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Earthquake effect on the Tehran's Niyayesh tunnel

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Abstract—**The effect of earthquake on Niayesh tunnel in Tehran city is investigated. First, by identifying the soil of the area, the amount of stress in the up, wall and bottom of the tunnel was calculated. Then, by using the acceleration data of large earthquakes that occurred in different directions of the tunnel construction, displacement and probable risk caused by earthquakes using PLAXIS software in three direct, static, quasi-static and dynamic modes after drilling, the tunnel was calculated. On average, this value was 45.6 mm on the surface of the earth. The values obtained in the dynamic state show that the movement of surface ground the area is restrained by the tunnel. The natural frequency for the Niayesh tunnel using Fourier spectrum calculations is 5.94 Hz for the building, which changes to 5 Hz during an earthquake, and the period of the building is 0.16 seconds and 2 seconds during an earthquake. These results are in applicable agreement with other results obtained in other underground spaces.**

Keywords- Tunnel; Earthquake; PLAXIS; Tehran

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1. Introduction

According to the earthquakes recorded in Iran, which have been used to design the depth of urban tunnels in the last few decades, tunnels have been drill between 30 meters and 40 meters. Considering the historical of Iran's earthquakes, such as Tabas, Manjil, Kojur and Bam, which have a focal depth of 8 to 10 km, and are among Iran's strong earthquakes, this study has been done. This study, the effect of earthquakes has been investigated with different magnitudes behave differently on underground spaces, which can be used to measure earthquakes based on the dynamic analysis of underground structures based on the maximum acceleration of the ground, which is calculated based on the magnitude of the earthquake (Afkar et al., 2012). Changes in the underground water level in the area of Tehran's Niayesh tunnel and its possible effects on the stability of the tunnel have always been considered (Khosroshahi et al., 2012). Quasi-static analysis of earthquake effect on underground spaces is always an important factor in determining stability, which is modeled based on different programming (Amel Sakhi, 2013). In this study, this modeling for Niayesh tunnel also shows good answers according to other analyses. Ashuri et al. (2014) performed the stability of Niayesh tunnel using PLAXIS software. Investigating the effects of soil overburden compression and depth on the seismic response of the soil and tunnel system using numerical analysis (Majidian, 2021) shows acceptable answers. Also the management of an underground space during an earthquake, all arrangements and suggestions should be modeled for drivers and all cars that travel in the tunnel (Ilkhani et al., 2023).

The arc section of the tunnel, the more sensitive it is to seismics. One of the cases of increasing the cross section of the tunnel is at intersections and subway stations. Also, the presence of two or more tunnels together usually causes the concentration of static stress between the tunnels. On the other hand, due to the inability of humans to predict the exact time of an earthquake, the type of destruction cannot be accurately predicted. The choice of design method depends on the importance of that structure. Therefore, in most cases, it is not economical or possible to design tunnels in such a way that they can resist all damaging factors, but these damages can be minimized by taking precautions. Therefore, modeling was done in three static, quasi-static and dynamic modes.

2. Methodology

In this research, in order to identify the subsurface layers and determine the geotechnical parameters, to evaluate the underground water level and the conditions of the subsurface layers, geotechnical studies were done. According to the results of these tests and geotechnical specifications, the soil of the area consists of sand and dense sand, both of which have some silit and clay, and in the soil classification, these soils contain different amounts of the materials are small dimension, and interlayers of silit and clay are also observed in them. Based on the test, the geotechnical parameters of the soil layers are given in table (1) (Kolivand et al., 2019).

Table 1. Geotechnical characteristics of the soil layers used for the structure model (Kolivand et al., 2019)

Depth	Specific weight Unsaturated (γ_{sat})	Specific weight Saturation (γ_{sat})	Modulus of elasticity of loading (E^{ref}_{rof})	Momentary elasticity model (E^{ref}_{rof})	Oedometer elasticity model (E^{ref}_{rof})	cohesion (C)	Pois son's ratio (ν_{u3})	Angle of internal friction (φ)	K_0^{nc}
(m)	(kN/m^2)		(kN/m^2)					**Degree**	
0-15	16	17	2.423×10^5	8.077×10^4	8.077×10^4	30	0.2	34	0.44
>15	18	19	2.827×10^5	9.423×10^4	9.423×10^4	40	0.2	36	0.41

