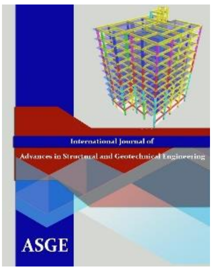

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Effect of Considering Seismic Loads on Horizontal Twin Tunnels

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Effect of Considering Seismic Loads on Horizontal Twin Tunnels

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ABSTRACT

It was common opinion that earthquake effects on underground structures are not very important. This is because these structures have generally experienced a low level of damage in comparison to constructions above ground. Nevertheless, in the urban areas the serviceability of underground networks (like roadway, railway, water and gas pipelines) were severely interrupted and limited after strong earthquakes and the seismic response of these structures have been addressed by many authors in the last years. The objective of this research is directed towards numerically investigating the seismic behaviour of the Greater Cairo metro line No.4 passes under the River Nile in Egypt land and evaluate the additional forces due to increasing seismic loads on this horizontal twin tunnel. For this purpose, 2D nonlinear dynamic analyses of soil–structure system are carried out with the aid of finite element software, PLAXIS 2D. The evaluation is done by modal analysis, with a numerical model of the tunnel, based on the finite element method. Finally, this study can set new guidelines for the design phase of an underground structure and address the effects of earthquakes on tunnels to protect it from damage caused by ground shacking.

Keywords: underground structure, twin tunnels, Greater Cairo metro line No.4 , numerical modeling.

INTRODUCTION

The vibration analysis of tunnels and surrounding grounds due to train movement had very little significance in the past because of locating tunnels in mountains and deserts and only a series of simplified assumptions and equivalent static loads were used for seismic design of tunnels. The BART system was one of the first structures of underground that was designed for seismic loads [1] and during Loma Prieta earthquake in 1989 spared from any damage. For the first time in 1960 British Petroleum engineers have done the seismic design of underground spaces for a tunnel project. One of the first people who examined the effect of earthquakes on underground structures is Newmark who proposed an easy way to calculate the effect of earthquake loads on long tunnels and calculate the relative strains of underground tubes in 1968. Keusel in 1969 devised a simple method for calculation of forces induced by earthquake on the linear tunnels that it has become the basis of many researches. Douglas and Warshaw (1971) offered the analysis results of the design of covered tunnel under the earthquake effect [2] .Dowding and Rozen examined the tunnel's response to the ground movements. Their studies on the rock tunnels showed that tunnels were much safer than aboveground structures for a given intensity of vibration. It was also shown that the deep tunnels were safer than shallow tunnels [3]. Owen and Scholl declared that duration of earthquake was an important factor in the severity of damage to underground structures and can be increased with the continuity of stresses returning on the previously damaged parts.The initial damages will increase by earth movements such as fault and landslide [4]. John and Zahrah have presented a research paper in the field of long circular tunnels design against earthquake [5]. Sharma and Judd collected qualitative data for 192 reported visits from 85 earthquakes around the world. The available information show more damages for built facilities in soil relative to appropriate rock [6]. Keusel et al. in 1996 offered a simple way about the analysis and design of linear tunnels [7]. With the review of the seismic behavior and design of underground structures in soft grounds, Kawashima in 1999 suggested the seismic deformation method in these situations in which conducted the seismic analysis with applying deformation on the tunnel which its behavior was assumed identical [8]. Chen et al. in 2012 examined the mechanisms of seismic damages on the tunnels with different depths and observed that surface tunnels in loose rocks and deep tunnels in resistant rocks were extremely vulnerable [9]. Wang and Zhang carried out the seismic damage classification and the risk assessment of occurring earthquake on mountain tunnels and offered a new method to this aim using seismic parameters, ground conditions and structural data [10]. Shen et al. investigated the seismic damage mechanism and the dynamic deformation analysis of 52 mountain tunnels after the Wenchuan earthquake in 2008 and observed that mainly the relative deformations occurred in the upper half of the tunnels was more than the values of the lower sections [11]. Abdel-Motaal et al. examined the seismic interaction between the tunnels with a diameter ranging from 6 to 10 meters and surrounding granular soil. Moreover, the impact of the earthquake magnitude and dimensions of tunnels on existing damage was investigated. Based on the obtained results, they declared that the seismic analysis was only necessary for areas with seismic acceleration more than 0.15 g [12]. Gomes et al. studied the seismic behavior of shallow circular tunnels in two-layered ground [13]. In another research, Pitilakis et al. interaction effects, focusing on the tunnel response. The problem is investigated in the transversal direction, by means of full dynamic time history analyses. The results show that the presence of the aboveground structures may have a significant effect on the seismic response of the tunnel, especially when the latter is stiff and located in shallow depths [14]. Chen and Shen also have clarified the mechanism of isolation layer on shock absorption, which is proved to be an effective method to improve the safety of tunnel against earthquake [15]. In another study, new damage classification criterion to classify and quantify tunnel damage based on data collected from major earthquakes. Seismic risk assessment of tunnels is important for an effective disaster management plan. A risk-based assessment technique is proposed as a way to quantify the seismic risk of tunnels [16]. In this research, they examined the behavior of tunnels in the grounds with a layer of sand located on a layer of clay with different strength parameters and declared that heterogeneity of the ground in which the tunnel was buried had significant effect on the seismic behavior. Accordingly, this study compared with the previous studies conducted in the field of seismic design of tunnels has the following advantages.

