to compensate for scaling effects
m_{Rd}	the resisting bending moment for a width of 1 m/m
N	is the external axial force applied to the section (compression force: negative sign)
$\sigma(\varepsilon)_d$	is the design value of the steel fiber reinforced concrete in tension, based on ε^f_{ct}
σ_{2d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R1,m}$
σ_{3d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R4,m}$
$\sigma_{s1,d}$	is the design stress of the reinforcing steel, based on ε_{s1}
x	is the depth of the compression zone
z_{cd}	is the distance from F^f_{cd} to the neutral axis of the cross section
z_{fd}	is the distance from F^f_{ct} to the neutral axis of the cross section
z_{s1}	is the distance from $F_{s1,d}$ to the neutral axis of the cross section
z_N	is the distance from N to the neutral axis of the cross section

Practical Recommendations and Conditions

Working joints have to be planned and detailed accurately according to the requirements. The effect of fibers must not be taken into account in the working joint. Thus additional rebar has to be placed there.

From experience, a steel fiber concrete with

- slump S3 / flow slump F3 or higher
- maximum aggregate size 16mm
- sieve curve B16

has proven to work.

Please consult Bekaert for further recommendations, mixing and dosing instructions.

A minimum distance in between the reinforcement of ~1,5•(fibre length) is recommended. Smaller distances may be possible but should be checked on beforehand. If so and also in any case of doubt, a preliminary test is always recommended.

In order to avoid a sieve effect, additional reinforcement (if any) has to be placed accurately, especially in the overlap zone.

General Remarks

This calculation refers to a specific application and is thus part of an overall design.

It has to be applied in this context and must not be used as a standalone design.

Area of Application

On the following pages, the bending moment capacity of a "Fiber only" or of a combined reinforced concrete section is determined.
However, checking the applicability of this bending moment to a certain structure is not part of this calculation. This has to be verified in a separate step.

Area of Application: CIP, User Defined ULS, slab type section

Design Approach

The moment capacity is calculated on the basis of: fib Model Code 2010

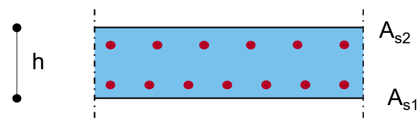
$$\sigma_{1d} = 1.0 \cdot f_{ctm} \cdot \max\{1.6m - d; 1.0\} \;(f_{ctm} \text{ used})$$
$$= \sigma_{2d} \;(f_{ctm} \text{ not used})$$
$$\sigma_{2d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R1} \cdot f_{R1,m} / \gamma^f{}_{ct}$$
$$\sigma_{3d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R3} \cdot f_{R3,m} / \gamma^f{}_{ct}$$

Input Data

Design Parameters	slab type section		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		
characteristic factor α_{char}	0.90	[-]	
external axial force N	0.00	[kN/m]	(compression force: negative sign)
system factor α_{sys}	1.00	[-]	

Geometry: slab type section

h	500	[mm]
h_2	-	[mm]
h_1	-	[mm]
h_w	-	[mm]
b_2	-	[mm]
b_1	1000	[mm/m]
b_w	-	[mm]

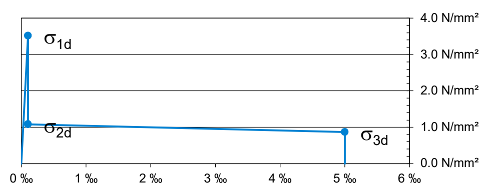


Steel Fibre Concrete

effective depth d	500	[mm]	
concrete class	C35/45		
characteristic strength f_{ck}	35	[N/mm²]	
partial factor γ_c	1.50	[-]	
factor α_{cc}	0.85	[-]	
α_{R1}: $f_{R1m} \rightarrow \sigma_2$	0.45	[-]	(conversion factor flexion → tension)
α_{R3}: $f_{R3m} \rightarrow \sigma_3$	0.32	[-]	(conversion factor flexion → tension)
$f_{R1,m}$	4.00	[N/mm²]	(test report NA)
$f_{R3,m}$	4.50	[N/mm²]	(test report NA)
κ_h	1.00	[-]	
partial factor γ^f_{ct}	1.50	[-]	

Dramix® fiber type	Dramix 4D 80/60 BGP	(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³	(test report NA)

Constitutive Law for Steel Fibre Concrete: σ - ε



σ -w / σ - ε

w_u	2.5	[mm]
l_{cs}	500	[mm]
ε_u	5.0	[‰]

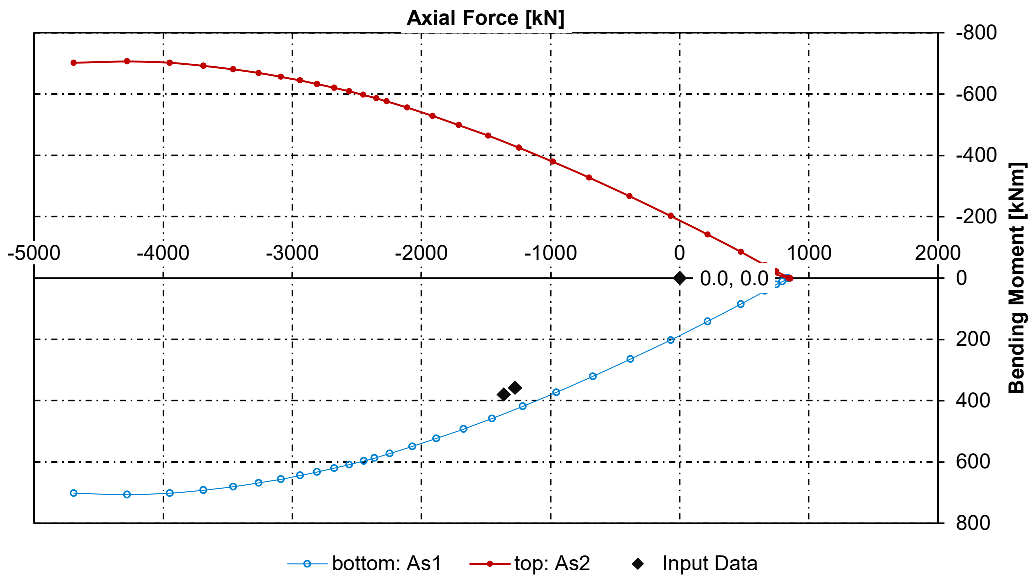
Reinforcement

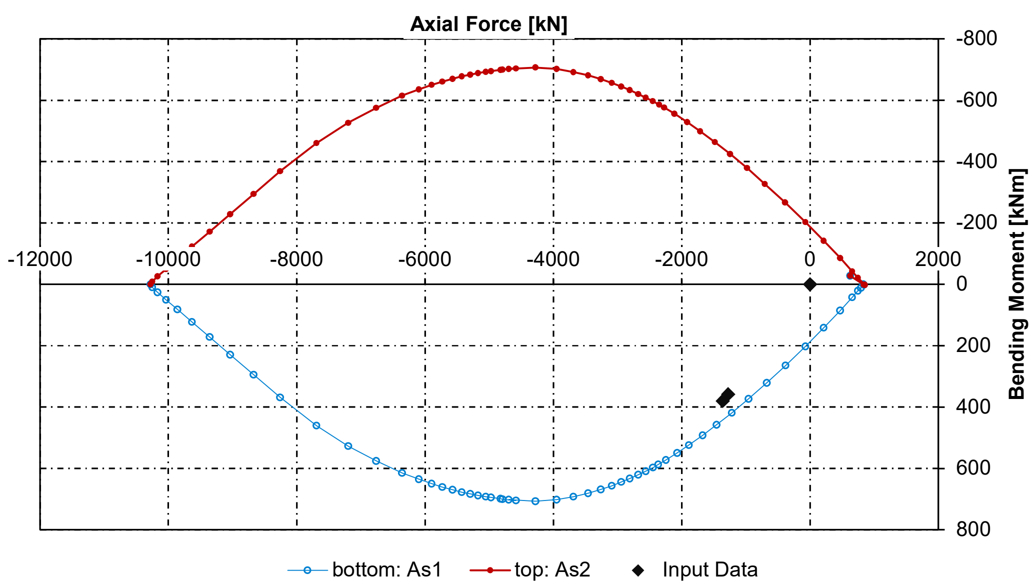
yield strength f_{yk}	500	[N/mm²]
partial factor γ_s	1.15	[-]
E-modulus	2,00,000	[N/mm²]

Reinforcement A_{s1} (bottom)			**Reinforcement A_{s2}** (top)		
effective depth d	444	[mm]	effective depth d	444	[mm]
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]

M-N-Envelope

5D4D3D





Input Data - N	-1276.0	0.0	-1362.0	0.0	0.0	N
Input Data - M	358.0	0.0	380.0	0.0	0.0	M

Conclusion and Proposal: CIP, User Defined ULS

This calculation is not a design on its own!

This calculation is part of an overall design and has to be applied within this context. It must not be used for any other application than described in this design note or for any other project.

5D4D3D

Moment Capacity	**slab type section**				
design approach	fib Model Code 2010				
safety factors	CIP, User Defined ULS				
reinforcement layout	Combined				
Geometry: slab type section					
h	500	[mm]			
b_1	1000	[mm/m]			
Fiber Concrete					
concrete class	C35/45				
residual strength $f_{R1,m}$	4.00	[N/mm²]			(test report NA)
residual strength $f_{R3,m}$	4.50	[N/mm²]			(test report NA)
Steel Fibers					
Dramix® fiber type	Dramix 4D 80/60 BGP				(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³				(test report NA)
Reinforcement					
yield strength f_{yk}	500	[N/mm²]			
Reinforcement A_{s1}	(bottom)		**Reinforcement A_{s2}**	(top)	
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
rebar cross section / m	452	[mm²/m]	rebar cross section / m	452	[mm²/m]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]
Bending Moment Capacity: see M-N-Envelope					
M_{Rd}	**n/a**				
N	n/a				

Data Base 2.1.0
Moment Capacity 4.0.2

3

Remarks

All input data provided to Bekaert is assumed to be correct and thus without Bekaert's responsibility. Assumptions made by Bekaert are evident for successful execution and thus have to be verified by the project engineer.

This design is only valid for Dramix®-steel fibers. Violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation.
In case other fiber types than specified above or fibers of other manufacturers are used, this design is null and void. In such a case, Bekaert rejects any liability for this design and for the consequences of putting it in practice. The same holds for applying this design to any other than the described application or project.

References

design	AS 3600:2018: Australian Standard - Concrete structures DAfStb: Technical Rule on Steel Fibre Reinforced Concrete, November 2012 EN 1992-1-1 *fib* Model Code 2010 IAPMO UES ER-465, North American Requirements for the design of Dramix Fiber-Reinforced Concrete members and Systems (US-BD-19) NZS 3101:2006: New Zealand Standard - Concrete structures standard RILEM TC 162-TDF: Test and design methods for steel fibre reinforced concrete SS 812310:2014: Fibre Concrete - Design of Fibre Concrete Structures
post crack strength	Test Report NA
materials	EN 206-1 and relevant national standards EN 10080 and relevant national standards EN 14889-1 and relevant national standards

Liability

Dramix® steel fibers, where added to concrete, will enable the latter to transfer stresses over a cracked section. In this respect, "Dramix® Section Design" is meant to be a methodology that is to allow the users of the Dramix® steel fibers (where such fibers are added to concrete) to determine the bending moment capacity of Dramix® steel fiber reinforced concrete, also in a combination with traditional reinforcement. The limitations of the methodology are explained in the design note, see above.

