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Analysis and Design of Shallow Rectangular Underground Water Tunnel

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Abstract – Water tunnels are very practical alternatives to cross physical obstructions (or) traverse through physical barriers such as mountains (or) snow bound areas. Underground water tunnels are tunnels used to transport water to areas with large populations (or) agriculture. The analysis and design of a underground water tunnel is presented in this dissertation work. Providing strength and stability are major purposes of analysis and design of a underground tunnel. The study done in this dissertation is to calculate the loads acting on the tunnel and analyze it both manually and in software STAAD. Pro, then comparing the results. This study compares the results obtained using manual calculations with those from results of STAAD. Pro software. Moment distribution method is used for analysis of tunnel for lateral loads. The outcomes of STAAD. Pro analysis and normal analysis (manual analysis) indicate that shallow rectangular tunnels are strongly affected by surrounding soil pressure and internal hydrostatic pressure. Racking i.e., displacement of sidewalls, is a major failure of rectangular tunnels. Specifically geometry of one-by-one twin barrel configuration is studied. A wide range of structural and geotechnical parameters are considered in this study. The presence of lateral load reflects major changes in stress value, moments and displacement. Based on the results of analysis, moments and displacements of underground shallow water rectangular tunnels under design loads without considering seismic forces are studied.

Key words: - Loads, Racking, design of tunnel, geometric specification, stresses, moments, hydrostatic pressure.

I. Introduction

An underground passageway is called a tunnel, which is dug through the surrounding rock/earth/soil and at each end not enclosed for entrance and exit, surroundings of tunnel are closed. Instead of traditional tunnel boring methods recently tunnels have used immersed tube construction techniques but pipeline is not a tunnel. Generally there are three types of tunnel construction methods. For construction of shallow tunnels cut and cover is a simple method and other methods are bored tunnel and immersed tunnels. In cut and cover a trench is excavated and covered at top with an overhead support system, which is strong to bear the load of what it carries above the tunnel. There are two major forms of cut and cover tunneling is available:

Bottom up method: The tunnel is constructed in a trench which is excavated, with ground support as necessary. In past days brick work was used as construction material. Presently precast concrete, prestressed concrete, insitu concrete, steel arches are used. After that trench is then backfilled and surface is restored.

Top down method: In this method supporting side walls and capping beams are constructed from ground level as continuous bored piling (or) grout walling. Then a shallow trench allows making the tunnel slab of concrete insitu (or) precast beams. Except for access openings the surface is than restored. This allows early restorement of services, road ways, other extra surface works. Base slab is constructed, by excavating under permanent tunnel roof.

II RESEARCH METHODOLOGY

- Basic study of geotechnical, structural, hydrological data. Briefly soil structure interaction and geometry of structure is studied.
- Analysis of shallow rectangular underground tunnel for gravity load, water pressure, earth pressure in first phase of work.
- The rectangular tunnel is divided into two barrels, each barrel has length= 4.40m and height= 2.00m.
- The depth of earth above tunnel is 1.0m and dry unit weight 18 kN/m3.
- Loads considered for analysis of tunnel referring IS4880 (part - 5) are self weight, internal hydrostatic pressure, earth pressures on top, bottom and side slabs.
- The wall thickness of tunnel is constant for top, bottom and side walls i.e., t= 350mm.
- The complete analysis and design of rectangular under tunnel is carried out manually for different loads as per IS codes.
- Firstly the magnitude of self weight, earth pressures, internal hydrostatic pressures are calculated by standard formulas and then complete normal analysis is carried out computationally using STAAD .Pro.
- For the analysis, moment distribution method is chosen.
- Parameters soil structure interaction and seismic forces is not considered.
- The analysis results came from STAAD .Pro are compared with the results for manual (normal) analysis for self weight, earth pressures, hydrostatic pressure loadings.

III. ANALYSIS

3.1 Loads on tunnel- The loads are taken from IS4880 (part-5) they are self weight, water pressure, earth pressure, uplift pressure are taken for analysis of rectangular under tunnel. Seismic forces are not considered.

3.2 Dimensions of tunnel- The effective span of each barrel are 4.4m and height of barrels is 2.00m. From IS4880 (part-5) the thickness of barrels are taken as 350mm. The depth of soil above top slab is 1.0m.

