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Design of Concrete Lining for Head Race Tunnel using STAAD

Singh Adarsh

Department of Civil Engineering, CBS Group of Institutions, Fatehpui, Jhajjar, Haryana, India
Affilated to Maharishi Dayanand University,

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Abstract - *Tunnels are enclosed underground passageway except for entrance and exit, dug through the surrounding rock/soil/earth. So, head race tunnel is underground excavated tunnel used to carry water to the powerhouse form the reservoir. Lining of the tunnel is done to minimize the headloss, limit the seepage flow in addition to increase the stability of tunnel and avoiding rock particles to enter the turbine and prevent is from damage. Therefore, its careful design is important.*

Key Words: Head Race Tunnel, Concrete Lining, Induced tensile stress, Induced compressive stress, maximum permissible tensile stress, maximum permissible compressive stress, radial and tangential spring stiffnesses.

1. INTRODUCTION

The headrace Tunnel carries water from intake to the power house by connecting the de-silting chamber to the surge shaft, from where water is further carried to turbines in power house. From constructability point of view a D-Shape or a modified D-Shape tunnel is preferred as it gives better progress for small size tunnel. The size of the tunnel shall be such that the equipment being used for construction can maneuver easily for good progress of the tunnel boring. However, the finished shape of the tunnel may be different – circular, horse-shoe, modified horse-shoe, D-shape or egg shaped. Structurally a circular shape tunnel is preferable than a D-shape tunnel. Horseshoe or modified-horse shape tunnel is a compromise between circular and D-shape sections. This paper covers concrete lining design of head race tunnel.

The tunnel would be concrete lined in its entire length; thickness of lining will vary depending upon the type of rock and water pressure.

2. CONCRETE LINING

The tunnel is excavated using the conventional drill and blast method. After excavation, adequate rock support measures are taken to avoid collapsing of rocks. The excavation profile is monitored for convergence of opening. With passage of time the deformations will stabilize and reach equilibrium. After attainment of this stage, lining is to be provided. Head race tunnel lining is concrete lined due to following reasons-

- Minimize the head losses due to friction in the tunnel.
- Prevent/ limit the seepage flows
- Prevent the loose rock particles entry into turbine by preventing erosion and washing out of joint fillings
- Ensure long term stability of tunnel under varying hydrostatic and hydrodynamic load conditions.

The concrete lining of headrace tunnel is essentially planned as un-reinforced that is easier to place, has better quality and is more durable. Leakage into and from the tunnel is effectively reduced by systematic grouting the rock around tunnel. However, in reaches where the tunnel will pass through very poor rock (Class V) or tunnel rock cover is low, reinforced concrete lining may be required. Design of reinforced concrete lining shall be carried out during execution stage as per actual site condition.

The choice of lining thickness is generally based on practical considerations; as a preliminary estimate, IS:4880 (Part IV): 1971, clause 7.2 recommends a lining thickness of about 6cm for every m of finished diameter of tunnel (circular), with a practical minimum for successful concreting of 150mm for unreinforced concrete and 300mm for reinforced concrete. **Thickness of lining shall be such that the induced stress in concrete does not exceed the allowable stress for particular grade of concrete.**

3. DESIGN LOAD

Loads acting of concrete lining and their use in design are discussed below:-

3.1 Dead Load

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

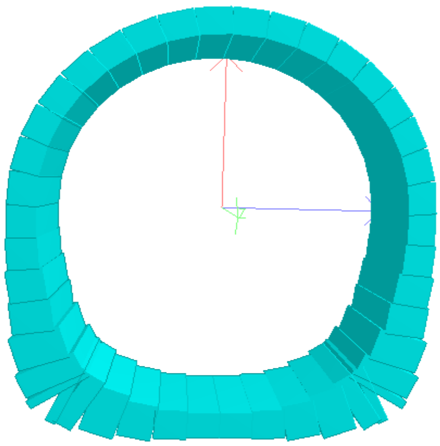


Fig 1- Horse- Shoe Shaped Concrete Lining of Head Race Tunnel

3.2 Internal Hydrostatic Pressure:

The hydrostatic pressure acting on concrete lining internally is equivalent to a column of water calculated as difference between full reservoir level and tunnel invert at any particular location.

