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ANALYSIS AND DESIGN OF UNDERGROUND RECTANGULAR RCC TUNNEL

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Abstract: The seismic analysis and design of a underground rectangular tunnel is presented in this paper. Providing the strength, stability and ductility are major purposes of seismic design. It is necessary to design a structure to perform well under seismic force. The tunnel has the following geometric specification, a)length of tunnel is 100 m long and the tunnel is divided into two cells e ach cell have the clear span of 5.5 m and clear height of 5.5 m. And thickness of top slab, bottom slab and side wall is 600 mm uniform throughout. The tunnel is passing through hard murum whose geotechnical properties like dry density and safe bearing capacity 8 kN/m^2 and 200 kN/m^3 respectively. The height of hard murmu cushion over the top of the tunnel is 5 m. the present work is carried out for the design of tunnel for gravity load, following are the various loads taken for design such as self weight, overlying pressure, backfill pressure ,vehicular load i.e.70 R(T) Breaking force having the magnitude of 3.42 kN/m^2) etc. Design is carried out with reference to understanding the the construction sequence, application of various loads during construction as well as service life. The analysis and design of tunnel segment of 100 m length is carried out by manually as well as software for the various combinations of loads by using the seismic coefficient method. This study has impressed the incite of rare structure, broader the understanding the design concepts in structural domain and performance when subjected to natural hazard like seismic force.

Keywords: Seismic Analysis, RCC Tunnel,

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INTRODUCTION

AIM: Analysis of underground rectangular RCC tunnel subjected to seismic force.

OBJECTIVE:

1. To study the concept of tunnel
2. To study behavior of tunnel subjected to overlying loads, self weight and uplift pressure.
3. To study design concept of tunnel subjected to gravity loading.
4. To study design concept for tunnel subjected to seismic forces.
5. To analyses the tunnel for seismic force.
6. Comparing structural design for gravity loading and seismic loading.
7. To verified overall structural stability and seismic resistivity as per the relevant IS code.
8. Structure should resist the seismic force.

1. **GENERAL CONCEPT:**

Definition Of Tunnel: It is an artificial underground passage to bypass safely without disturbing the overburden i.e. land above it o carry freights, passengers, sewage water etc**.** A tunnel is an underground or underwater passageway, dug through the surrounding soil/earth/rock and enclosed except for entrance and exit, commonly at each end. A pipeline is not a tunnel, though some recent tunnels have used immersed tube construction techniques rather than traditional tunnel boring methods. A tunnel may be for foot or vehicular road traffic, for rail traffic, or for a canal. The central portions of a rapid transit network are usually in tunnel. Some tunnels are aqueducts to supply water for consumption or for hydroelectric stations or are sewers. Utility tunnels are used for routing steam, chilled water, electrical power or telecommunication cables, as well as connecting buildings for convenient passage of people and equipment**.**

Need:

The purpose of this study was to make the preliminary design and analysis of a underground tunnel subjected to seismic force.

- The preferred analysis and design as per IS-Code.

- There are number of tunnel are design for the gravity loading but the design with considering the effect of seismic force are carried out to reduced the structural damage.
- To design a tunnel for well performance under seismic loading.

2. Description Of Structure:

The tunnel has a width of 5.5 m in each box and clear height 5.5 m and length 100 m receptively. The height murum cushion on the top of the tunnel is 5 m. The tunnel is passed through hard murum having dry unit weight 18 kN/m^3.Safe bearing capacity of hard murum is 200 kN/m^2. And the coefficient of earth pressure in case of box-type tunnel is 0.5.

Main Features:

1. Tunnel carry a overburden pressure of hard murum having 5 m depth.

2. Backfill is available along the sides of each tunnel segment. And live surcharge is also available having a depth of 2 m

3. A box type tunnel is considered for design

Following are the properties of material through which tunnel is passing:-

MATERIAL DENSITIES:

Material	Dry density KN/m^3	Safe bearing capacity kN/m^2
Water	9.81	---
Murum	18	200
Backfill	18	200

Loads on Tunnel:

Following are the loads are acting on the tunnel

- Self weight
- Earth Pressure

- Water Pressure
- Uplift Pressure
- Live load
- Overlying pressure
- Temperature stresses
- Seismic force.

Self Weight:

The self-weight of the structure is the most critical because it is the biggest influence on the settlement of soil. Once the basic sizing is known, the self-weight can be calculated for use in structural design and settlement analysis. The weight of ventilation equipment and other M&E plants is not generally included in the permanent loadings as it has to be removed and replaced as part of the maintenance regime. This self weight is different at different stages due to changes in density of concrete. At this stage dry density of concrete is considered.

Overlying Pressure:-

It is the pressure of the earth above the slab of the tunnel element which is acting in downward direction. The depth for this is considered as 5 m. The earth above the tunnel element creates a huge amount of pressure on the top slab of the element. This earth pressure can be calculated as:-

Earth Pressure above the top slab=h x γd ………………….. Eq-1.1

Where:- 1)h= Dry density of earth

2) γd =Height of earth above the top of tunnel

• The most important potential loads acting on underground structures are earth/rock pressures and water pressure.

