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Seismic Analysis of Underground Rectangular RCC Tunnel

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***Abstract* - Road tunnels are very practical alternatives to cross physical obstructions or traverse through physical barriers such as mountains or snow bound areas. The seismic analysis and design of a underground rectangular tunnel is presented in this dissertation work. Providing the strength, stability and ductility are major purposes of seismic analysis. Seismic forces bring one of the major natural hazards, it becomes at most important to analse structure against it. The study done in this dissertation is seismic analysis of tunnel. To study the change in critical zone and forces in presence and absence of seismic forces, initially tunnel is analyses for normal forces ,later on same tunnel is analysed for normal and seismic forces both. The presence of lateral load reflects major changes in stress value, moments and displacement. This study will impress there of structure, broader the understanding the design concepts in structural domain and performance when subjected to natural hazard like seismic force. Seismic coefficient method is used for the analysis of tunnel for seismic forces.**

Keywords:. Loads, Breaking force, design of tunnel, geometric specification.

1. INTRODUCTION

Road tunnels are very practical alternatives to cross physical obstructions or traverse through physical barriers such as mountains or snow bound areas. In cases of road passing through hilly terrain, a tunnel can shorten the length of road to be travelled thereby reducing hazardous emissions. Reduction in length of road to be constructed avoids many a scars highway engineers are forced to put on beautiful hill faces definition, are sustainable features. Most tunnel structures were designed and built, however, without regard to seismic effects. In the past, seismic design of tunnel structures has received considerably less attention than that of surface structures, perhaps because of the conception about the safety of most underground structures cited above. Yet one certainly would not want to run away from a well-designed building into a buried tunnel when seismic events occur if that tunnel had been built with no seismic considerations. as tunnel is very important way communication so it is necessary to analyses structure with considering the effect of seismic force to achieved the safety of human life. If the underground structure are not analysed for seismic loading then it may lead to loss of life and destruction of structure. For achieved the seismic stability and resistivity analysis and design of structure by considering the effect of seismic forces is necessary.

1.1 Research methodology

- Basic study of geological, geotechnical. Hydrological data. Soil structure interaction geometry of structure etc. studied in brief.
- Analysis of underground rectangular RCC tunnel for the gravity loading is carried out in Phase one work.
- The tunnel is divided into two boxes, each box has effective span of 5.0 m and height= 6.0m.
  The height of earth above the top slab of tunnel is 2.5 m and dry unit weight and safe bearing capacity of murum are 18 kN/m^3 and 200 kN/m^2 respectively.
- Loads are considered for analysis of the structure by referring the IRC 6-2000.
  a) Self Weight structure b) Earth load on top slab c) Horizontal pressure of earth d) Live surcharge
  e)Water pressure f) The live load for design of bottom slab 70R (T) breaking force &self-weight of wearing course of bitumen is taken.
- The wall thickness of tunnel is constant at top. Bottom slab and side wall= 300 mm.
- The complete analysis & design of RCC box is carried out manually for the various load combinations as per relevant I.S. Codes.
- Firstly the Magnitude of seismic forces are calculated for tunnel subjected to ground condition and different loading combinations given by IS 1893 and then complete normal analysis & seismic analysis is carried out computationally using STADD-PRO.
- For the analysis work, seismic coefficient method is chosen.
- Soil structure interaction is considered.
- Comparison between analysis for gravity and seismic forces is done.
- The analysis results came from STADD-PRO are compared with the results for normal analysis i.e. manual analysis for the gravity loading.

1.2 Loads on Tunnel

The Various types of load such as self-weight, Earth pressure, water pressure, uplift pressure, Vehicular live load, overlying pressure and seismic force are taken for analysis of underground structure. The above loads are taken from IRC 6-2000. Self-weight, Earth Pressure Water Pressure Uplift Pressure Live load Overlying pressure Temperature stresses Seismic force

2. SEISMIC DESIGN APPROACH

2.1 Loading Criteria

Maximum Design Earthquake (MDE)The performance goals of the MDE (i.e. Public safety), the recommended seismic loading combinations using the load factor design method are as follows

2.1.1 Tunnel Structures

- **U = D + L + E1+ E2 +EQ**

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. EQ = effects due to design earthquake (MDE).