During the initial filling of the tunnel, the water pressure in the surrounding rock will start to increase. Due to presence of radial and longitudinal cracks in lining (due to shrinkage, temperature, construction joints), there is a tendency of balancing of pressure on either side of tunnel. Due to time lag in balancing of the pressure, some net internal pressure will act on the lining at any given time during the filling up operation. Evidently, location of maximum internal pressure will be just upstream of surge shaft.

Maximum internal pressure head acting on the lining (at tunnel section just upstream of surge shaft) is calculated as:

hi = FRL – Tunnel invert

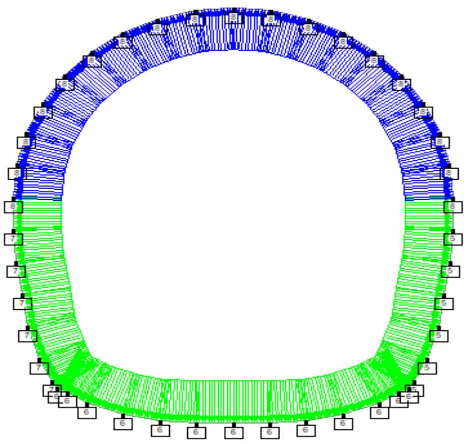


Fig 2- Internal Water Pressure on Concrete Lining

3.3 Transient Hydrostatic Pressure:

During transient surge condition, the time period of the hydraulic transient being very small, the external and internal water pressure would not have sufficient time to balance out and some differential pressure will, therefore, will be exerted on the lining. However, effect of this transient loading during normal operation is much less compared to initial filling of tunnel condition, hence can be ignored while calculation.

3.4 External Hydrostatic Pressure

During dewatering of tunnel, the internal pressure on the lining is reduced to zero and external pressure will develop due to pressure exerted by water from outside. The headrace tunnel section near upstream of surge shaft will be subject to maximum external pressure, as external pressure is calculated as the difference between full reservoir level and invert of tunnel at location of interest.

Thus, maximum external pressure head working on the lining:

hext = FRL – Tunnel invert near surge shaft

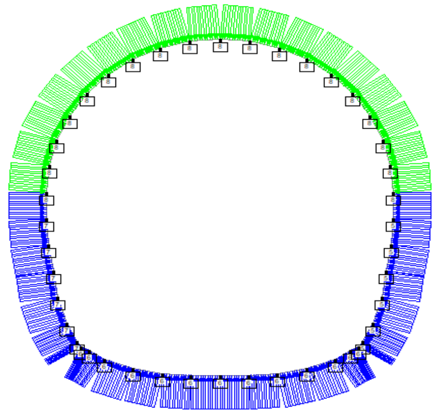


Fig 3- External Water Pressure on Concrete Lining

3.5 Grouting Pressure

Contact grouting/ consolidated grouting is to be done between the lining and the surrounding rock mass to ensure uniform contact and proper transfer of internal water pressure from lining to the rock mass.

Generally contact grouting is done at assumed maximum pressure and the lining design has to be verified to safely resist this grout pressure.

After completion of excavation, concrete lining of tunnel is started. The assumed contact grouting pressure, act on lining as external pressure. The lining thickness is checked for its adequacy.

Also, maximum permitted grout pressure over area on the lining is equal to one-quarter of the tunnel diameter (as shown in Figure-4), and a maximum of 1.5 m (i.e.5ft) (Refer US Army Corps of Engineers, EM-1110-2-2901, Box 9-1, Page 9-8).

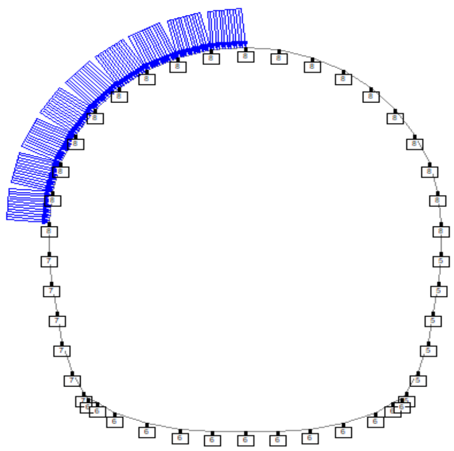


Fig 4- Grouting Pressure (Critical) on Concrete Lining

3.6 Rock Loads

Due to considerable time difference between tunnel excavation and installation of concrete lining, all rock loads are assumed to be fully supported by permanent rock supports.

