"THE INFLUENCE OF TUNNELS ON THE NEARBY BUILDINGS UNDER SEISMIC LOADINGS CONDITIONS", CASE STUDY: SHIRAZ UNDERGROUND-IRAN.

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ABSTRACT:

One of the most important factors affecting the design of the structures, is the impact of the earthquake loadings on the forces and the design displacements. Nevertheless, the influences of the near structures on the existing buildings, that sometimes can cause great changes in forces and displacements, can never be forgotten. Thus, the induced displacement in the adjacent buildings of a newly constructed underground tunnel, have been investigated in this study. Having the results of the study, it can be evaluated, whether the amount of variations in forces and displacements are in the allowable ranges, and what measures are needed to save the structures in case of having excess changes in these parameters. In this paper, the site characteristics of an underground tunnels are first investigated. Then the excavation of the tunnel is modeled, while the adjacent structures are taking into account. Finally, the impact of the excavation on the adjacent structures under different earthquake loadings are studied and investigated. The corrected accelerograms of the Naghan and El-Centro earthquakes have been used for seismic analyses and a one and two stories buildings have been modeled as the adjacent buildings. In this study since the impact of the tunnels excavations on adjacent buildings under seismic conditions are only concentrated, the radial deformation of the surrounding soils have been neglected.

Key word: Tunnel, excavation ,Case study, Earthquake.

1-INTRODUCTION:

The response of the super structures, such as buildings, bridges, under seismic conditions are highly affected by the underlying soil layer. So far, extensive studies on the impact of the earthquakes on underground and ground buildings have been carried out. The implemented studies prove that underground structures are less vulnerable than the superstructures [1], and even large number of tunnels and underground spaces without a seismic design, have resisted against heavy earthquakes. For example, the Mexico-city underground tunnel during 1985 earthquake [2]and the Los Angeles subway during earthquake escaped quite undamaged while many surface buildings were largely damaged [3]. As a results, the investigation of earthquake impact on the surface buildings is highly important. Particularly if it is planned a tunnel crosses through the ground in the area of covered greatly by residential and old ancient cultural buildings. For this reason a great attempt has been afforded to study and investigate the effect of different earthquakes on the adjacent buildings located on the path of the Shiraz-underground (one of the ancient and important city of Iran by many cultural Heritages). The effect of the earthquake on super structures have been studied before construction of the underground and has been compared with those induced after excavation of the tunnel. Regarding the seismicity of the city of Shiraz, based on the Iranian code of practice for seismic resistant design of buildings[4], the city is recognized as a zone by relatively high risk in the seismic zonation of the Iran. According to the results of the past studies in the region, in spite of heavy earthquakes which have caused sever damages to the city of Shiraz, the existing monuments and historical buildings remained stable although some damages have been reported. Thus, despite some accurate assessments of seismic behaviors of super-structures and underground tunnels individually, their seismic responses need to be reevaluated together in which the interaction between underground tunnels and adjacent structures plays an important role and may lead to different and new results. In the following section the method of this evaluation and the procedures of the analyses are presented and described in details.

2-EVALUATION AND SPECIFICATION OF THE SELECTED SITE

The selected site is part of the historical city of Shiraz , the capital of the FARS province , which is

located in the south-western part of Iran (fig No.1). The position of the site in Shiraz has been located where the Zand subway, which is among the area having many monuments, is situated. Based on the Shiraz underground studies, the underground tunnels will pass beneath the existing Zand subway (fig.No.2).The diameter of each tunnel is 6.91 meters and their embedment depth from the ground surface is 15 meters. The horizontal distance of the tunnels from the adjacent buildings is about 10 meters. The tunnels will be excavated by means of TBM (Tunnel Boring Machine) using the sheet-pile of EPB to protect the excavated trenches. To reduce the effects of the boundary conditions on structures, model dimensions are considered more than five times the dimensions of structures[5]. It results in reducing the errors of stresses up to six percent. So the effects of boundary conditions on analyses can be negligibled.