1) The analysis of vibrations caused by simultaneously passing of two trains in two passing horizontal twin tunnels .

2) Analysis of the soil subsidence due to excavation of two passing horizontal twin tunnels in soft soil.

3) Two-dimensional seismic analysis of the two passing horizontal twin tunnels.

CASE STUDY: GREATER CAIRO METRO LINE NO. 4.

The Greater Cairo metro line No.4 passes under the River Nile in Egypt land. Phase No.1 of line No. 4 will extend from El-Malek El-Saleh station on line No. 1 to Remaya square station. It will meet the route of line No. 2 in Giza station. The study area for Greater Cairo Metro Line No. 4 starts from Station No. 1 (El-Malek El-Saleh) and extend up to Station No. 6 (Madkor Station) AS SHOWN IN Fig.1 [17].

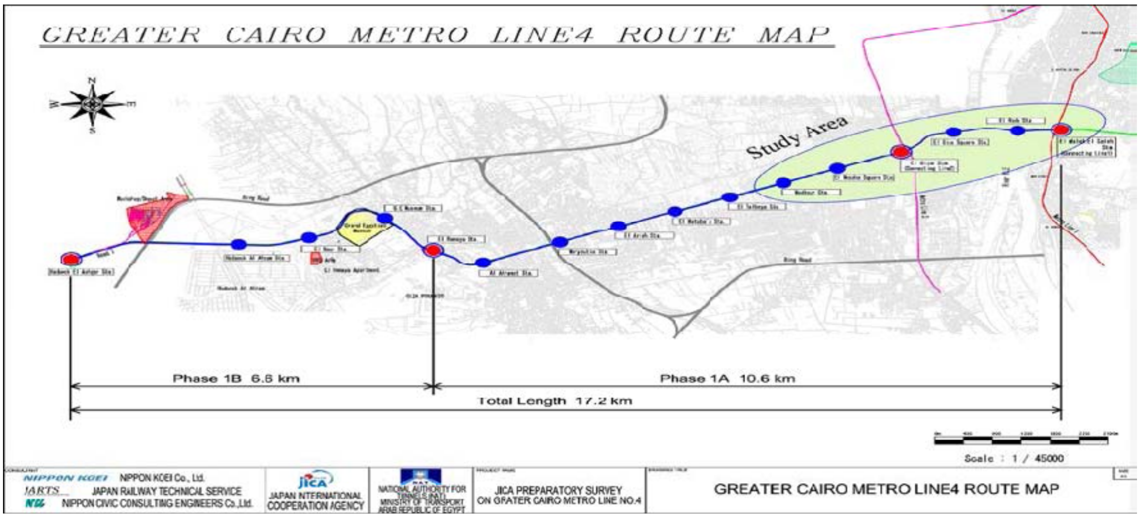

Fig 1: General Layout of Greater Cairo Metro Line No. 4 (Phase No.1) [17]

Recently (NAT) [17] suggested twin tunnel system for metro line No.4, as shown in Fig.2 (b). In this study, the analysis of this system with another system proposed by the authors which is a single tunnel system, as shown in Fig. 2(a), will be presented. The proposed cross section by the contractor for twin tunnels shows that the outside diameter is 6.40 m and lining segment thickness 0.30 m. Also, cross section of single tunnels show that the outside diameter of the tunnel is 9.10 m and lining segment thickness is 0.50 m. Therefore the studied problem consists of two proposed systems (single and twin tunnels) as shown in Fig. 2(a) and Fig.2 (b).

- **Single tunnel system:** For proposed system single tunnel starts from station No.1 to station No.5. In this paper, the numerical analysis of single tunnel will be between station No.3 and station No.4 (Section No.1), as shown in Fig.2 (a).
- **Twin tunnel system :** Horizontally aligned twin tunnels are a widely used for tunnel configuration in urban metro projects. But, vertical aligned twin tunnels are used between station No.3 and station No.4 because a narrow street between these two stations. For that, diagonally aligned twin tunnels are used to connect the vertical and horizontal alignment, as shown in Fig.2 (b). The numerical analysis of twin tunnels will only the horizontal alignment between station No.5 and station No.6 (Section No 4), as shown in Fig.2 (b).