Table1 Material Densities

Material	Dry density kN/m3
Water	9.81
Backfill	18
concrete	24

3.3 Manual Computations

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

Case-2: Analysis of underground rectangular RCC tunnel subjected to water pressure, earth pressure.

- Hydrostatic (water) pressure varies linearly along side walls and partition walls. Total hydrostatic pressure is

  $P = \rho gh = 1000 * 9.81 * 2.35 = 26.487$ kN/m2.
- Earth pressures on top, bottom, side walls vary uniformly (assumption).
- The active earth pressures on side walls are calculated by considering coefficient of earth pressure and angle of internal friction (ϕ= 30°).

- Pressure at top corner = due to earth pressure + dead load = Ca ∗ γd ∗ height of earth above + Ca ∗ dead load = 0.33∗ 1.80 ∗ 1.00 + 0.33 ∗ 6 ∗ 0.35 ∗ 2.16 = 12.10 t/m2.
- Pressure at bottom corner = pressure at A + Ca ∗ γd ∗ height of side wall = 2.10 t/ m2 + 0.33 ∗ 1.8 ∗ 2.7 = 25.35 KN/M2
- Pressure on top slab : Assume both top and bottom soil gives uniform pressure = weight of dry earth + weight of top slab + dead load
- ×Height of top soil ∗ γd + γc (specific weight of concrete) ∗ t + dead load = 1.8 ∗ 1 + 0.35 ∗ 2.5 + 4.5 = 47.1750 kN/m^2.
- Pressure on bottom slab : total dead load (weight of barrels per unit length) + γd × effective length of horizontal member + dead load × length of horizontal member = (1 × 4.75 + 2 × 2.35) × 0.35 × 2.5 + 1.8 × 4.75 +4.5×4 = 38.19 t.

3.4 Moments

- As the barrels are rigidly joined, they are designed as continuous structure.
- Here, I followed moment distribution method. This method only accounts for flexural effects and ignores axial and shear effects.
- Thickness of bottom slab / top slab / side wall = 0.35 m
- The effective length of horizontal member = 4.75 m.
- The effective length of vertical member = 2.35 m.
- Stiffness factor : Pin end supported at far end K = 3EI/L , Fixed supported at far end K = 4EI/L
- Distribution factors : D.F = K / Σ K
- At joint A: For member AB = 2.35 / 2.35+ 4.75 = 0.33, for member AD = 4.75 / 2.35 + 4.75 = 0.67.
- At joint D: For member DA = 4.75 / 2.35 + 4.75 = 0.67, for member DC = 2.35 / 2.35 + 4.75 = 0.33.
- On span AD = uniformly distributed load (top slab) = wl2 / 12 = 7.175 ∗ 4.75′2 / 12 = 13.50 t- m
- On span CB = uniformly distributed load (bottom slab) = wl2 / 12 = 8.04 ∗ 4.75 ′2 / 12 = 15.12 t-m
- On span AB = both rectangular and triangular portions.
- So, fixed end moments due rectangular portion = wl2 / 12 = 12.10 ∗ 2.35 ′ 2 / 12= 0.97 t-m.
- Fixed end moments due to triangular portion = MAB = wl^2 / 30 = 14.9 ∗ 2.35^2 / 12 = 0.26 t- m.
- MBA = wl2 / 20 = 14.9 ∗ 2.35 ′2 / 20 = 0.39 t-m.
- Total fixed end moments at A = MAB (rect) + MAB (triangle) = 0.97 + 0.26 = 1.23 t-m.
- Total fixed end moments at B = MAB (rect) + MBA (traingle) = 1.36 t-m.