According to geotechnical studies in the area, two different soil layers can be observed(fig No.2). The top layer is a loose man-filled soil having 4 meters thickness. Below that a fine cohesive soil layer (down to the studied depth) can be seen. The underground water table is located at 9 meters below the ground surface. It has to be noted that the dynamic elastic modules of the 2nd layer(cohesive soil) below the water table increases sharply to 825000 **(kN/m^2)**, while other mechanical parameters do not change considerably. The model of soils are mohr-coulomb with undrained behavior. The specifications of these two layers are given in table No.1.

3-THE METHOD OF NUMERICAL MODELING

In this study the finite element package of PLAXIS-2D which is capable of doing dynamic analysis of soil-structure interaction using the ground accelerograms has been implemented. Since it is planned to investigate the impact of a
tunnel construction on the response of the adjacent buildings, two different cases have been taken into account:

I)In the first case the seismic analysis of the buildings before excavating the underground tunnel has been done. Two different accelerograms were used to calculate the displacements of the buildings at different elevations. As can be seen in fig.No.3, the relative display-cement of top of the building (point B) to that in the ground level (point A), or the differential displacements are calculated.

Fig 1- The position of the selected site in the city of Shiraz, and Fars province in IRAN
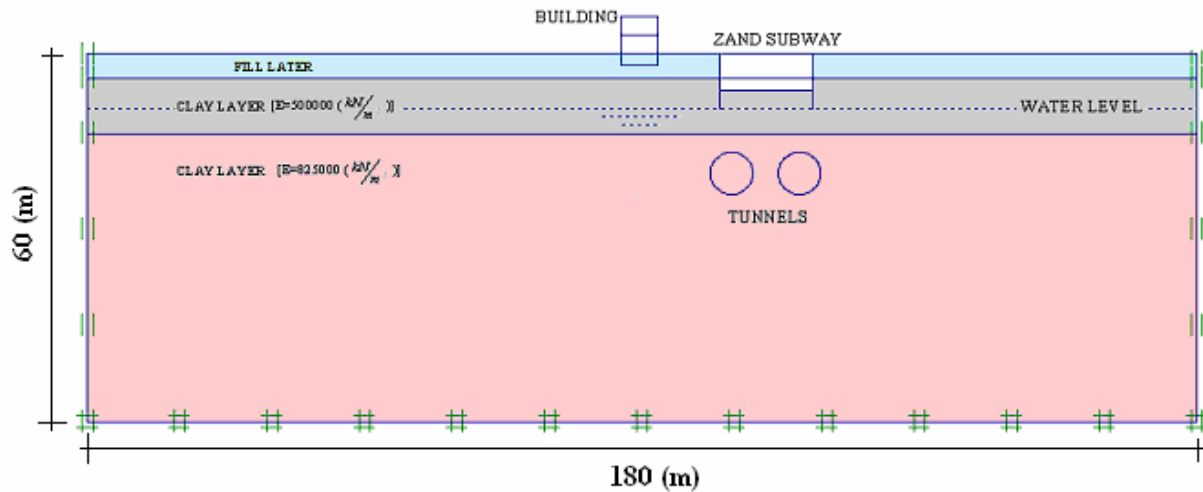
Fig 2- Ground profile and the positions of the existing structures in the selected site

Table 1- The geotechnical characteristics of the soil layers

Soil layers	Depth (m)	Soil Type	Dry unit Weight γ_d ,(kN/m³)	The elastic parameters		The shear strength parameters		The coefficient of permeability, K (m/s)	
				Posson's Ratio,(V)	Elastic modulus E (kN/m²)	Friction angle, φ (degree)	Cohesion, C (kN/m²)	k_h	k_v
1	4	Loose man fill	17	0.30	78000	25	20	10^{-5}	10^{-5}
2	9	Fine cohesive soil	16.7	0.25	500000	30	35	10^{-6}	10^{-6}

II) In the second case, the dynamic analysis of the building under the same accelerograms are carried out, while the underground tunnel has already been excavated (fig No.4). In this case the differential displacements of the buildings again are calculated. To study the impact of the underground tunnel on the seismic displacement of the buildings these two values are compared with each other.