Whereas BEKAERT is confident with the scientific quality of "Dramix® Section Design" and whereas, as a result thereof, BEKAERT warrants the validity of the software and the resulting calculation as a methodology, BEKAERT is nevertheless unable to have an insight in (and a control over) the correctness of the data (such as but not limited to correct geometry, materials and design conditions) that are actually being used by others for the purpose of any calculation that is being made on the basis of the software.

In addition, BEKAERT is also unable to have an insight in (and a control over) the respect by others of the conditions (such as but not limited to the mixing of Dramix® steel fibers with concrete according to BEKAERT specifications, the timely curing of the concrete, the use of adequate concrete composition) that are precedent to Dramix® steel fiber reinforced concrete performing as intended.

In respect of what precedes, BEKAERT hereby declines any liability whatsoever for losses and/or damages of whatever kind (and sustained by whomever) that might result either from use by others of erroneous data (where used for the purpose of any calculation that is being made on the basis of the software) or from disrespect by others of any of the conditions that are precedent to Dramix® steel fiber reinforced concrete performing as intended. BEKAERT can not be considered to be nor to become an architect and/or building engineer on the sole basis of BEKAERT providing to others this design note and in the same respect, BEKAERT can not be considered to accept any of the liabilities that may possibly devolve on architects and/or building engineers.

This calculation is part of an overall design and has to be applied in this context. It must not be used for any other application than mentioned in this calculation or for any other project. In any case, this calculation is not a stand alone design.

Finally, this design note does not relieve others to test the material properties, especially post-crack tensile strength, of the Dramix® steel fiber reinforced concrete according to the standards stated above and other applicable requirements.

By the single fact of utilizing this design note, the user accepts and agrees that this utilization is considered to be done or to have been done under the terms and conditions stated above. By the same fact, the user agrees to waive all rights of subrogation against BEKAERT and/or to hold BEKAERT harmless from and against all claims for all losses and/or damages (of whatever kind and by whomever sustained) for which BEKAERT, pursuant to what precedes, declines liability.

This design note may not be used for any other purpose than for making calculations in respect of the Dramix® steel fibers; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation. At all times, the rights of intellectual property over this design note will remain vested in BEKAERT; the single fact of the utilization by others of this design note can under no circumstances be considered to constitute a transfer to others of the rights of intellectual property over this design note. The sales of this design note (and/or the commercializing thereof in any other way) to others is strictly prohibited; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation.

Moment Capacity for Dramix® Steel Fiber Reinforced Concrete in User Defined ULS for CIP

Detailed Design Note and Basic Theory

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This calculation must not be applied to any other application or project than what is being mentioned below.

Project	**Fotu La Tunnel**
object	E750
street	Cross Passage
location	Side wall Top
remark	Hybrid

Customer	**Rites**
street	-
location	-
e-mail	-
phone	INPUT
contact	INPUT
internet	INPUT

date	25-2-2025

This report was prepared by:

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Moment Capacity 4.0.2

Terms and Definitions

α_{cc}	is the coefficient taking account of long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied.
α_{char}	is the coefficient taking account of the variation of the material properties for the selected application
α_{sys}	is the coefficient taking account of effects due to fibre orientation, size and load redistribution for the selected application (if applicable)
$\alpha_{R,c}$	is a coefficient for the calculation of the resulting compressive force
$A_{s,1}$	is the cross sectional area of the bending reinforcement
b	is the width of the cross section, for panel-type sections it is 1000 mm/m
c_{nom}	is the nominal concrete cover of the reinforcing bars (if any)
d	is the effective depth of a cross-section, with d = h for "fibers only" and d = d for combined reinforcement
d_s	is the bar diameter
ε_c	is the actual compressive strain in the concrete
ε_{cu}	is the ultimate compressive strain in the concrete
ε^f_{ct}	is the actual tensile strain in the steel fiber concrete
$\varepsilon^f_{ct,max}$	is the ultimate tensile strain in the steel fiber concrete
E_s	is the design value of the modulus of elasticity of the reinforcing steel
ε_{s1}	is the actual tensile strain in the reinforcing steel
ε_{su}	is the ultimate tensile strain in the reinforcing steel
f_{cd}	is the design value of the concrete compressive strength
f_{ck}	is the characteristic value of the concrete compressive strength
F_{cd}	is the design value of the force in the compression zone
F^f_{ct}	is the design value of the force in the tension zone due to the steel fiber concrete
$f_{R1,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 0.5 mm
$f_{R3/4,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 2.5 / 3.5 mm
$F_{s1,d}$	is the design value of the force in the tension zone due to the reinforcing bars
f_{yd}	is the design yield strength of the reinforcement
f_{yk}	is the characteristic yield strength of the reinforcement
γ_c	is the partial factor for concrete in compression
γ^f_{ct}	is the partial factor for steel fiber concrete in tension
γ_s	is the partial factor for reinforcing steel
h	is the overall depth of a cross-section
k_a	is a coefficient for the calculation of lever arm of the resulting compressive force
κ_h	is a coefficient to compensate for scaling effects
m_{Rd}	the resisting bending moment for a width of 1 m/m
N	is the external axial force applied to the section (compression force: negative sign)
$\sigma(\varepsilon)_d$	is the design value of the steel fiber reinforced concrete in tension, based on ε^f_{ct}
σ_{2d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R1,m}$
σ_{3d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R4,m}$
$\sigma_{s1,d}$	is the design stress of the reinforcing steel, based on ε_{s1}
x	is the depth of the compression zone
z_{cd}	is the distance from F^f_{cd} to the neutral axis of the cross section
z_{fd}	is the distance from F^f_{ct} to the neutral axis of the cross section
z_{s1}	is the distance from $F_{s1,d}$ to the neutral axis of the cross section
z_N	is the distance from N to the neutral axis of the cross section

Practical Recommendations and Conditions

Working joints have to be planned and detailed accurately according to the requirements. The effect of fibers must not be taken into account in the working joint. Thus additional rebar has to be placed there.

From experience, a steel fiber concrete with

- slump S3 / flow slump F3 or higher
- maximum aggregate size 16mm
- sieve curve B16

has proven to work.

Please consult Bekaert for further recommendations, mixing and dosing instructions.

A minimum distance in between the reinforcement of ~1,5•(fibre length) is recommended. Smaller distances may be possible but should be checked on beforehand. If so and also in any case of doubt, a preliminary test is always recommended.

In order to avoid a sieve effect, additional reinforcement (if any) has to be placed accurately, especially in the overlap zone.

General Remarks

This calculation refers to a specific application and is thus part of an overall design.

It has to be applied in this context and must not be used as a standalone design.

Area of Application

On the following pages, the bending moment capacity of a "Fiber only" or of a combined reinforced concrete section is determined.
However, checking the applicability of this bending moment to a certain structure is not part of this calculation. This has to be verified in a separate step.

Area of Application: CIP, User Defined ULS, slab type section

Design Approach

The moment capacity is calculated on the basis of: fib Model Code 2010

$$\sigma_{1d} = 1.0 \cdot f_{ctm} \cdot \max\{1.6m - d; 1.0\} \text{ (}f_{ctm}\text{ used)}$$

$$= \sigma_{2d} \text{ (}f_{ctm}\text{ not used)}$$

$$\sigma_{2d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R1} \cdot f_{R1,m} / \gamma^f{}_{ct}$$

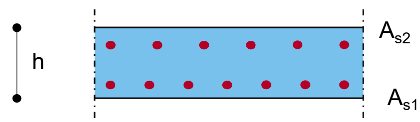
$$\sigma_{3d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R3} \cdot f_{R3,m} / \gamma^f{}_{ct}$$

Input Data

Design Parameters	slab type section		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		
characteristic factor α_{char}	0.90	[-]	
external axial force N	0.00	[kN/m]	(compression force: negative sign)
system factor α_{sys}	1.00	[-]	

Geometry: slab type section

h	300	[mm]
h_2	-	[mm]
h_1	-	[mm]
h_w	-	[mm]
b_2	-	[mm]
b_1	1000	[mm/m]
b_w	-	[mm]

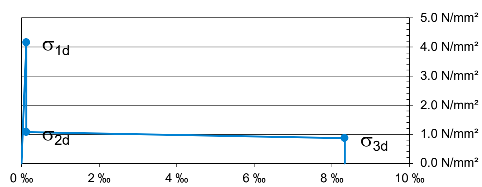


Steel Fibre Concrete

effective depth d	300	[mm]	
concrete class	C35/45		
characteristic strength f_{ck}	35	[N/mm²]	
partial factor γ_c	1.50	[-]	
factor α_{cc}	0.85	[-]	
$\alpha_{R1}: f_{R1m} \rightarrow \sigma_2$	0.45	[-]	(conversion factor flexion → tension)
$\alpha_{R3}: f_{R3m} \rightarrow \sigma_3$	0.32	[-]	(conversion factor flexion → tension)
$f_{R1,m}$	4.00	[N/mm²]	(test report NA)
$f_{R3,m}$	4.50	[N/mm²]	(test report NA)
κ_h	1.00	[-]	
partial factor γ^{f}_{ct}	1.50	[-]	

Dramix® fiber type	Dramix 4D 80/60 BGP	(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³	(test report NA)

Constitutive Law for Steel Fibre Concrete: σ - ε



σ -w / σ - ε

w_u	2.5	[mm]
l_{cs}	300	[mm]
ε_u	8.3	[‰]

Reinforcement

yield strength f_{yk}	500	[N/mm²]
partial factor γ_s	1.15	[-]
E-modulus	2,00,000	[N/mm²]

Reinforcement A_{s1} (bottom)

effective depth d	244	[mm]
bar diameter d_s	12	[mm]
bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]

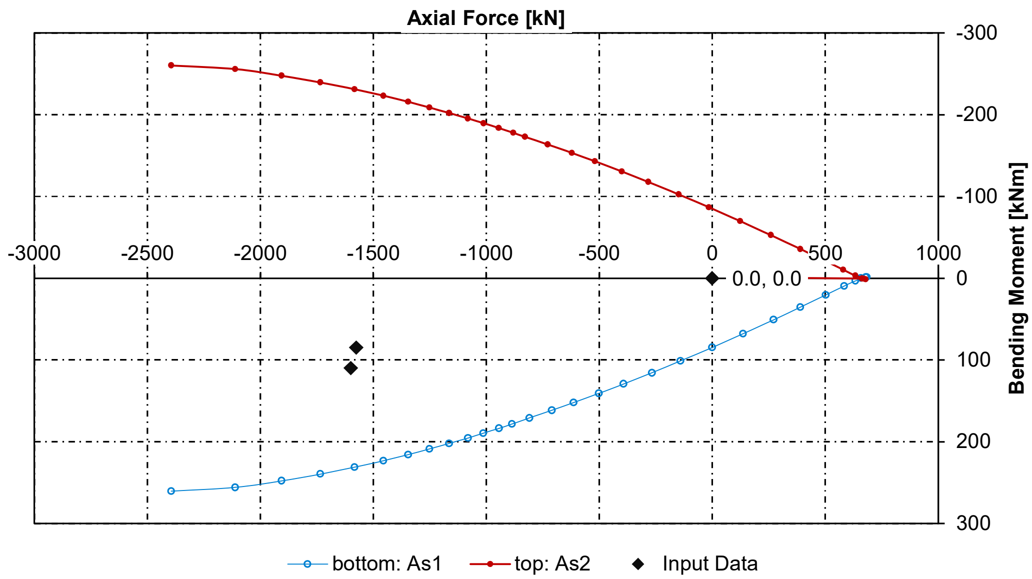
Reinforcement A_{s2} (top)

