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A Comprehensive Evaluation of Racking Deformation for Earthquake Response of Underground Rectangular Metro Station Box Located in Bangalore

Eshwarayya B L [1], Basavana Gowda[2], K Shijina[3]
[1]Research scholar, Civil Engineering, Reva University Bengaluru, India
[2]Assistant professor, Civil Engineering M S Ramaiah Institute of Technology, Karnataka, India
[3]Assistant professor, Civil Engineering, Reva University, Bengaluru, India

***Abstract* - Substructure facilities are most important part of the modern society and are used for many applications like subways, highways, railways, material storage and sewage and water transport. Underground structures constructed in earthquake prone areas must withstand both seismic and static loadings. Generally, underground structures are subjected to lower rate of damage than surface structures. The present state of seismic analysis and design of the underground structures are briefly explained in this thesis. For this thesis work, an effort has been made to find the racking deformation of underground metro station box located in Bangalore, India using the PLAXIS 8.2 (FEM) software. The computed racking deformation is then validated with that obtained by analytical method considering various soil parameters.**

Key Words: Soil- Structure Interaction, Free-field Deformation, Flexibility Ratio, Racking Deformation.

1. INTRODUCTION

1.1 General

The present seismic design of structures mainly consists of two different methods. (i). Force-based (ii) displacement (deformation)-based method. The force – based method involves prediction of equivalent dynamic forces by considering some of the modification factors to carry out the seismic analysis. Later displacement approach includes the calculation of displacement. In this approach deformation is calculated based upon the seismic forces and capacity ratios. So that the simpler approaches are more widely used, i.e., displacement based method used for the investigation of earthquake response of the structures.

Earthquake response of underground structure is different from the response of a super structure at the ground surface. In the underground structure seismic reaction is determined by the action of the surrounding soil medium. But in case of superstructure earthquake analysis is carried out by considering the magnitude, velocity and acceleration because it is a free-vibrating system. Underground structures deforms with surrounding soil, hence deformation-based method is used to analyze such problems and also requires skilled engineer performs the seismic design of such structural buildings.

In underground structural design and analysis soil properties are the major factors to assess the difficulties. From the previous research have shown that the bending moments and shear forces values in the structures are more when soil – structure interaction is considered.

1.2 Soil Structure Interaction

The response of soil influences the motion of the structure and, the motion of structure influences the response of soil then this process is termed as “SOIL –STRUCTURE INTERACTION”.

The interaction of soil-structure may influence the inertial effects of soil gives the significant changes in the shear strain at the structure. Shear strain in the soil near to the cavity should be more than the free field shear strain because of soil is unlined. Lesser free-field can be achieved by inserting the stiff structure into the cavity of soil. Shear strain may be more than the free-field in a flexible structure. Soil-structure interaction effects in an underground structure can be assessed by defining the shear strain deformation and flexibility ratios.

Soil- structure interaction with springs indicates the bonding between the structure and soil layer by introducing the springs. It acts as a supporting element for the structure as well as soil. The parameters to be considered for introducing the springs into the structure and soil depend on embedment depth. Springs values can be determined according to the aspect ratio and width of the structure. The basic assumptions are as follows:

- The rectangular box structure should be rigid.
- Static loading conditions should be applied to the structure.
- Perfect bonding between the structure and the soil.
- Linear static theory should be taking into the account.

1.3 Racking Deformation

The Ova ling or Racking deformation of a tunnel structure may develop when the waves propagate in a direction perpendicular axis of the tunnel, resulting in a distortion of the cross-sectional shape of the underground structure. Ova ling or Racking deformation may be caused by vertically, horizontally or obliquely propagating dynamic forces of any type. An evaluation of racking deformation of rectangular underground structure subjected to seismic ground motion can be undertaken using following steps:

i. Finding the free-field peak shear strain in the soil at the average depth of structure.
ii. Evaluation of the elastic and post-elastic stiffness of the structure.
iii. Calculation of racking deformation of the structure from the free-field strain, stiffness of the structure and soil-structure interaction curves.
iv. From the racking deformation to find the member forces in the structure.