To proceed the analysis program, first, the Zand subway and adjacent buildings of 1 and 2 stories (the existing condition) are modeled. The specifications of the buildings are given in table No.2.Then, the effect of the traffic loading on the existing buildings are considered. The earthquake loadings in this case is applied to the model by different accelerograms. In case II after applying the traffic loadings to the model, the excavation of tunnel having 6.91m diameter(similar to that excavated for the Shiraz underground) is applied to the model. The specification of the tunnel lining are also given in table No.2.

Finally, the impact of the underground tunnel on the adjacent buildings during different earthquake loadings can be evaluated. It has to be noted that, the radial displacements of the surrounding soils always have been ignored. It means that, the gap between the tail-skin and cutter-head of the excavating machine is perfectly filled by grouting.

The triangular elements of 15 nodes are used to do the finite element mesh of the model (fig No.5). The smaller elements have been taken around the tunnel and buildings, where there are areas of highly stress concentration, to increase the accuracy of the analysis. In the static analyses, the boundary conditions at the end of the model are hinged support and at the sides of the model are roller support.

Table 2- The characteristics of the adjacent

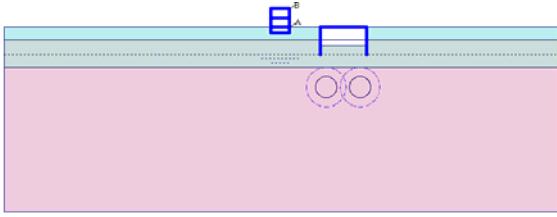| Type of the material/ structure	The behavioral model	EA (kN/m)	EI (kN.m²/m)	Unit weight of the length (kN/m/m)	Poisson's Ratio (V)
Zand subway	Elastic	$5*10^6$	9000	5	0
Adjacent buildings	Elastic	$1.18*10^7$	$2.329*10^6$	12	0.1
Tunnel segment	Elastic	$6.708*10^6$	$5.03*10^4$	7.10	0

Fig 3- The view of the model in case I
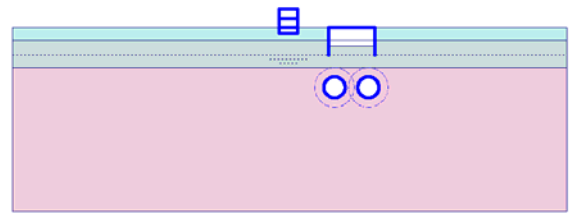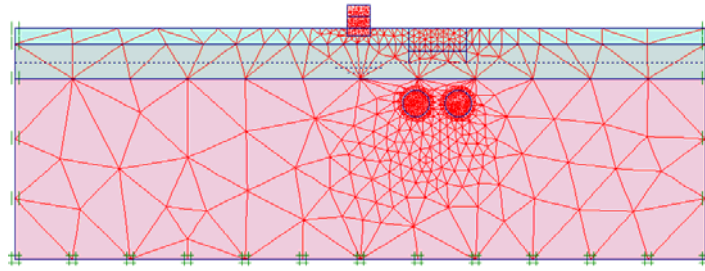

