7th National Congress on Civil Engineering, 7-8 May 2013
University of Sistan and Baluchestan, Zahedan, Iran

Interaction of tunnel-building in the low gradient ground surface

M. Mousivand[1], M. Bayat[2]

1- Department of Civil Engineering, Gonbad Kavoos Branch, Islamic Azad University, Gonbad Kavoos, Golestan, Iran

2- Young Researchers Club, Khomein Branch, Islamic Azad University, Khomein, Iran

Mohsenmousivand@gmail.com
m.bayat.civil@gmail.com

Abstract

The aim of this work is to study the effects of gradient of ground surface, structural weight and position of underground tunnel on the horizontal and vertical movements of soil profile. Ground materials, tunnel geometry and excavator device that are presented in the current study are related to a part of metro tunnel of Tehran. The obtained results from this theoretical work indicate that gradient of ground surface has important role in the ground movement. Also this effect is more prominent when there is a structure at ground surface. Beside, gradient of ground surface has more important in shallow tunnels than deep tunnels.

Keywords: gradient of ground; EPB, tunnel-structure interaction; PLAXIS.

1. INTRODUCTION

Increasing demand on infrastructures increases attention to soft ground tunneling methods in urbanized areas. So the need for tunnels in urban areas, especially for public transportation purposes, has increased markedly in recent years and the vertical movement due to tunnel excavation can be significant, particularly when tunnels are embedded in soft and compressible soils (Bernat and Cambou, 1998; Liu et al., 2008). Influence on adjacent buildings is major interest for tunneling operations in urban areas, due to the high interaction between tunneling and existing structures (Pickhavar et al., 2010; Dimmock and Mair, 2008) and it is of prime importance to predict the possible interaction between the structures during the design stage in order to maintain a stable tunneling operation.

In some cities, geotechnical and underground conditions mean that new tunnels must be constructed under structure that builds on ground surface. The construction of these tunnels must be carried out without imposing damage either to buildings located above the excavation or to the subsurface infrastructure, because, these vertical movements can cause damage to buildings in the neighborhood of an urban tunneling site (Mroueh and Shahrour, 2003). So, in engineering practice, empirical formula based upon field observations, such as Gaussian distribution curve proposed by Peck (1969), is often used to describe the tunneling induced ground vertical movement profile not only for its similarity in shape to the observed profile but also for its simplicity of formula form defined by a few parameters. Among others, Kolymbas (2005) derived the vertical movement curve analytically.

Generally, the problem of tunnel-induced vertical movements has interested many researchers over the past 40 years and many literature presented (among others, by Peck, (1969); Cording et al., (1975); Mair et al., (1996), (1997); Attewell et al., (1982), (1984); Rankin, (1988); New et al., (1991); Leblais et al., (1995). Moreover, Selby (1988)) based on a numerical modeling studied transmission of vertical movements upwards to the surface in a homogeneous medium and in a layered medium with different consistency of the strata. Further, because of recent progress in the ability of tunneling machines to cope with difficult ground conditions, the ground movements produced have been greatly reduced. A Summary of the literature review on vertical movement of ground surface due to tunnel excavation is presented; Many researchers, such as Phoon and Kulhawy, (1999), Baecher and Christian (2003) and Baker et al., (2006), have investigated the variability of soil properties. These researchers described soil properties via their mean values and standard deviations, as well as the spatial fluctuation via random fields. This approach is also present in geostatistical literature (Chiles and Delfiner, 1999; Christakos, 1992; Journel and Huijbregts, 1978; Vanmarcke, 1983).

Also recently Maleki et al. (2011) indicated that the stiffness of adjacent structure controls the ground movement distribution induced by tunnel excavation and also, as it was predicatively, increasing in structure weight leads to create the large displacement components in the ground and the structure width plays also a significant role in displacement distribution of ground. Beside they mentioned that adjacent building was modeled by two methods: (a) equivalent beam, (b) real geometry. The comparison of obtained analysis results indicates that the equivalent beam method for practical purposes can be used as a simple way for introducing the adjacent building characteristics in tunnel–adjacent structure interaction problems.