Acceleration and velocity were evaluated through detailed geophysical, tectonic and soil mechanics investigations. In the 2800 law (Road, Housing and Urban Development Research Center), base accelerations on the design compared to the acceleration of gravity (g) are divided into four categories for different regions of the country. According to the fourth edition of Iran's 2800 Law, Tehran is located in an area with high relative risk of seismicity, that the acceleration based on the design in such a region is recommended to be a=0.35 g (Road, Housing and Urban Development Research Center). Also, the land where the Niayesh tunnel is constructed is of the fourth floor soil type, the velocity obtained is Vs=147.2 (*m/s*) and according to the selection of the land type according to the regulations, the natural vibration period of the soil is To=0.15, Ts=0.1. The wave Vp in a limited one-dimensional body depends on the hardness E_{oed} and the density ρ of the medium, relationship (1):

$$\rho = \frac{\gamma}{g}\,,\; E_{oed} = \frac{(1-\upsilon)E}{(1+\upsilon)(1-2\upsilon)}\,,\;,\; V_p = \sqrt{\frac{E_{oed}}{\rho}}\,,\; G = \frac{E}{2(1+\upsilon)}\; V_s = \sqrt{\frac{G}{\rho}} \qquad (1)$$

where E is Young's modul, υ is Poisson's ratio, γ total unit weight, and g is gravitational acceleration (9/8 m⁄s^2). The same expression can be found for shear wave Vs.

Numerical analysis based on limited element is a constitutive model for nonlinear, time-dependent and anisotropic behavior of soil or rock. Tunnel projects include construction modeling and the interaction between the construction and the soil. Modeling the Niayesh tunnel using the mentioned inputs. After applying the history of the acceleration map, the earthquake propagates as movements and shocks in all directions. Displacement after digging the tunnel, the deformation of the whole soil mass was calculated in static mode, this amount of displacement is 22.55 mm on the surface of the ground and 28.83 mm on the up arc of the tunnel and the amount of elevation in the tunnel floor was calculated to be 28.70 mm.

3. Discussion

In quasi-static analysis, time has no effect and an apply the horizontal acceleration value considered for the analysis directly during the calculations. This acceleration is based on the design of underground structures, 0.35 gal. The amount of displacement on the surface of the earth is much higher than the upper part of the earth. This value is calculated to be 88 mm. The obtained displacement is a considerable amount and is considered in the design of underground structures.

Then, in the dynamic mode, by applying an earthquake with a magnitude of 4.9 on the Richter scale, with a maximum acceleration of 72.38 (cm/s2), it was applied to the model. The displacement obtained was calculated as 26.34 mm on the ground surface. The maximum acceleration 432 (cm/s2), was applied with the earthquake mapping acceleration model with a magnitude of 5.9 on the Richter scale. The total displacement on the ground surface is 105 mm, it is found that it corresponds to the quasi-static state, and finally, it is related to the acceleration model of earthquake mapping with a magnitude of 7.7 on the Richter scale, with maximum acceleration 635.31 (cm/s2), the amount of total displacement was calculated according to figure (1) on the ground surface of 270 mm.

As a result, displacement is larger. The pressure comes from the depth of the earth upwards. If the force of the earthquake is not dampened or if the carrying capacity of the structure is low, it will cause failure. The phenomenon of interaction between the ground and the tunnel will play a more significant role as a result of increasing seismic shear displacement. In this method, the lateral force of the earthquake is determined by using the dynamic reflection that the structure shows due to the earth movement caused by the earthquake. The effect of time in the analysis is how much of the structure will be resistant to the force of the earthquake during the applied period of time.

