IJBPAS, December, 2015, 4(12), Special Issue: 1408-1422

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

ANALYSIS OF BUILDING SETTLEMENT RISK DUE TO MECHANIZED TUNNELING WITH ENTIRE CROSS SECTION

MAHDI ABEDPOUR KARIZAKI[1], MOHAMMAD JALAL ARSHADI[2], MOHAMMADMAHDI RAJAEI[3], SALIM POURMAND[4]

1 Department of Civil Engineering, Torbat-e-heydarieh Branch, Islamic Azad University, Torbat-e-heydarieh, Iran

2 Departments of Civil Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran

3 Master of mining engineering, Mechanized excavation supervisor at the second line 0f Tabriz subway from the Imensazan Consultant Engineers Institute and mm.rajaei2003@gmail.com

4 M.S.C Student of Rock Mechanics, Department of mining Engineering Sahand university of Technology and salim.pourmand@yahoo.com

ABSTRACT

Today, using Tunnel Boring Machine (TBM) in mechanized excavation operations, especially for large tunnels with high operation speed, has become prevalent. In recent years, in tunneling projects, particularly excavation systems with TBM, many incidents has been occurred. Mashhad Urban Railway Line 2 (MURL2) with a length of 14.3 km and rail depth of 16 to 25 m is under construction. Because the passing route of TBM is in one of the populated areas with high building density and high risk, so assessment and analyzing of the settlements and encountered risks from the preliminary phases to execution phase should be considered. In this paper, a combinational method for assessing settlement risk of buildings located on the excavation route is introduced. Also the settlements of an important building along the route of MURL2 is calculated and consequently settlement risk of this building is evaluated with the introduced method. Finally, according to level of risk, an appropriate settlement compensating method can be used.

Keywords: Settlement risk, tunnel boring, TBM, Mashhad urban railway line 2, building class

1. INTRODUCTION

In recent years using whole section tunnel boring machine (TBM) in underground Tunnels and urban areas is so widespread [Shahriar et al. 2009]. Boring a tunnel with a shielded TBM will always yield settlements and displacements. Depending on the state and nature of the buildings and infrastructural objects and the amount of settlement that will occur, damage may be induced to the buildings and infrastructure (Sozio, 1998). It is therefore good practice to conduct a Settlement Risk Assessment (SRA) prior to the start of the boring and construction activities. The problem of tunnel-induced settlements and related risk assessments of building damages has interested many researchers over the last 40 years. Many references are presented, among others, Peck, 1969; Cording et al., 1975; Burland et al., 1977; Attewell et al., 1982, 1984; Rankin, 1988; Boscardin and Cording, 1989; Clough and O'Rourke, 1990; New and O'Reilly, 1991; Leblais et al., 1995; Mair et al., 1996, 1997. Zaw Zaw et al. (2006) presented methods that were adopted in the prediction of excavation and tunneling induced ground movement and building damage risk-assessment.

It is therefore good practice to conduct a Settlement Risk Assessment (SRA) prior to the start of the boring and construction activities. During the constructional phase of the project, based on the SRA a swift overview can be obtained of possible risks and through monitoring actual deformations that occur the SRA can be updated. If required necessary precautions to prevent damage can be taken.

This article presents the inventarisation of the buildings along the route, which may be directly or indirectly influenced by ground deformations due to the tunnel boring process. The objective of the article is to describe each building qualitatively, based on a number of items, and from the available information of each building determine the building class, which describes the vulnerability of each building to possible damage.

2. Inventarisation of buildings and required information:

The measures taken to determine risk of settlements, strongly depend on the presence of surface or subsurface level structures in the direct vicinity of the bored tunnel and the vulnerability of these structures to the expected settlements. Therefore, it is first of all of importance to determine the nature of the buildings and infrastructural objects which are within the settlement risk zone above the bored tunnel.

Extensive research has been done into the allowable displacement of, and consequently the damage inflicted on, structures. A number of internationally accepted methods and guidelines resulting from this research are available. The methodology which will be adopted, for the SRA for the MURL2P will be based on the methods described by Boscardin and Cording (1989) and Mair et al. (1996).