Fig 4- The view of the model in case II
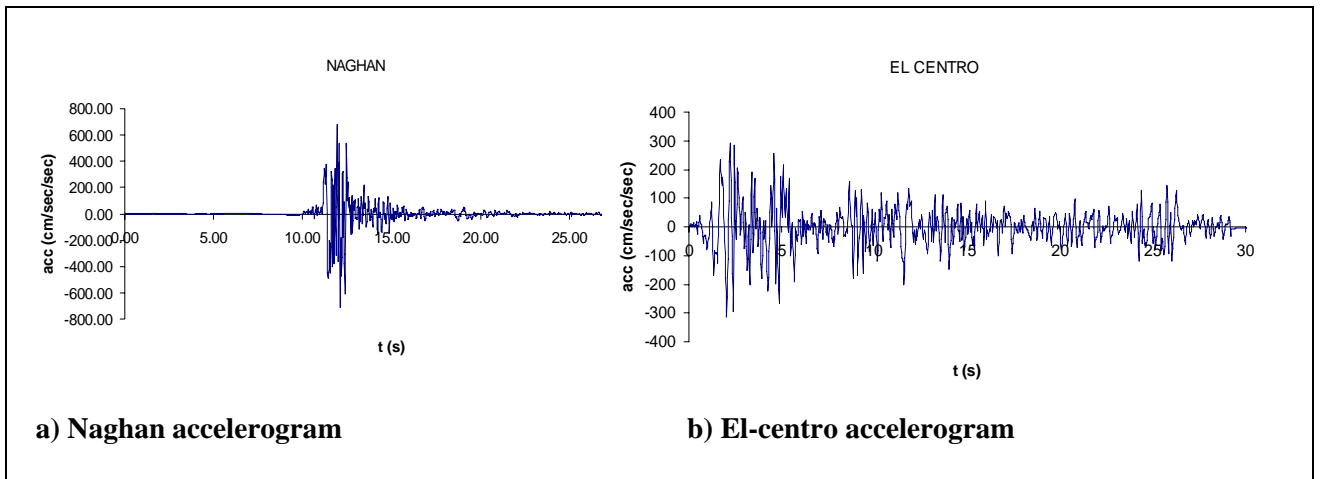

Fig 5- The finite element mesh of the numerical model

a) Naghan accelerogram

b) El-centro accelerogram

Fig 6- The selected accelerograms.
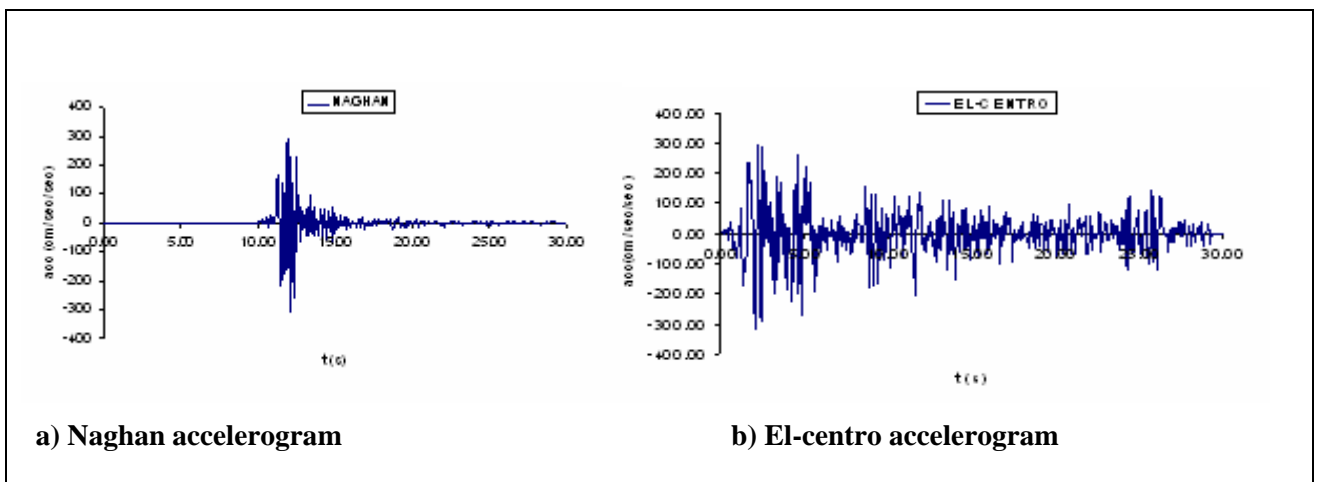

a) Naghan accelerogram

b) El-centro accelerogram

Fig 7- The corrected accelerograms.

