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STRESS ANALYSIS OF TUNNEL IN SOFT SOIL: A STATE OF ART REPORT

M. A. Khan[1], M. R. Sadique[2], M. M. Alam[3]

[1,2,3]Department of Civil Engineering, ZHCET, Aligarh Muslim University, (India)

ABSTRACT

Underground facilities are an important part of the infrastructure of modern world and are used for extensive range of applications, including material storage, sewage, subways, railways, highways and water transport. In general, various factor are essential to consider while designing the tunnel in soft soil to optimise the cost of construction and safety also. Loads for underground structures are considered in terms of the strains and deformations imposed on the structure by the adjacent ground, often due to the collaboration between the two. The report discusses the various factor responsible for the stresses in tunnel lining in soft soil. This paper also gives brief idea about the method of analysis and construction of tunnel developed in recent year.

Keywords:Method of tunnelling, Numerical modeling, Seismic effect on tunnel, Soil-structure interaction, tunnel boring machine

I.INTRODUCTION

A tunnel has been described as a long, narrow, mostly linear excavated underground opening, in which one dimension i.e. length greatly exceeds other two i.e. opening width or height. (Walhstrom, 1973). Factors like urban development, population growth and limited space have emphasised a considerable growth in tunnel construction for subways, underpasses and urban highways for providing the better services to transportation all around the world. Engineers and Planners has shown interest in shallow tunnels for modern sustainable development of cities due to the fact that underground structure performed better than superstructure during an earthquake. However, limiting the surface and subsurface settlement and stresses in lining produced due to tunnelling in shallow and soft ground has been perceived as the main challenge of any geotechnical engineer. Due to the advancement and development of technology better solution are available to overcome the problems faces during the tunnelling. The present paper is an attempt to summarize the importance of tunnel construction, method of soil tunnelling and analysis of stresses in tunnel lining to economise the tunnel construction. Several essential parameters influencing the planning and design of tunnel in soft soil has been discussed.

II.METHOD OF TUNNELLING

Construction of tunnel in soft ground has always been challenging due to stability issue of tunnel face, settlement of nearby sub-surface soil and tunnelling-induced damage to superstructures. It is essential to select the suitable technique of excavation by keeping the various factor in mind regarding stand-up time, access for

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equipment, safety of workers etc. There has been various excavation technique developed for tunnel construction in different soil condition.

For strong clayey soil conditions of small works like sewage pipes installations etc. *Lay kicking method* of tunnel construction has been adopted. However, *Cut and cover method* of construction used to build shallow tunnels, by making a trench in the soil and providing some support which should be capable of bearing the convergence pressure. This method has been widely implemented for construction of Underground metro rail stations in soft soil. *Pipe jacking method* is used to construct tunnels under existing structures like road ways, railways using specially made pipes of diameter of 2-3m which are driven into underground using hydraulic jacks [1].

Besides conventional excavation methods the *New Austrian Tunnelling Method (NATM*) has now been a well-established method, capable of tunnelling in a wide range of soils and difficult conditions such as high pore pressures in soft soils or small cover depths. NATM has been equipped with precise control of cutter face and simultaneous backfill ground system, hence, make it possible to build a tunnel without loosening of surrounding ground as shown in fig 1. It is characterized by relatively complex construction processes and interactions between the ground and the tunnel boring machine(TBM), the tunnel lining and the tail void grouting [2]