All buildings along the route within the settlement risk zone will be categorized into a number of classes. To categorize each building into a building class, technical information of each building should be available as detailed as possible. The information required for each building is indicated in Table 1 on the following page.

In this article, a cross section of route of Mashhad urban railway line 2 (MURL2) at trajectory kilometre 10+091, has been chosen. In this section, an important building , which is introduced with the name “8B19”, is located. Example values for each parameter of this building are given in the right-hand column of table 1 and also in figure 2.

It is stressed that the descriptions in table 1 are qualitative and partly on engineering judgment. The combination of the above mentioned items results in a building class. Distinction is made into 5 building classes A to E, ranging from a low vulnerability to settlement induced damage in class A, to a high vulnerability to settlement induced damage in class E (refer to Table 2 below). According to tables 1 and 2, If the example of Table 1 (Building 8B19) is taken, than the building class would result in class E.

3. Settlement Determination

In the process of the risk assessment of buildings along the tunnel route, the settlements should be calculated. As the values of building settlement due to tunnel boring depends on differnrt factors, so the settlement calculations are approximate from exact values. In various articles, many researches have been carried out about this problem. Analysis of some different tunnels have been presented in many references: Peck (1969), Attewell et al. (1986), Sagaseta (1987), Loganathan & Poulos (1998). In references Attewell et al. (1986), Higgins (1996) and Potts & Addenbrook (1996), relation between effect of tunnel boring and existing buildings has been discussed. Before settlement calculations can be performed, boundary conditions and starting points need to be established. These can be summarized in the following four main points:

• Soil properties;

• Tunnelling method and causes for settlement;

• Tunnel- and TBM properties;

• Properties surroundings.

Here, the settlement calcutions is done by the PLAXIS finite element software code (Vermeer and Brinkgreve, 1998) and by using the hardening soil model (HS). The hardening soil (HS) model is based on hardening plasticity rather than plastic-elastic theory (as is used for Mohr-Coulomb (MC) models). Therefore, in the HS-model the soil stiffness is described more accurately than, for instance, in a MC model. The hardening soil model accounts for stress dependency of stiffness moduli. So all stiffnesses increase with pressure increase. All the input stresses therefore relate to a reference stress (usually 100 kPa). For this model there are also advanced modelling features, which require additional parameters. The basic parameters used for this model are listed below:

Young's modulus (E), Poisson's ratio (ν), Friction angle (ϕ), Cohesion (C), Secant stiffness in standard drained triaxial test (E_{50}^{ref}), Unloading/reloading stiffness (E_{ur}^{ref}).

For the calculations performed for this cross section, the soil parameters, earned from geotechnic reports, presented in table 3. The groundwater level is determined at -30m below surface level [Arthe Civil & Structure, 2010].

The cross section of considered building and the tunnel route along with soil leyer condition is showed in figure 2.

In table 4, the loads for the buildings present in figure are presented. In figures 3 and 4, the Plaxis model and the plaxis analysis result for cross section are shown, respectively. The minimum and maximum settlements underneath the building are presented in figure 5 and table 5.

As it comes from figure 4, the maximum value of the settlement trough above the heart of the tunnel tube is $36*10^{-3}$ m and according to figure 5 and table 5, the maximum difference in settlement over the width of the foundation (northern corner to southern corner) of the building 8B19 is equal to approximately $2*10^{-3}$ m.

4. Damage classification

In order to determine the possible damage to each building, the vertical settlements should be related to building deformations. From this relationship, the strains and rotations that occur at each building can be calculated. Subsequently the damage to each building can be estimated and categorized into damage categories. For the classification of the damage, the generally accepted classification of Boscardin and Cording

(1989) is adopted. The damage classification is described in the table 6.

Plotting the data in figure 6 subsequently yields the damage category, resulting in category 1 for this building. This is illustrated in figure 7.

