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STRESSES BELOW EXISTING STRUCTURES DURING TUNNEL EXCAVATION USING TUNNEL BORING MACHINE (TBM)

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Abstract

The Finite element (FE) analysis include the response of structures to horizontal & vertical dynamic forces and consider all site characteristics, such as soils and geologic conditions. The induced stresses under the foundation of adjacent buildings during newly constructed underground tunnel through TBM, were investigated in this study. Results of this study were examined to find out whether the amount of variations in forces and stresses are in the allowable ranges or not. In this paper, soil parameters used for the study are based on the existing Delhi Metro tunnel site. Using these soils parameters, tunnel excavation through TBM has been modelled in PLAXIS Tunnel-3D and the adjacent structures have also been included in the model.

Introduction

During the construction of the Metro tunnel especially under the monuments, old & newly constructed buildings and important structure etc., it is necessary to analyse the foundation of the structures through various FE software. In the present scenario, demand of TBM has been suddenly increased worldwide to construct the Metro tunnels in Metropolitan cities, but issues related to vibrations caused by use of TBM to nearby structures have been a matter of concern. TBM is one of source of high vibration which causes distortion due to the result of impact and displacements of material under the foundation of structures.

The problem of tunnel-induced stresses produced at the time of construction and related risk assessments of buildings damages has attracted attention of investigators over the last many years. On this deliberation, many references have already been taken into consideration viz. Cording and Hansmire [7]; Burland et al. [5]; Abe et al. [1]; O'Reilly & New [12]; New and O'Reilly [10] and Mair et al. [9] and Bharti et al. [12]. In these papers, authors expressed that: “Dynamics software are useful to provide quick and detailed predictions of ground movements due to the most complex underground excavations”. Attewell et al. [2,3]; Rankin [11]; Boscardin and Cording [6]; Leblais et al. [8]; Verruijt and Booker [14]; Boone [4] and Zaw Zaw et al. [16] have presented methods which were adopted in the prediction of excavation, tunneling-induced ground movement and building damage risk-assessment. Moreover, Selby [14] studied transmission of settlements upwards to the surface in a homogeneous medium and in a layered medium with different consistency of the strata through numerical modelling. Attewell and Woodman [2] introduced the Greenfield movements due to tunnelling for the case of a single-tube tunnel in a homogeneous medium. Also, Peck (1969) from over 20 case histories obtained the semi-empirical Gaussian curve expressing the long term ‘Greenfield’ settlements induced by single tunnel. The curve represents the two basic important parameters, maximum settlement and influence range, but this Gauss curve is unable to give surface movement or stress distribution. The numerical analysis must include the response of structures to horizontal & vertical dynamic forces and consider all site characteristics, such as soils, rocks and geological conditions.

The induced stresses under the foundation of adjacent buildings during newly constructed underground tunnels through TBM, were investigated in this study. Results of this study were evaluated to find out whether the amount of variations in forces and stresses are in the allowable ranges or not.

SITE GEOLOGY

In this paper, soil parameters are based on the Delhi Metro tunnel site as taken by Bharti et al. [12]. Site is located between Malviya Nagar to Saket area of Delhi. The soils along the corridor consist primarily of sandy silt with some intermediate zone of silty sand. Quartzite rock layer was also recorded at the depth 8.8 to 27 meter and RQD were measured as nil to 96%. Ground water table is as deep as 35 meter to 40 meter i.e. tunnel area is in dry condition.

Using these soils parameters, tunnel excavation through TBM has been modelled in PLAXIS Tunnel-3D and the adjacent structures have also been included in the model. TBM used during the excavation, was 6.61 meter diameter with EPB shield as per the site condition.

NUMERICAL MODELLING

Three dimensional finite element method were used in this paper to predict the stresses in the residential buildings during operation of tunnel. Three dimensional finite element models allow the analyst to account for the extent and geometry of each of stratum to predict the stresses below foundation of the buildings due to TBM operations. The PLAXIS Tunnel-3D software was used to construct the model and three-dimensional step by step constructions were employed for the ground and the tunnel lining.