2.1.2 Seismic Coefficient Method

The seismic coefficient method is used for the analysis of tunnel.

The seismic force to be resisted by bridge component shall be competed as follows

F = Ah W

Where

F = Horizontal seismic force to be resisted

W = Weight of mass under consideration ignoring reduction due to buoyancy or uplift

Ah = Design horizontal seismic coefficient as

Horizontal Seismic Coefficient Ah- The design horizontal seismic coefficient, Ah shall be determined from following expression IS Used for calculation the design horizontal seismic coefficient.

Ah =(Sa/g x Z/2 x I/R)

Provided that for any structure with T< 0.1 sec, the value of Ah will not be taken less than Z/2 whatever be the value of I/R

Where,

Z = Zone factor

I = Importance factor Refer Table No 2 Of IS 1893 Part *III*

R = Response reduction factor Refer Table No 3 IS 1893 Part III

Sa/g = Average Acceleration coefficient for rock or soil sites

Table No 1 -Zone factor (IS 1893-2002)

Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very Severe
Zone Factor(Z)	0.10	0.16	0.24	0.36

2.1.3 Description of structure-The tunnel has effective width of 5.0 m in each box and clear height 5.7 m and length 100 m receptively. As per the IRC the width of two lanes carriageway are 7.5 m and height of double deck vehicle is 4.75 m. The height of murum cushion on the top of the tunnel is2. 5 m. The tunnel is passed through hard murum having dry unit weight of 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 considered for analysis.

Following are the properties of material through which tunnel is passing

Table 2 Material densities

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

2.3 COMPUTATIONAL ANALYSIS

Case 1: Analysis of underground rectangular RCC tunnel subjected to gravity load (Normal Case of Analysis)

Case-II Analysis of underground rectangular RCC tunnel subjected to seismic forces (Seismic analysis of structure)

The above specified cases are computationally analyzed using STAAD-Pro software and observations are tabulated so as to comment on it.

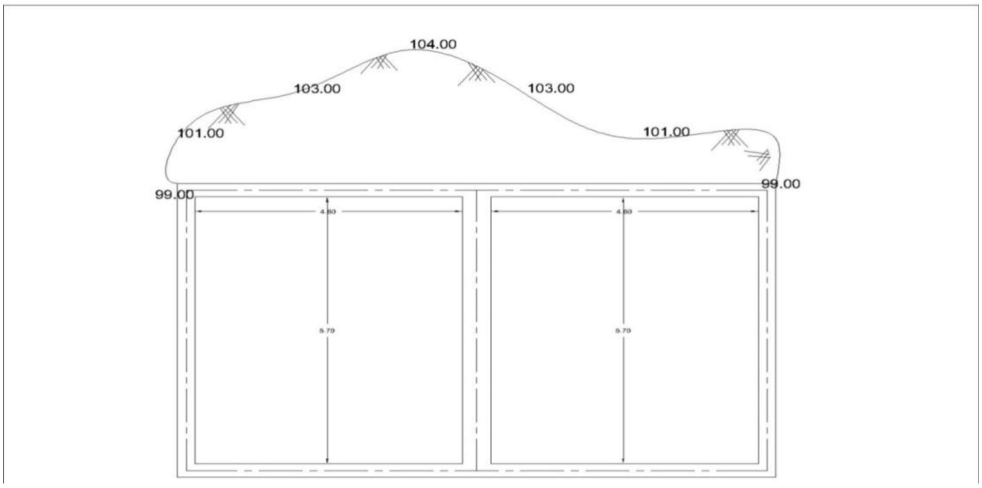

Fig.1 Profile of tunnel structure

2.3.1 OBSERVATIONS AND REMARKS

Analysis of proposed structure is carried out by STADD-Pro software

Case-I

Analysis of underground Rectangular RCC tunnel subjected to gravity loading (Normal loading case)

Case-II

Analysis of underground Rectangular RCC tunnel subjected to seismic forces (Seismic Loading)