Relaxation of rock and stress redistribution is considered to be fully stabilized prior to installation of concrete lining. As such, no rock loads from excavation are assumed to be transferred to the lining or may vary as per site condition.

3.7 Seismic Loads

Generally location of Headrace tunnel is underground where super-incumbent cover varies, due to this cover the effect of ground motion will reduce substantially. Because of the fact that the lining is in direct contact with fully grouted surrounding rock, during earthquake the system will oscillate as a single unit. Thus, there will not be any dynamic loading on the concrete lining. Due to this reason, seismic loads are not considered for the design of lining.

3.8 Temperature Loads

Temperature difference on either side of lining is assumed to be insignificant; as such temperature loading has not been accounted for the design of Tunnel.

4. LOAD COMBINATIONS

During the service life of the tunnel, tunnel lining is subjected to different loading conditions. Combinations to be considered for analysis are:-

(i) Normal Operation Case

External and internal water pressures are balanced due to water seepage through the concrete (due to presence of radial and longitudinal cracks in lining) and surrounding rock.

(ii) Initial Water-filling Case

External water pressure has not yet had time to balance the internal water pressure, resulting internal water pressure to act outwards.

(iii) Tunnel Dewatering Case

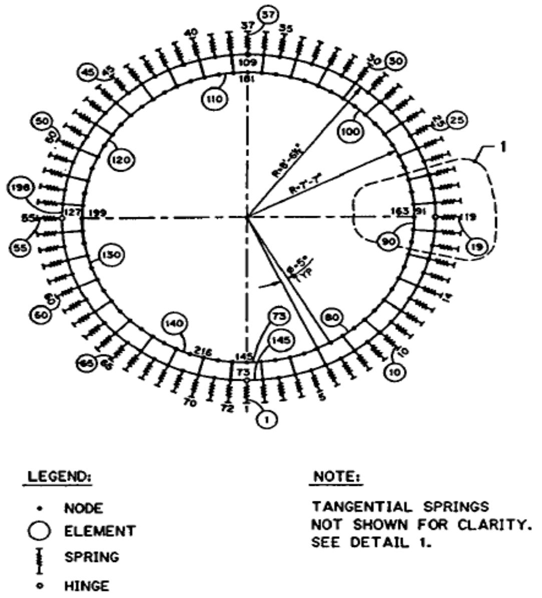
Intake gate closed; the tunnel has drained through the turbine while the wicket gate is closing. So, External water pressure is acting inwards.

(iv) Tunnel Construction Case

Loading due to grouting during construction

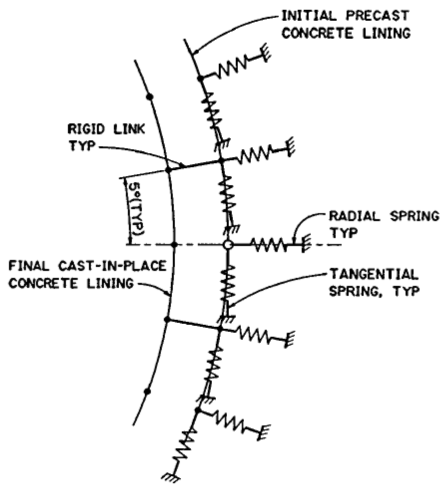
5. FEM ANALYSIS

FEM analysis can be carried out using STAAD Pro software. Beam elements have been modeled to analyze the structure. Compression only surface spring (modulus of subgrade reaction) is considered to generate the support condition. Tangential and radial springs are applied at each node to simulate elastic interaction between the lining and the rock. The interface between lining and rock cannot withstand tension; therefore, interface elements may be used or the springs deactivated when tensile stresses occur. Thus, rock participation wherever required will be taken care of by this compression only spring. The radial and tangential Spring stiffnesses for unit length of tunnel lining is worked out based on US Army Corps of Engineers, EM-1110-2-2901 by using following formula:-



BEAM-SPRING MODEL

BEAM-SPRING MODEL



DETAIL 1

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

$K_t = K_r / (G.E_r) = 0.5\ K_r / (1+\mu_r)$

Where, K_r and K_t = radial and tangential spring stiffnesses respectively

G = shear modulus

θ = arc substended by the beam element (radian)

b = length of tunnel element considered

The value for modulus for deformation, E_r can be obtained from equations in EM-1110-2-2901 or can be calculated by using geotechnical design data i.e. GSI, mi, D (disturbance factor) etc. on software like Roclab.