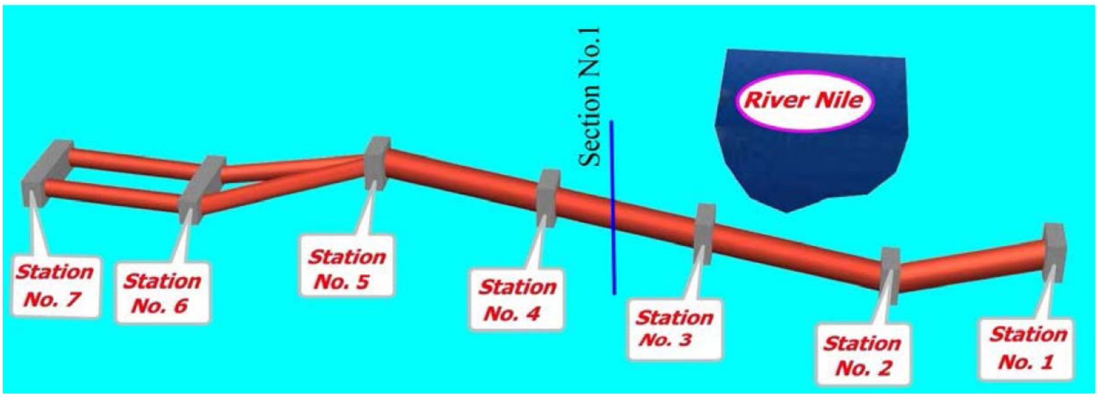

Fig. 2 (a): Proposed single tunnel system [17]

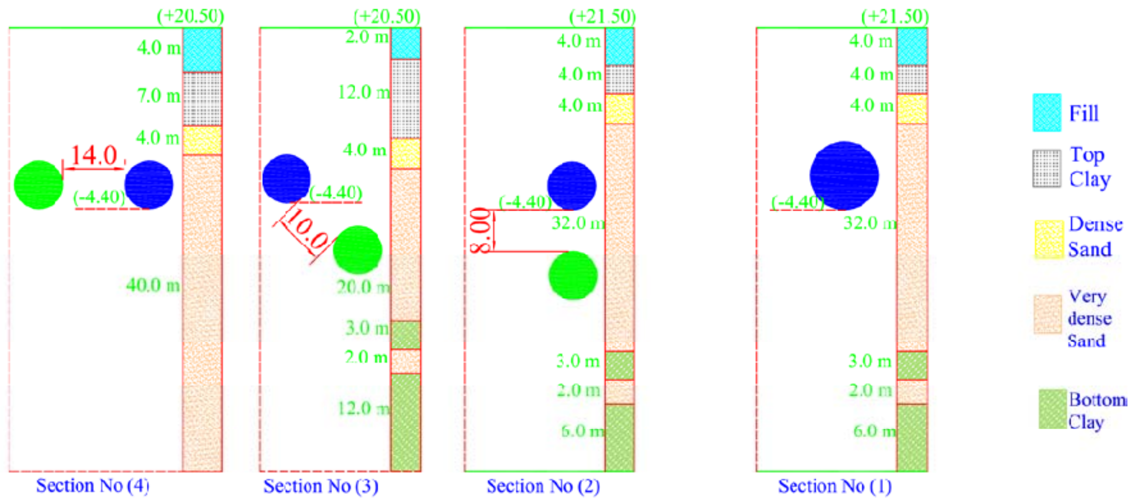

Fig. 2 (b): Proposed twin tunnel system [17]

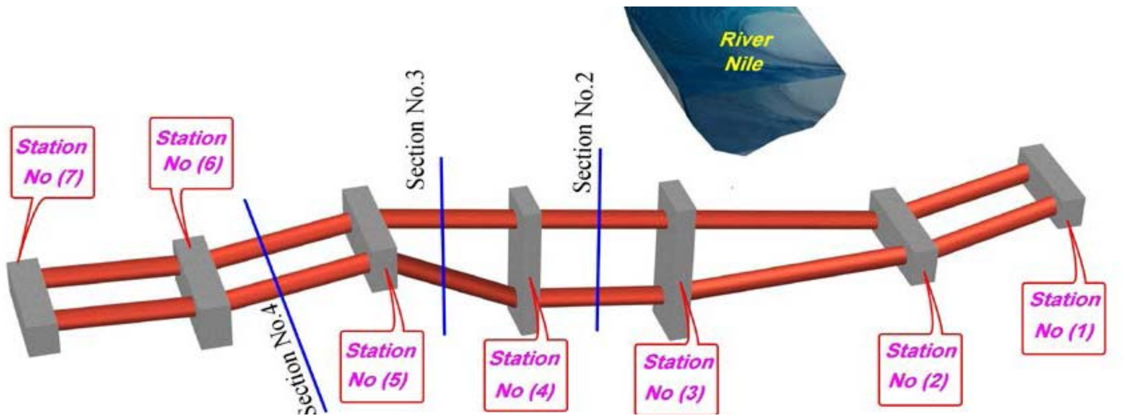

Fig. 3: Geological cross sections and different configuration of tunnels.[17]

NUMERICAL MODELING

In this study, Finite Element Analysis was conducted using PLAXIS[18] Finite Element program. In PLAXIS program, a 2-D plane strain model were used for soil modeling and 2-D beam elements for tunnel lining modeling. To simulate the soil behaviour, 15-node triangular element was used. Standard earthquake boundaries have a convenient default setting to generate standard boundary conditions for earthquake loading. These boundaries consist of a combination of absorbent boundaries and prescribed displacements, velocities or accelerations. The vertical boundaries were taken relatively far away from the tunnel. It is constituted by a rectangular domain 120m wide and 55 m high, in order to place far enough the lateral boundaries as shown in Fig.4.