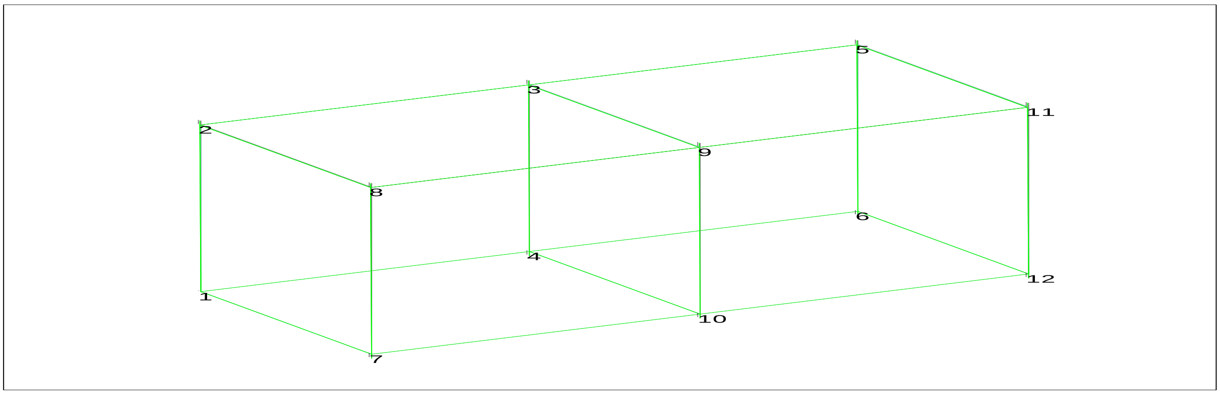

Fig. 2 Various nodes of the structure

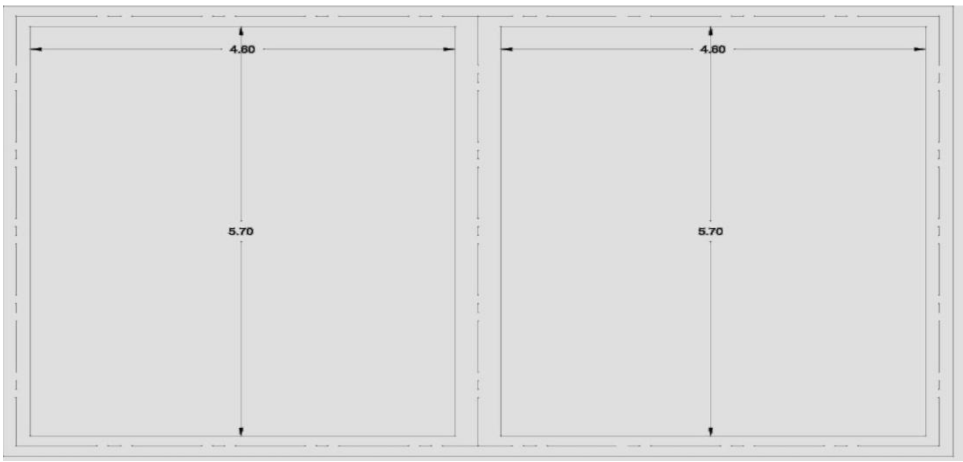

Fig 3 Proposed geometry of tunnel structure

Table No. 3 Nodal Displacement Value (Case-I and Case-II)

		Horizontal	Vertical	Horizontal	Resultant	Rotational		
Node	Case	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
1	Case-I	0	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0	0
2	Case-I	0.195	-0.213	-0.073	0.298	0	0	0
	Case-II	14.339	-0.275	-0.377	14.34	0	0	0.002
3	Case-I	0.001	-1.07	-0.032	1.071	0	0	0
	Case-II	14.142	-1.076	-0.486	14.183	0	0	0
4	Case-I	0	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0	0
5	Case-I	-0.194	-0.216	-0.075	0.299	0	0	0
	Case-II	-14.339	-0.347	-0.409	14.341	0	0	0.002
6	Case-I	0	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0	0
7	Case-I	0	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0	0
8	Case-I	0.195	-0.216	0.077	0.301	0	0	0
	Case-II	14.342	-0.347	0.379	14.343	0	0	0.002
9	Case-I	0.001	-1.07	0.034	1.071	0	0	0
	Case-II	14.143	-1.076	0.488	14.184	0	0	0
10	Case-I	0	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0	0
11	Case-I	-0.193	-0.216	0.075	0.299	0	0	0
	Case-II	-14.339	-0.347	0.379	14.262	0	0	0.002
12	Case-I	0	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0	0