Table 1: Technical information of buildings for determination of building class

Description of information	Type of information	Example values (Building 8B19)
Type of building (use)	Descriptive	Residential
Foundation type	Strip / raft / other	Raft (Mat)
Foundation depth	Relative to surface level	14 m
Number of basement levels	N	3
Number of stories	N	10
Structural type	concrete structure / steel structure / all masonry / other	Concrete
Wall type	Concrete / Masonry / Other	Concrete
Relative age of building	new: 1 – 15 years / medium: 15 – 50 years / old: > 50 years	New
Structural state	Good / Moderate / Poor	Good

Table 2: Overview of building classes and the relation to vulnerability to settlement induced damage

Building class	Vulnerability to settlement induced damage	Description
A	Low vulnerability	Low rise buildings (max. 1 storey) with a high structural integrity and low importance
B	Slight vulnerability	Low rise buildings (max. 1 storey) with a low structural integrityor a high importance
C	Moderate vulnerability	Medium rise buildings (max. 3 storeys) with a high structural integrity and low importance
D	High vulnerability	Buildings (max. 3 storeys) with a low structural integrity and high importance or Buildings > 4 storeys with a high structural integrity and low Importance
E	Extreme vulnerability	Buildings > 4 storeys with a low structural integrity and high importance High rise buildings (> 10 storeys) or Very important buildings (etc. hospitals)

Table 3: Geotechnical parameters used in settlement calculation [Arthe Civil & Structure, 2010]

Depth to Surface level [m]		Soil Class	γ_{bulk}[kN/m^3]	γ_{dry}[kN/m^3]	$\emptyset'$[deg]	C'[kPa]	E_{50}^{ref} [MPa]	E_{ur}^{ref} [MPa]	m
Top	Bottom								

0.0	-4.0	SC-SM	18.5	17.0	32.2	4.9	50	200	0.5
-4.0	-10.0	CL	18.0	16.5	30.0	14.5	25	100	0.6
-10.0	-16.0	GC	20.5	18.5	34.7	12.6	60	240	0.5
-16.0	-30.0	CL	18.0	16.5	30.0	14.5	25	100	0.6

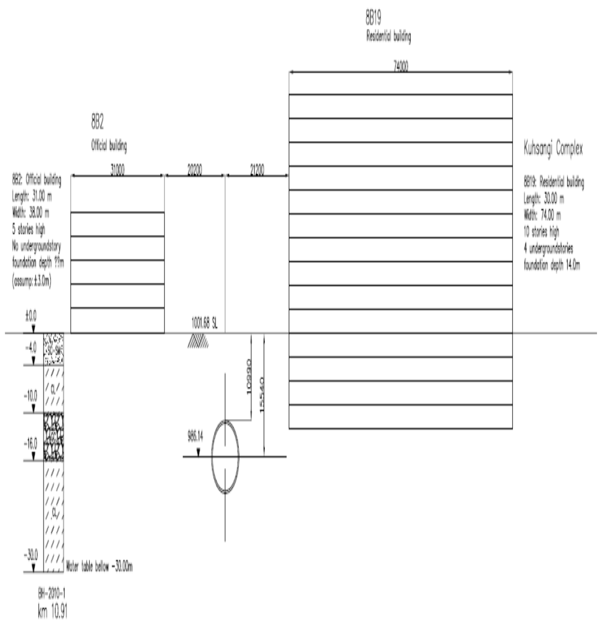


Figure 2: Schematic cross section of building 8B19, tunnel and geotechnic borehole

Table 4: Loads of surrounding buildings

Building	No. floors on the ground	No. Basements	Load floor (kN/m^2)	Load basement (kN/m^2)	Total load (kN/m^2)
8B19	8B19	3	12	20	180
8B2	8B2	-	12	20	60