The Mohr-Coulomb constitutive model was used for the soil. The wave velocities Vp and Vs has been calculated related to the stiffness parameters E and n. The material damping (Rayleigh) in the soil is generally caused by its viscous properties, friction and the development of plasticity. The Rayleigh damping term is assumed that is proportional to the mass and stiffness of the soil material. The Rayleigh parameters α and b were assumed 0.01 and 0.01 respectively. The damping coefficient C is assumed to be proportional to the soil mass M and stiffness K by means two coefficients α and b. The damping coefficient C is obtained by next matrix equation.

$$C = \alpha M + \beta K \qquad (1.0)$$

The time integration scheme (newmark) parameters are setting for the iterative procedures determine the numeric time integration according to the implicit new-mark scheme. The dynamic model analysis uses a different time parameter than other types of models. These times are time stepping, time interval and realized end time.
In numerical computation, the earthquake loading was often imposed as an acceleration time history at the base of the model. Load multiplier from data file of the 1992 Dahshour Earthquake was considered for 2D analysis using PLAXIS [18].
The time integration scheme (new mark) adapted in the analysis are constant and assumed as α = 0.3025 and b =0.60. The wave absorption coefficients were used with constant values, where C1 = 1 for dissipation in the direction normal to the boundary and C2= 0.25 in the tangential direction. The soil Rayleigh damping parameters α and b were assumed with constant value 0.01 and 0.01 respectively. The time interval for the duration of the earthquake loading was 40 sec. and the time inclement was chosen 1 sec.

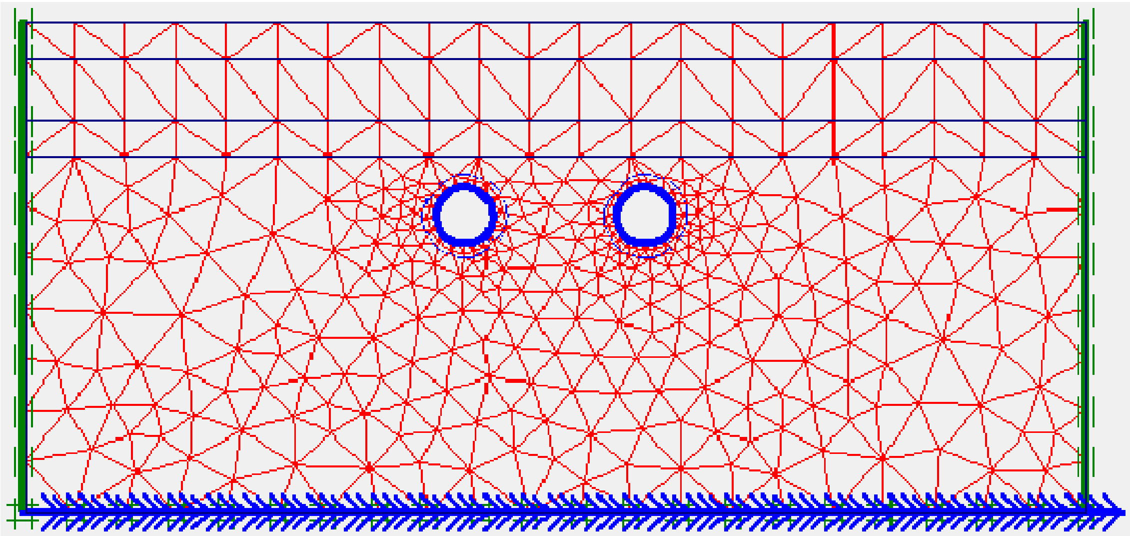

Fig.4: A typical PLAXIS model with boundary conditions for Greater Cairo Metro Line 4 Section No. (4)

THE PARAMETERS OF MATERIALS

The geological formations along the bored tunnel are typical Cairo Nile Alluvial Deposits as shown in Fig.2 (b) section No. (4) and five main units are recognized as follows:

Fill
Top Clay
Dense Sand
Very Dense Sand
Bottom Clay

Geotechnical parameters are based on the geotechnical investigation report [17]. The soil parameters are given in Table 1.0. The water table was at the ground surface.

The tunnel lining is from concrete and the properties of concrete segment are shown in Table 2.0.

Table 1.0: Geotechnical soil parameters [17]

	Unit Weight γ (kN/m3)	Young Modulus E (MPa)	Poisson Ratio ν	Fiction Angle ϕ^o	Cohesion Cu (kPa)
Fill	18	10	0.35	27	0
Dense Sand	20	75	0.29	36	0
Very Dense Sand	20	100	0.28	38	0
Top Clay	19	8.5	0.40	20	8.5
Bottom Clay	19	30	0.40	20	20

Table 2.0: Properties of concrete segment [17]

Property	Value
Design Standard Strength (MPa)	Fcu=50
Modulus of Elasticity , Ec(MPa)	31500
Poisson Ratio (ν)	0.20
Unit Weight of Concrete (kN/m^3)	25