• Live loads due to vehicle traffic on the surface can be safely neglected, unless the tunnel is a cut and cover type with a very small depth of overburden.

• It may be generally stated, that the dimensioning of tunnel sections must be effected either against the overburden weight (geostatic pressure) or against loosening pressure (i.e. the weight of the loosened zone, called also protective or Trumpeter's zone).

• Design approach should include these elements:

• Experience, incorporating features of empiricism based on an understanding of ground characteristics and on successful practices in familiar or similar ground.

• Reason, using analytical solutions, simple or more complex as the situation may demand, based on a comprehensive data on the ground conditions

• Observation of the behaviour of the tunnel during construction, developing into monitoring with systematic pre-designed modification of supports.

• Lateral pressures are also much more affected by latent residual geological stresses introduced into the rock mass during its geological history which are released upon excavation and whose magnitude depends on the deformation suffered by, and the elasticity of the rock, but it is unpredictable. Genuine mountain pressure and swelling pressure that cannot be evaluated numerically may act in full on the sidewall

• Load due to Earth pressure can be calculated by following formula

• Load due to earth pressure= h x γd

• Where h=height of earth in m

• γd= dry density of earth material.

Live load:

Vehicular Load (Traffic Load):

Similar to transient vertical loads, the localized loads due to vehicles will need to be considered at the middle slab. The magnitude of the loads to apply will be as per IRC: 6-2010. According to IRC: 6-2010, the tunnel element is classified for IRC Class 70R loading and Class A loading case under clause 201.1. For both the cases analysis is done and results were obtained. Both the cases are described below in detail.

Case I: 70R loading

The design live load consists of standard wheeled vehicles as given in IRC. For each standard vehicle all the axles of a unit of vehicles shall be considered as acting simultaneously in a position causing maximum stresses.

Case II: Class A loading

Loading and analysis for this type of loading is 3.42 kN/m^2 ground contact area and wheel loads are according to clause 204.1.

Backfill Pressure:

The backfill provided over the sides of tunnel segment causes pressure on it. This backfill pressure is minimum at the upper slab and maximum at lower slab i.e. varying in a trapezoidal shape. The well compacted backfill material causes pressure on the side walls. The coefficient of earth pressure for water (Kw) is 1 and that for soil (K0) is 0.5 considering the rest condition. This pressure can be calculated as:-

Earth Pressure above the top slab:- =(dry density of earth x height of Backfill).

Temperature Stresses:

Concrete immersed tunnel elements are typically massive members that have a large thermal lag. Combined with being surrounded by an insulating soil backfill that maintains a relatively constant temperature, the temperature gradient across the thickness of the members can be measurable. But these loads will depend on local climate and seasonal changes. As the proposed site is not affective the drastic variation of temperature changes these loads are negligible.

c) area where road and railway meet a river at different level. To minimizing the above problem tunnel are provided for vehicular traffic.

- Basic study of geological, geotechnical. Hydrological data. Soil structure interaction geometry of structure etc are studied in brief.

3. Design Concept

Normal Design Concept:-

Normal design of tunnel is done for gravity loading only in this seminar work design of RCC tunnel for gravity loading is presented and the complete design is done by manually.

Loading Criteria:-

For Tunnel Structure:-

U=D+L+E1+E2 ………………………… Eq-4.1

Where

U = required structural strength capacity

D = effects due to dead loads of structural components

L = effects due to live loads

E1 = effects due to vertical loads of earth.

E2 = effects due to horizontal loads of earth.

In the normal design of a tunnel, only a gravity load is considered for design. For the load combination given in eq-4.1 design moment and shear force are calculated. For the calculation of design moment. Moment distribution methods are adopted. After getting all the design moment and shear force actual design is carried out as per the relevant I.S. code method.

4. Design Of Tunnel For Gravity Loading:-

Design Consideration:-

Design of underground rectangular tunnel for gravity loading:-

1) Clear span:-5.5 m

2) Height=5.5 m

3) Thickness of top slab=600 mm

4) Thickness of bottom slab=600 mm

5) Thickness of side wall=600 mm

6) Grade of concrete= M-30 mpa

7) Grade of steel=fe-500 mpa

8) Unit wt.of Murum= 18 kN/m3

9) Angle of repose=30°

10) Coefficient of active earth pressure=0.5

11) Total depth of murum cushion on top slab=5 m

12) SBC of soil=200 kN/m^2

Solution

Step 1. Loading Calculation

- loads on top slab=h x γd

= 5 x 18

= 90 kN/m^2

Self weight=bDγ

=1 x 0.6 x25

= 15 kN/m^2

Total load= 105kN/m^2

Factored load= 1.5 x 105

= 157.50 kN/m^2

- Loads On Bottom Slab

Load from top slab= 157.50 kN/m^2

Self wt. of bottom slab= 15 kN/m^2

Wearing course = .10 x 1 x 22

Live Load = 4.52 kN/m^2

Total Load on bottom slab=190.08kN/m

As SBC=200 kN/m^2

Factored load= 268.83 kN/m(on bottom slab)