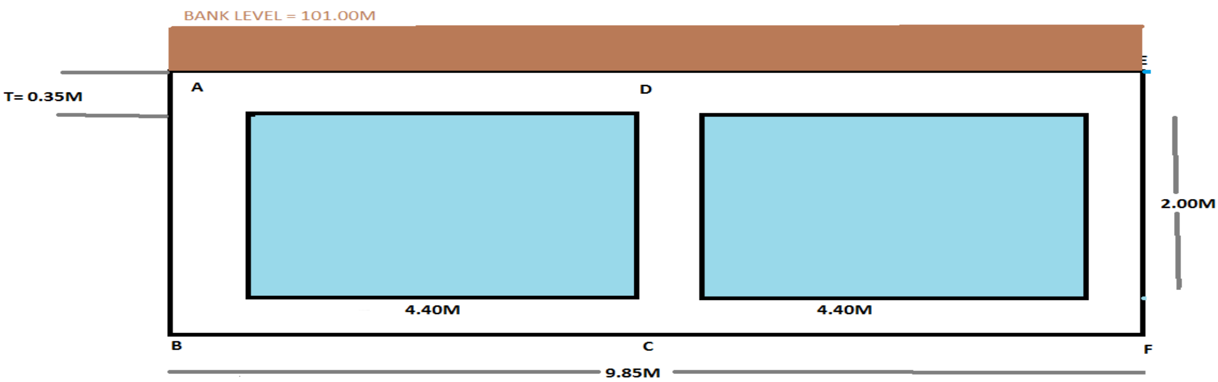

Fig 1 Profile of tunnel structure

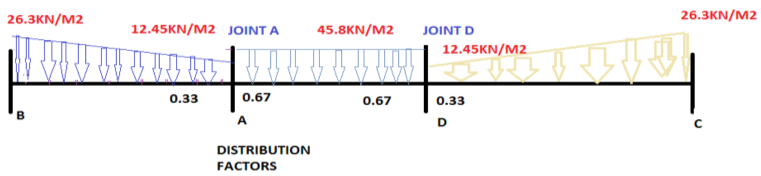

Fig 2 Various loads on the barrel

Table 2 Distribution of moments

JOINTS	C	D		A		B
MEMBER		DC	DA	AD	AB	
Distribution factors		0.33	0.67	0.67	0.33	
Fixed end moments	15.12	15.12	-1.36	1.23	-13.5	13.50
Balance		-4.60	-9.18	8.18	4.10	
Carry over	-2.30		4.09	-4.59		2.05
Balance		-1.37	-2.73	3.06	1.53	
Carry over	-0.68		1.53	-1.36		0.77
Balance		-0.15	-1.02	0.91	0.46	
Carry over	-0.26		0.46	-0.51		0.23
Balance		-0.15	-0.30	0.34	0.17	
Total	-18.3	9.91	-8.51	7.26	-9.84	16.54

3.5 Observations And Remarks –

Analysis of proposed structure is carried out by

STAAD. Pro software.

Case-1: Analysis of underground rectangular water tunnel subjected to gravity loading, earth pressures, water pressure except seismic forces.

- Here instead of beams and columns, concrete slabs (plates) are used in STAAD. Pro.
- Supports are fixed at bottom slab, because of assumption hard gravel strata ground.
- Loads applied are self weight= 1.8 t/m2, water pressure= 26.48 kN/m^2, earth pressures on side slabs on right and left at top corner and bottom corner 12.10 kN/m^2, 25.35 kN/m^2, earth pressure on top slab= 25.8 kN/m^2, earth pressure on bottom slab= 89 kN/m^2.