THE CHARACTERISTICS OF DYNAMIC LOAD

On 12 October 1992, a significant earthquake (Mb = 5.8) occurred southwest of Cairo in the vicinity of the Dahshour region, about 25 km SW of downtown Cairo, at the coordinates 29.77°N, 31.07°E, the focal depth of this event was 23 km. This event is the largest instrumentally recorded earthquake in the region. Where The October 12, 1992, earthquake is the first disastrous event to have occurred in this region since the 1847 event, after a lapse of 145 years [19].
The synthetic ground motion generated by the author has been used as earthquake acceleration file at bedrock level. The author generated the synthetic ground motion using SMSIM- program for simulating ground motions, seismological model by Boore [20]. The strong motion data simulated the 1992 Dahshour earthquake with (Mb=5.8). Figure 5.0 shows the synthetic time histories of the 1992 Dahshour Earthquake at bedrock level.
In numerical computation, the earthquake loading was often imposed as an acceleration time history at the base of the model. Seismic action was considered for 2D analysis using PLAXIS, load multiplier from data file (Dahsour 1992) was scaled from (0.1g to 0.6g).

ANALYSIS OF OUTPUT RESULTS

The purpose of this study is to evaluate the behavior of horizontal twin tunnels under seismic action. This study can set new guidelines for the design phase of an underground structure. The evaluation is done by modal analysis, with a numerical model of the tunnel, based on the finite element method. Parameters to be analyzed: - Increase seismic forces.
The results of the analysis of the models show a significant increase of the internal forces that act on the lining. Furthermore the deformations in the segmental lining increase with the effect of the dynamic loads. Table 3 shows a parametric study using Dahshour earthquake time history scaling from 0.1 g up to 0.6 g to indicate and comparatively results the effect of the seismic excitation on the stability and safety of the TBM tunneling for the increase of the internal forces in lining and its deformations. It can be noted that, the earthquake excitation has large effect on the time history of shearing forces and bending moments. The results of the static load for the internal forces and deformation may be observed in Figure 5 through Figure 8.

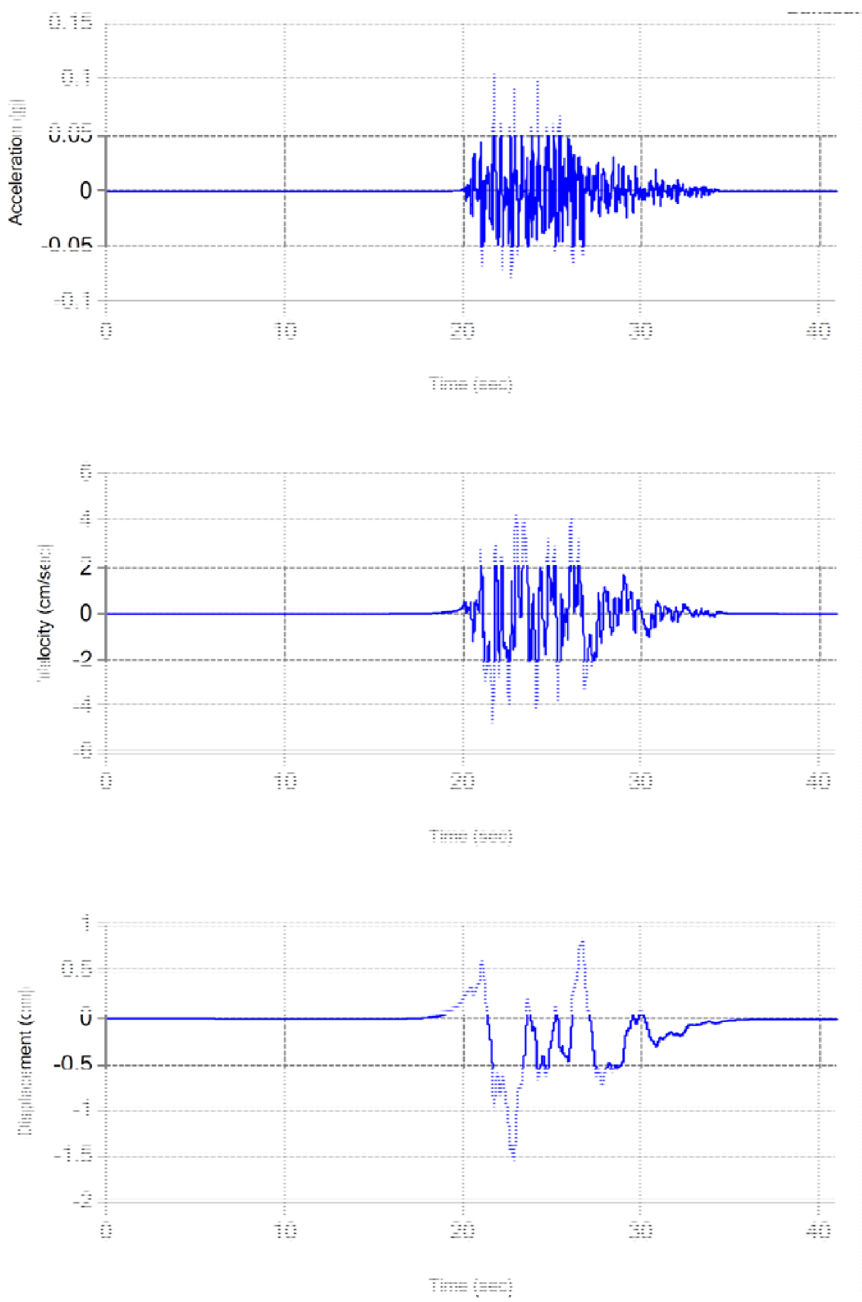

Fig.5: The synthetic time histories of the 1992 Dahshour Earthquake at bedrock level