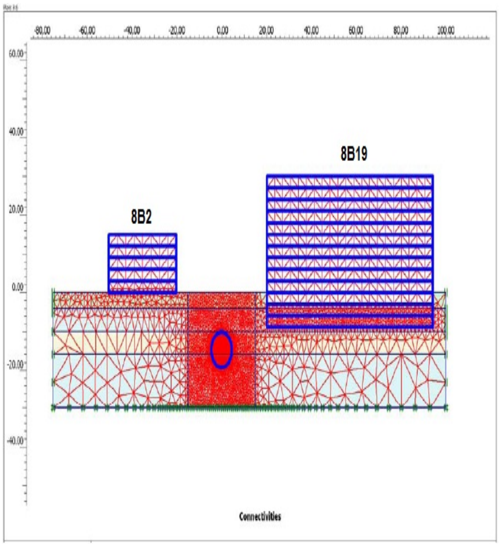


Figure 3: Plaxis model for cross section

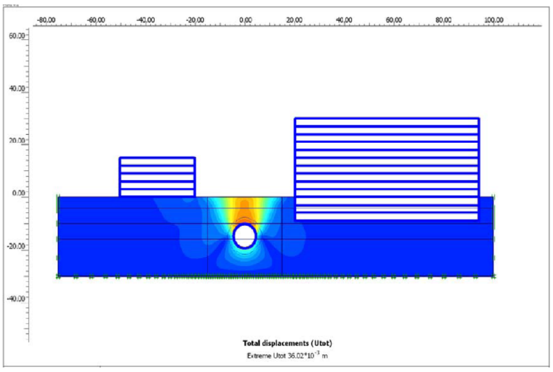


Figure 4: Plaxis analysis result and settlement values

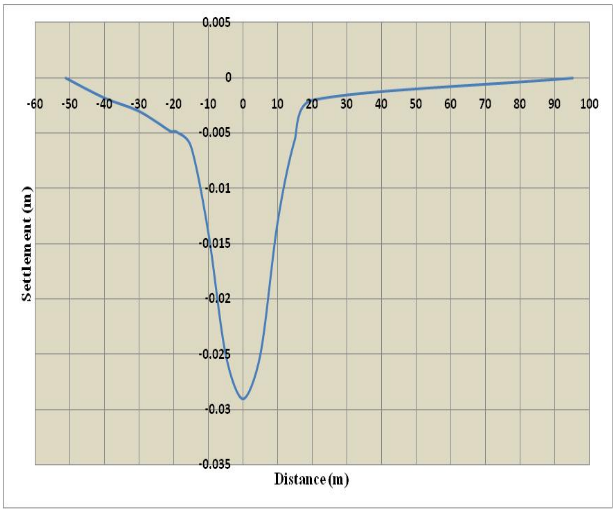


Figure 5: Settlement troughs underneath building

Table 5: Results numerical settlement calculations final stage

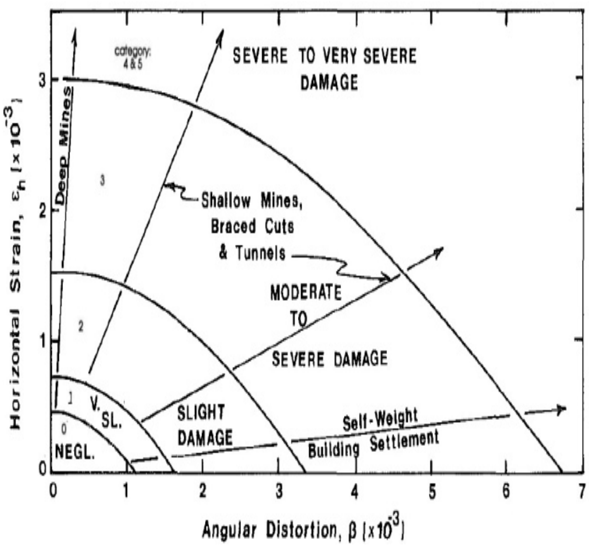
Building	Min. settlement at north corner (m)	Max. settlement at South corner (m)
8B19	0	$2*10^{-3}$

Table 6: Damage classification (Boscardin and Cording, 1989)