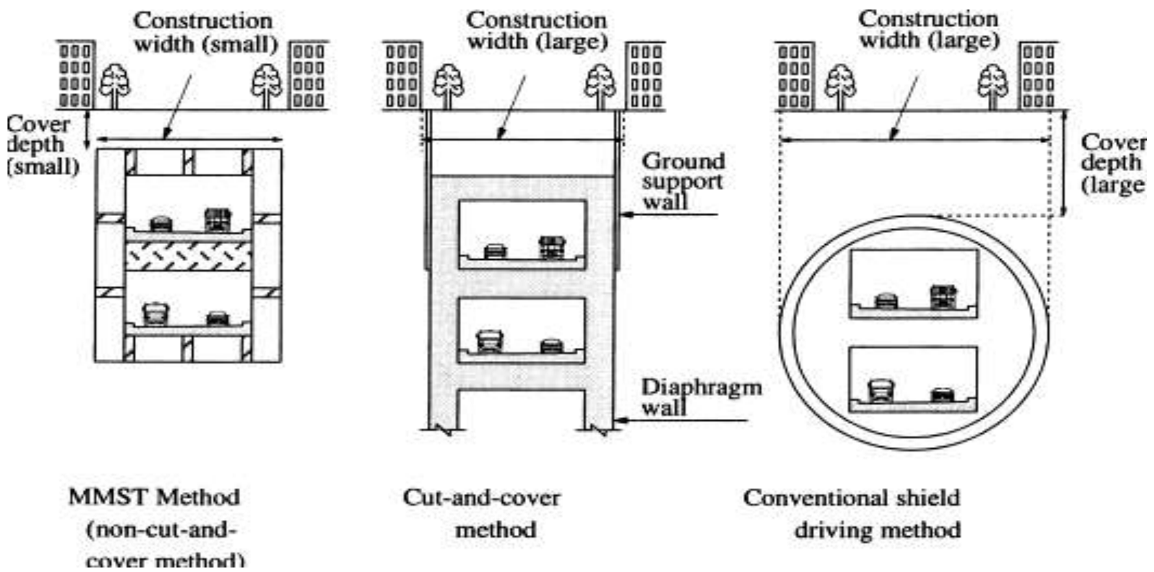

Fig 1: showing the different construction technique in Tunnel engineering [1]

In many countries *sequential excavation method* (SEM) has been adopted to perform the soft ground tunnelling without a tunnel boring machine [3]. Researchers had emphasised the necessity to use the appropriate techniques and technologies in all phase of tunnel construction. Yu and Chern [4] had developed a diagram as shown in (Fig 2) for selection of tunnel excavation methods based on span size and the ratio of tunnel confining ground uniaxial compressive strength to vertical stress.

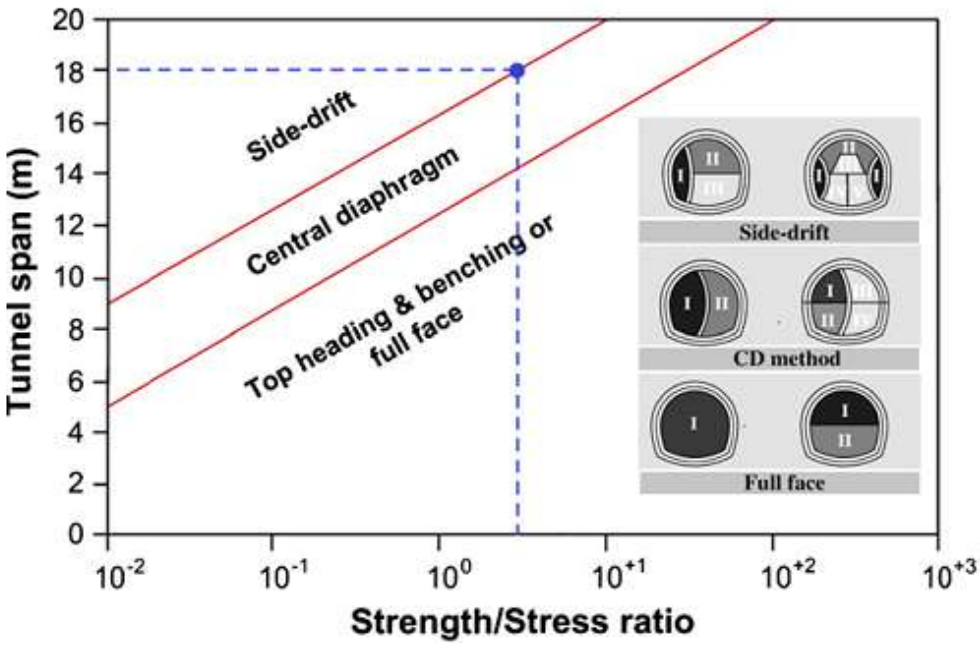

Fig 2: Empirical determination of excavation method based on span size and the ratio of UCS to vertical stress on the tunnel (Yu and Chern [4])