Table 3. Lining Stresses and Total Displacement for the left and right tunnel of Al Azhar Twin Tunnels

Dahshour Earthquake Time History Scaling	Left Tunnel				Right Tunnel			
	Total disp (m)	Axial Force (KN/m)	Shear Force (KN/m)	Bending (KN.m/m)	Total disp (m)	Axial Force (KN/m)	Shear Force (KN/m)	Bending (KN.m/m)
Static Excavate Left Tunnel	0.00300	-1210	30.55	-48.69	0	0	0	0
Static Excavate Right Tunnel	0.00473	-1210	29.39	-46.53	0.00471	-1210	-29.95	-47.55
0.1g	0.05522	-1210	28.63	-45.17	0.05518	-1200	-31	-49.41
0.2 g	0.10754	-1200	-29.78	-45.77	0.10723	-1190	45.6	-55.89
0.3 g	0.15228	-1190	-43.21	56.69	0.15125	-1180	64.56	77.77
0.4 g	0.18503	-1180	-69.02	96.15	0.18202	-1180	81.41	-102.11
0.5 g	0.20834	-1190	-97.58	146.73	0.20025	-1180	97.76	130.57
0.6 g	0.22412	-1200	-126.86	196.91	0.20886	-1180	120.61	172.77

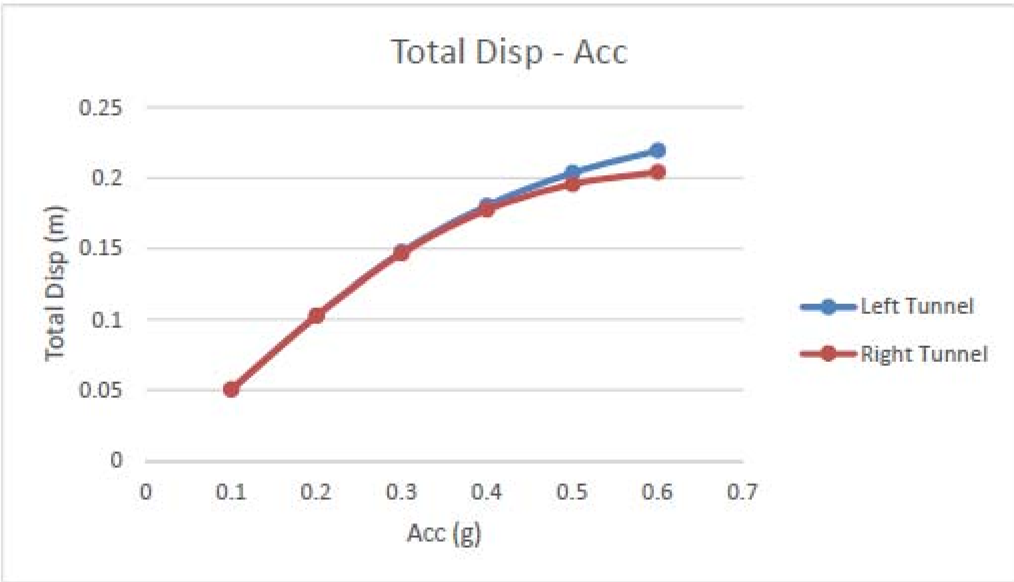

Fig. 5. Total displacement (m) of both left and right tunnel along with the seismic acceleration (g) start from 0.1g up to 0.6 g

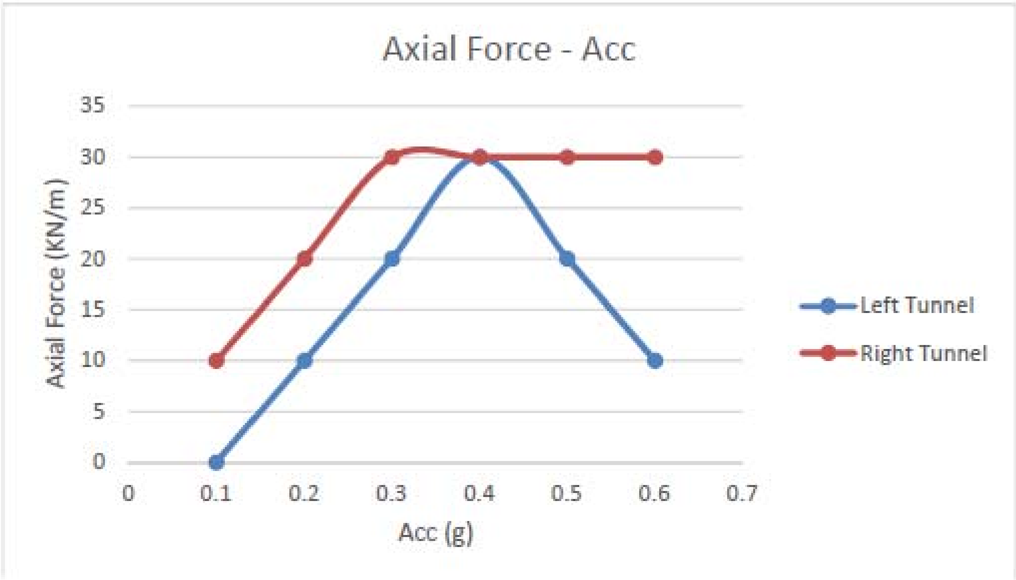

Fig. 6. Axial Force (kN/m)) of both left and right tunnel along with the seismic acceleration (g) start from 0.1g up to 0.6 g