As was stated here, so far many studies have been conducted on vertical movement due to tunnel excavation, while the tunnel-building interactions in many types of soils are well known in this state. However soil movements due to tunnel excavation in the ground gradient with or without building at ground surface are not known completely. In the current study, interaction among tunnel, ground gradient and adjacent structure was done using a finite element method (PLAXIS). Tunnel geometry and ground properties are corresponding to a part of metro tunnel of Tehran city which was constructed using a slurry shield machine with an outside diameter of 9.0 m.

2. MODELING AND PARAMETERS

PLAXIS 3D code only generates the triangle mesh, but it can use the meshes in very fine size. Meshing is introduced in five modes: Very coarse, coarse, medium, fine and very fine. The important ability of code is to make finer meshing regarding a region and or surround of a line. However, the precision is increased by use of finer mesh in a region but causes time to add for run problem (PLAXIS code manual, 2005). Medium mesh mode is used in present work and in more sensitive zones, mesh dimension gets finer. Selection of this size of mesh is not worrying, because coarse meshes have been used in 3D vertical movement analysis by PLAXIS 3D code in some projects. Fig. 1 shows a view of the model; the horizontal (x) and vertical (z) directions are 200 and 50 m, respectively as shown in figure 2.

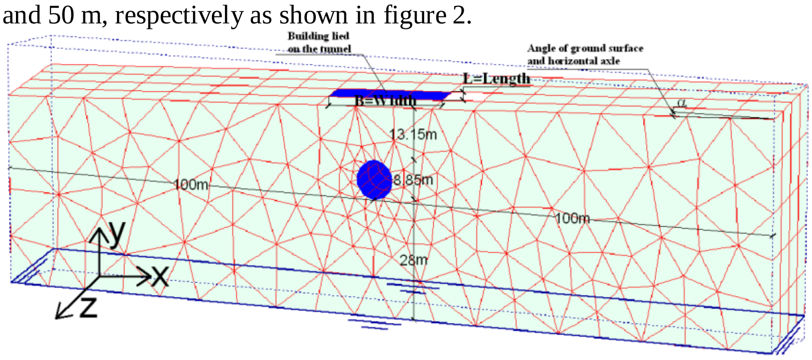


Figure1. FE mesh and lines of soil movement measurement

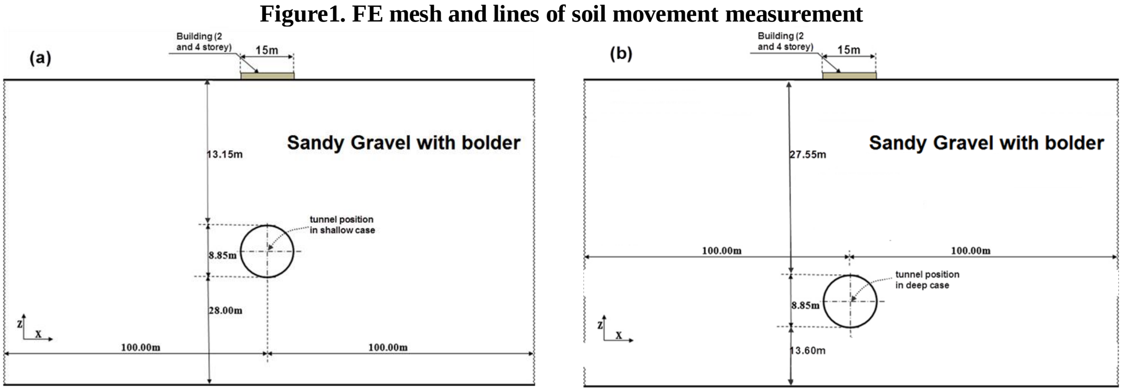


Figure 2. tunnel position: (a) in shallow case (b) in deep case

According to geotechnical information, the parameters of constitutive model were estimated. The values of parameters are listed in Table 1. Also thickness and mechanical parameters of tunnel lining are presented in Table 2.