To reduce the effect of stress-reflection, the absorbent boundaries are used in the model. This will absorb the energy of the incident stress to the boundaries and prevent them reflecting into the model. Also, a Raighly-damping of 0.01 for α and β ratios is considered in dynamic modeling.

4-SELECTION OF ADEQUATE ACCELEROGRAPHS

The recorded accelerograms of Naghan (1977) and El-centro (1940) earthquakes are shown in figure No.(7-a). Since there are no accelerogram available (neither recorded, nor predicted based on the seismic risk analyses) in the area, the above accelerograms selected for seismic analyses of the model. According to the Iranian code of practice for seismic resistant design of buildings(standard 2800), the city of Shiraz is classified as the area by relatively high seismic risk, and the design acceleration of the area is recommended to 0.3g. Thus the above mentioned accelerograms have been scaled and corrected for this amount [6], which are shown in figure No.(7-b).In this study the modified accelerograms have been used to do the seismic analysis of the model.

5-THE ANALYSES RESULTS AND DISCUSSIONS

The dynamic analyses of model before and after excavation of the underground tunnel (case I & case II) using the corrected accelerograms of the Naghan and El-centro earthquakes were carried out. The adjacent buildings were considered to be1 and 2 stories (similar to existing type of structures in the area). Based on the analyses results, the variations of the horizontal displacements of the buildings at points (A&B) versus the time of the dynamic analysis are shown in figure 8 to 11. The differential displacements between points A&B are calculated and given in table No.3. The percentage of the variation of the maximum differential displacements after excavation of the tunnel are also presented in the same table.

According to this table, the maximum percentage of variations of the differential displacements after excavation of the tunnel is about +3(%) for El-centro and about -2.5 (%) for Naghan earthquakes. Although the absolute variations of the horizontal differential displacements never exceed 3(%) which means the excavation of the underground tunnel does not have any destructive effect on the adjacent buildings, the trend of the variations is highly dependent on the frequency content of the earthquake and the type of the structure.
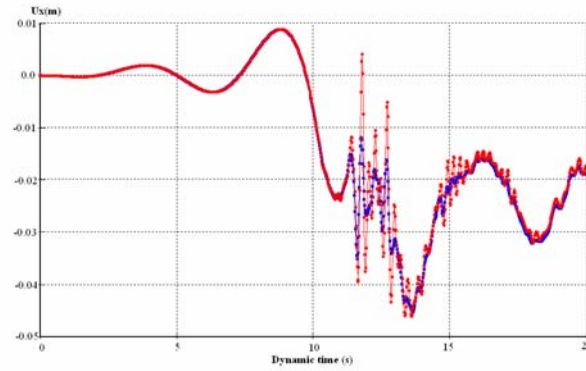
The induced maximum bending moment in the Zand subway before and after the tunnel excavation using Naghan and El-centro earthquakes are given in table No.4.
Regarding the result presented in this table, the bending moment in the existing subway increases after tunnel excavation to about 2(%) for Naghan and 10(%) for El-centro earthquakes. The results also show that the type of super-structure and the frequency content of the earthquake have major effects on the variations of the bending moments in the existing subway
in the area.

Table 3- The differential displacements of the adjacent buildings due to earthquake loadings before and after the underground tunnel excavation.

| Earthquakes	Type of building	Max. differential seismic displacements before tunnel excavation (cm)	Max. differential seismic displacements after tunnel excavation (cm)	Changes in Max. differential displacements (cm)	Percentages of changes in Max. differential displacements (%)
Naghan	1(story)	1.82	1.78	-0.04	-2.25
El-centro	1(story)	2.89	2.91	0.02	0.7
Naghan	2(stories)	2.80	2.76	-0.04	-1.45
El-centro	2(stories)	4.28	4.41	0.13	2.95