GEOMETRY METHODOLOGY

Before the model, full 3D parallel planes are included with two tunnels and two residential buildings. The model is 55.0 meter wide and it extends 28.0 meter in the z-direction and 25.0 meter deep from the existing ground surface. The model is sufficiently large to allow for any possible collapse mechanism and to avoid any influence from the model boundaries. Centre to Centre distances of both the tunnels are 15.33 meter and the diameters are 5.7 meter.

The 15-node elements are adopted for this analysis. Beam elements are used in PLAXIS software to model the bending of tunnel lining and the behaviour of these beam elements are defined by flexural rigidity, normal stiffness & ultimate bending moment. The interaction between the TBM and soil are modelled by means of an interface which is intermediate between smooth and fully rough. Thin zone of interface elements are required to calculate soil-tunnels interaction. The tunnel construction process is simulated in thirteen construction stages. The first four phases are assigned for existing buildings and other nine phases for the construction of twin the tunnels.

MATERIAL PROPERTIES

In the analysis, the various stresses below foundation of the buildings are calculated. To study the impact of vibration on existing two buildings over twin's tunnel during TBM operation, all values of stresses at the different elevations are compared with each other. Site visited before 3D modelling for better understanding of condition of soil or materials. The model for soil is Mohr-Coulomb with undrained condition.

Through the geotechnical investigation, two layers of soil and rock has been considered in the 3D numerical modelling. Soil layer is sandy silty with intermediate zones of silty sand and rock met at varying depth 8.5 to 27 meter along the alignment of the tunnels. Underlying rock classified as quartzite and refusal is met on the soil-rock interface. In general, the older alluvium is encountered in the most parts of the South Delhi underlain by quartzite because Delhi located at amidst the ranges of Himalaya and the Aravalli.

The measured water levels are recorded on the individual soil and rock profiles which is very low. At different location up to a maximum depth of 39.0 meter, groundwater was not encounter during field investigation. Since, water table is quite deep in the area, the model phreatic level was kept at the bottom of the rock layer i.e. tunnel is in dry condition, therefore TBM is easy to install at the appropriate place. Material properties of soil and rock layers are mentioned in the Table 1 and the engineering properties, Bharti et al. [12] for tunnels & buildings are mentioned in the Table 2.

Table 1. Material Property of Soil Layers

Name	**Top layer**	**Bottom Layer**
Soil Type	**Sandy Silt**	**Rock (Quartzite)**
Unit weight, (kN/m^3)	18	20
Poisson ratio, ν	0.35	0.25
Elastic Modulus, (kN/m^2)	2.32E+04	2E+05
Friction angle, (^{o})	34	-
Cohesion, (kN/m^2)	0	-

Table 2. MATERIAL PROPERTY OF TUNNEL AND BUILDINGS

Tunnel and Building Parameter		
TBM Properties		
Axial stiffness, EA	$6.74*10^6$ kN/m	20
Flexural rigidity, EI	$5.00*10^4$kNm^2/m	0.25
Equivalent thickness, d	0.3 m	2E+05
Weight, w	7.1 kN/m/m	-
Poisson's ratio, ν	0	-
Concrete Sprayed Lining		
Unit weight, γ	24.0 kN/m^3	-
Elastic Modulus, E	$2.64*10^7$ kN/m^2	-
Poisson's ratio, ν	0.2	-
Building Properties		
Unit weight	24.0 kN/m^2	-
Poisson's ratio, ν	0.2	-

In the model, the plane strain computation is adopted for the actual structure and analysis as follow:

- Number of elements = 4350
- Number of nodes = 14286
- Number of stress points = 26100