Table 1. Soil physical properties.

R_{inter}	$E_{ur}^{res}(kN/m^2)$	$E_{oed}^{ref}(kN/m^2)$	$E_{50}^{ref}(kN/m^2)$	υ_{ur}	$\psi(^o)$	$\varphi(^o)$	$C(kN/m^2)$
0.7	1.75E5	5.6E4	5.67E4	0.2	10	40	0.25

Table 2. Mechanical parameters of tunnel ining

$EA(kN/m)$	$EI(kN/m)$	$Tunnel\ lining\ (cm)$
8.05E6	8.218E4	35

In the current study, the most suitable constitutive model presented in PLAXIS code was selected. This model is elastoplastic with the isotropic hardening mechanisms. It can be considered as development of non-associated Mohr–Coulomb model. In fact, major limitations of Mohr–Coulomb model are removed by adding a cap surface to describe plastification under isotropic stress, and an isotropic hardening mechanism to express non-linear plastic behavior before the failure. Evolution of yield surface in deviatoric mechanism is controlled via deviatoric plastic strain. Volumetric plastic strain controls the cap evolution. The plastic hardening and elastic modulus are properly considered as function of confining pressure.

In this study, the structure of adjacent building is considered by an equivalent elastic beam with length of L and width of B (Fig. 2). Bending stiffness (EI) and axial stiffness (EA) represent the overall stiffness of the structure. The advantages of this method are; simplicity in considering adjacent building stiffness according to structural system and weight of building and also the small amount of computational resources is required and therefore the ability to perform extensive parametric studies can be achieved. Considered structure in analyses was as 4 stories and diverse parameters of structure have been presented in Table 3.

Table 3. Parameters of modeled structure

$EA(kN/m)$	$EI(kN/m)$	$W\ (kN/m/m)$	$Structure$
1.725E7	3.989E8	40	4-Storey

Factors such as nonlinear behavior of soil, stress history, overburden depth and the diameter of a tunnel have a major influence on the development of ground deformation. In the last two decades, many researchers have tried to simulate the tunneling process by using the finite element method. They have used Mohr–Coulomb and von Mises criteria for 2D or 3D modeling (Shahrour and Ghorbanbeigi, 1994; Dias and Kastner, 2000; Mroueh and Shahrour, 2003; Meguid and Rowe, 2006). For this reason, in the current study, for analysis of the tunnel–soil-structure system, a Mohr- Coulomb model is applied by using the finite element program in PLAXIS.

A section of line 1 of Teheran metro near 7tir square station was modeled to achieve the aims of this study. Shield method was used for tunnel construction. The information concerning the soil properties, tunnel geometry and tunneling device were taken from Tehran urban and suburban railway organization. Concerning the geological aspects, 7tir station is located in the end part of nonhomogeneous alluvial formation in Tehran north and its lithological composition consists of sand, gravel, cobblestone and clay. Formation of this area is of a good permeability and depth of groundwater table is 74 m. Geotechnical data of this station shows the in situ sandy gravel with bolder. Values of geotechnical parameters are obtained based on jacking and direct shear tests (figure 1)

3. *Discussion On Results Analysis*

3.1. *Free Field Ground Movements*

This section presents the results of the interaction between building and tunnel. It is note that the focus is on ground horizontal displacement and ground vertical movement distribution. Vertical movement distribution of ground surface in two cases (i.e. shallow and deep tunnel) without building on ground has been presented in Figure 3. It is clear that vertical movement distribution is strongly affected by tunnel depth. In other words, as expected for a given gradient of ground surface, the vertical movement of ground surface is more prominent in shallow tunnel than deep tunnel. Also, as shown in this figure, gradient of ground surface has a regular effect on vertical movement distribution curve. There is a direct relation between the gradient values and the vertical movement in the end of mesh width (i.e. the upstream side of slope) and also it has an irregular effect on the maximum vertical movement. As shown in Figure 4 the amount of gradient has more effects on the vertical displacement of the upstream of slope than the middle of mesh width (i.e. above of the tunnel center line).