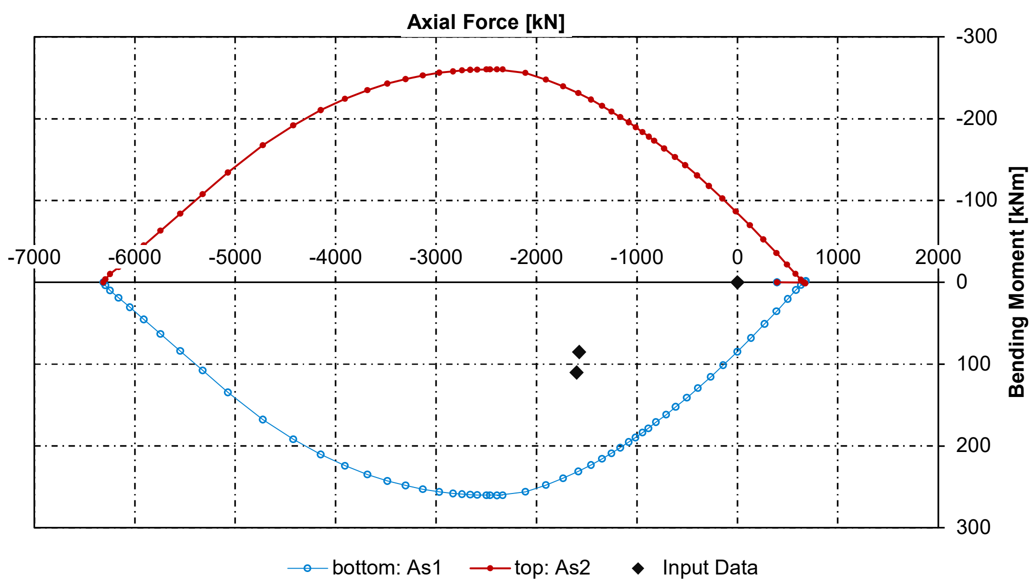
effective depth d	244	[mm]
bar diameter d_s	12	[mm]
bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]

Bekaert

M-N-Envelope

5D4D3D





Input Data - N	-1575.0	0.0	-1600.0	0.0	0.0	N
Input Data - M	85.0	0.0	110.0	0.0	0.0	M

Conclusion and Proposal: CIP, User Defined ULS

This calculation is not a design on its own!

This calculation is part of an overall design and has to be applied within this context. It must not be used for any other application than described in this design note or for any other project.

5D4D3D

Moment Capacity	**slab type section**				
design approach	fib Model Code 2010				
safety factors	CIP, User Defined ULS				
reinforcement layout	Combined				
Geometry: slab type section					
h	300	[mm]			
b_1	1000	[mm/m]			
Fiber Concrete					
concrete class	C35/45				
residual strength $f_{R1,m}$	4.00	[N/mm²]			(test report NA)
residual strength $f_{R3,m}$	4.50	[N/mm²]			(test report NA)
Steel Fibers					
Dramix® fiber type	Dramix 4D 80/60 BGP				(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³				(test report NA)
Reinforcement					
yield strength f_{yk}	500	[N/mm²]			
Reinforcement A_{s1}	(bottom)		**Reinforcement A_{s2}**	(top)	
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
rebar cross section / m	452	[mm²/m]	rebar cross section / m	452	[mm²/m]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]
Bending Moment Capacity: see M-N-Envelope					
M_{Rd}	**n/a**				
N	n/a				

Data Base 2.1.0
Moment Capacity 4.0.2

3

Remarks

All input data provided to Bekaert is assumed to be correct and thus without Bekaert's responsibility. Assumptions made by Bekaert are evident for successful execution and thus have to be verified by the project engineer.

This design is only valid for Dramix®-steel fibers. Violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation.
In case other fiber types than specified above or fibers of other manufacturers are used, this design is null and void. In such a case, Bekaert rejects any liability for this design and for the consequences of putting it in practice. The same holds for applying this design to any other than the described application or project.

References

design	AS 3600:2018: Australian Standard - Concrete structures DAfStb: Technical Rule on Steel Fibre Reinforced Concrete, November 2012 EN 1992-1-1 *fib* Model Code 2010 IAPMO UES ER-465, North American Requirements for the design of Dramix Fiber-Reinforced Concrete members and Systems (US-BD-19) NZS 3101:2006: New Zealand Standard - Concrete structures standard RILEM TC 162-TDF: Test and design methods for steel fibre reinforced concrete SS 812310:2014: Fibre Concrete - Design of Fibre Concrete Structures
post crack strength	Test Report NA
materials	EN 206-1 and relevant national standards EN 10080 and relevant national standards EN 14889-1 and relevant national standards

Liability

Dramix® steel fibers, where added to concrete, will enable the latter to transfer stresses over a cracked section. In this respect, "Dramix® Section Design" is meant to be a methodology that is to allow the users of the Dramix® steel fibers (where such fibers are added to concrete) to determine the bending moment capacity of Dramix® steel fiber reinforced concrete, also in a combination with traditional reinforcement. The limitations of the methodology are explained in the design note, see above.

Whereas BEKAERT is confident with the scientific quality of "Dramix® Section Design" and whereas, as a result thereof, BEKAERT warrants the validity of the software and the resulting calculation as a methodology, BEKAERT is nevertheless unable to have an insight in (and a control over) the correctness of the data (such as but not limited to correct geometry, materials and design conditions) that are actually being used by others for the purpose of any calculation that is being made on the basis of the software.

In addition, BEKAERT is also unable to have an insight in (and a control over) the respect by others of the conditions (such as but not limited to the mixing of Dramix® steel fibers with concrete according to BEKAERT specifications, the timely curing of the concrete, the use of adequate concrete composition) that are precedent to Dramix® steel fiber reinforced concrete performing as intended.

In respect of what precedes, BEKAERT hereby declines any liability whatsoever for losses and/or damages of whatever kind (and sustained by whomever) that might result either from use by others of erroneous data (where used for the purpose of any calculation that is being made on the basis of the software) or from disrespect by others of any of the conditions that are precedent to Dramix® steel fiber reinforced concrete performing as intended. BEKAERT can not be considered to be nor to become an architect and/or building engineer on the sole basis of BEKAERT providing to others this design note and in the same respect, BEKAERT can not be considered to accept any of the liabilities that may possibly devolve on architects and/or building engineers.

This calculation is part of an overall design and has to be applied in this context. It must not be used for any other application than mentioned in this calculation or for any other project. In any case, this calculation is not a stand alone design.

Finally, this design note does not relieve others to test the material properties, especially post-crack tensile strength, of the Dramix® steel fiber reinforced concrete according to the standards stated above and other applicable requirements.

By the single fact of utilizing this design note, the user accepts and agrees that this utilization is considered to be done or to have been done under the terms and conditions stated above. By the same fact, the user agrees to waive all rights of subrogation against BEKAERT and/or to hold BEKAERT harmless from and against all claims for all losses and/or damages (of whatever kind and by whomever sustained) for which BEKAERT, pursuant to what precedes, declines liability.

This design note may not be used for any other purpose than for making calculations in respect of the Dramix® steel fibers; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation. At all times, the rights of intellectual property over this design note will remain vested in BEKAERT; the single fact of the utilization by others of this design note can under no circumstances be considered to constitute a transfer to others of the rights of intellectual property over this design note. The sales of this design note (and/or the commercializing thereof in any other way) to others is strictly prohibited; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation.

Moment Capacity for Dramix® Steel Fiber Reinforced Concrete in User Defined ULS for CIP

Detailed Design Note and Basic Theory

This calculation must be used within the context of an overall design.

This calculation is only valid for Dramix® steel fibres.
Using fibers of any other kind is strictly prohibited and Bekaert will refuse any liability or warranty.

This calculation must not be applied to any other application or project than what is being mentioned below.

Project	**Fotu La Tunnel**
object	E1300
street	Cross Passage
location	Crown
remark	Hybrid

Customer	**Rites**
street	-
location	-
e-mail	-
phone	INPUT
contact	INPUT
internet	INPUT

date	25-2-2025

This report was prepared by:

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Moment Capacity 4.0.2

Terms and Definitions

α_{cc}	is the coefficient taking account of long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied.
α_{char}	is the coefficient taking account of the variation of the material properties for the selected application
α_{sys}	is the coefficient taking account of effects due to fibre orientation, size and load redistribution for the selected application (if applicable)
$\alpha_{R,c}$	is a coefficient for the calculation of the resulting compressive force
$A_{s,1}$	is the cross sectional area of the bending reinforcement
b	is the width of the cross section, for panel-type sections it is 1000 mm/m
c_{nom}	is the nominal concrete cover of the reinforcing bars (if any)
d	is the effective depth of a cross-section, with d = h for "fibers only" and d = d for combined reinforcement
d_s	is the bar diameter
ε_c	is the actual compressive strain in the concrete
ε_{cu}	is the ultimate compressive strain in the concrete
ε^f_{ct}	is the actual tensile strain in the steel fiber concrete
$\varepsilon^f_{ct,max}$	is the ultimate tensile strain in the steel fiber concrete
E_s	is the design value of the modulus of elasticity of the reinforcing steel
ε_{s1}	is the actual tensile strain in the reinforcing steel
ε_{su}	is the ultimate tensile strain in the reinforcing steel
f_{cd}	is the design value of the concrete compressive strength
f_{ck}	is the characteristic value of the concrete compressive strength
F_{cd}	is the design value of the force in the compression zone
F^f_{ct}	is the design value of the force in the tension zone due to the steel fiber concrete
$f_{R1,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 0.5 mm
$f_{R3/4,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 2.5 / 3.5 mm
$F_{s1,d}$	is the design value of the force in the tension zone due to the reinforcing bars
f_{yd}	is the design yield strength of the reinforcement
f_{yk}	is the characteristic yield strength of the reinforcement
γ_c	is the partial factor for concrete in compression
γ^f_{ct}	is the partial factor for steel fiber concrete in tension
γ_s	is the partial factor for reinforcing steel
h	is the overall depth of a cross-section
k_a	is a coefficient for the calculation of lever arm of the resulting compressive force
κ_h	is a coefficient to compensate for scaling effects
m_{Rd}	the resisting bending moment for a width of 1 m/m
N	is the external axial force applied to the section (compression force: negative sign)
$\sigma(\varepsilon)_d$	is the design value of the steel fiber reinforced concrete in tension, based on ε^f_{ct}
σ_{2d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R1,m}$
σ_{3d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R4,m}$
$\sigma_{s1,d}$	is the design stress of the reinforcing steel, based on ε_{s1}
x	is the depth of the compression zone
z_{cd}	is the distance from F^f_{cd} to the neutral axis of the cross section
z_{fd}	is the distance from F^f_{ct} to the neutral axis of the cross section
z_{s1}	is the distance from $F_{s1,d}$ to the neutral axis of the cross section
z_N	is the distance from N to the neutral axis of the cross section

Practical Recommendations and Conditions

Working joints have to be planned and detailed accurately according to the requirements. The effect of fibers must not be taken into account in the working joint. Thus additional rebar has to be placed there.