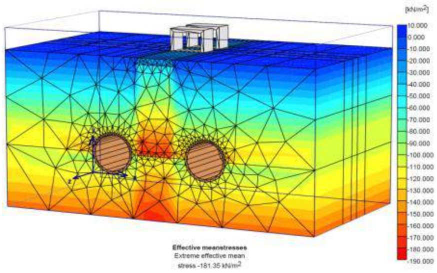

Figure1 Effective mean stresses

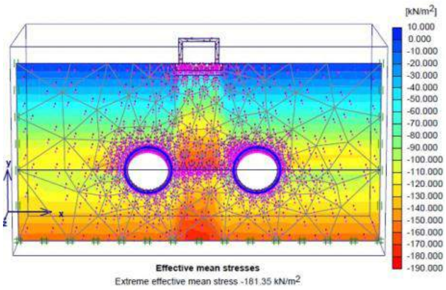

Figure 2 Effective mean stresses below the foundation of 1st building

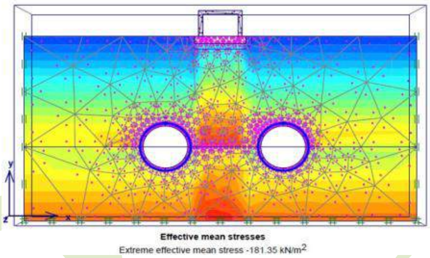

Figure 3 Effective mean stresses below the foundation of 2nd building

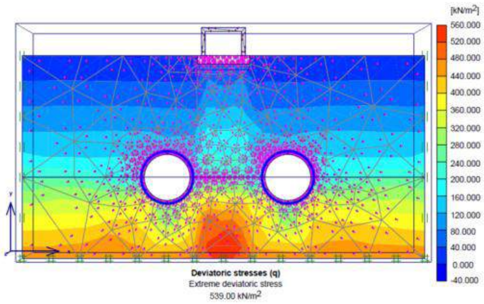

Figure 4 Deviatoric stresses below the foundation of 1st building

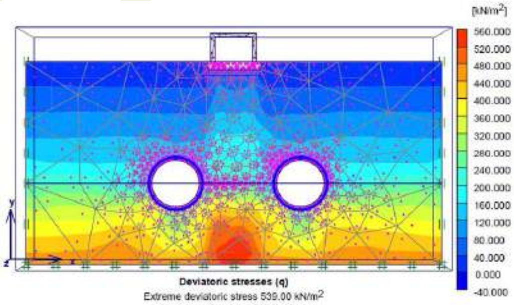

Figure 5 Deviatoric stresses below the foundation of 2nd building

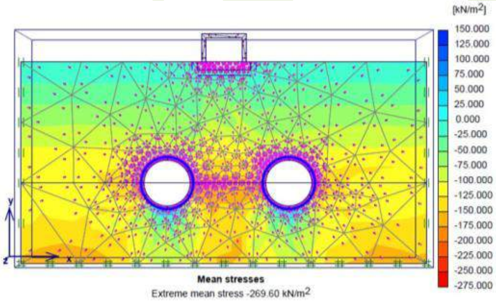

Figure 6 Mean stresses below the foundation of 1st building

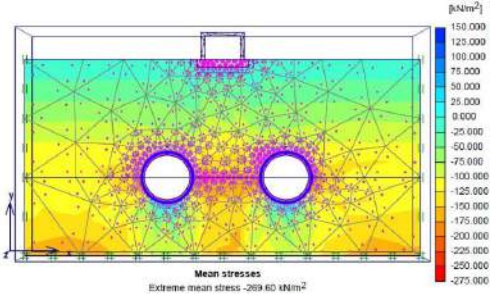

Figure 7 Mean stresses below the foundation of 2nd building

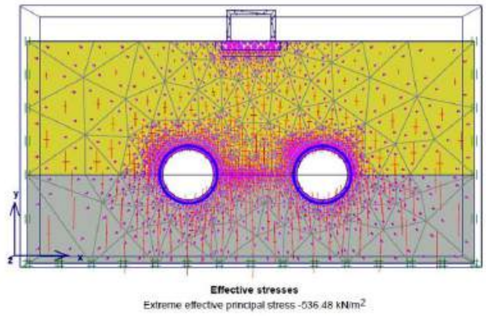

Figure 8 Effective stresses below the foundation of 1st building

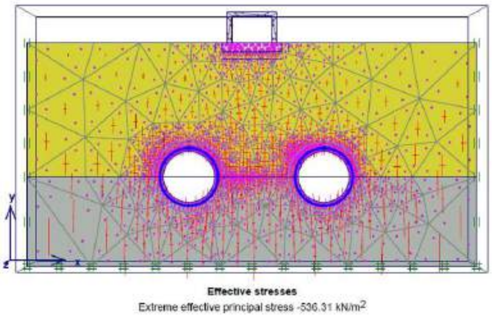

Figure 9 Effective stresses below the foundation of 2nd building

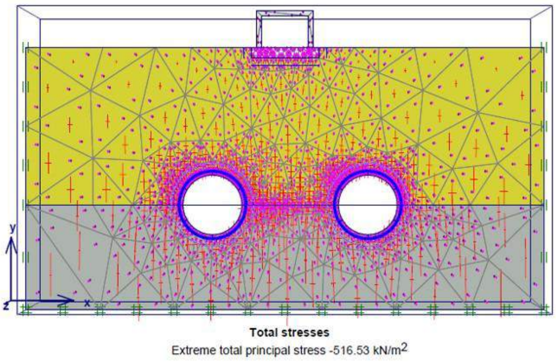

Figure 10 Total stresses below the foundation of 1st building

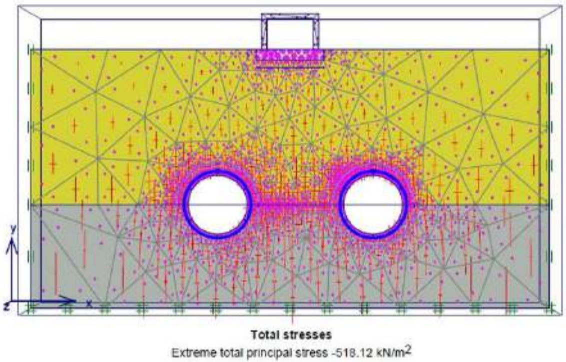

Figure 11 Total stresses below the foundation of 2nd building

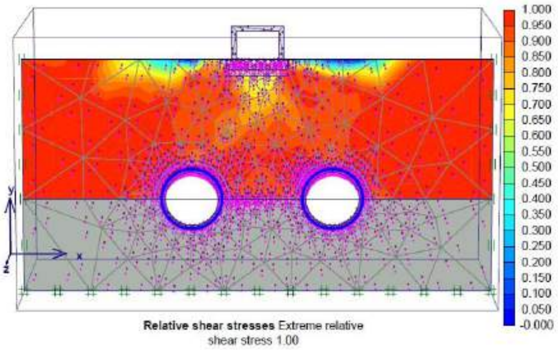