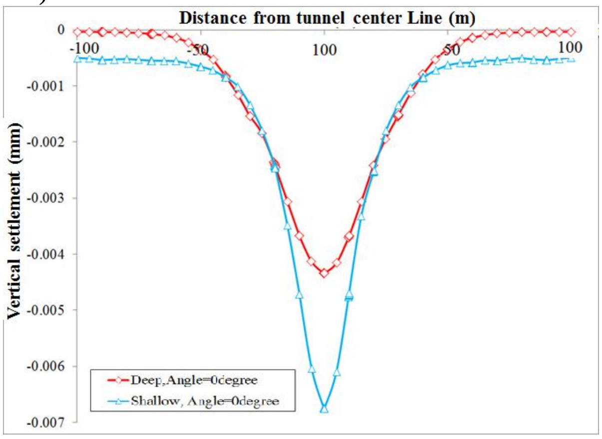
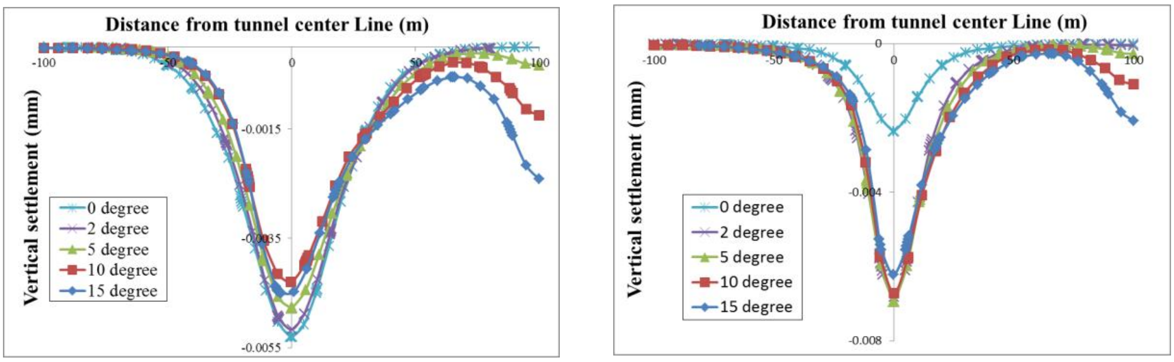


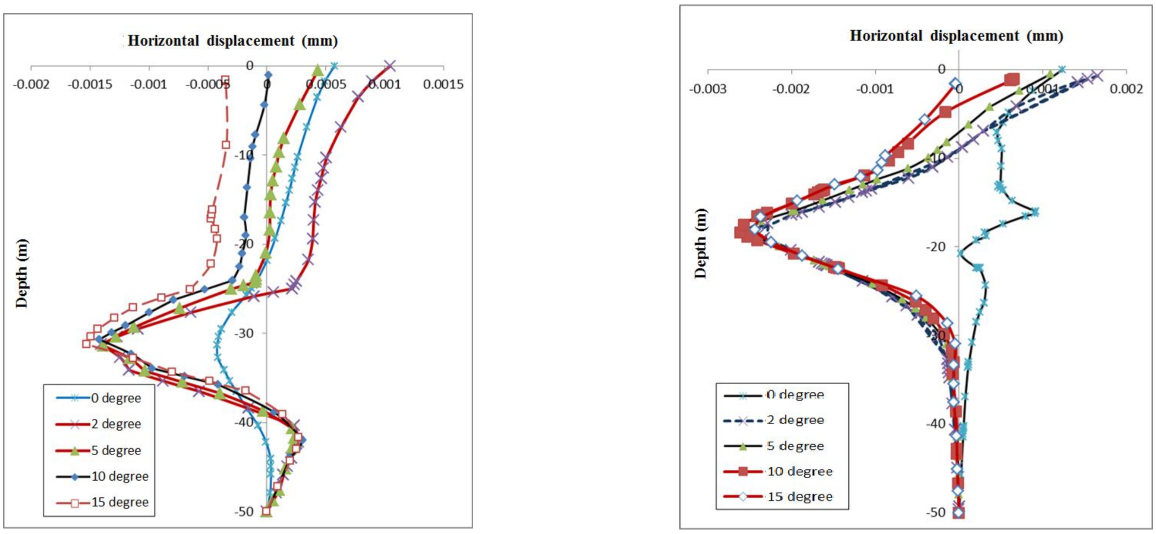
Fig. 3 vertical soil movement profile of ground surface in shallow and deep tunnels