1.4 Evaluation of racking deformation and structural earthquake response by using PLAXIS 8.2 software

The location to be considered for the present study near the K R Market, Chickpete Metro station box in Bangalore (India). The structure is 3.5m below ground level, width and height of the structure are 24 m and 18 m respectively. The model has been obtained details collected from COASTAL-TTS (JV) Bangalore Metro. Which contains Young's Modulus, Saturated density, Unsaturated density, Poisson's ratio, Cohesion of soil, Angle of internal friction and also the depth of soil layer for the analysis was considered to be 30m deep from the ground level. There are three different layer of soil were considered such as sand, dense sand and weathered rock. For every soil layer should assign the material properties and modeled in PLAXIS 8.2 software. Earthquake details were collected from the Pacific Earthquake Engineering Research (PEER) which is very important input for the dynamic analysis in PLAXIS 8.2. Whereas static analysis there is no need of earthquake data's. The obtained racking deformation was compared with the analytical expression.

2. SOIL AND STRUCTURAL PARAMETERS

COASTAL –TTS (JV) had carried out geotechnical investigation at pre identified locations along Bangalore Metro UG 1 corridor and at station locations. The geotechnical investigation work for the same was awarded to SECON Private limited dated 18th February 2010. Nine (09) boreholes were carried out along the tunnel portion of the underground corridor and Eight (08) boreholes were carried out at the proposed station locations. Soil investigation covers the details of borehole drilled, CBR tests conducted, sub-soil profile noticed in the boreholes, field and laboratory test results of soil and rock samples collected from the boreholes and interpretation of the same for Safe Bearing Capacity (SBC).

2.1 General site condition

The proposed Bangalore metro UG starts from Kempe Gowda Institute of Medical Science V. V. Puram to Mantri Square, Sampige Road, Malleshwaram.

2.1.1 Sub – Soil profile (Chickpete Metro station)

Boreholes were drilled at the proposed Chickpete Metro station location. Generally three layer sub – soil profile was noticed in the boreholes, discussed as follows:

Layer I: Sandy silt

This layer is the top most layer in the borehole. The thickness of this layer should be recorded by N- values in this layer was 7

Layer II: Silty sand/ highly weathered rock

This layer was noticed below the sandy silt. The N-values for this layer varies from 12 to 23, which indicates the medium in-situ compactness of the soil. SPT values in the highly weathered rock layer are greater than 100, indicating 'very dense' in-situ compactness of soil.

Layer III: Hard Rock

Hard Rock was noticed below Silty sand/Highly weathered rock layer in the borehole.

2.2 Structural Parameters

Considered structure was a rectangular underground metro station box which is 3.5m below ground level having width and height of 24 m and 18 m respectively. The thickness of the base slab and roof slab was found to be 1.3m. The thickness of the side wall was 1.2m. The grade of concrete used for the construction was 35N/mm^2.

3 MODELLING AND ANALYSIS USING PLAXIS 8.2 SOFTWARE

The software named Plaxis 8.2 is a FEM package which deals with geotechnical aspect of the structure under study. This is mainly used by professionals and researchers in field of geotechnical for the analysis of structures like dams, bridges, road embankment, substructure such as subway stations, culverts, underground passages etc. It can also be used for finding the stability of the structures.

The method adopted in software (Plaxis 8.2) for modeling and analysis was finite element analysis (FEM). Soil layer in finite element assessment are modeled as linear elastic. To use FEM, the entire model should be divided into number of elements with suitable geometry; hence number of nodes in each element should be specified for detailed analysis. In this FEM package the options available for section of elements are 6-Node and 15-Node as shown in figure 6.1. For the accuracy of the results 15-Node elements has been adopted.

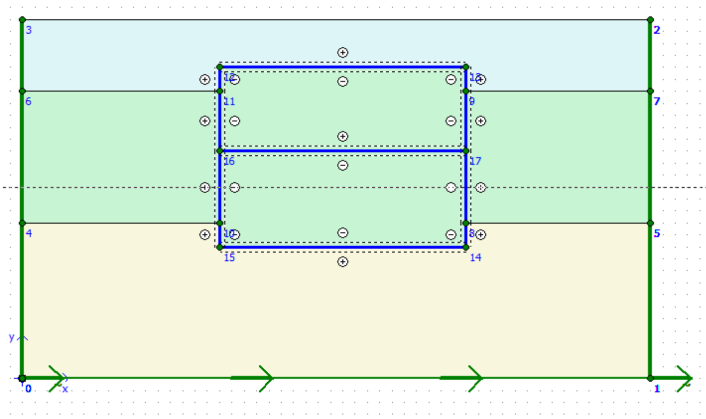

Fig-1: Generated structural and soil model.