Figure 12 Relative shear stresses below the foundation of 1st building

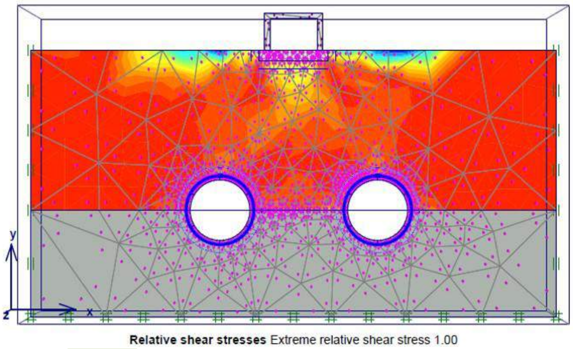

Figure 13 Relative shear stresses below the foundation of 2nd building

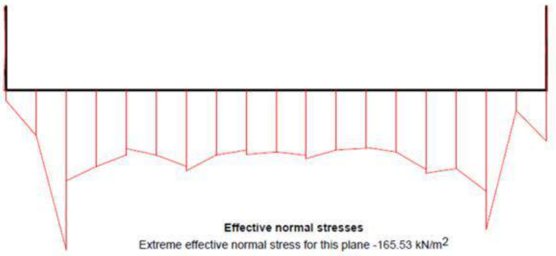

Figure 14 Effective stresses below the foundation of 1st building (Front Side)

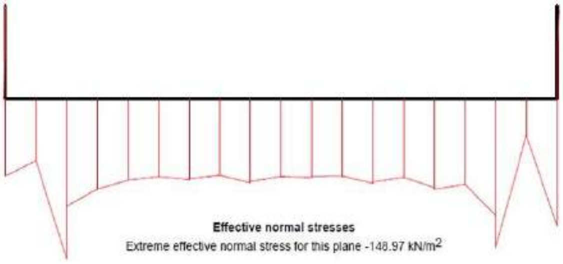

Figure 15 Effective stresses below the foundation of 2nd building (Front Side)

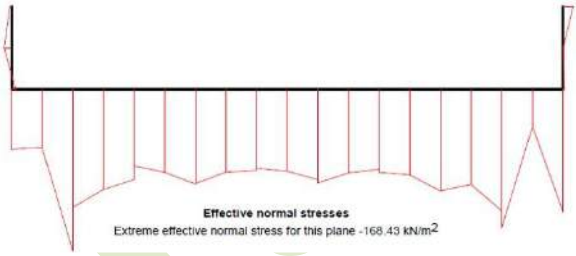

Figure 16 Effective stresses below the foundation of 1st building (back Side)

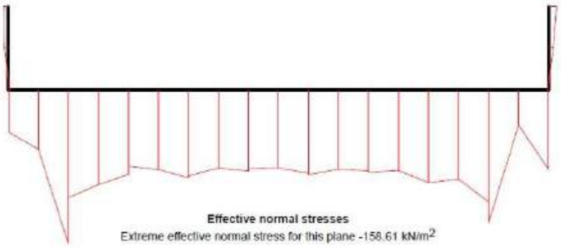

Figure 17 Effective stresses below the foundation of 1st building (Front Side)

RESULT AND CONCLUSIONS

Based on the PLAXIS results, effective mean stresses in the 3D view, effective mean stresses, deviatory stresses, mean stresses, effective stresses, total stresses, relative shear stresses and effective stresses are shown in the Fig. 1 and 2 to 17 below the foundations of 1st & 2nd building during the operation of TBM for construction of Metro train tunnels. A serendipity fifteen node element was used in the analysis. Obtained results for a case study of the Hauz

Khas tunnel in Delhi were compared with field data. The predictions from the modified generalized plasticity model show good agreement with field data, while obtained results by the Mohr–Coulomb model show less settlement and stress due to excavation through TBM. FEM model show good interaction between the two tunnels and the buildings foundation. Also, induced stresses at ground surface due to the tunnelling process is very less. The lining of the tunnel is designed for a more internal force when the analysis is implemented by the use of the Mohr–Coulomb criterion. The lining of the tunnel is designed for a more internal force when the analysis is implemented by the use of the Mohr–Coulomb criterion. Therefore, the model is more closely modelled with actual site situation. As per the various parameters considered under this study it is concluded that due to the operation of TBM machine, the buildings in the vicinity are not affected critically.

References

[1] Abe, T., Sugimoto, Y. & Ishihara, K. (1978), '*Development and application of environmentally acceptable new soft ground tunnelling method*', Proceedings of the International Symposium on Tunnelling under Difficult Conditions, Tokyo, pp 315-320.