III.TYPES OF DEFORMATION IN TUNNEL

The deformations in tunnel may be due to surcharge load, redistribution of in situ stresses, creep phenomenon or seismic loading. Chen et.al [5] has listed failures as follows;

(a) Lining Crack

(b) Shear failure of lining

(c) Deformation of sidewall/invert damage

(d) Portal cracking

Seismic wave has been assumed as the governing parameter for inducing transient ground deformation. The deformation has quite been complex due to the interaction of seismic waves with surficial soft deposits and the generation of surface waves. Underground structures have been classified to undergo three primary modes of deformation during seismic shaking,

Axial and Curvature deformations developed in a horizontal or nearly horizontal linear tunnel when seismic waves propagate either parallel or obliquely to the tunnel. The tunnel lining design reflections for these types of deformations has been basically in the longitudinal direction along the tunnel axis. Fig.3 shows the illustrations of axial and curvature deformations respectively. The general behaviour of a linear tunnel was similar to that of an elastic beam subject to deformations or strains imposed by the surrounding ground [6].

The ovaling or racking deformations of a tunnel structure has been developed due to the propagation of waves in nearly perpendicular direction to the tunnel axis, resulting in a distortion of the cross-sectional shape of the tunnel lining. Design considerations for such type of deformation are in the transverse direction. Fig.3 shows the ovaling distortion and racking deformation associated with circular and rectangular tunnels, respectively. Ovaling and racking deformations have been caused by vertically, horizontally or obliquely propagating seismic waves of any type. Many studies have suggested, however, that vertically propagating shear wave is the predominant form of an earthquake loading that governs the tunnel lining design against ovaling/racking as Ovaling deformation is more critical than the axial and curvature deformations [6].