It can be observed from table above that the tunnel subjected to seismic forces(Case-II)are having very high displacement values in lateral x and z direction as compared to displacement of tunnel subjected to normal design forces. Further the displacement in y-direction i.e. vertical displacement is very much similar indicating no extra attention required load design. Rotational displacement are almost absent in both tunnel cases .Theresultant displacement in seismic force subjected tunnel is approximate 14 times higher as that of normal force subjected tunnel.

Table No. 4 Maximum Reaction value at various node For Case-I and Case-II

		Horizontal	Vertical	Horizontal	Moment		
Node	Case	Fx kN	Fy kN	Fz kN	MxkNm	My kNm	MzkNm
1	Case-I	*-591.327*	*581.387*	*215.37*	-277.003	*4.438*	*-14.202*
	Case-II	*-720.13*	*-315.611*	*230.830*	-242.629	*-105.584*	*-454.523*
4	Case-I	*-0.001*	*755.10*	*-0.577*	*-0.89*	-0.002	0.005
	Case-II	*83.126*	*843.44*	*-0.564*	*-0.861*	0.009	240.786
6	Case-I	*591.367*	*582.604*	*216.415*	*-277.774*	*-4.418*	*14.037*
	Case-II	*716.588*	*819.016*	*382.961*	*-310.868*	*-114.077*	*468.092*
7	Case-I	*-591.392*	*582.52*	*-215.352*	276.754	*-4.391*	*-13.96*
	Case-II	*-716.132*	*818.763*	*-231.560*	280.436	*-104.312*	*-467.247*
10	Case-I	*-0.007*	1079.55	*0.569*	*0.863*	-0.003	*0.023*
	Case-II	*-83.108*	1079.55	*2.422*	*7.482*	-0.078	*240.762*
12	Case-I	591.36	582.637	*-216.425*	*277.79*	*4.412*	*14.051*
	Case-II	716.737	819.038	*-382.972*	*310.617*	*114.302*	*468.353*

When the observations are made for reaction developed or needed for stability of tunnel, it can be seen that for tunnel subjected to seismic forces are having very high magnitude forces values, both translational and moment. The huge difference in reaction values between normal force analysis and seismic force analysis indicates need of sound support for preventing tunnel failure due to sinking, uneven settlement as well as shearing. Value of forces in x and z direction are having huge difference similarly moment My and Mz are showing greater vales at specific fix support locations

Table No 5. Beam End Forces Normal And Seismic Load(Case-I and Case-II)

Beam	L/C	Node	Fx kN	Fy kN	Fz kN	MxkNm	My kNm	MzkNm
	Case-I	Start 2	113.729	13.855	0.548	-0.172	-1.903	13.01
	(Normal)	End 3	-113.729	10.001	-0.548	0.172	-0.836	-3.374
	Case-II	Start 2	*145.117*	*33.179*	-0.096	-0.311	-2.253	*87.329*
2	(Seismic)	End 3	*-145.117*	*33.179*	0.096	0.311	-0.993	*18.926*
	Case-I	Start2	-97.918	10.737	0	0.001	-1.187	9.959
	(Normal)	End8	97.918	10.734	0	-0.001	1.187	-9.952
	Case-II	Start	*-112.743*	10.747	*0.045*	*0.152*	-1.363	*10.341*
7	(Seismic)	End	*112.743*	10.723	*-0.045*	*-0.152*	1.514	*-10.287*
	Case-I	Start 3	-43.641	10.733	0	-0.001	-0.001	9.08
	(Normal)	End 9	43.641	10.737	0	0.001	0	-9.089
	Case-II	Start	*43.648*	*11.264*	*0.030*	*-1.952*	*-0.036*	10.276
8	(Seismic)	End	*43.648*	*10.206*	*-0.030*	*1.952*	*-0.099*	-7.895
	Case-I	Start 8	113.72	13.839	-0.548	0.177	1.903	12.966
	(Normal)	End 9	-113.72	10.017	0.548	-0.177	0.835	-3.41
13	Case-II	Start 8	*145.029*	*32.833*	-0.702	-0.034	*2.175*	*86.139*
	(Seismic)	End 9	*-145.029*	*25.004*	0.702	-0.247	*1.285*	*-25.205*

The comparative values of beam end forces for both normal and seismic forces, shows that the values of forces induced are more in structure subjected to seismic forces and that too in x and z lateral direction similarly, high moment is developed in z-direction whereas the forces in vertical direction are almost same.