a **b**

Fig. 4 Effects of Gradient on the vertical displacement of ground surface: (a) deep tunnel (b) shallow tunnel

Figure 5 presents the profiles of horizontal ground movement at a distance 6m from the tunnel center line in free field condition (without any building on the ground surface). As can be seen the most horizontal movement of the ground surface occurred in 2 degree tilt for the shallow and deep tunnels; Also the gradient of ground surface has not any effect on the vertical position of the maximum horizontal movements.This is an important that displacement increased by increasing ground surface gradient. The maximum horizontal movement at all gradients of ground surface in the ground surface is the same place. However the gradient of ground surface has the irregular effect in the maximum horizontal movement in the horizontal center line of tunnel. With comparing the two figures (i.e. Figs. 5a and 5b), it can be concluded that position of tunnel (i.e. deep or shallow) has effects on the horizontal movement in ground surface. The horizontal movement in ground surface of the shallow tunnel is more prominent than the deep tunnel. Our results are in good agreement with previous research findings (such as Maleki et al., 2011). Another result from figure 5 can be find is increasing of horizontal displacement by increasing in slope angle of ground surface. deep tunnel problem amplititude this values.

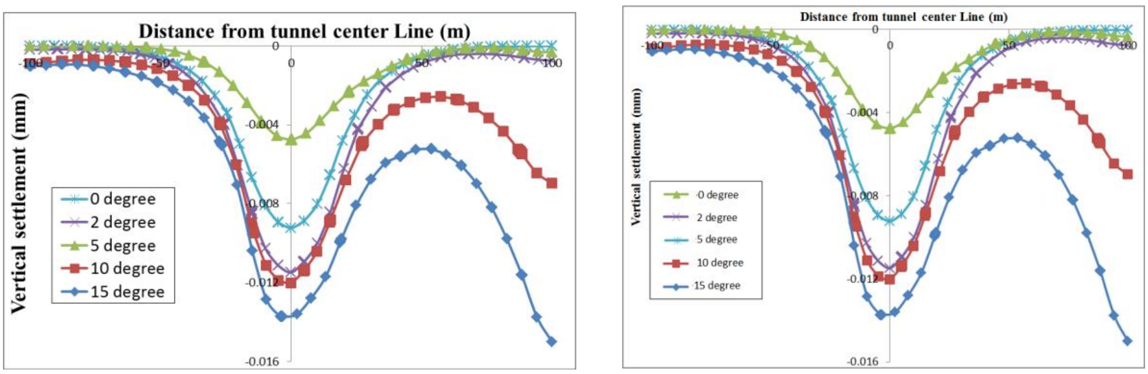


a b

Fig.5 Horizontal movement of soil in various gradients of ground surface in distance of 6 m from tunnel axis: (a) deep tunnel (b) shallow tunnel