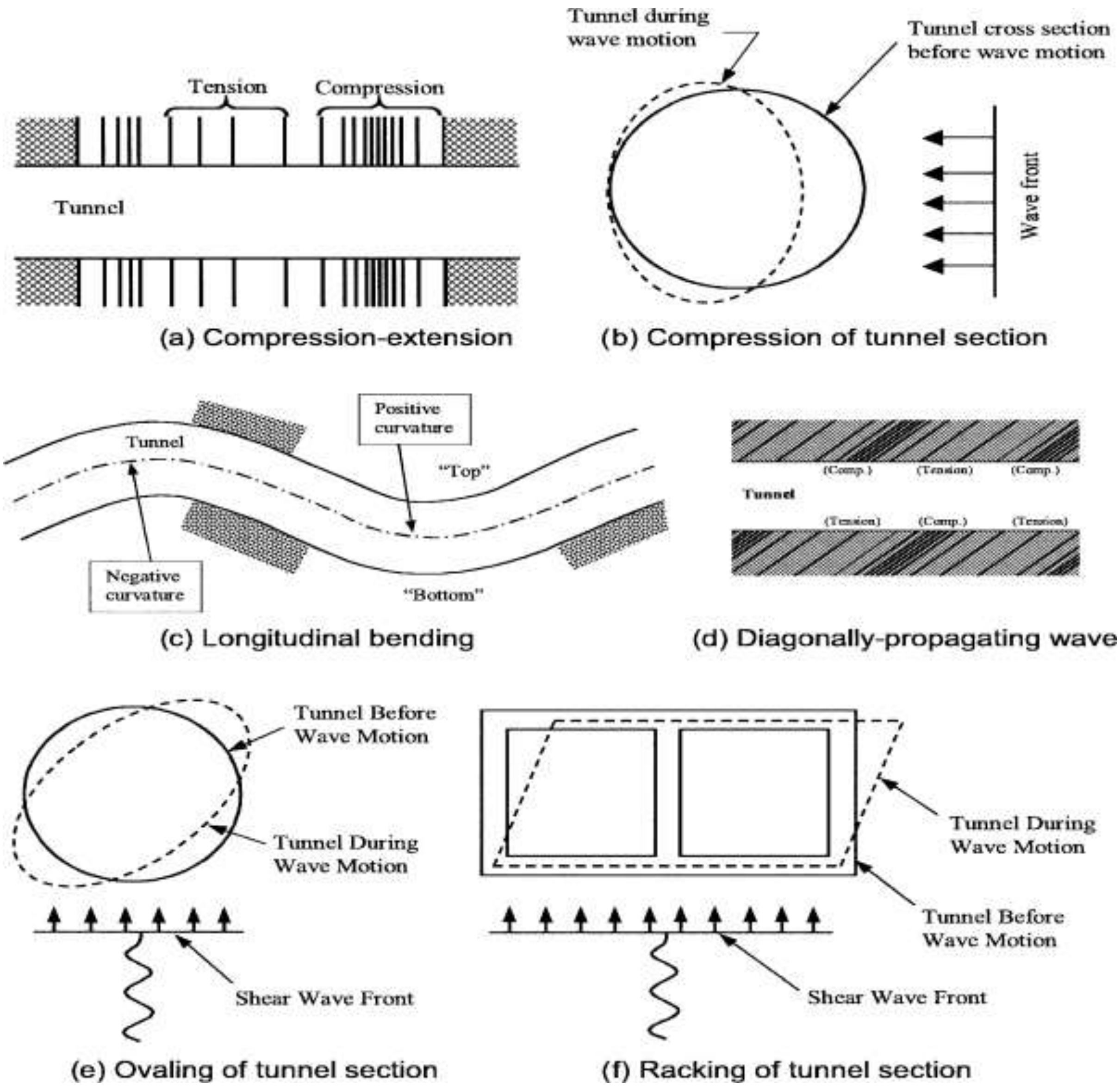

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Fig 3 Deformation modes of tunnels due to seismic waves by Owen and Scholl [6]

IV.METHOD OF ANALYSIS OF STRESSES

To optimise the design and to achieve the economy it has been necessary to analyse the stresses developed in the tunnel due to various factor such as stratification of soil, seismic loading etc. There are some methods available in the literature such as analytical, experimental and numerical to analyse the forces developed in the tunnel liner.

several researchers have developed some empirical formula for evaluating the forces in lining on the response of seismic loading on the basis of some assumption [7]

(a) The homogeneous soil mass and the tunnel lining are assumed to be linear elastic and mass less materials.

(b) Tunnel is circular with uniform thickness and without the joints.

(c) The effect of the construction sequence is not considered.

Wang [8] has been developed some empirical formula used to study the seismic behaviour of tunnels. Hashash et al. [9] gave excellent summaries of the available methods for seismic analysis of tunnels. There has been various method developed for investigate the seismic response analytically [24].

(a) Free field deformation approach

(b) Soil-structure interaction approach

(c) Dynamic earth pressure method

Experimental method has also provided the solution to calculate the stresses in lining during last decade. Several researchers have evaluated lining stresses experimentally and validate the results by numerical modeling [10-11]. Nunes and Meguid [10] have developed the experimental setup using the metal plate and perpex sheet and aluminium lining to study the behaviour of stratified soil in tunnel lining. Kiani et al [11] has been determined the failure mechanism of a tunnel, including its segmental lining by centrifuge modeling test on segmented tunnel subjected to normal faulting.

The advancement in computer technology and progress in computational mechanics have lead attention toward the numerical simulation in tunnelling in recent decades. Various researcher has been carried out 2D and 3D modeling analysis in tunnel construction with the help of finite element software [e.g. Potts & Addenbrooke [12], Lambrughi et al. [13], Hajihassani et al. [14]. Various software has established like SAP, ANSYS, PLAXIS 3D, and ABAQUS etc for performing the complex simulation. Tunnelling has been modelled in 2D although it is a three-dimensional (3D) problem just to make easier and less time consuming in simulation. Numerical modeling has been proposed to take account of the stress and strain changes ahead of the tunnel face when adopting 2D plane strain analyses to simulate tunnel construction.