Table No 6. Shear Force And Bending Moment

Beam	L/C	Dist m	Fx kN	Fy kN	Fz kN	MxkNm	My kNm	MzkNm
		Start	113.729	13.855	0.548	-0.172	-1.903	13.01
	Case-I	Middle	113.729	1.927	0.548	-0.172	-0.534	-6.718
		End	113.729	-10.001	0.548	-0.172	0.836	3.374
2		Start	***145.117***	*33.179*	0.692	-0.249	-2.253	***87.329***
	Case-II	Middle	***145.117***	*21.251*	0.692	-0.249	-0.63	***19.292***
		End	***145.117***	*-25.324*	0.692	-0.249	0.993	***-18.926***
		Start	-97.918	10.737	0	0.001	-1.187	9.959
	Case-I	Middle	-97.918	0.001	0	0.001	-1.187	-2.122
		End	-97.918	-10.734	0	0.001	-1.187	9.952
7		Start	***-112.743***	10.737	***0.045***	***0.152***	-1.187	10.341
	Case-II	Middle	***-112.743***	0.001	***0.045***	***0.152***	-1.188	-1.764
		End	***-112.743***	-10.734	***0.045***	***0.152***	-1.288	10.287

8	Case-I	Start	-43.641	10.733	0	-0.001	-0.001	9.08
		Middle	-43.641	-0.002	0	-0.001	0	-2.993
		End	-43.641	-10.737	0	-0.001	0	9.089
	Case-II	Start	-43.648	-11.268	***0.024***	-0.009	***-0.036***	***10.276***
		Middle	-43.648	0.53	***0.024***	-0.009	***0.032***	***-3.039***
		End	-43.648	-10.206	***0.024***	-0.009	***0.099***	***10.283***
13	Case-I	Start	113.72	13.839	-0.548	0.177	1.903	12.966
		Middle	113.72	1.911	-0.548	0.177	0.534	-6.722
		End	113.72	-10.017	-0.548	0.177	-0.835	3.41
	Case-II	Start	***145.029***	***32.833***	-0.702	0.264	***2.39***	***86.139***
		Middle	***145.029***	***-29.01***	-0.702	0.264	***0.636***	***-29.722***
		End	***145.029***	***20.14***	-0.702	0.264	***-1.119***	***-18.4***

From the values tabulated above it can be seen that more shear and bending forces are developing in beams. The values are approximately 20 % more than that of normal load subjected tunnel. This indicates more chances to failure due to shearing and bending development in beams and thus needs to be strengthened.

Table No 7. Column End Forces

Column No	Case	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
12 and 16	Case-I	Start	214.113	-1.792	0.984	-1.577	-1.535	-2.466
		End	-158.449	1.792	-0.984	1.577	-4.667	-8.825
	Case-II	Start	327.163	-43.357	1.914	-1.952	-5.414	-171.441
		End	-271.498	43.357	-1.914	1.952	-6.646	-101.707
14	Case-I	Start	596.398	0.007	-0.569	-0.003	2.638	0.023
		End	-633.508	-0.007	0.569	0.003	0.948	0.024
	Case-II	Start	899.405	83.108	-2.65	-0.078	8.813	270.355
		End	-955.07	-83.108	2.65	0.078	7.879	253.228

The forces induced in column are more in horizontal x direction as compared to z and vertical y direction similarly the values of moment is changing for My and Mz. This indicates low force development in z direction where lateral RCC walls are present