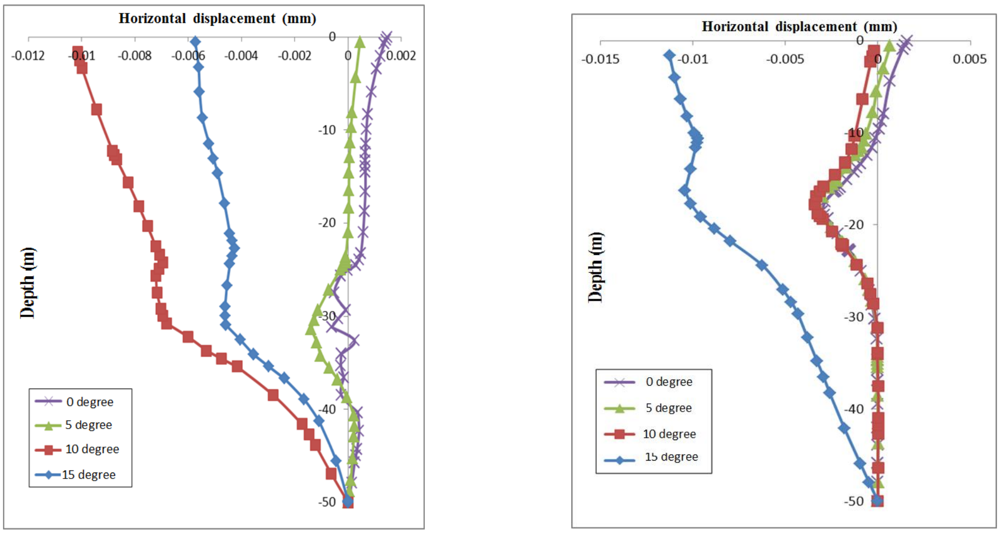
3.2. EXISTED BUILDING ON THE TUNNEL

Investigation of building effects on displacements induced by tunneling are studied in this part., For this purpose, a 4storey building has been assumed on the ground surface in the gradient values of 0˚, 2˚,5˚, 10˚ and 15˚. As expected, the presented results in Figuer 6 indicate that the maximum vertical displacement in the deep tunnel condition is less than the shallow tunnel condition for a given of gradient and building. Beside, increasing of gradient from 0˚ to 2˚ and 5˚ to 15˚ vertical movement in the deep tunnel condition likely to the shallow tunnel condition, vertical settelements are increased but in range of angle between 2˚ to 5˚ the adverse result can be seen (i.e. the vertical displacements reduced by increasing the angle).
Figure 7 presents the profiles of horizontal ground movement at a distance 6m from the tunnel center line for the shallow and deep tunnels The dependency of horizontal displacements to grandinet can be seen in figure 7. As increasing this angle of ground surface from 0˚ to 15˚, ground experienced more displacement; however this issue is attenuated by reducing overburden soil on tunnel (shallower tunnels).



a b

Figure 6. vertical soil movement profile of ground surface in gradients of o˚ and 2˚: (a) deep tunnel and (b) shallow tunnel



a b

Fig. 7. Horizontal soil movement profile of ground surface in gradients of o° and 2° in distance of 6 m from tunnel axis: (a) deep tunnel and (b) shallow tunnel

4. *CONCLUSION*

In the current study a set of FE analyses were performed to study the effects of building and gradient on the horizontal and vertical movement due to tunnel excavation (shallow or deep tunnel). For this purpose, the adjacent structure was modeled by equivalent beam method. The conclusions from this study are summarized as following:

1- For a given gradient of ground surface, the vertical movements of the ground surface caused by excavation of shallow tunnel are prominent than deep tunnel.

2- The amount of gradient has the more effects on the vertical movement of upstream of slope than the above of the tunnel center line. The vertical movement in the upstream of slope increased with the increasing of gradient. However the gradient of ground surface has irregular effect on the maximum vertical movement.

3- Most horizontal movement of ground surface occurred in 2 degree . Also the gradient of ground surface has the irregular effect on the vertical position of maximum horizontal movement at the downstream side of slope.

4- Position of tunnel (i.e. deep or shallow) has important effect on the horizontal movement in ground surface. In other words, the horizontal movement in ground surface due to shallow tunnel excavation is more significant than deep tunnel excavation.

5- Increasing of gradient has significantly effect on the profiles of horizontal ground movement in deep tunnel than shallow tunnel. So this parameter must be noted to design of tunnels in ground surface with non zero angle..