Loading Calculation On Side Wall

Consider 2 m height live surcharge

Pressure due to live surcharge= 2 x 18 x0.5 =19 kN/m^2

Pressure due to earth surcharge=5 x 18x 0.5= 45 kN/m^2

Pressure due t earth fill=0.5 x 18 x6.70 = 60.30 kN/m^2

Total load = 124.30 kN/m^2

Factored load = 1.5 x 124.30

= 186.43 kN/m

Fixed End Moment Calculation

1)**At Top Slab**:-157.50x6.1x6.1/12

= 488.38kN-m

2) At Bottom slab:-

a) Due to dead loadz

=(183.30x6.1x6.1/12)

=568.38 kN-m

b) Due to live load

= 4.52x6.1x6.1/12

= 140.02 kN-m

c) Total Moment= 582.40kN-m

3) Side wall

a) FEM due to dead load=(67.50x6.1x6.1/12) +(90.45x6.1x6.1/30)

= 321.50 kN-m

b) FEM due to live load= 28.5x6.1x6.1/12=88.37 kN-m

Total Factored Moment on structure=409.87 kn-m

5. Observation:

Final Moment on Structure:

Moment Distribution Method

Table 1:-Final Moment on Structure

Joint	A		B		C		D	
Member	AB	AD	BA	BC	CB	CD	DC	DA
DF	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
FEM	-488.38	409.87	488.38	-409.87	382.24	-582.40	582.40	-382.24
	39.26	39.26	-39.26	-39.26	100.08	100.08	-100.08	-100.08
CO	-19.63	.50.08	19.63	50.04	-19.63	-50.08	50.08	19.63
DIST.	34.86	34.86	-34.86	-34.86	34.86	34.86	-34.86	-34.86
CO	-17.42	-17.42	17.43	17.43	-17.42	-17.42	17.42	17.42
DIST	17.42	17.42	-17.42	-17.42	17.42	17.42	-17.42	-17.42
CO	-8.72	-8.72	8.72	8.72	-8.72	-8.72	8.72	8.72
DIST	8.72	8.72	-8.72	-8.72	8.72	8.72	-8.72	-8.72
CO	-4.36	-4.36	4.36	4.36	-4.36	-4.36	4.36	4.36
DIST	4.36	4.36	-4.36	-4.36	4.36	4.36	-4.36	-4.36
Final	-433.89	433.89	433.91	433.91	497.55	-497.55	497.54	-497.54

Total Free End Moment

At top slab	**Mab=mba**	**157.5x6.1x6.1/8**	**732.57 kN-m**
At bottom slab	Mdc=Mcd	190.08x6.1x6.1/8	884.11 kN-m
At side wall	Mad=Mda	186.43x6.1x6.1/8	867.13 kN-m

Total Net Moment:

At top slab	**Mab=mba**	**732.57-433.91**	**298.66 kN-m**
At bottom slab	Mdc=Mcd	884.11-497.54	386.57 kN-m
At side wall	Mad=Mda	867.13-497.55	369.58 kN-m

Design Of Top Slab:-

MR=433.91 kN-m

Equating

433.91x10^6=0.133x30x1000xd^2

D required=329.77=330

cover=50 mm used 20 mm Φ bar

d provided=550 mm

2Check For Shear

Vu=157.50x6.1/2=480.38 kN

Nominal shear stress=480.38x10^3/(1000x550)

Nominal shear stress=0.87 N/mm^2

Permisible shear stress=0.422 N/mm^2

As Nominal shear stress> Permisible shear stress

Hence shear reinforcement is required

Design of Shear reinforcement

= 238.38 kN

Used 10 mm 2-legged stirrups @ 300 mm c/c

Design Summary:

Description	Thickness of member (mm)	Area of steel (mm^2)	Bar dia. And spacing(mm)	Shear Reinforcement
Top slab	600	1930	20 mm Φ @ 160 mm C/C	10 mm Φ 2-legged stirrups @ 300 mm c/c
Bottom Slab	600	2330	Used 25 mm ϕbar @200 mm c/c	Used 10 mm ϕ@100 mm c/c
Side wall	600	2330	Used 25 mm ϕbar @200 mm c/c	Used 10 mm ϕ@100 mm c/c

CONCLUSION:

From the analysis done and observation made, when the tunnel is subjected to forces like overlying pressure, backfill of earth, live load(vehicular load no bottom slab) i.e. 70 R T Breaking force, uplift pressure, live surcharge, various stress and moment zones are created like moment at top 433.91 kN-m due to overlying pressure and self weight of slab, whereas moment at bottom slab due to live load and self weight is 497.54 kN-m and the moment at side wall is due to backfill pressure and self weight is 497.54 kN-m. Further the designed tunnel consideration provided stable as the check for deflection and shear shows satisfactory resistive results.

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