Table No 8. Plate Centre stresses load combination

Plate No	Case	SQX(N/mm2)	SQY(N/mm2)	SX(N/mm2)	SY(N/mm2)	SXY(N/mm2)	MX(kNm/m)	My(kNm/m)	MXy(kNm/m)
18	Case-I	0.011	0.000	-0.45	-0.041	-0.000	1.53	-1.19	0.0020
18	Case-II	0.110	-0.001	-0.510	-0.068	0.112	27.79	-5.512	0.184
21	Case-I	0	0	0	0	0	0	0	0
21	Case-II	0	0	0	0	0	0	0	0
23	Case-I	0.000	-0.008	-0.152	-0.57	0.000	-1.61	-1.715	0.0013
23	Case-II	0.000	-0.131	-0.158	-0.673	0.245	-4.94	-19.66	-0.12

Table No 9 Plate Corners stresses Max Value

Plate No	Case	SQX(N/mm2)	SQY(N/mm2)	SX(n/mm2)	SY(N/mm2)	SXY(N/mm2)	MX(kNm/m)	MY(kNm/m)	MXY(kNm/m)
18	Case-I	0.011	0.000	-0.085	-0.305	-0.332	6.896	-2.540	2.598
	Case-II	0.110	0.003	1.055	-0.43	0.445	-79.686	-15.246	25.141
21	Case-I	0	0	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0	0	0
23	Case-I	0.000	-0.008	-0.556	0.819	0.185	-3.572	-5.486	2.381
	Case-II	0.000	0.132	-0.626	-1.294	0.344	14.473	84.280	37.94

Table No 10. Shear Membrane And bending Moment

		Shear		Membrane		Bending Moment	
Plate	Case	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	MxkNm/m	My kNm/m
18	Case-I	0.011	0	-0.454	-0.041	1.526	-1.191
	Case-II	0.105	0.001	-0.454	-0.068	27.789	-5.502
21	Case-I	0	0	0	0	0	0
	Case-II	0	0	0	0	0	0
23	Case-I	0	-0.008	-0.152	-0.568	-1.61	-1.715
	Case-II	0	-0.131	-0.158	-0.673	-4.297	-19.664

It Can be observed that more stresses are induced in seismic force subjected to tunnels as compared to normal tunnel .Further It Can Be observed that location wise maximum stress are developed in top plates whereas the horizontal plates shows variation with fall in values of stress at bottom section where supports are provided. Similarly it can be mark out that the stress development is compressive 25 % in bottom plate as compare to top plates.

CONCLUSION

From the study done over here in dissertation work for analysis of tunnel subjected to various forces, it can be seen that when the tunnel is analyzed for normal loads and combinations which includes surcharge, self-weight earth pressure, vehicular load, uplift pressure, active soil pressure , the forces and stresses are majorly developed in top plate as compared to any other component of tunnel. The development of high reaction values can be justified by provision of raft or inverted slab base. Thus, in normal load analysis the critical zone of failure may be at top of tunnel section.

Further when the study and analysis is done for consideration of seismic forces in lateral direction that is in both horizontal directions, it can be observed from analysis results and remarks that Hugh amount of forces and moments are developed in such tunnels. The development of forces is more in x and z direction where as in y that is vertical direction seems to be negligibly changed. The analysis shows that high amount of reaction forces are developed similarly very high amount of displacement is occurring in tunnel subjected to lateral seismic forces. The beams of the tunnels are showing high values of shear forces as well as bending moment , similarly columns of the tunnel is reflecting high shear force development. However, the vertical or gravity force is same for columns.

The observations made for plate center and corner stress shows that very high amount of stresses are getting developed on top plate of tunnel with decreasing values on side walls and the bottom slab is showing small stresses development. The study reflects that the value so stresses, shear forces, moments, displacements and reactions increases in the tunnel when subjected to seismic forces and thus need to tackle these forces keenly. The critical zone of failures in the tunnels is top slab due to high stress development and corners of horizontal plate where columns are provided with high shear force values. The analysis of tunnel subjected to seismic forces shows behavior of tunnel against seismic resistivity and thus laterals and shear stability becomes grater matter of concern for designers.

Future Scope

Tunnel can be analysed for the region with water saturated soil condition as pressure of soil on structure changes with moisture content in it. Similarly effect of seismic forces on various geometrical shapes of tunnel can be studied so as to find most resistive shape.

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