From experience, a steel fiber concrete with

- slump S3 / flow slump F3 or higher
- maximum aggregate size 16mm
- sieve curve B16

has proven to work.

Please consult Bekaert for further recommendations, mixing and dosing instructions.

A minimum distance in between the reinforcement of ~1,5•(fibre length) is recommended. Smaller distances may be possible but should be checked on beforehand. If so and also in any case of doubt, a preliminary test is always recommended.

In order to avoid a sieve effect, additional reinforcement (if any) has to be placed accurately, especially in the overlap zone.

General Remarks

This calculation refers to a specific application and is thus part of an overall design.

It has to be applied in this context and must not be used as a standalone design.

Area of Application

On the following pages, the bending moment capacity of a "Fiber only" or of a combined reinforced concrete section is determined.
However, checking the applicability of this bending moment to a certain structure is not part of this calculation. This has to be verified in a separate step.

Area of Application: CIP, User Defined ULS, slab type section

Design Approach

The moment capacity is calculated on the basis of: fib Model Code 2010

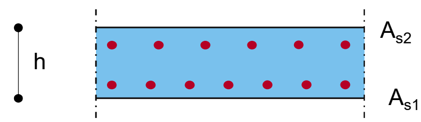
$$\sigma_{1d} = 1.0 \cdot f_{ctm} \cdot \max\{1.6m - d; 1.0\} \quad (f_{ctm} \text{ used})$$
$$= \sigma_{2d} \quad (f_{ctm} \text{ not used})$$
$$\sigma_{2d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R1} \cdot f_{R1,m} / \gamma^f{}_{ct}$$
$$\sigma_{3d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R3} \cdot f_{R3,m} / \gamma^f{}_{ct}$$

Input Data

Design Parameters	slab type section		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		
characteristic factor α_{char}	0.90	[-]	
external axial force N	0.00	[kN/m]	(compression force: negative sign)
system factor α_{sys}	1.00	[-]	

Geometry: slab type section

h	300	[mm]
h_2	-	[mm]
h_1	-	[mm]
h_w	-	[mm]
b_2	-	[mm]
b_1	1000	[mm/m]
b_w	-	[mm]

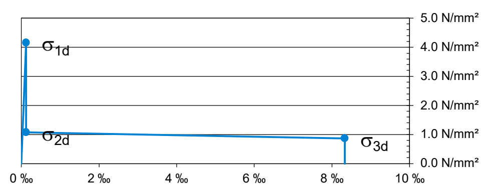


Steel Fibre Concrete

effective depth d	300	[mm]	
concrete class	C35/45		
characteristic strength f_{ck}	35	[N/mm²]	
partial factor γ_c	1.50	[-]	
factor α_{cc}	0.85	[-]	
$\alpha_{R1}: f_{R1m} \rightarrow \sigma_2$	0.45	[-]	(conversion factor flexion → tension)
$\alpha_{R3}: f_{R3m} \rightarrow \sigma_3$	0.32	[-]	(conversion factor flexion → tension)
$f_{R1,m}$	4.00	[N/mm²]	(test report NA)
$f_{R3,m}$	4.50	[N/mm²]	(test report NA)
κ_h	1.00	[-]	
partial factor γ^f_{ct}	1.50	[-]	

Dramix® fiber type	Dramix 4D 80/60 BGP	(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³	(test report NA)

Constitutive Law for Steel Fibre Concrete: σ - ε



σ -w / σ - ε

w_u	2.5	[mm]
l_{cs}	300	[mm]
ε_u	8.3	[‰]

Reinforcement

yield strength f_{yk}	500	[N/mm²]
partial factor γ_s	1.15	[-]
E-modulus	2,00,000	[N/mm²]

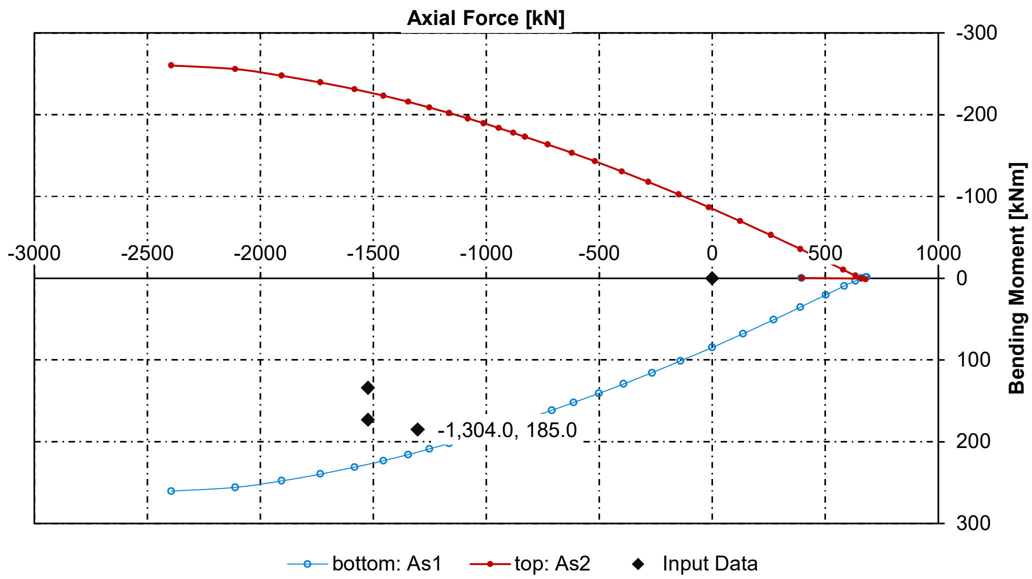
Reinforcement A_{s1} (bottom)

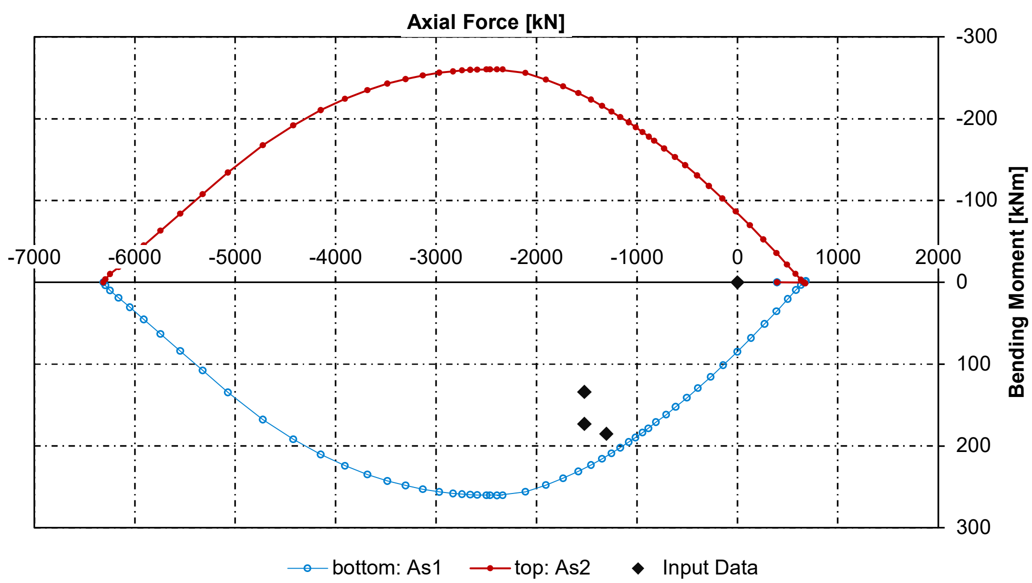
effective depth d	244	[mm]
bar diameter d_s	12	[mm]
bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]

Reinforcement A_{s2} (top)

effective depth d	244	[mm]
bar diameter d_s	12	[mm]
bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]

M-N-Envelope





Input Data - N	-1524.0	-1304.0	-1524.0	0.0	0.0	N
Input Data - M	173.0	185.0	134.0	0.0	0.0	M

Conclusion and Proposal: CIP, User Defined ULS

This calculation is not a design on its own!

This calculation is part of an overall design and has to be applied within this context. It must not be used for any other application than described in this design note or for any other project.

5D4D3D

Moment Capacity	**slab type section**		
design approach	fib Model Code 2010		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		
Geometry: slab type section			
h	300	[mm]	
b_1	1000	[mm/m]	
Fiber Concrete			
concrete class	C35/45		
residual strength $f_{R1,m}$	4.00	[N/mm²]	(test report NA)
residual strength $f_{R3,m}$	4.50	[N/mm²]	(test report NA)
Steel Fibers			
Dramix® fiber type	Dramix 4D 80/60 BGP		(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³		(test report NA)
Reinforcement			
yield strength f_{yk}	500	[N/mm²]	

Reinforcement A_{s1}	(bottom)		**Reinforcement A_{s2}**	(top)	
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
rebar cross section / m	452	[mm²/m]	rebar cross section / m	452	[mm²/m]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]

Bending Moment Capacity: see M-N-Envelope

M_{Rd}	**n/a**
N	n/a

Data Base 2.1.0
Moment Capacity 4.0.2

3

Remarks

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post crack strength	Test Report NA
materials	EN 206-1 and relevant national standards EN 10080 and relevant national standards EN 14889-1 and relevant national standards

Liability

Dramix® steel fibers, where added to concrete, will enable the latter to transfer stresses over a cracked section. In this respect, "Dramix® Section Design" is meant to be a methodology that is to allow the users of the Dramix® steel fibers (where such fibers are added to concrete) to determine the bending moment capacity of Dramix® steel fiber reinforced concrete, also in a combination with traditional reinforcement. The limitations of the methodology are explained in the design note, see above.

Whereas BEKAERT is confident with the scientific quality of "Dramix® Section Design" and whereas, as a result thereof, BEKAERT warrants the validity of the software and the resulting calculation as a methodology, BEKAERT is nevertheless unable to have an insight in (and a control over) the correctness of the data (such as but not limited to correct geometry, materials and design conditions) that are actually being used by others for the purpose of any calculation that is being made on the basis of the software.

In addition, BEKAERT is also unable to have an insight in (and a control over) the respect by others of the conditions (such as but not limited to the mixing of Dramix® steel fibers with concrete according to BEKAERT specifications, the timely curing of the concrete, the use of adequate concrete composition) that are precedent to Dramix® steel fiber reinforced concrete performing as intended.

In respect of what precedes, BEKAERT hereby declines any liability whatsoever for losses and/or damages of whatever kind (and sustained by whomever) that might result either from use by others of erroneous data (where used for the purpose of any calculation that is being made on the basis of the software) or from disrespect by others of any of the conditions that are precedent to Dramix® steel fiber reinforced concrete performing as intended. BEKAERT can not be considered to be nor to become an architect and/or building engineer on the sole basis of BEKAERT providing to others this design note and in the same respect, BEKAERT can not be considered to accept any of the liabilities that may possibly devolve on architects and/or building engineers.