4.ANALYTICAL METHOD TO FIND RACKING DEFORMATION

Racking deformation for underground rectangular station box is obtained from analytical method as per Y. M. A. Hashash et. al.., 2001[9]. The data's are needed for this numerical method is as follows:

Soil and seismic force parameters

- Peak Magnitude of previous earthquake at study site(M_w) = 5.4
- Site to source distance = 60 km
- PGA at surface (a_{max}) = 0.24g
- S- wave velocity of propagation in soil (C_m) = 229.33 m/sec[COASTAL-TTS JV]
- Peak ground velocity at surface (V_s) = 2.093m/s
- Soft soil medium with, soil density (ρ_m) = 1900 Kg/m^3

Structural parameters

Structure considered for the analytical method was rectangular tunnel (Bangalore metro station box). The dimensions of the tunnel are as mentioned below.

- Width of the station box (L) = 24 m.
- Height of the station box (H) = 18 m
- Depth soil layer to the top of the station box (D) = 3.5 m.

Per unit length for the rectangular cross section is considered.

4.1 Determination of the free- field deformation ($\Delta_{free\text{-}field}$) (Hashash et al.., 2001)

The shear strain due to body waves and surface waves are calculated by knowing the earthquake data and peak ground velocity at surface, if Peak ground velocity at surface is not given, then PGV at surface can be calculated by using below table

Table 1: Ratio between PGV to PGA at the surface in rock and soil medium

Magnitude (M_w)	Ratio of peak ground velocity (cm/s) to peak ground acceleration(g)		
	Source to site distance (Km)		
	0- 20	20-50	50-100
Rock			
6.5	66	76	86
7.5	97	109	97
8.5	127	140	152
Stiff soil			
6.5	94	102	109
7.5	140	127	155
8.5	180	188	193
Soft soil			
6.5	140	132	142
7.5	208	165	201
8.5	269	244	251

4.2 Determination of flexibility ratio (F_R). (J. H. Wood-2004[8])

Flexibility ratio (F_R) is given by

$$F_R = \frac{\text{Shear flexibility of free standing structure while not soil interaction}}{\text{Shear flexibility layer of soil of same overall dimensions as structure}}$$

$$F_R = \frac{fst}{fs}$$

Using the above relation flexibility ratio computed was F_R= 0.43386

4.3 Evaluation of ova ling or racking effect of the structure.

Using the relation between flexibility ratios and racking co-efficient shown in the figure5.2, defined by Hashash et al.., 2001[1] Value of racking co-efficient will be obtained.

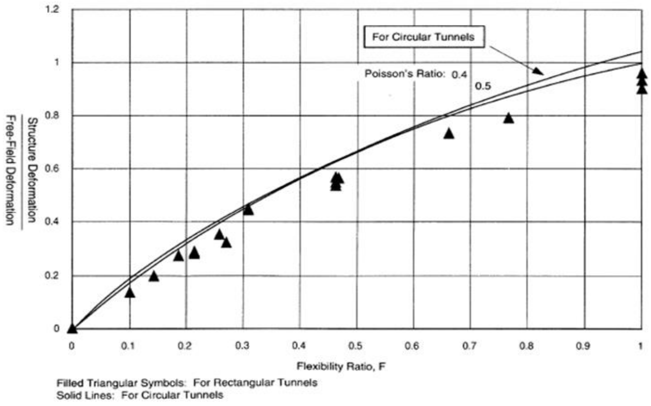

Fig -2: Structural deformations of circular and rectangular tunnels.

Multiplying racking coefficient (R) with free- field deformation, Racking deformation of the structure has found to be 7.05mm.

5. CONCLUSIONS

The seismic analysis of underground structure was carried out by using the PLAXIS 8.2 software and same was validated analytically. An important parameter of racking deformation of underground structure was majorly studied in this present thesis and following conclusion was made.

- Deformation of structure during soil structure interaction is dependent on flexibility ratio of the structure.
- Computed free-field deformation and Racking deformation using analytical method by Hashash et al.., 2001[1] were 16.42mm and 7.12mm respectively.
- Racking deformation computed using analytical method proposed by Power et. al…,1996 was found to be 7.055mm.
- Racking deformation obtained using PLAXIS 8.2 software was found to be 7.3mm.
- The racking deformation obtained for rectangular tunnel using PLAXIS 8.2 software and analytical method was found to be nearly equal.

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