Limiting tensile strain εlim(%)	Δ (cm)	Approx. crack width	Desciption of typical damage	Damage category	
0 - 0.05	< 3	< 0. 1 mm	Hairline cracks	Negligible	0
0.05 - 0.075	3 – 4	1 mm	Very slight damage includes fine cracks that can be easily treated during normal decoration, perhaps an isolated slight fracture in building, and cracks in external brickwork visible on close inspection	Very slight	1
0.075 - 0.15	4 – 5	5 mm	Slight damage includes cracks that can be easily filled and redecoration would probably be required; several slight fractures may appear showing on the inside of the building; cracks that are visible externally and some repointing may be required; doors and windows may stick	Slight	2

3	**Moderate**	**Moderate damage includes cracks that require some opening up and can be patched by mason; recurrent cracks that can be masked by suitable linings; repointing of external brickwork and possibly a small amount of brickwork replacement may be required; doors and windows stick; service pipes may fracture; weathertightness is often impaired**	**5 to 15 mm or a number of cracks > 3mm**	**5 – 8**	**0.15 - 0.3**
4	**Severe**	**Severe damage includes large cracks requiring extensive repair work involving breaking out and replacing sections of walls (especially over doors and windows); distorted windows and door frames, noticeably sloping floors; leaning or bulging walls; some loss of bearing in beams; disrupted service pipes**	**15 to 25 mm but also depends on number of cracks**	**8 – 13**	**> 0.3**

5	Very severe	Very severe damage often requires a major repair job involving partial or complete rebuilding; beams lose bearing; walls lean and require shoring; windows are broken with distortion; there is danger of structural	Usually > 5 mm but also depends on number of cracks	> 13	> 0.3



	Damage Category						
Building Class	0	1	2	3	4	5	
A	I	I	I	II	III	IV	I
B	I	I	II	III	IV	V	II
C	I	II	II	III	IV	V	III
D	I	II	III	IV	V	V	IV
E	I	III	IV	V	V	V	V

Figure 6: Relationship of damage to angular distortion and horizontal extension strain (Boscardin et al. 1989)

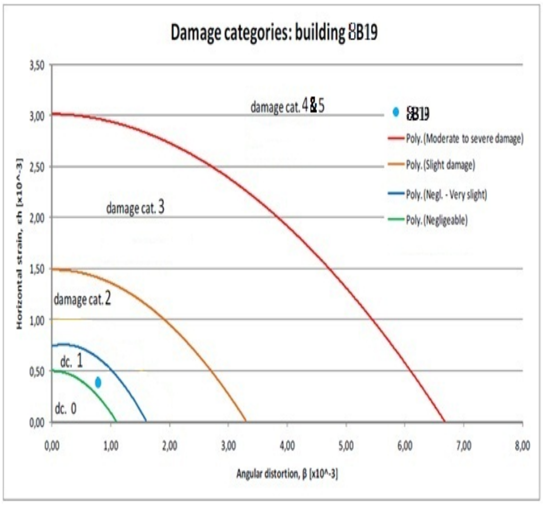


Figure 7: Determination of damage category for building 8B19

5. Risk class determination

The final step in the SRA comprises the combination of the probable damage due to settlements (damage category) with the vulnerability to the damage (building class) of each building. The possible damage that may occur has been determined from the settlements as described in part 4.

When determining the risk class from the building class and occurring damage category a logical system of rules is applied. The combination of these classifications results in the risk class, which is shown in table 7. According to this table, for the example of this study (building 8B19), the building will be in risk class III (figure 8).

Finally, a typical description of different risk classes presented in table 8. According to this table, appropriate decisions can be made about buildings located on the tunnel route. Table 7: Ditemination of risk class according to building class and damage category.