a) **The impact of the Naghan earthquake on 1 story building before excavation**
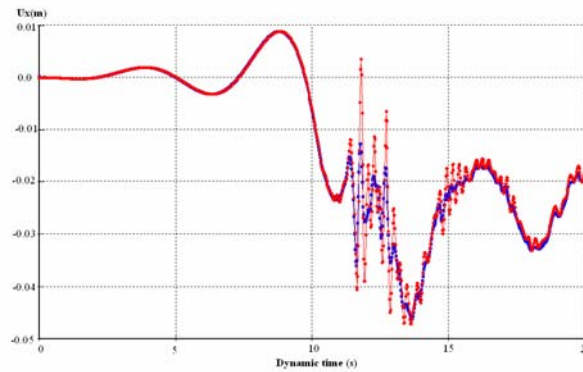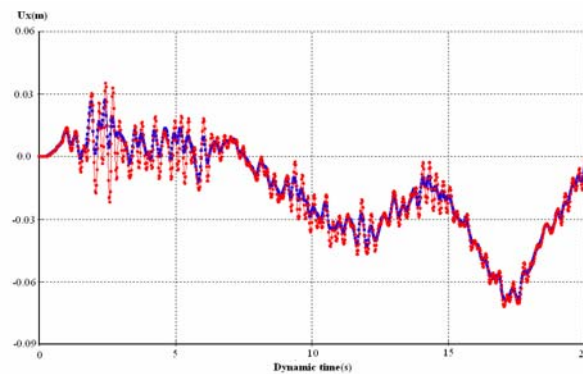

b)The impact of the Naghan earthquake on 1 story building after excavation
Fig 8- Horizontal displacements of a typical one story building due to Naghan earthquake before and after excavation of the Shiraz underground tunnel.
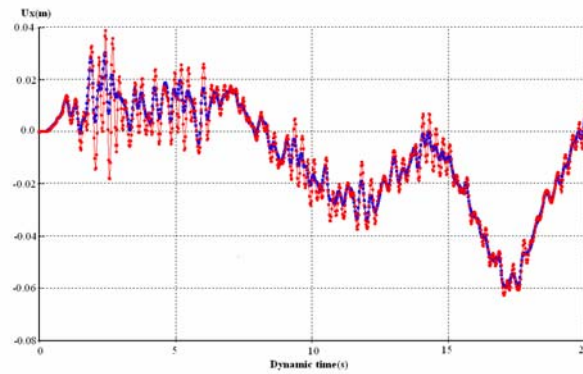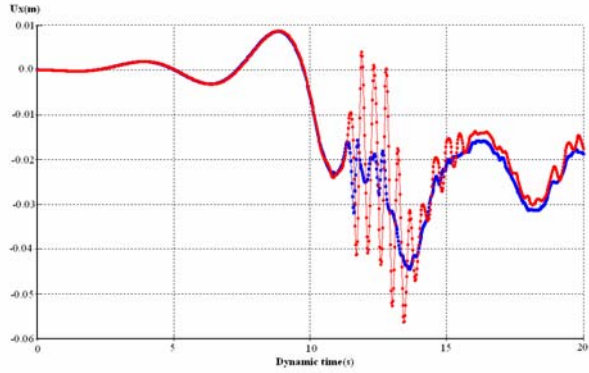

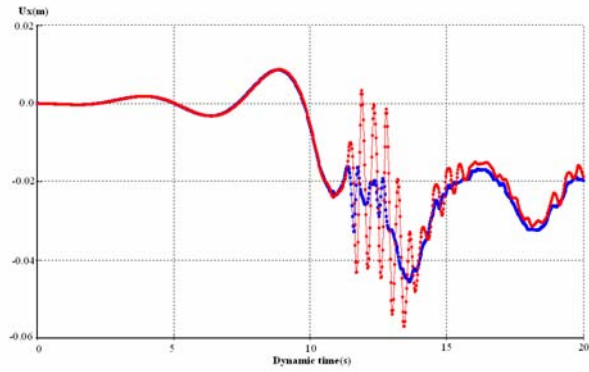a)The impact of the El-centro earthquake on 1 story building before excavation