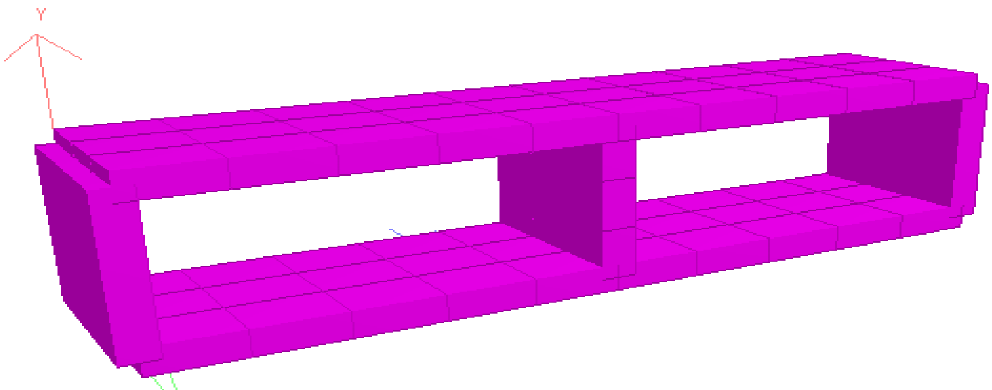

Fig 3 STAAD. Pro model of tunnel

Table 3 Comparison of moments

Distribution of moments	Calculated moments	STAAD. Pro moments
MAD	7.26 kN-m	7.69 kN-m
MAB	0.984 kN-m	1.178 kN-m
MCD	0.991 kN-m	1.178 kN-m
MH	0.866 kN-m	1.045 kN-m
MBC	0.00 kN-m	0.00 kN-m

- MAD-Moment of the top slab
- MAB - Moment of left slab (earth pressure)
- MH - Moment of slab (hydrostatic pressure)
- MBC - Moment of bottom slab
- MCD - Moment of right slab (earth pressure)

It can be observed that more stresses are induced at corners of the tunnel due to cavitations losses and unequal pressures. It can be mark out that stresses will be more at joint of top slab and side slabs compare to bottom slab. The tunnel material is concrete for total slabs. Design in STAAD. Pro is based on code IS 456-2000 plain cement concrete i.e. limit state design method. Soil moisture content is not considered here and assumed to be dry.

IV. 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, uplift pressure, active soil pressure, the forces and stresses are majorly developed in top plate as compared to any other component of tunnel. The maximum moment of 7.69 kN-m occurs at top slab, which is increasing towards the meeting edges of side walls and top slab. Maximum moment of side slab is 1.178 kN-m, maximum stress is more at corners which is contact with top slab. The displacement shown in STAAD .Pro model of rectangular under tunnel shows the deflection at the joint of top slab with side walls. Bottom slab shown zero moment, due to assumption of hard gravelly strata i.e., fixed supports are assigned. Maximum moment due to hydrostatic pressure on side walls and partition wall is 1.045 kN-m. Comparing moments form normal analysis and software analysis, the maximum moment is at joint of top slab and side wall and failure of model was occurring at these joint. Failure of rectangular water tunnel is mainly due to cavitations, corner losses and unbalanced pressure between hydrostatic pressure and surrounding soil pressure. To avoid this racking type of failure sharp corners are rounded i.e., hatching, it leads to reduction of failure of tunnel.

V. REFERENCES

[1] J.H.Wood,‘‘Earthquake Design Procedures For Rectangular Underground Structures, “American Journal of Engineering Research, john wood consulting , point Howard 17th July 2004.

[2] E. Debiasi, A. Gajo, D. Zonta , ‘‘On the seismic response and design of rectangular tunnels,” Dipartimento di Ingegneria Civile, Ambientale e Meccanica, Università di Trento, Via Mesiano 77, I-38123 Povo, Trento, Italy, Issue 30, April 2013.

[3] GrigiosTsinids, Kyriazis Pitilakis,Gopal Madabhushi, ‘‘ Seismic Response And Design Of Rectangular Tunnels” SECED 2015 Conference on Earthquake Risk and Resilient World, Issue 10, July 2015.

[4] Christos Vrettos, Basil Kolias, Thomas Richter,‘‘Sesimic Response Analysis Of An Immersed Tunnel Using Imposed Deformation”The 4th International Conference on Earthquake Geotechnical Engineering, June 25-28, 2007.

[5] J.N.Wang, G.A.Munfakh, ‘‘Sesimic Design of Tunnels,” Transactions on the Built Environment vol 57, 2001 WIT Press, www.witpress.com, ISSN 1743-3509.

[6] Mr.Sunil, J.Payagan, Prof. A.R.Gupta,‘‘Sesimic Analysis Of Underground Rectangular Rcc Tunnel,” International Journal of Engineering Research and Technology, Volume 4, Issue 6, June 2015.

[7] Dr.P.N.Modi, S.M.Seth, ‘‘Hydraluics And Fluid Mechanics,” Standard Book House Since 1990.

[8] pal Ranjan, A.S.R Rao,‘‘Basic And Applied Soil Mechanics,” New Age International, 2007