This calculation is part of an overall design and has to be applied in this context. It must not be used for any other application than mentioned in this calculation or for any other project. In any case, this calculation is not a stand alone design.

Finally, this design note does not relieve others to test the material properties, especially post-crack tensile strength, of the Dramix® steel fiber reinforced concrete according to the standards stated above and other applicable requirements.

By the single fact of utilizing this design note, the user accepts and agrees that this utilization is considered to be done or to have been done under the terms and conditions stated above. By the same fact, the user agrees to waive all rights of subrogation against BEKAERT and/or to hold BEKAERT harmless from and against all claims for all losses and/or damages (of whatever kind and by whomever sustained) for which BEKAERT, pursuant to what precedes, declines liability.

This design note may not be used for any other purpose than for making calculations in respect of the Dramix® steel fibers; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation. At all times, the rights of intellectual property over this design note will remain vested in BEKAERT; the single fact of the utilization by others of this design note can under no circumstances be considered to constitute a transfer to others of the rights of intellectual property over this design note. The sales of this design note (and/or the commercializing thereof in any other way) to others is strictly prohibited; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation.

Moment Capacity for Dramix® Steel Fiber Reinforced Concrete in User Defined ULS for CIP

Detailed Design Note and Basic Theory

This calculation must be used within the context of an overall design.

This calculation is only valid for Dramix® steel fibres.
Using fibers of any other kind is strictly prohibited and Bekaert will refuse any liability or warranty.

This calculation must not be applied to any other application or project than what is being mentioned below.

Project	**Fotu La Tunnel**
object	E1300
street	Cross Passage
location	Side wall Bottom
remark	Hybrid
Customer	**Rites**
street	-
location	-
e-mail	-
phone	INPUT
contact	INPUT
internet	INPUT
date	25-2-2025

This report was prepared by:

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http://www.bekaert.com/building

Moment Capacity 4.0.2

Terms and Definitions

α_{cc}	is the coefficient taking account of long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied.
α_{char}	is the coefficient taking account of the variation of the material properties for the selected application
α_{sys}	is the coefficient taking account of effects due to fibre orientation, size and load redistribution for the selected application (if applicable)
$\alpha_{R,c}$	is a coefficient for the calculation of the resulting compressive force
$A_{s,1}$	is the cross sectional area of the bending reinforcement
b	is the width of the cross section, for panel-type sections it is 1000 mm/m
c_{nom}	is the nominal concrete cover of the reinforcing bars (if any)
d	is the effective depth of a cross-section, with d = h for "fibers only" and d = d for combined reinforcement
d_s	is the bar diameter
ε_c	is the actual compressive strain in the concrete
ε_{cu}	is the ultimate compressive strain in the concrete
ε^f_{ct}	is the actual tensile strain in the steel fiber concrete
$\varepsilon^f_{ct,max}$	is the ultimate tensile strain in the steel fiber concrete
E_s	is the design value of the modulus of elasticity of the reinforcing steel
ε_{s1}	is the actual tensile strain in the reinforcing steel
ε_{su}	is the ultimate tensile strain in the reinforcing steel
f_{cd}	is the design value of the concrete compressive strength
f_{ck}	is the characteristic value of the concrete compressive strength
F_{cd}	is the design value of the force in the compression zone
F^f_{ct}	is the design value of the force in the tension zone due to the steel fiber concrete
$f_{R1,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 0.5 mm
$f_{R3/4,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 2.5 / 3.5 mm
$F_{s1,d}$	is the design value of the force in the tension zone due to the reinforcing bars
f_{yd}	is the design yield strength of the reinforcement
f_{yk}	is the characteristic yield strength of the reinforcement
γ_c	is the partial factor for concrete in compression
γ^f_{ct}	is the partial factor for steel fiber concrete in tension
γ_s	is the partial factor for reinforcing steel
h	is the overall depth of a cross-section
k_a	is a coefficient for the calculation of lever arm of the resulting compressive force
κ_h	is a coefficient to compensate for scaling effects
m_{Rd}	the resisting bending moment for a width of 1 m/m
N	is the external axial force applied to the section (compression force: negative sign)
$\sigma(\varepsilon)_d$	is the design value of the steel fiber reinforced concrete in tension, based on ε^f_{ct}
σ_{2d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R1,m}$
σ_{3d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R4,m}$
$\sigma_{s1,d}$	is the design stress of the reinforcing steel, based on ε_{s1}
x	is the depth of the compression zone
z_{cd}	is the distance from F^f_{cd} to the neutral axis of the cross section
z_{fd}	is the distance from F^f_{ct} to the neutral axis of the cross section
z_{s1}	is the distance from $F_{s1,d}$ to the neutral axis of the cross section
z_N	is the distance from N to the neutral axis of the cross section

Practical Recommendations and Conditions

Working joints have to be planned and detailed accurately according to the requirements. The effect of fibers must not be taken into account in the working joint. Thus additional rebar has to be placed there.

From experience, a steel fiber concrete with

- slump S3 / flow slump F3 or higher
- maximum aggregate size 16mm
- sieve curve B16

has proven to work.

Please consult Bekaert for further recommendations, mixing and dosing instructions.

A minimum distance in between the reinforcement of ~1,5•(fibre length) is recommended. Smaller distances may be possible but should be checked on beforehand. If so and also in any case of doubt, a preliminary test is always recommended.

In order to avoid a sieve effect, additional reinforcement (if any) has to be placed accurately, especially in the overlap zone.

General Remarks

This calculation refers to a specific application and is thus part of an overall design.

It has to be applied in this context and must not be used as a standalone design.

Area of Application

On the following pages, the bending moment capacity of a "Fiber only" or of a combined reinforced concrete section is determined.
However, checking the applicability of this bending moment to a certain structure is not part of this calculation. This has to be verified in a separate step.

Area of Application: CIP, User Defined ULS, slab type section

Design Approach

The moment capacity is calculated on the basis of: fib Model Code 2010

$$\sigma_{1d} = 1.0 \cdot f_{ctm} \cdot \max\{1.6m - d; 1.0\} \; (f_{ctm} \text{ used})$$

$$= \sigma_{2d} \; (f_{ctm} \text{ not used})$$

$$\sigma_{2d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R1} \cdot f_{R1,m} / \gamma^f{}_{ct}$$

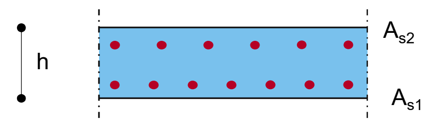
$$\sigma_{3d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R3} \cdot f_{R3,m} / \gamma^f{}_{ct}$$

Input Data

Design Parameters	slab type section		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		
characteristic factor α_{char}	0.90	[-]	
external axial force N	0.00	[kN/m]	(compression force: negative sign)
system factor α_{sys}	1.00	[-]	

Geometry: slab type section

h	500	[mm]
h_2	-	[mm]
h_1	-	[mm]
h_w	-	[mm]
b_2	-	[mm]
b_1	1000	[mm/m]
b_w	-	[mm]

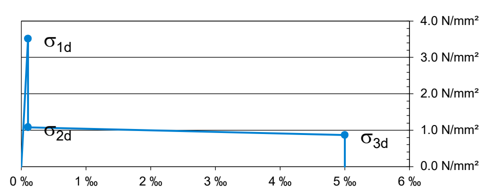


Steel Fibre Concrete

effective depth d	500	[mm]	
concrete class	C35/45		
characteristic strength f_{ck}	35	[N/mm²]	
partial factor γ_c	1.50	[-]	
factor α_{cc}	0.85	[-]	
$\alpha_{R1}: f_{R1m} \rightarrow \sigma_2$	0.45	[-]	(conversion factor flexion → tension)
$\alpha_{R3}: f_{R3m} \rightarrow \sigma_3$	0.32	[-]	(conversion factor flexion → tension)
$f_{R1,m}$	4.00	[N/mm²]	(test report NA)
$f_{R3,m}$	4.50	[N/mm²]	(test report NA)
κ_h	1.00	[-]	
partial factor γ^f_{ct}	1.50	[-]	

Dramix® fiber type	Dramix 4D 80/60 BGP	(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³	(test report NA)

Constitutive Law for Steel Fibre Concrete: σ - ε



σ -w / σ - ε

w_u	2.5	[mm]
l_{cs}	500	[mm]
ε_u	5.0	[‰]

Reinforcement

yield strength f_{yk}	500	[N/mm²]
partial factor γ_s	1.15	[-]
E-modulus	2,00,000	[N/mm²]

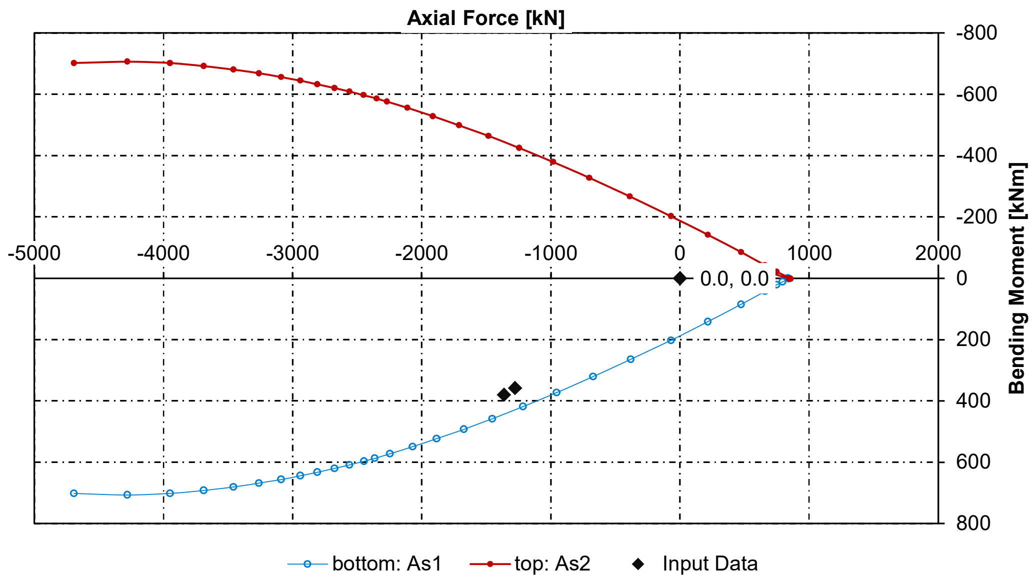
Reinforcement A_{s1} (bottom)

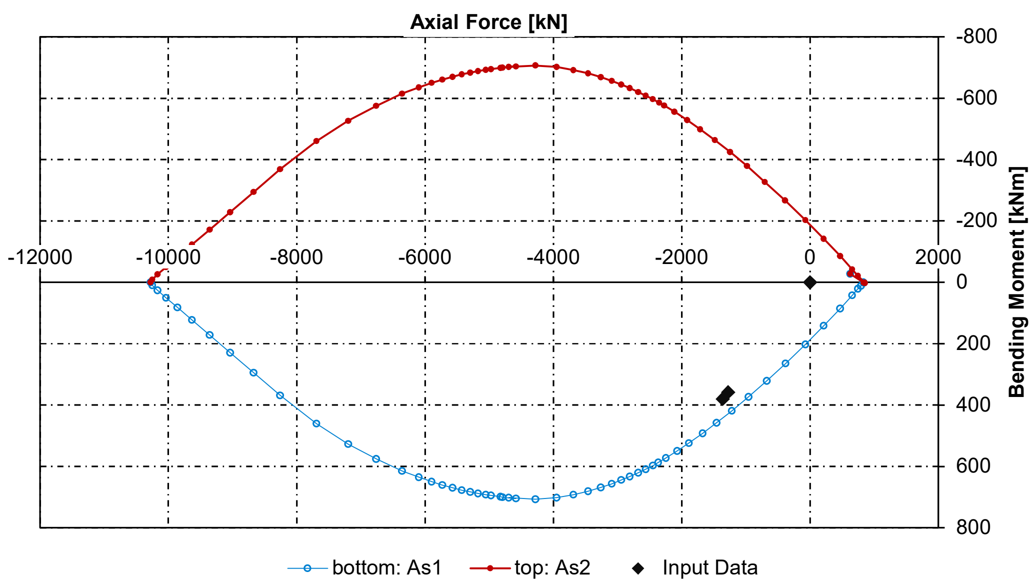
effective depth d	444	[mm]
bar diameter d_s	12	[mm]
bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]

Reinforcement A_{s2} (top)

effective depth d	444	[mm]
bar diameter d_s	12	[mm]
bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]

M-N-Envelope





Input Data - N	-1277.0	0.0	-1362.0	0.0	0.0	N
Input Data - M	358.0	0.0	380.0	0.0	0.0	M

Only for use with Dramix-Steel fibers!