All the possible loads are applied under suitable load combinations and analyzed. Analysis is done using software and induced stresses in the lining are obtained and thickness of lining shall be such that the induced stress in concrete does not exceed the allowable stress for particular grade of concrete which is being used for lining.

The stress diagram obtained for the various loading combinations are as follows:

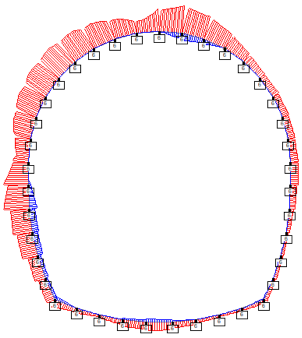


Fig 5- Stress in Concrete Lining due to Grouting Pressure during Construction

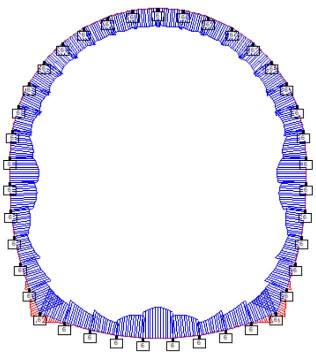


Fig 6- Stress in Concrete Lining during Initial Filling Condition

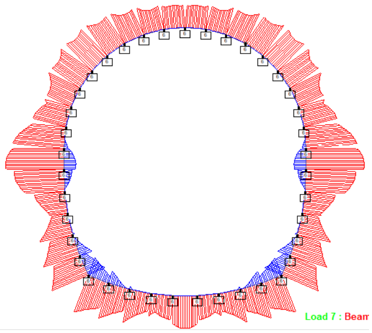


Fig 7- Stress in Concrete Lining during Dewatering Condition

Now, here is an example to illustrate the design of lining for head race tunnel on STAAD.

Let us consider a case where, the tunnel invert level be EL 1025.76 m and FRL be EL 1080.60m. Now, calculating all the value as discussed above and putting it in STAAD.

A horse-shoe concrete lining of 225 mm is made, taking the centre of lining distributing the lining in beam elements of equal size.

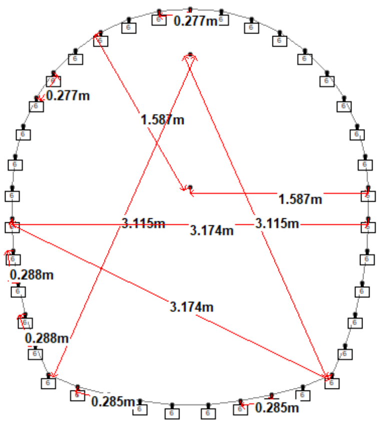


Fig 8- Horse- Shoe Concrete Lining in STAAD

Loads to be considered for analysis (Refer Figure 1,2,3 & 4) are –

1. Dead Load = Self weight of Concrete Lining
2. Internal Hydrostatic Pressure,

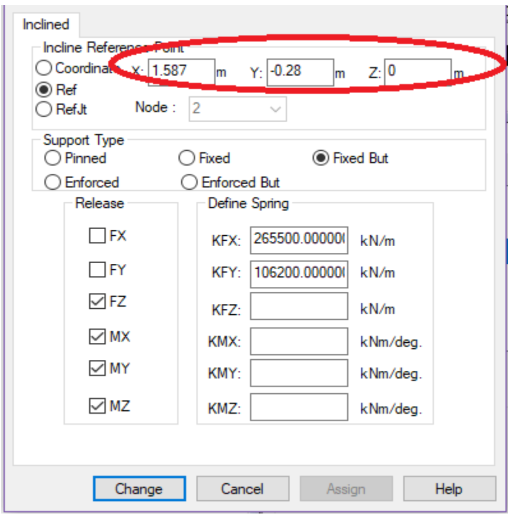
   Pi = (FRL – Tunnel invert level) x 9.8 kN/m
   = 0.5 (1080.6m – 1025.76m) x 9.8 ≈ 270.00 kN/m
   (head loss of about 50% may be safely considered)
3. External Hydrostatic Pressure,