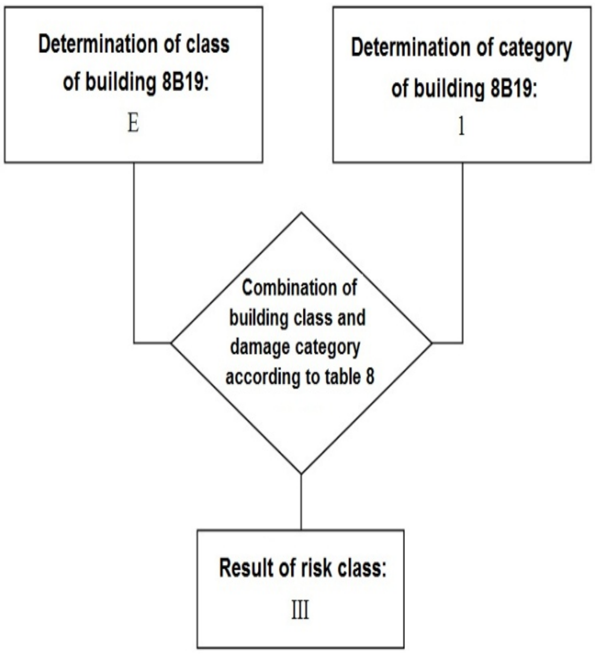


Figure 8. Process of risk class determination for building 8B19

Table 8: Description of risk class of buildings[Guglielmetti, 2007]

Risk class	Description
I	**Negligible risk, standard observation of building during construction**
II	**Low risk, standard observation of building during construction**
III	**Medium risk, take mitigative measures**
IV	**High risk, mitigative measures required to prevent damage**
V	**Very high risk, damage unavoidable**

6. CONCLUSIONS

- The process of the settlement risk assessment and determination of risk classes for the buildings along the route, which may be directly or indirectly influenced by ground deformations due to the tunnel boring process, is presented in this paper with a new combinational approach. It should be noted that here an optimal operation of the TBM is assumed. Operational aspects of TBM which may adversely affect the amount of ground deformations (e.g. applying insufficient face pressure, excavating too much soil in relation to advancement of the TBM, applying insufficient grout and/or grouting pressures etc.), have not been accounted for in the risk assessment.

- In this paper, a high and important building along the at the Mashhad urban railway line 2 route was analysed, the method of risk level assessment was well defined and the risk level of this building was classified in class III. The result of settlement calculations for this building showed that the settlements at foundation level have small values and so the building under study is not much influenced by tunnel boring operation. The reasons are: suitable condition of structure, existence of appropriate soil with high resistant parameters around the under study region, locating the groundwater lower than the tunnel level, distance of building from the tunnel axis, and also the shape of tunnel cross section (circular).

- If the building is in high level of risk, choosing an appropriate treatment method would be very important. The choice of the method that should be applied is, among others, related to the purpose of ground treatment in a particular circumstance, which will be determined in relation to the project condition. Beside this, soil condition has also noticeable importance. Along the tunnel route, soil has variable condition. Therefore for different points of a project, the settlement compensating method might be different. In order to perform a design for soil improvement for a specific situation, the following information about the soil to be treated will need to be known:

Soil type, Soil consistency, Bulk density, Grain size distribution, Water content, Atterberg limits.

In situ and laboratory tests may have to be performed to be able to determine the best suited injection mix or fluid for certain local soil conditions. The parameters listed above will have to be determined before an accurate design can be made to improve soils.

- The buildings that are at high risk for structural damage and possible loss of structural integrity, large and serious countermeasures should be taken if the relevant building is to be protected from serious damage. On the other hand, For the buildings that are over the tunnel axis, the tunnelling induced settlements will inevitably influence the buildings. The most feasible countermeasures that are to be taken are therefore the application of settlement compensation methods, such as compaction grouting or fracture grouting. Finally, monitoring of the building is highly necessary during the passage of the TBM because of thedifferential settlements. Building monitoring should be used to control the settlement compensation methods. Especially during the passage of the TBM, extensive monitoring should be applied at the buildings that are to be protected. Even when settlement compensation methods and good monitoring is applied, it may be required to temporarily preventively evacuate the building to guarantee the safety of the people using the building. The necessity to evacuate the building should be assessed for each building individually, regarding the building type, its structure type and the function of the building.

REFERENCES

[1] Arthe Civil & Structure b.v. (2010): report: “Determination of final geotechnicalparameters for calculations”, report no.: MUR2-ART-RE-E.01R01.

[2] Attewell, P.B. and Taylor, R.K. 1984. Ground Movements and their Effects on Structures, Chapman and Hall, New York, U.S.A., pp. 132-140.