V.PARAMETER THAT EFFECT THE STRESS IN TUNNELLING IN SOFT SOIL

Surface and subsurface subsidence have been caused by several factors, such as ground loss at the tunnel face, behind the rail of the shield and through the tunnel support lining. Other factors include the consolidation process of the soil with reference to the reduction of ground water level or the new equilibrium of pore pressures due to the redistribution of stresses within the ground after tunnel excavation. Besides ground settlements, also tunnelling can produce lateral deformations of the ground and longitudinal movements ahead of the tunnel face.

Various parameter is accountable for the deformation and the stresses in the lining of the tunnel such as layering of soil, depth of the tunnel from ground surface, types of soil, diameter of tunnel, liner material, surcharge loading (e.g. building) and seismic loading etc.

5.1Stratification of Soil

Stratification has an important role to develop the stresses in the lining of tunnel. Many researchers have explained the effect of soft clay, stiff clay, dense sand on the tunnel lining. Effect of stratification have studied by several researchers with the help of experimental and numerical method (e.g. [10,15,16-18]. Nunes & Meguid [10] has evaluated the effects of overlying sandy layers above a tunnel excavated in soft ground first experimentally and validate the result numerically. They concluded that, the bending stresses reduces up to 70% when the stiff layer was closer to the tunnel as compare from case of homogeneous clay. Mazek& Almannaei [18] have performed the numerical analysis to investigate the effect of volume loss (V_L) (the ratio of the difference between excavated soil volume and tunnel volume over excavated soil volume) in stratified soil. The result pointed out that volume loss is the important parameter which impact on tunnel liner stresses and settlement effectively and good agreement with field observation. Katebi et al. [2] performed a finite element analysis to observed the existence of surface buildings in layered soil by taking 2D plane strain condition. It has been observed that the existence of surface buildings in 2D plane strain analysis will cause the lining loads increases as compared to the green-field condition and also found that existence of silty layer above the sandy soil has not considerable effects on lining loads. Although while tunnel excavated in silty soil lining loads increase intensively compared to tunnels excavated in sand. Zhang et al. [16] has investigated the influence of the layered soils in terms of their relative stiffness and thickness of layer, on the lining behaviour (i.e. inner force and convergence) with model test using adjustable loading frame. It has been observed that, for two-layered soil condition, the increase of the relative stiffness of the overlying sandy layer leads approximately to a 45% reduction of the bending moment and a 50% reduction of the convergence and for a three-layered soil condition, the increase of the relative thickness of the sandwiched clay layer leads to an increase of approximately 90% of both the moment and the convergence.

5.2Soil-Structure Interaction:

Soil–structure interaction(SSI) is one of the most major subjects in the domain of earthquake engineering, has been paid complete attention internationally in recent decades. SSI phenomena concern the wave propagation in a coupled system structures built on or in the soil surface ([e.g.19,20-21]). Bernat & Cambou [19] by using numerical analysis, has developed the procedure for predicting the movement caused by shield tunnelling in shallow lined tunnel in homogeneous soft soil. They introduced a stage of modeling (called ``phase modeling") taking into account different phases which simulate the different kinds of interactions between the tunnel and the soil. Wang et al. [20] have investigated the effect of the shear wave in the underground structure numerically. The neighbouring low-slung buildings around underground structure may heavily affected. Farrell et at. [21] evaluate tunnel-induced ground response in soft clay considering soil structure-interaction and degradation behaviour during tunnelling with the help of finite-element program and comparing the result by field measurement and analytical formula. They found that the numerical simulation with soil tunnel interaction has an important parameter for stresses in lining due to the dynamic loading.