Conclusion and Proposal: CIP, User Defined ULS

This calculation is not a design on its own!

This calculation is part of an overall design and has to be applied within this context. It must not be used for any other application than described in this design note or for any other project.

Moment Capacity	**slab type section**				5D4D3D
design approach	fib Model Code 2010				
safety factors	CIP, User Defined ULS				
reinforcement layout	Combined				
Geometry: slab type section					
h	500	[mm]			
b_1	1000	[mm/m]			
Fiber Concrete					
concrete class	C35/45				
residual strength $f_{R1,m}$	4.00	[N/mm²]			(test report NA)
residual strength $f_{R3,m}$	4.50	[N/mm²]			(test report NA)
Steel Fibers					
Dramix® fiber type	Dramix 4D 80/60 BGP				(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³				(test report NA)
Reinforcement					
yield strength f_{yk}	500	[N/mm²]			
Reinforcement A_{s1}	(bottom)		**Reinforcement A_{s2}**	(top)	
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
rebar cross section / m	452	[mm²/m]	rebar cross section / m	452	[mm²/m]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]
Bending Moment Capacity: see M-N-Envelope					
M_{Rd}	**n/a**				
N	n/a				

Data Base 2.1.0
Moment Capacity 4.0.2

3

Remarks

All input data provided to Bekaert is assumed to be correct and thus without Bekaert's responsibility. Assumptions made by Bekaert are evident for successful execution and thus have to be verified by the project engineer.

This design is only valid for Dramix®-steel fibers. Violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation.
In case other fiber types than specified above or fibers of other manufacturers are used, this design is null and void. In such a case, Bekaert rejects any liability for this design and for the consequences of putting it in practice. The same holds for applying this design to any other than the described application or project.

References

design	AS 3600:2018: Australian Standard - Concrete structures DAfStb: Technical Rule on Steel Fibre Reinforced Concrete, November 2012 EN 1992-1-1 *fib* Model Code 2010 IAPMO UES ER-465, North American Requirements for the design of Dramix Fiber-Reinforced Concrete members and Systems (US-BD-19) NZS 3101:2006: New Zealand Standard - Concrete structures standard RILEM TC 162-TDF: Test and design methods for steel fibre reinforced concrete SS 812310:2014: Fibre Concrete - Design of Fibre Concrete Structures
post crack strength	Test Report NA
materials	EN 206-1 and relevant national standards EN 10080 and relevant national standards EN 14889-1 and relevant national standards

Liability

Dramix® steel fibers, where added to concrete, will enable the latter to transfer stresses over a cracked section. In this respect, "Dramix® Section Design" is meant to be a methodology that is to allow the users of the Dramix® steel fibers (where such fibers are added to concrete) to determine the bending moment capacity of Dramix® steel fiber reinforced concrete, also in a combination with traditional reinforcement. The limitations of the methodology are explained in the design note, see above.

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Finally, this design note does not relieve others to test the material properties, especially post-crack tensile strength, of the Dramix® steel fiber reinforced concrete according to the standards stated above and other applicable requirements.

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Moment Capacity for Dramix® Steel Fiber Reinforced Concrete in User Defined ULS for CIP

Detailed Design Note and Basic Theory

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This calculation must not be applied to any other application or project than what is being mentioned below.

Project	**Fotu La Tunnel**
object	E1300
street	Cross Passage
location	Side wall Top
remark	Hybrid
Customer	**Rites**
street	-
location	-
e-mail	-
phone	INPUT
contact	INPUT
internet	INPUT
date	25-2-2025

This report was prepared by:

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Moment Capacity 4.0.2

Terms and Definitions

α_{cc}	is the coefficient taking account of long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied.
α_{char}	is the coefficient taking account of the variation of the material properties for the selected application
α_{sys}	is the coefficient taking account of effects due to fibre orientation, size and load redistribution for the selected application (if applicable)
$\alpha_{R,c}$	is a coefficient for the calculation of the resulting compressive force
$A_{s,1}$	is the cross sectional area of the bending reinforcement
b	is the width of the cross section, for panel-type sections it is 1000 mm/m
c_{nom}	is the nominal concrete cover of the reinforcing bars (if any)
d	is the effective depth of a cross-section, with d = h for "fibers only" and d = d for combined reinforcement
d_s	is the bar diameter
ε_c	is the actual compressive strain in the concrete
ε_{cu}	is the ultimate compressive strain in the concrete
ε^f_{ct}	is the actual tensile strain in the steel fiber concrete
$\varepsilon^f_{ct,max}$	is the ultimate tensile strain in the steel fiber concrete
E_s	is the design value of the modulus of elasticity of the reinforcing steel
ε_{s1}	is the actual tensile strain in the reinforcing steel
ε_{su}	is the ultimate tensile strain in the reinforcing steel
f_{cd}	is the design value of the concrete compressive strength
f_{ck}	is the characteristic value of the concrete compressive strength
F_{cd}	is the design value of the force in the compression zone
F^f_{ct}	is the design value of the force in the tension zone due to the steel fiber concrete
$f_{R1,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 0.5 mm
$f_{R3/4,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 2.5 / 3.5 mm
$F_{s1,d}$	is the design value of the force in the tension zone due to the reinforcing bars
f_{yd}	is the design yield strength of the reinforcement
f_{yk}	is the characteristic yield strength of the reinforcement
γ_c	is the partial factor for concrete in compression
γ^f_{ct}	is the partial factor for steel fiber concrete in tension
γ_s	is the partial factor for reinforcing steel
h	is the overall depth of a cross-section
k_a	is a coefficient for the calculation of lever arm of the resulting compressive force
κ_h	is a coefficient to compensate for scaling effects
m_{Rd}	the resisting bending moment for a width of 1 m/m
N	is the external axial force applied to the section (compression force: negative sign)
$\sigma(\varepsilon)_d$	is the design value of the steel fiber reinforced concrete in tension, based on ε^f_{ct}
σ_{2d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R1,m}$
σ_{3d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R4,m}$
$\sigma_{s1,d}$	is the design stress of the reinforcing steel, based on ε_{s1}
x	is the depth of the compression zone
z_{cd}	is the distance from F^f_{cd} to the neutral axis of the cross section
z_{fd}	is the distance from F^f_{ct} to the neutral axis of the cross section
z_{s1}	is the distance from $F_{s1,d}$ to the neutral axis of the cross section
z_N	is the distance from N to the neutral axis of the cross section

Practical Recommendations and Conditions

Working joints have to be planned and detailed accurately according to the requirements. The effect of fibers must not be taken into account in the working joint. Thus additional rebar has to be placed there.

From experience, a steel fiber concrete with

- slump S3 / flow slump F3 or higher
- maximum aggregate size 16mm
- sieve curve B16

has proven to work.

Please consult Bekaert for further recommendations, mixing and dosing instructions.

A minimum distance in between the reinforcement of ~1,5•(fibre length) is recommended. Smaller distances may be possible but should be checked on beforehand. If so and also in any case of doubt, a preliminary test is always recommended.

In order to avoid a sieve effect, additional reinforcement (if any) has to be placed accurately, especially in the overlap zone.

General Remarks

This calculation refers to a specific application and is thus part of an overall design.

It has to be applied in this context and must not be used as a standalone design.

Area of Application

On the following pages, the bending moment capacity of a "Fiber only" or of a combined reinforced concrete section is determined.
However, checking the applicability of this bending moment to a certain structure is not part of this calculation. This has to be verified in a separate step.

Area of Application: CIP, User Defined ULS, slab type section

Design Approach

The moment capacity is calculated on the basis of: fib Model Code 2010

$$\sigma_{1d} = 1.0 \cdot f_{ctm} \cdot \max\{1.6m - d; 1.0\} \ (\text{f}_{\text{ctm}} \text{ used})$$

$$= \sigma_{2d} \ (\text{f}_{\text{ctm}} \text{ not used})$$

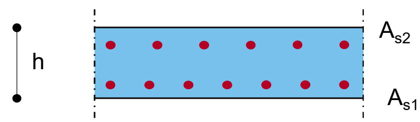
$$\sigma_{2d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R1} \cdot f_{R1,m} / \gamma^f{}_{ct}$$

$$\sigma_{3d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R3} \cdot f_{R3,m} / \gamma^f{}_{ct}$$

Input Data

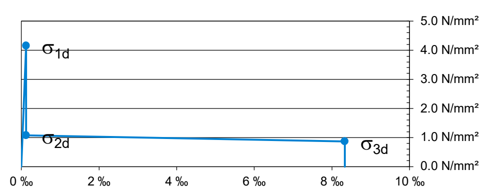
Design Parameters	slab type section		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		
characteristic factor α_{char}	0.90	[-]	
external axial force N	0.00	[kN/m]	(compression force: negative sign)
system factor α_{sys}	1.00	[-]	

Geometry: slab type section		
h	300	[mm]
h_2	-	[mm]
h_1	-	[mm]
h_w	-	[mm]
b_2	-	[mm]
b_1	1000	[mm/m]
b_w	-	[mm]



Steel Fibre Concrete			
effective depth d	300	[mm]	
concrete class	C35/45		
characteristic strength f_{ck}	35	[N/mm²]	
partial factor γ_c	1.50	[-]	
factor α_{cc}	0.85	[-]	
α_{R1}: $f_{R1m} \rightarrow \sigma_2$	0.45	[-]	(conversion factor flexion → tension)
α_{R3}: $f_{R3m} \rightarrow \sigma_3$	0.32	[-]	(conversion factor flexion → tension)
$f_{R1,m}$	4.00	[N/mm²]	(test report NA)
$f_{R3,m}$	4.50	[N/mm²]	(test report NA)
κ_h	1.00	[-]	
partial factor γ^f_{ct}	1.50	[-]	
Dramix® fiber type	Dramix 4D 80/60 BGP		(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³		(test report NA)