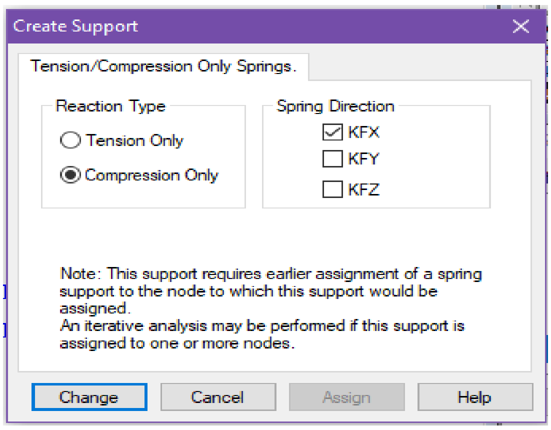
   Pe = (FRL – Tunnel invert level) x 9.8 kN/m
   = 0.5 (1080.6m – 1025.76m) x 9.8 ≈ 270.00 kN/m
   (head loss of about 50% may be safely considered)
4. Grout Pressure, Pg = 250 kN/m (assumed)

Modulus of deformation, Er for the rock is now calculated on basis of geotechnical design data using Roclab, comes to be 1780 N/mm2. Calculating Spring Stiffnesses using this value:-

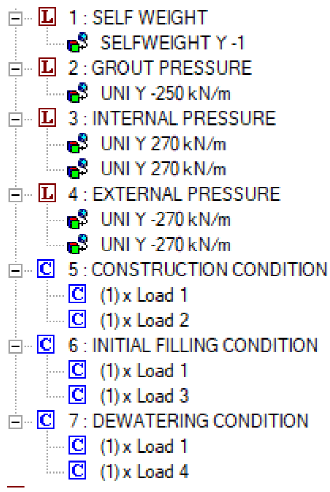
SUPPORT SPRING STIFFNESS			
Spring stiffness for unit length is worked out based on EM-1110-2-2901			
Radial Spring stiffness, Kr	=	Er.b.Φ / (1 + μr)	
Tangential Spring stiffness, Kt	=	Kr / (G.Er)	
	=	0.5 Kr / (1 + μr)	
Where,			
Modulus of Deformation for Rock Mass, Er	=	1780	N/mm^2
Width of Element under consideration, b	=	1000	mm
Average Length of outer member	=	0.275	m
Inner radius (width/2) of Lining	=	1.475	m
Lining Thickness	=	0.225	m
Outer radius (width/2) of Lining	=	1.7	m
Angle substended by the element in Radians (Φ= l/r)	=	0.186441	Radians
Poisson's Ratio of Rock, μr	=	0.25	
Radial Spring stiffness, Kr	=	265491.5	kN/m
Tangential Spring stiffness, Kt	=	106196.6	kN/m

The spring stiffnesses are assigned to the support and ref is defined (centre coordinates of radius of lining) for individual arc. The value of coordinates (for ref) changes according to centre of the arc on which that support is to be assigned. Also, the supports are defined as compression only.





Now, after assigning the supports and above calculated loads on the lining elements, critical load combinations are applied and lining is checked for loading conditions.



After analysis, the maximum tensile stress and maximum compressive Stress in N/mm2 and Stress diagram (refer figure-5,6 & 7) are obtained from post processing option, which is further compared with maximum allowable tensile and compressive Stress.

Table -1: Comparision of induced & allowable Stresses

Sl No	Loading Condition	Induced Stress in Lining due to applied Load			
		Max. Tensile Stress (N/mm2)	Element No. / Load Case	Max. Comp. Stress (N/mm2)	Element No. / Load Case
1.	Construction Condition	**2.381**	39 / 6	0.774	30 / 6
2.	Initial Filling Condition	1.795	31 / 7	**5.59**	20 / 7
3.	Dewatering Condition	0.945	26 / 5	3.343	14 / 5
Maximum Stress		2.381		5.59	
Permissible Stress (IS 456:2000) for M-25		3.2		8.5	
Result		**Safe**		**Safe**	