5.3Effect of dynamic loading

Earthquake is quite uncertain natural disaster which occur in any region without warning. It is necessary to analyse and design the underground structure to withstand the such calamities. Underground structures have features that make their seismic behaviour distinct from most surface structures, most notably by Hashash et al. [9].

Asheghabadi and Matinmanesh [22] presented an idealized two-dimensional plain strain finite element seismic soil-tunnel interaction. The analysis performed by considering three actual ground motion recording seismic wave with low, intermediate and high frequency content by using visco-elastic constitutive model. The result pointed out that the existence of tunnel amplifies the seismic waves on the soil surface and the maximum amplification occurs on the interface of the tunnel and soil. Azadi [23] performed numerical analysis and observed that the effect of the pore pressure variation during earthquake on underground structure. The damage resulting from seismic loading in soft saturated soil may cause underground structure to deform and settle due to decrease in bearing capacity and increase in latera earth pressure. Motaal et al. [24] examined the seismic interaction between tunnels and the surrounding granular dry soil with non-linear dynamic finite element method. They demonstrated that the bending moment increases with increasing tunnel embedment depth, starting from the ground surface up to certain depth. And also, results have shown that deformations are directly proportional with increasing tunnel diameter or reducing lining thickness. Anh do et al. [25] have done the parametric studied considering joint distribution, joint stiffness, influence of axial stiffness (ka) radial stiffness (Rs), influence of geometrical parameter etc. under the seismic loading numerically in segmental tunnelling. Result observed that the influence of joint distribution of segmental lining under seismic and static condition are different, an increase of joint number results in a reduction in absolute magnitude of the maximum /minimum values of B.M. and normal forces induced in tunnel lining. Hashash et al. [9] have investigated that the seismic response of tunnel numerically and conclude that Deep tunnels seem to be safer and less susceptible to earthquake shaking than are shallow tunnels.

V.CONCLUSION

Tunnel is the most important underground structure as the urban development increasing day by day. Recent advancement and development in tunnel engineering made easier to excavate deeper and provide stable configuration. Various studies have been made to understand the behaviour of tunnel lining due to different parameter to optimise the design of tunnel. From above study it has concluded that stresses in the liner affected by the various parameter such as method of tunnelling, soil stratification, type of soil and dynamic loading etc. Method such as experimental, analytical and numerical modeling are available in literature to analyse the tunnel lining stresses. Experimental and analytical method gives approximate result due to various assumption and sometime under & overestimate the liner stresses. it is not easy to simulate the actual ground condition but numerical modeling is an advance technique to analyse the stresses in lining from the last decade, which prove economical and reliable in the geotechnical field. Linear and non-linear model with soil-tunnel interaction have been used to simulate the actual ground condition but the pore pressure and building response on tunnel lining is not evidently studied on the tunnel.

REFERENCES

[1] Constructor civil engineering home, *Tunnel Construction Techniques and Their Details* ,2017.

[2] H. Katebi A. H. Rezaei and M. Hajialilue-Bonab, The Influence of Surface Buildings and Ground Stratification on Lining Loads Applying the Finite Element Method, *Electrononc Journal of Geotechnical Engineering,18(1*), 2013,1845-1861.

[3] V. Romero, NATM in soft ground: a contradiction of term⁈ *World tunnel* 2002,338-343.

[4] Yu. Chand, C.W. Chern, Expert system for D&B tunnel construction in underground spaces, *The 4th dimension of metropolises London 2007.*

[5] Z. Chen, C. Shi, T. Li, Y. Yuan, Damage characteristics and influence factors of mountain tunnels under strong earthquakes, *Natural Hazards 61* (2012) 387–401

[6] G, N Owen, R.E. Scholl, Earthquake engineering of large underground structures, Final Report, Apr. 1978 - Sep. URS/*Blume (John A.) and Associates, Casen Francisco*, (1981)

[7] G.V. Sederat, P.N. kongai, seismic response of underground structure, *Soil Dynamics and Earthquake engineering 2*,2005,343-350

[8] J. Wang, Seismic design of tunnels – a simple state-of-the-art design approach, *Monograph 7, Parsons Brinckerhoff*, One Penn Plaza, New York 1993

[9] Y. Hashash, J. Hook, B. Schmidt, J. Yao, Seismic design and analysis of underground structures, *Tunnelling Underground Space Technology16* (2001) 247–293.