5. *REFERENCES*

Attewell PB, Taylor R K (1984) Ground Movements and their Effects on Structures, Chapman and Hall.

Attewell PB, Woodman (1982) Predicting the Dynamics of Ground Settlement and its Derivatives Caused by Tunneling in Soil, Ground Eng. 15(8): 13–22.

Baecher GB, Christian JT (2003) Reliability and statistics in geotechnical engineering. John Wiley & Sons Inc.

Baker J, Calle E, Rackwitz R (2006) Joint committee on structural safety probabilistic model code, section 3.7: Soil properties, updated version. Technical report, Joint Committee on Structural Safety, August.

Bernat S, Cambou B (1998) Soil-structure interaction in shield tunneling in soft soil. J. Comput. Geotech 22: 221–242.

Chiles JP, Delfiner P (1999) Modeling spatial uncertainty. New York: Wiley.

Cording E J, Hansmire W H (1975) Displacements around Soft Ground Tunnels, Proc.: 5th Pan American Conf. Soil Mechanics and Foundation Engineering, Buenos Aires, (4): 571–633.

Christakos G (1992) Random field models in earth sciences. Academic Press.

Dimmock PS, Mair RJ (2008) Effect of building stiffness on tunneling-induced ground movement. J. Tunnel. Undergr. Space Technol 23: 438–450.

Journel AG, Huijbregts CJ (1978) Mining geostatics. Academic Press, London.

Kolymbas D (2005) Tunelling and Tunnel Mechanics: A Rational Approach to Tunneling, Springer-Verlag Berlin Heidelberg, Germany.

Leblais Y, Andre D, Chapeau C, Dubois P, Gigan JP, Guillaume J, Leca E, Pantet, A, Riondy G (1995) Settlements Induced by Tunneling, AFTES Recommendations.

Liu HY, Small JC, Carter JP (2008) Full 3D modelling for effects of tunnelling on existing support systems in the Sydney region. J. Tunnel. Undergr. Space Technol 23: 399–420.

Mair RJ, Taylor RN, Burland JB (1996) Prediction of Ground Movements and Assessment of Risk of Building Damage, Geotechnical Aspects of Underground Construction in Soft Ground: 712-718, Balkema, Rotterdam.

Mair RJ, Taylor RN (1997) Bored tunnelling in the urban environment. Theme Lecture, Plenary Session 4, 14th International Conference on Soil Mechanics and Foundation Engineering, Hamburg, 6-12 September.

Maleki M, Sereshteh H, Mousivand M, Bayat M (2011) An equivalent beam model for the analysis of tunnel-building interaction. journal of Tunnelling and Underground Space Technology 26: 524–533.

Mroueh H, Shahrour I (2003) A full 3-D finite element analysis of tunneling– adjacent structures interaction. J. Comput. Geotech 30: 245–253.

New BM, O'ReilIy MP (1991) Tunneling Induced Ground Movements; Predicting their Magnitude and Effects, the 4th International Conference on Ground Movements and Structures, invited review paper, Pentech Press, Cardiff pp 671–697.

Peck RB (1969) Deep excavation and tunnelling in soft ground. In: Proceedings of 7th International Conference on Soil Mechanic Foundation Engineering, Mexico, State-of-the-Art Volume, pp 225–290.

Phoon KK, Kulhawy FH (1999) Characterization of geotechnical variability. Canadian Geotechnical Journal 36: 612–624.

Pickhavar JA, Burd HJ, Houlsby GT (2010) An equivalent beam method to model masonry building in 3D finite element analysis. J. Comput. Geotech 88: 1049–1063.

PLAXIS 3D Tunnel 2.00 Manual (2005).

Rankin WJ (1988) Ground Movements Resulting from Urban Tunneling: Predictions and Effects Eng. Geol. of Underground Movements, pp79–92.

Selby A R (1988) Surface Movements Caused by Tunneling in Two-layer Soil. Eng. Geol. of Underground Movements, Nottingham, pp 71–77.

(1983) Random fields: analysis and synthesis. The M.I.T., 3rd edition.