STAAD FILE
****

STAAD SPACE
START JOB INFORMATION
ENGINEER DATE 20-April-17
END JOB INFORMATION
INPUT WIDTH 79
UNIT METER KN
JOINT COORDINATES
2 1.587 0 0; 3 1.56289 0.27558 0; 4 1.49129 0.542786 0; 5 1.37438 0.7935 0;

```
6 1.21571 1.0201 0; 7 1.0201 1.21571 0; 8 0.7935 1.37438
0;
9 0.542786 1.49129 0; 10 0.27558 1.56289 0; 11
9.71725e-017 1.587 0;
12 -0.27558 1.56289 0; 13 -0.542786 1.49129 0; 14 -
0.7935 1.37438 0;
15 -1.0201 1.21571 0; 16 -1.21571 1.0201 0; 17 -1.37438
0.7935 0;
18 -1.49129 0.542786 0; 19 -1.56289 0.27558 0; 20 -1.587
1.94345e-016 0;
21 1.587 -0.28 0; 22 -1.587 -0.28 0; 23 1.57394 -0.567668
0;
24 1.53486 -0.852968 0; 25 1.47008 -1.13355 0; 26
1.38014 -1.40711 0;
27 1.26577 -1.67139 0; 28 -1.57394 -0.567668 0; 29 -
1.53486 -0.852968 0;
30 -1.47008 -1.13355 0; 31 -1.38014 -1.40711 0; 32 -
1.26577 -1.67139 0;
34 -1.00001 -1.77527 0; 35 -0.725863 -1.8544 0; 36 -
0.445624 -1.9081 0;
37 -0.161645 -1.93595 0; 38 1.00001 -1.77527 0; 39
0.725863 -1.8544 0;
40 0.445624 -1.9081 0; 41 0.161645 -1.93595 0;
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10 11 12;
11 12 13; 12 13 14; 13 14 15; 14 15 16; 15 16 17; 16 17 18;
17 18 19; 18 19 20;
20 20 22; 26 22 28; 27 28 29; 28 29 30; 29 30 31; 30 31 32;
31 32 34; 32 34 35;
33 35 36; 34 36 37; 39 37 41; 40 41 40; 41 40 39; 42 39 38;
43 38 27; 44 27 26;
45 26 25; 46 25 24; 47 24 23; 48 23 21; 49 21 2;
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POISSON 0.17
DENSITY 24
ALPHA 1e-005
DAMP 0.05
TYPE CONCRETE
STRENGTH FCU 25000
END DEFINE MATERIAL
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1 TO 18 20 39 49 PRIS YD 0.225 ZD 1
MEMBER PROPERTY INDIAN
26 48 PRIS YD 0.246 ZD 1
27 47 PRIS YD 0.291 ZD 1
28 46 PRIS YD 0.326 ZD 1
29 45 PRIS YD 0.4125 ZD 1
30 44 PRIS YD 0.5025 ZD 1
34 40 PRIS YD 0.258 ZD 1
33 41 PRIS YD 0.316 ZD 1
32 42 PRIS YD 0.4125 ZD 1
31 43 PRIS YD 0.5025 ZD 1
CONSTANTS
BETA 180 MEMB 20 26 TO 34 39 TO 49
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265500 KFY 106200
22 28 TO 31 INC REF 1.587 -0.28 0 FIXED BUT FZ MX MY
MZ KFX 265500 KFY 106200
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MZ KFX 265500 KFY 106200
27 32 34 TO 41 INC REF 0 1.175 0 FIXED BUT FZ MX MY
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SELFWEIGHT Y -1
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MEMBER LOAD
10 TO 18 UNI Y -250
LOAD 3 LOADTYPE None  TITLE INTERNAL PRESSURE
MEMBER LOAD
20 26 TO 34 39 TO 49 UNI Y 270
1 TO 18 UNI Y 270
LOAD 4 LOADTYPE None  TITLE EXTERNAL PRESSURE
MEMBER LOAD
1 TO 18 UNI Y -270
20 26 TO 34 39 TO 49 UNI Y -270
LOAD COMB 5 CONSTRUCTION CONDITION
1 1.0 2 1.0
LOAD COMB 6 INITIAL FILLING CONDITION
1 1.0 3 1.0
LOAD COMB 7 DEWATERING CONDITION
1 1.0 4 1.0
PERFORM ANALYSIS
FINISH
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6. CONCLUSION

The induced stresses in the lining i.e. maximum tensile stress and maximum compressive Stress are obtained in N/mm2 and thickness of lining shall be such that the induced stress in concrete does not exceed the allowable stress for particular grade of concrete which is being used for lining and in case the induced stress exceeds allowable stress, the lining thickness may be increased or reinforcement can be provided for the exceeding stress.

REFERENCES

[1] US Army Corps of Engineers (USACE), Tunnels and Shaft in Rock, EM-1110-2-2901

[2] Hydro Power Structures by R.S. Varshney

[3] IS 456:2017- Plain and Reinforced concrete-code of practice