b)The impact of the El-centro earthquake on 1 story building after excavation
Fig 9- Horizontal displacements of a typical one story building due to El-centro earthquake before and after excavation of the Shiraz underground tunnel.
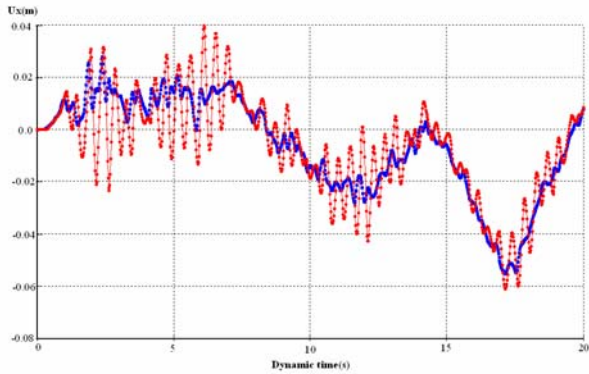
a)The impact of the Naghan earthquake on 2 stories building before excavation
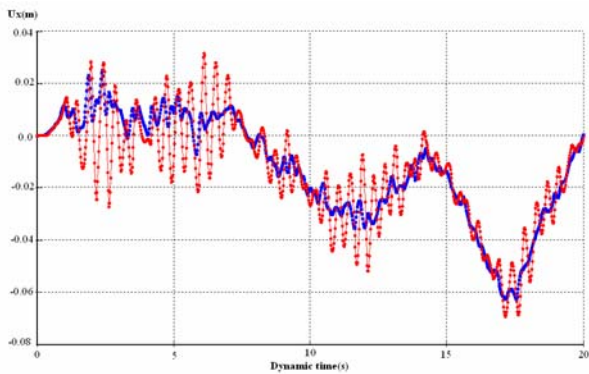

b)The impact of the Naghan earthquake on 2 stories building after excavation
Fig 10- Horizontal displacements of a typical two stories building due to Naghan earthquake before and after excavation of the Shiraz underground tunnel.

a)The impact of the El-centro earthquake on 2 stories building before excavation

b)The impact of the El-centro earthquake on 2 stories building after excavation
Fig 11- Horizontal displacements of a typical two stories building due to El-centro earthquake before and after excavation of the Shiraz underground tunnel.

Table 4- The induced maximum bending moment of the Zand subway due to earthquake loadings before and after the tunnel excavation.

Earthquakes	Type of building	Max. bending moment before excavation of the tunnel (kN.m/m)	Max. bending moment after excavation of the tunnel (kN.m/m)	Changes in Max. bending moment (kN.m/m)	Percentages of changes in Max. bending moment (%)
Naghan	1(story)	192.2	197.4	5.2	2.63
El-centro	1(story)	297.9	329.6	31.7	9.62
Naghan	2(stories)	184.8	188.9	4.0	2.12
El-centro	2(stories)	297.6	335.6	38.0	11.32

6- SUMMARY AND CONCLUSIONS

The impact of the underground tunnel excavation on the seismic responses of the adjacent buildings has been studied and investigated. The site under study is a part of the Shiraz city where many valuable monuments and historical buildings are located and Zand subway has been constructed in the past. The PLAXIS-2D finite element package capable of doing dynamic analysis has been used to model the site and existing buildings, and the Naghan and El-centro accelerograms are used to apply the seismic loadings to the model. Typical 1 and 2 stories buildings were concentrated in this study, since the existing structures are in the same type in the area.

According to the obtained results, the maximum variations of the horizontal displacement of the buildings after tunnel excavation during the above earthquakes changes between 1 and 3 (%) which is not of considerable value. The variations of the maximum induced bending moment in the existing subway (Zand) after the tunnel excavation during those earthquakes changes between 2 and 10(%) which is relatively high. Based on the present studies, both the horizontal displacements and bending moments induced in the adjacent buildings and structures , highly depend on the type of the structures and the frequency content of the earthquake.

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