[10] M.A. Nunes, M.A. Meguid, A study on the effects of overlying soil strata on the stresses developing in a tunnel lining, *Tunnelling and Underground Space Technology*, *24* (2009) 716–722

[11] Majid Kiani, Tohid Akhlaghi, Abbas Ghalandarzadeh, Experimental modeling of segmental shallow tunnels in alluvial affected by normal faults, *Tunnelling and Underground Space Technology 51* (2016) 108–119

[12] D.M. Potts, and TI. Addenbrooke, A structure's influence on tunnelling induced ground movements, *Proc. Instn. Civil engineers. Geotechnical Engineering*, *125*, (1997) 109-125.

[13] A. Lambrughi, L. Medina, and R. Castellanza, Development and validation of a 3D numerical model for TBM-EPB mechanized excavations, *Computers and Geotechnics.*, *40*, (2012) 97-113.

[14] M. Hajihassani, and D.J Armaghani, Effects of geotechnical conditions on surface settlement induced by tunnelling in soft grounds, *Electronic journal of geotechnical engineering (EJGE).*, *18,* bund F, (2013), 1163-1170.

[15] Ngoc-Anh Do, Daniel Dias, Pierpaolo Oreste and Irini Djeran-Maigre, A 2D numerical investigation of segmental tunnel lining behaviour, *Tunnelling and Underground Space Technology*, *37*, (2013) 115–127

[16] Dong-ming Zhang, Hong-wei Huang, Qun-fang Hub and Fan Jiang, Influence of multi-layered soil formation on shield tunnel lining,*Tunnelling and Underground Space Technology*, *47*, (2015) 123–135

[17] RuiCarrilhoGomes, FátimaGouveia, DiogoTorcato, Jaime Santos, Seismic response of shallow circular tunnels in two-layered ground, *Soil Dynamics and Earthquake Engineering*, *75*, (2015) 37–43

[18] S.A. Mazek, H.A. Almannaei "Finite element model of Cairo metro tunnel-Line 3 performance" Ain Shams Engineering Journal 4 (2013) 709–716

[19] S. Bernat & S. Cambou, Soil-structure Interaction in Shield Tunnelling in Soft Soil, *Computers and Geotechnics,2* (1998) 221-242

[20] Huai-feng Wang, Meng-lin Lou, XiChen, Yong-mei Zhai, Structure–soil–structure interaction between underground structure and ground structure, *Soil Dynamics and Earthquake Engineering*, *54*, (2013) 31–38

[21] Ruaidhri Farrella, RobertMairb, Alessandra Sciottic, Andrea Pigorinic, Building response to tunnelling, *Soils and Foundations,54(3),* (2014) 269–279

[22] M. Saleh Asheghabadi and H. Matinmanesh, Finite Element Seismic Analysis of Cylindrical Tunnel in Sandy Soils with Consideration of Soil-Tunnel Interaction, *Procedia Engineering of ELSEVIER*, *14,* (2011) 3162–3169

[23] M. Azadi, The Seismic Behaviour of Urban Tunnels in Soft Saturated Soils, *Procedia Engineering of ELSEVIER 14*, (2011) 3069–3075

[24] Mohamed Ahmed Abdel-Motaal, Fathalla Mohamed El-Nahhas, Mutual seismic interaction between tunnels and the surrounding granular soil, *HBRC Journal,10,* (2014) 265–278

[25] Ngoc-Anh Do, Daniel Dias, Pierpaolo Oreste, Irini Djeran-Maigre "2D Numerical investigation of segmental tunnel lining under seismic loading" Soil Dynamics and Earthquake Engineering *72* (2015) 66-76