[3] Attewell, P. B.,Yeates, J. and Selby, A. R. (1986). “ Ground movements induced by tunneling and their effects on pipeline and structures ”, Chapman and Hall, New York.

[4] Attewell, P.B. and Woodman, J.P. 1982. Predicting the dynamics of ground settlement and its derivatives caused by tunneling in soil. Ground Engineering. 15, 13-22.

[5] Boscardin M. D. and Cording E. J. (1989). “Building Response to Excavation-Induced Settlement”, Journal of Geotechnical Engineering, American Society of Civil Engineers, Vol. 115, No. 1, pp. 1-21.

[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] Clough, G.W. and O’Rourke, T.D. 1990. Construction induced movements of in-situ walls. P. Lambe and L.A. Hansen, Editors. American Society of Civil Engineers

(ASCE), Geotechnical Special Publication, Reston, Virginia, U.S.A., pp. 439-470.

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

[9] Guglielmetti, V., Grasso, P., Mahtab, A., Xu, S. (2007): "Mechanized Tunnelling in Urban Areas". Design methodology and construction control. A BALKEMA BOOK. Turin, Italy.

[10] Higgins, K. G., Mair, R. J. and Potts, D. M. (1996). " Numerical modeling of the influence of the Westminiter station excavation and tunneling on the Big Ben Clock tower", Geotechnical Aspects of Underground Construction in Soft Ground, Mair & Taylor(eds.).

[11] 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.

[12] Loganathan, N. and Poulos, H. G. (1998). " Analytical prediction for tunneling-induced ground movements in Clay" journal of Geotech. and Geoenvi. Eng., Vol.124, No.9, pp. 846-856.

[13] Mair, R.J., Taylor, R.N., (1997): "Bored Tunneling in the Urban Environment". 14th international Conference on Soil Mechanics and Foundation Engineering, Hamburg, Balkema: Rotterdam, p. 2353-2358.

[14] Mair, R. J., Tailor, R. N. and Bracegirdle, A. (1993). "Surface settlement profiles above tunnels in clay", Geotechnique, Vol. 43, No.2. pp.315-320.

[15] 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, 1996, 712-718.

[16] New, B. M. and O'ReilIy, M. P. 1991. Tunneling induced ground movements; Predicting their magnitude and effects. Proceedings of the 4th International Conference on Ground Movements and Structures, invited review paper, Cardiff, Pentech Press, London, July 7, 1991, 671-697.

[17] Peck, R. B. 1969. Deep excavations and tunneling in soft ground. Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering,

State-of-the-art volume, Mexico city, 1969, 225-290.

[18] Potts, D. M. and Addenbrooke, T. I. (1996). "The influence of an existing surface structure on the ground movements due to tunneling: GAUC, Mair & taylor (eds). PP. 573-578.

[19] Rankin, W. J. 1988. Ground movements resulting from urban tunneling: Predictions and effects. Engineering Geology of Underground Movements. 5, 79-92.

[20] Sagaseta, C. (1987). "Analysis of underground soil deformation due to ground loss", Geotechnique, Vol. 37, No.3, PP. 300-330.

[21] Shahriar K, Rostami J, KhademiHamidi J, editors. (2009). "TBM tunneling and analysis of high gas emission accident in Zagros long tunnel",

[22] Sozio, L.E., 1998. General Report: Urban Constraints on Underground Works. World Tunnel Congress98 on Tunnels and Metropolises. Balkema, Sao Paulo, Brazil. pp. 879–897.

[23] Vermeer, P.A. and Brinkgreve, R.B.J. 1998. PLAXIS Finite Element Code for Soil and Rock Analysis, Balkema, Rotterdam-Brookfield, Netherlands, pp. 1-114.

[24] Zaw Zaw, A., Dhiraj, K. and Christian S. 2006. Ground movement prediction and building damage risk-assessment for the deep excavations and tunneling works in Bangkok subsoil. Proceedings of the International Symposium on Underground Excavation and Tunneling, Bangkok, Thailand, February 2-4, 2006, 281-297.