Constitutive Law for Steel Fibre Concrete: σ - ε



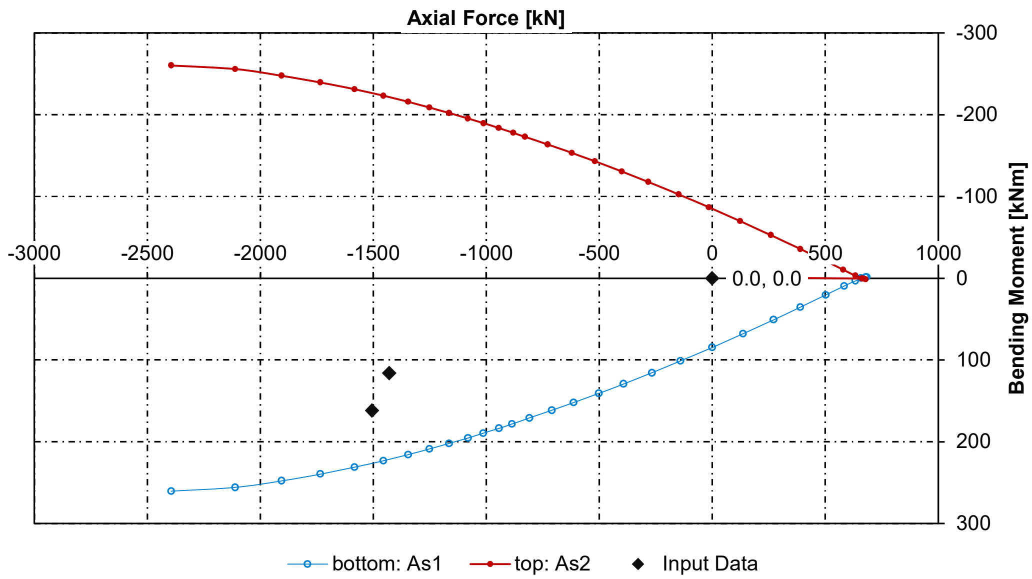
σ -w / σ - ε

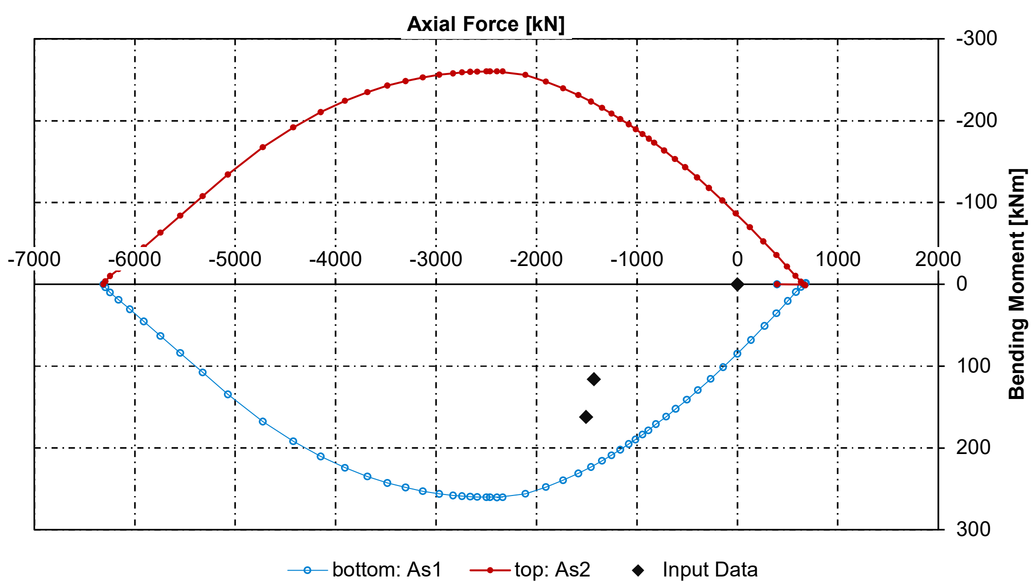
w_u	2.5	[mm]
l_{cs}	300	[mm]
ε_u	8.3	[‰]

Reinforcement		
yield strength f_{yk}	500	[N/mm²]
partial factor γ_s	1.15	[-]
E-modulus	2,00,000	[N/mm²]

Reinforcement A_{s1}	(bottom)		**Reinforcement A_{s2}**	(top)	
effective depth d	244	[mm]	effective depth d	244	[mm]
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]

M-N-Envelope





Input Data - N	-1430.0	0.0	-1506.0	0.0	0.0		N
Input Data - M	116.0	0.0	162.0	0.0	0.0		M

Conclusion and Proposal: CIP, User Defined ULS

This calculation is not a design on its own!

This calculation is part of an overall design and has to be applied within this context. It must not be used for any other application than described in this design note or for any other project.

5D4D3D

Moment Capacity	**slab type section**				
design approach	fib Model Code 2010				
safety factors	CIP, User Defined ULS				
reinforcement layout	Combined				
Geometry: slab type section					
h	300	[mm]			
b_1	1000	[mm/m]			
Fiber Concrete					
concrete class	C35/45				
residual strength $f_{R1,m}$	4.00	[N/mm²]			(test report NA)
residual strength $f_{R3,m}$	4.50	[N/mm²]			(test report NA)
Steel Fibers					
Dramix® fiber type	Dramix 4D 80/60 BGP				(EN 14889-1: System '1' - Structural Use)
dosage	25 kg/m³				(test report NA)
Reinforcement					
yield strength f_{yk}	500	[N/mm²]			
Reinforcement A_{s1}	(bottom)		**Reinforcement A_{s2}**	(top)	
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
rebar cross section / m	452	[mm²/m]	rebar cross section / m	452	[mm²/m]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]
Bending Moment Capacity: see M-N-Envelope					
$\mathbf{M_{Rd}}$	**n/a**				
N	n/a				

Data Base 2.1.0
Moment Capacity 4.0.2

3

Remarks

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References

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post crack strength	Test Report NA
materials	EN 206-1 and relevant national standards EN 10080 and relevant national standards EN 14889-1 and relevant national standards

Liability

Dramix® steel fibers, where added to concrete, will enable the latter to transfer stresses over a cracked section. In this respect, "Dramix® Section Design" is meant to be a methodology that is to allow the users of the Dramix® steel fibers (where such fibers are added to concrete) to determine the bending moment capacity of Dramix® steel fiber reinforced concrete, also in a combination with traditional reinforcement. The limitations of the methodology are explained in the design note, see above.

Whereas BEKAERT is confident with the scientific quality of "Dramix® Section Design" and whereas, as a result thereof, BEKAERT warrants the validity of the software and the resulting calculation as a methodology, BEKAERT is nevertheless unable to have an insight in (and a control over) the correctness of the data (such as but not limited to correct geometry, materials and design conditions) that are actually being used by others for the purpose of any calculation that is being made on the basis of the software.

In addition, BEKAERT is also unable to have an insight in (and a control over) the respect by others of the conditions (such as but not limited to the mixing of Dramix® steel fibers with concrete according to BEKAERT specifications, the timely curing of the concrete, the use of adequate concrete composition) that are precedent to Dramix® steel fiber reinforced concrete performing as intended.

In respect of what precedes, BEKAERT hereby declines any liability whatsoever for losses and/or damages of whatever kind (and sustained by whomever) that might result either from use by others of erroneous data (where used for the purpose of any calculation that is being made on the basis of the software) or from disrespect by others of any of the conditions that are precedent to Dramix® steel fiber reinforced concrete performing as intended. BEKAERT can not be considered to be nor to become an architect and/or building engineer on the sole basis of BEKAERT providing to others this design note and in the same respect, BEKAERT can not be considered to accept any of the liabilities that may possibly devolve on architects and/or building engineers.

This calculation is part of an overall design and has to be applied in this context. It must not be used for any other application than mentioned in this calculation or for any other project. In any case, this calculation is not a stand alone design.

Finally, this design note does not relieve others to test the material properties, especially post-crack tensile strength, of the Dramix® steel fiber reinforced concrete according to the standards stated above and other applicable requirements.

By the single fact of utilizing this design note, the user accepts and agrees that this utilization is considered to be done or to have been done under the terms and conditions stated above. By the same fact, the user agrees to waive all rights of subrogation against BEKAERT and/or to hold BEKAERT harmless from and against all claims for all losses and/or damages (of whatever kind and by whomever sustained) for which BEKAERT, pursuant to what precedes, declines liability.

This design note may not be used for any other purpose than for making calculations in respect of the Dramix® steel fibers; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation. At all times, the rights of intellectual property over this design note will remain vested in BEKAERT; the single fact of the utilization by others of this design note can under no circumstances be considered to constitute a transfer to others of the rights of intellectual property over this design note. The sales of this design note (and/or the commercializing thereof in any other way) to others is strictly prohibited; violation hereof shall entail legal proceedings by BEKAERT in view of indemnification of all losses that BEKAERT may sustain as a result of such violation.

Moment Capacity for Dramix® Steel Fiber Reinforced Concrete in User Defined ULS for CIP

Detailed Design Note and Basic Theory

This calculation must be used within the context of an overall design.

This calculation is only valid for Dramix® steel fibres.
Using fibers of any other kind is strictly prohibited and Bekaert will refuse any liability or warranty.

This calculation must not be applied to any other application or project than what is being mentioned below.

Project	**Fotu La Tunnel**
object	E750
street	Cross Passage
location	Crown
remark	Hybrid

Customer	**Rites**
street	-
location	-
e-mail	-
phone	INPUT
contact	INPUT
internet	INPUT

date	25-2-2025

This report was prepared by:

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Moment Capacity 4.0.2

Terms and Definitions

α_{cc}	is the coefficient taking account of long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied.
α_{char}	is the coefficient taking account of the variation of the material properties for the selected application
α_{sys}	is the coefficient taking account of effects due to fibre orientation, size and load redistribution for the selected application (if applicable)
$\alpha_{R,c}$	is a coefficient for the calculation of the resulting compressive force
$A_{s,1}$	is the cross sectional area of the bending reinforcement
b	is the width of the cross section, for panel-type sections it is 1000 mm/m
c_{nom}	is the nominal concrete cover of the reinforcing bars (if any)
d	is the effective depth of a cross-section, with d = h for "fibers only" and d = d for combined reinforcement
d_s	is the bar diameter
ε_c	is the actual compressive strain in the concrete
ε_{cu}	is the ultimate compressive strain in the concrete
ε^f_{ct}	is the actual tensile strain in the steel fiber concrete
$\varepsilon^f_{ct,max}$	is the ultimate tensile strain in the steel fiber concrete
E_s	is the design value of the modulus of elasticity of the reinforcing steel
ε_{s1}	is the actual tensile strain in the reinforcing steel
ε_{su}	is the ultimate tensile strain in the reinforcing steel
f_{cd}	is the design value of the concrete compressive strength
f_{ck}	is the characteristic value of the concrete compressive strength
F_{cd}	is the design value of the force in the compression zone
F^f_{ct}	is the design value of the force in the tension zone due to the steel fiber concrete
$f_{R1,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 0.5 mm
$f_{R3/4,m}$	is the mean residual flexural strength of steel fiber concrete according to EN 14651, at a crack mouth opening displacement of 2.5 / 3.5 mm
$F_{s1,d}$	is the design value of the force in the tension zone due to the reinforcing bars
f_{yd}	is the design yield strength of the reinforcement
f_{yk}	is the characteristic yield strength of the reinforcement
γ_c	is the partial factor for concrete in compression
γ^f_{ct}	is the partial factor for steel fiber concrete in tension
γ_s	is the partial factor for reinforcing steel
h	is the overall depth of a cross-section
k_a	is a coefficient for the calculation of lever arm of the resulting compressive force
κ_h	is a coefficient to compensate for scaling effects
m_{Rd}	the resisting bending moment for a width of 1 m/m
N	is the external axial force applied to the section (compression force: negative sign)
$\sigma(\varepsilon)_d$	is the design value of the steel fiber reinforced concrete in tension, based on ε^f_{ct}
σ_{2d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R1,m}$
σ_{3d}	is the design value of the steel fiber reinforced concrete in tension, based on $f_{R4,m}$
$\sigma_{s1,d}$	is the design stress of the reinforcing steel, based on ε_{s1}
x	is the depth of the compression zone
z_{cd}	is the distance from F^f_{cd} to the neutral axis of the cross section
z_{fd}	is the distance from F^f_{ct} to the neutral axis of the cross section
z_{s1}	is the distance from $F_{s1,d}$ to the neutral axis of the cross section
z_N	is the distance from N to the neutral axis of the cross section

Practical Recommendations and Conditions

Working joints have to be planned and detailed accurately according to the requirements. The effect of fibers must not be taken into account in the working joint. Thus additional rebar has to be placed there.

From experience, a steel fiber concrete with

- slump S3 / flow slump F3 or higher
- maximum aggregate size 16mm
- sieve curve B16

has proven to work.

Please consult Bekaert for further recommendations, mixing and dosing instructions.

A minimum distance in between the reinforcement of ~1,5•(fibre length) is recommended. Smaller distances may be possible but should be checked on beforehand. If so and also in any case of doubt, a preliminary test is always recommended.

In order to avoid a sieve effect, additional reinforcement (if any) has to be placed accurately, especially in the overlap zone.

General Remarks

This calculation refers to a specific application and is thus part of an overall design.

It has to be applied in this context and must not be used as a standalone design.

Area of Application

On the following pages, the bending moment capacity of a "Fiber only" or of a combined reinforced concrete section is determined.
However, checking the applicability of this bending moment to a certain structure is not part of this calculation. This has to be verified in a separate step.

Area of Application: CIP, User Defined ULS, slab type section

Design Approach

The moment capacity is calculated on the basis of: fib Model Code 2010

$$\sigma_{1d} = 1.0 \cdot f_{ctm} \cdot \max\{1.6m - d; 1.0\} \text{ (}f_{ctm}\text{ used)}$$

$$= \sigma_{2d} \text{ (}f_{ctm}\text{ not used)}$$

$$\sigma_{2d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R1} \cdot f_{R1,m} / \gamma^f{}_{ct}$$

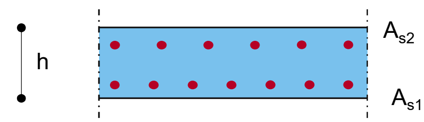
$$\sigma_{3d} = \alpha_{sys} \cdot \alpha_{char} \cdot \kappa_h \cdot \alpha_{R3} \cdot f_{R3,m} / \gamma^f{}_{ct}$$

Input Data

Design Parameters	slab type section		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		
characteristic factor α_{char}	0.90	[-]	
external axial force N	0.00	[kN/m]	(compression force: negative sign)
system factor α_{sys}	1.00	[-]	

Geometry: slab type section

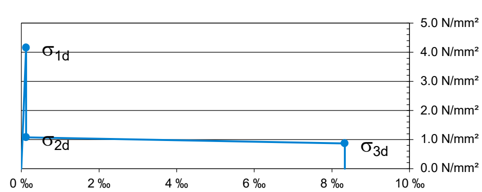
h	300	[mm]
h_2	-	[mm]
h_1	-	[mm]
h_w	-	[mm]
b_2	-	[mm]
b_1	1000	[mm/m]
b_w	-	[mm]



Steel Fibre Concrete

effective depth d	300	[mm]	
concrete class	C35/45		
characteristic strength f_{ck}	35	[N/mm²]	
partial factor γ_c	1.50	[-]	
factor α_{cc}	0.85	[-]	
$\alpha_{R1}: f_{R1m} \rightarrow \sigma_2$	0.45	[-]	(conversion factor flexion → tension)
$\alpha_{R3}: f_{R3m} \rightarrow \sigma_3$	0.32	[-]	(conversion factor flexion → tension)
$f_{R1,m}$	4.00	[N/mm²]	(test report NA)
$f_{R3,m}$	4.50	[N/mm²]	(test report NA)
κ_h	1.00	[-]	
partial factor γ^f_{ct}	1.50	[-]	
Dramix® fiber type	Dramix 4D 80/60 BGP		(EN 14889-1: System '1' - Structural Use)
dosage	40 kg/m³		(test report NA)

Constitutive Law for Steel Fibre Concrete: σ - ε



σ -w / σ - ε

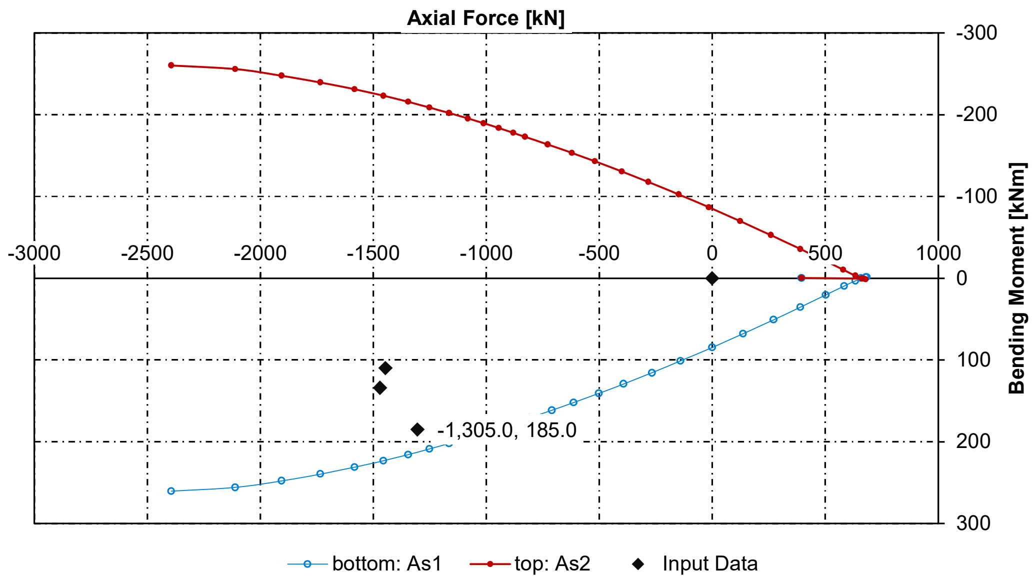
w_u	2.5	[mm]
l_{cs}	300	[mm]
ε_u	8.3	[‰]

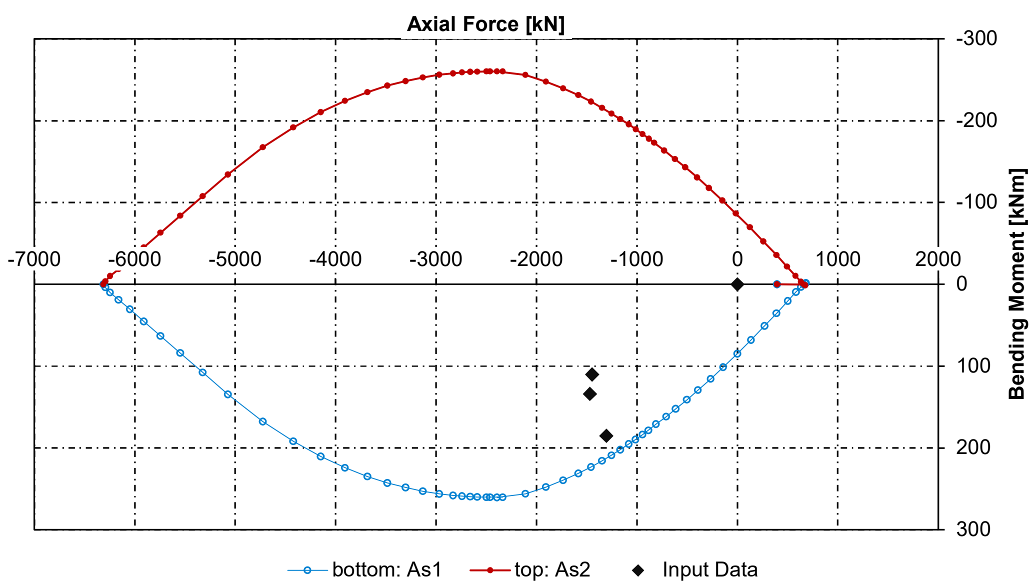
Reinforcement

yield strength f_{yk}	500	[N/mm²]
partial factor γ_s	1.15	[-]
E-modulus	2,00,000	[N/mm²]

Reinforcement A_{s1} (bottom)			**Reinforcement A_{s2}** (top)		
effective depth d	244	[mm]	effective depth d	244	[mm]
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]

M-N-Envelope





Input Data - N	-1470.0	-1305.0	-1446.0	0.0	0.0	N
Input Data - M	134.0	185.0	110.0	0.0	0.0	M

Conclusion and Proposal: CIP, User Defined ULS

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Moment Capacity — **slab type section**

design approach	fib Model Code 2010		
safety factors	CIP, User Defined ULS		
reinforcement layout	Combined		

Geometry: slab type section

h	300	[mm]
b_1	1000	[mm/m]

Fiber Concrete

concrete class	C35/45		
residual strength $f_{R1,m}$	4.00	[N/mm²]	(test report NA)
residual strength $f_{R3,m}$	4.50	[N/mm²]	(test report NA)

Steel Fibers

Dramix® fiber type	Dramix 4D 80/60 BGP	(EN 14889-1: System '1' - Structural Use)
dosage	40 kg/m³	(test report NA)

Reinforcement

yield strength f_{yk}	500	[N/mm²]

Reinforcement A_{s1}	(bottom)		**Reinforcement A_{s2}**	(top)	
bar diameter d_s	12	[mm]	bar diameter d_s	12	[mm]
bar distance s	250	[mm]	bar distance s	250	[mm]
rebar cross section / m	452	[mm²/m]	rebar cross section / m	452	[mm²/m]
concrete cover c_{nom}	50	[mm]	concrete cover c_{nom}	50	[mm]

Bending Moment Capacity: see M-N-Envelope

M_{Rd}	**n/a**
N	n/a

Data Base 2.1.0
Moment Capacity 4.0.2

3

Remarks

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post crack strength	Test Report NA
materials	EN 206-1 and relevant national standards EN 10080 and relevant national standards EN 14889-1 and relevant national standards

Liability

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