[2] Akhaveissy, A. H. (2011), '*Analysis of tunnel and super structures for excavation'*, Scientia Iranica, Vol. 18, Issue 1, Feb. 2011, pp 1–8.

[3] Attewell, P. B. & Woodman, J. P. (1982), '*Predicting the dynamics of ground settlement and its derivatives caused by tunnelling in soil'*, Ground Engineering, vol. 15, no. 8, pp 13-22 and 36.

[4] Attewell, P. B. and Yeates, J. (1984), '*Tunnelling in soil, ground movements and their effects on structures'*, edited by P. Attewell & R.K. Taylor, pp 132-215, Surrey University Press, London.

[5] Boone, S. J. (1996), '*Ground-movement-related building damage, Journal of Geotechnical Engineering*, ASCE, Vol. 122, No. 11, pp. 886-896.

[6] Burland, J.B., Broms, J.B. and De Mello, V.F.B. (1977), '*Behavior of foundations and structures on soft ground, Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering (SMFE)*', Tokyo, Japan, July 10- 15, 1977, 495-546.

[7] Boscardin, M.D. and Cording, E.J. (1989), '*Building response to excavation-induced settlement*', Journal of Geotechnical Engineering, ASCE, vol. 115, pp 1-21.

[8] Cording, E.J. and Hansmire, W.H. (1975), '*Displacements around soft ground tunnels*', *Proceedings of the 5th Pan-American Conference on Soil Mechanics and Foundation Engineering*, Buenos Aires, Argentina, October 27-31, 571-633.

[9] Leblais, Y., Andre, D., Chapeau, C., Dubois, P., Gigan, J.P., Guillaume, J., Leca, E., Pantet, A. and Riondy, G. (1996), '*Settlements induced by tunneling, Recommendations of Workgroup of French Association of Tunnels and Underground Space (AFTES)*', Paris, France.

[10] Mair, R.J., Taylor, R.N. and Burland, J.B. (1996), '*Prediction of ground movements and assessment of risk of building damage due to bored tunneling, Proceedings of the International Symposium on Geotechnical Aspects of Underground Construction in Soft Ground'*, Balkema, Rotterdam, Netherlands, 712-718.

[11] New, B.M. and O'Reilly, M.P. (1991), '*Tunnelling induced ground movements, predicting their magnitude and effects, Proceedings of the Fourth International Conference on Ground Movements and Structures'*, Cardiff, UK, pp 671-697.

[12] Rankin, W. l. (1988), '*Ground movements resulting from urban tunnelling: Predictions and effects, Engineering Geology of Underground Movements'*, edited by F.G. Bell et al., pp 79-92. Geological Society, London.

[13] Bharti, R. K., Kumar, M. and Kumar N. (2014), ‘*Vibration Monitoring of Structures during Tunnel Excavation using Tunnel Boring Machine (TBM)’*, IGC, Kakinada chapter, India, Dec. 18-20, pp. 1804–1808.
[14] O’Reilly, M.P. and New, B.M. (1982), ‘*Settlements above tunnels in the United Kingdom their magnitude and prediction’*, Proc. of Tunnelling’82 Symposium, London, pp. 173-181.
[15] Selby, A. R. (1988), ‘*Surface movements caused by tunnelling in two-layer soil’*, Engg. Geology of Underground Movements, 5, 71-77.
[16] Verruijt, A. and Booker, J.R. (1996), ‘*Surface settlements due to deformation of a tunnel in an elastic half plane*’, Geotechnique, Vol. 46, No. 4, pp. 753-756.
[17] Zaw Zaw, A., Dhiraj, K. and Christian S. (2006), ‘*Ground movement prediction and building damage risk-assessment for the deep excavations and tunnelling works in Bangkok subsoil’, Proceedings of the International Symposium on Underground Excavation and Tunneling, Bangkok*, Thailand, February 2-4, 281-297.