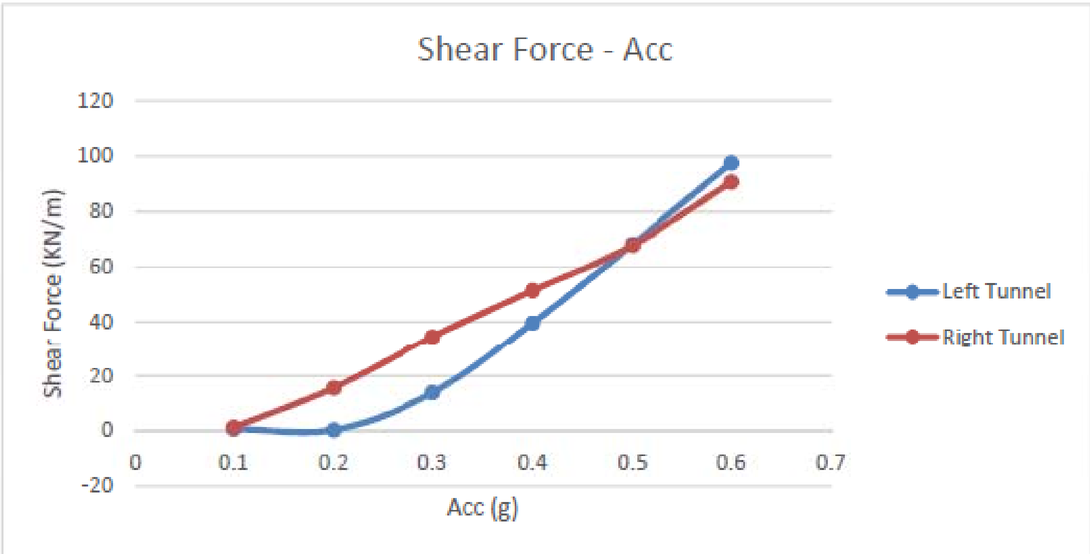

Fig. 7. Shear Force (kN/m)) of both left and right tunnel along with the seismic acceleration (g) start from 0.1 g up to 0.6 g

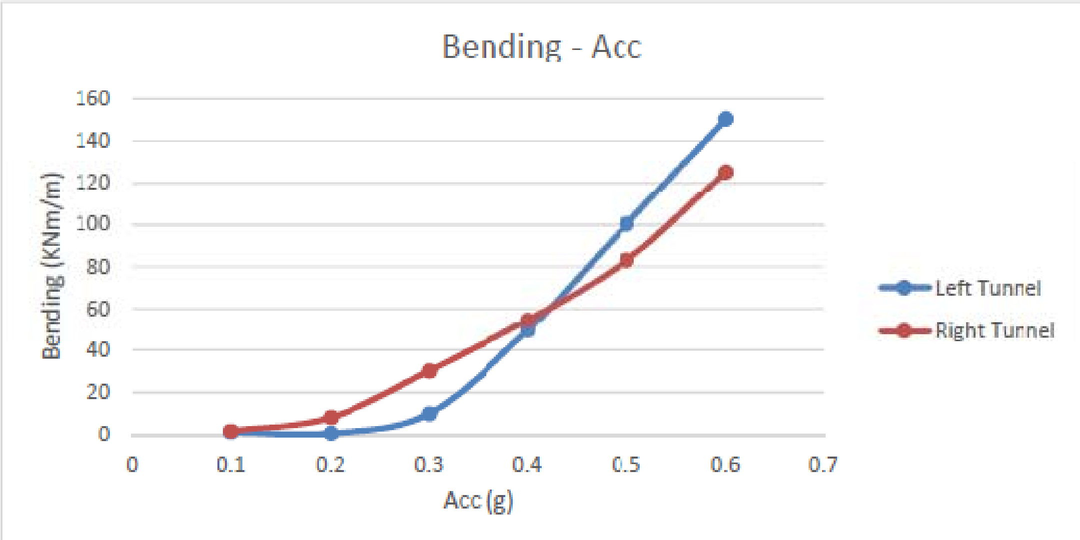

Fig. 8. Bending Moment (kNm/m)) of both left and right tunnel along with the seismic acceleration (g) start from 0.1g up to 0.6 g

CONCLUSIONS

The evaluating of seismic performance of structures associated with transportation system is very important. Hence, in this paper, the seismic behavior of underground tunnel under seismic loads has been investigated. In order to determine the severity of possible damages, the base of judgment was placed on the occurred deformations in the body of the tunnel. Based on the analysis performed following results were obtained.

- The finite element dynamic analysis showed the effect of the kinematic interaction on the calculation of the internal forces, since the presence of the tunnel usually reduces the free-field strains.
- This reduction is simulated by full dynamic analyses, but neglected when using analytical closed form solutions.
- The stress generated in the concrete liner was low so that the concrete does not entered to the failure area.
- The displacement of two tunnels relative to each other was low; therefore, it does not create a particular problem in the structure.
- Finally the finite element dynamic analysis used in this study appear to be useful for both seismic preliminary design of tunnel linings and full dynamic detailed analysis.

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REFERENCES

1. T. R. Keusel, “Earthquake design criteria for subways,” Journal of Structural Division, vol. 95, no. 6, pp.1213-1231, 1969.
2. W. S. Douglas and R. Warshaw, “Design of seismic joint for San Francisco Bay Tunnel,” Journal of Structural Division, vol. 97, no. 4, pp. 1129-1141, 1971.
3. [C. Dowding and A. Rozen, “Damage to rock tunnels from earthquake shaking,” Journal of Geotechnical Engineering, vol. 104, no. 2, pp. 175-191, 1978.

4. G. N. Owen and R. E. Scholl, “Earthquake engineering of large underground structures,” Report No. FHWA/RD-80/195, Federal Highway Administration and National Science Foundation, 1981.
5. [C. M. St. John and T. F. Zahrah, “A seismic design of underground structures,” Tunnelling and Underground Space Technology, vol. 2, no. 2, 1987.
6. S .Sharma and W. R. Judd, “Underground opening damage from earthquakes,” Engineering Geology, vol. 30, pp. 263–276, 1991.
7. T. R. Kuesel, E. H. King, and J. O. Bickel, Tunnel Engineering Handbook, 2nd ed. Springer, 1996.
8. K, Kawashima, “Seismic design of underground structures in soft ground: A review,” in Geotechnical Aspects of Underground Construction in Soft Ground, O. Kusakabe, K. Fujita, and Y. Miyazaki, Eds. Rotterdam: Balkema, 2000.
9. C. H .Chen, T. T .Wang, F. S. Jeng, and T. H. Huang, “Mechanisms causing seismic damage of tunnels at different depths,” Tunnelling and Underground Space Technology, vol. 28, pp. 31–40, 2012.
10. Z. Z. Wang and Z. Zhang, “Seismic damage classification and risk assessment of mountain tunnels with a validation for the 2008 Wenchuan earthquake,” Soil Dynamics and Earthquake Engineering, vol. 45, pp. 45–55, 2013.
11. Y. Shen, B. Gao, X. Yang, and S .Tao, “Seismic damage mechanism and dynamic deformation characteristic analysis of mountain tunnel after Wenchuan earthquake,” Engineering Geology, vol. 180, pp. 85–98, 2014.
12. [M. A. Abdel-Motaal, F. M. El-Nahhas, and A. T. Khiry, “Mutual seismic interaction between tunnels and the surrounding granular soil,” HBRC Journal, vol. 10, no. 3, pp. 265–278, 2014.
13. R. C. Gomes, F. Gouveia, D. Torcato, and J .Santos, “Seismic response of shallow circular tunnels in two-layered ground,” Soil Dynamics and Earthquake Engineering, vol. 75, pp. 37–43, 2015.
14. K. Pitilakis, G. Tsinidis, A. Leanza, and M. Maugeri, “Seismic behaviour of circular tunnels accounting for above ground structures interaction effects,” Soil Dynamics and Earthquake Engineering, vol. 67, pp. 1–15, 2014.
15. Z. Y. Chen and H. Shen, “Dynamic centrifuge tests on isolation mechanism of tunnels subjected to seismic shaking,” Tunnelling and Underground Space Technology, vol. 42, pp. 67–77, 2014.
16. Z. Z. Wangn and Z. Zhang, “Seismic damage classification and risk assessment of mountain tunnels with a validation f for the 2008 Wenchuan earthquake,” Soil Dynamics and Earthquake Engineering, vol. 45, pp. 45–55, 2013.
17. H. H.A.Abd-el.rahim, M. Enieb, A. A. Khalil and , A. Ahmed,”Seismic Analysis of Urban Tunnel Systems for the Greater Cairo Metro Line No.4” EJGE journal , Vol. 20, pp.4207-4222, 2015.
18. Brinkgreve R.B.J.(2002) PLAXIS 2D Manual version 8.0, A.A. Balkema Publisher, Lisse. Penzien J., Wu C., (1998), Stresses in linings of bored tunnels, International Journal of Earthquake Engineering and Structural Dynamics, v.27, 1998.
19. Abd el-Aal, A. (2010) Modelling of seismic hazard at the northeastern part of greater Cairo metropolitan area, Egypt. Journal of Geophysics and Engineering, Volume 7, Pp. 75-90.
20. Boore, D.M. (2005) SMSIM: Fortran programs for simulating ground motions from earthquakes, Version 2.3: A revision of OFR 96-80-A, U.S. Geological Survey Open-File Report.