Using PLAXIS software, a two-dimensional element was considered to perform stability and deformation analysis in order to model the nonlinear behavior of the soil. By using the characteristics of the soil of the area, which was of sand type up to 15 meters deep and dense sand from 15 meters to 50 meters deep, modeling was done and these calculations were based on the dimensions of the tunnel frame. Then, in static mode, the total displacement was calculated after drilling the tunnel. Its value was 22.55 mm on the ground, 28.83 mm on the tunnel up, and 28.70 mm on the tunnel floor. In the quasi-static state, which was checked by applying 0.35 gal, the displacement of the ground surface was 88 (mm). Dynamic state, according to the deformation caused by the accelerogram modeling, the minimum displacement value around the tunnel was 26.34 mm, which shows that the displacement of the ground around the tunnel is restrained by the tunnel. The maximum of displacement was obtained after applying the accelerogram of Manjil earthquake, which can be seen even in the depth of the displacement ground. Therefore, if an earthquake with a magnitude of 7.7 occurs in Tehran and this earthquake force enters the tunnel, this force must be damped, otherwise it will cause the tunnel to damage. Also, the amount of acceleration in this earthquake was between 0.5 and 0.7 gal, which will be more. Also, the effect of earthquake frequency in the tunnel was investigated, and its modeling shows that the shear stresses in the tunnel wall are greater than in the up and bottom of the tunnel and this amount decreases towards the surface of the earth. Axial and shear force, bending moment in the tunnel surface were modeled for three accelerogram. The maximum axial force was 76.551 (KN/m) in the 7.7 earthquake. The amount of total displacement at a point on the ground surface for the first soil type, which has an elasticity modulus E=12.5x104 (KN/m2), was calculated as 0.25 (mm). The second soil model, where the value of E=10.1×104 (KN/m2), the value of 0.21 (mm) was obtained. For the third soil model, was E=8.077×104 (KN/m2), the value was 0.15 mm, for the fourth soil model E=6.9×104 (KN/m2), The displacement was 0.13 (mm) for the fifth soil model was E=5.2×104 (KN/m2), the value was obtained 0.073 (mm). This value shows (Fig 2-6) that the maximum displacement is for the first state and the maximum acceleration was calculated as 0.917. This shows that with the increase in the modulus of elasticity of the soil, the amount of displacement increases, and the amount of acceleration decreases. The natural frequency for the Niayesh tunnel using Fourier spectrum calculations is 5.94 (Hz) for the building. Which changes to 5 (Hz) during an earthquake and the construction period is 0.16 seconds that during an earthquake, it changes 2 seconds. These results are in good agreement with other results obtained in other underground spaces. Therefore, the axial force, shear force and bending anchor force were modeled in the tunnel surface, and the calculated bending anchor force.

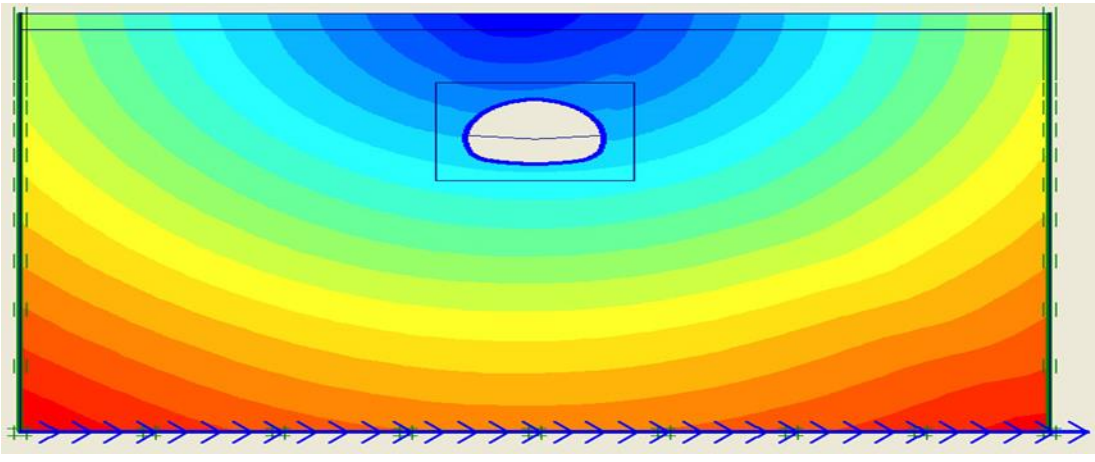

Figure 1. Total displacement after the maximum earthquake by numerical method

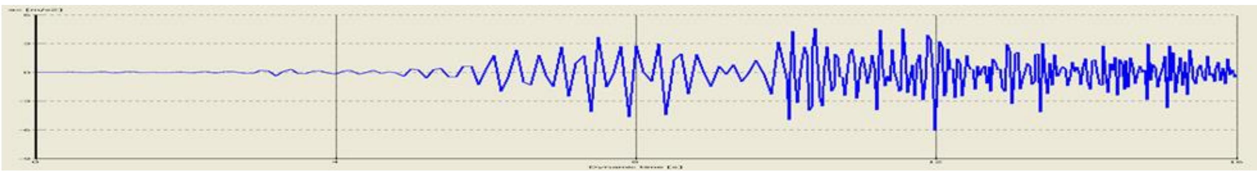

Figure 2. Acceleration, a point on the earth's surface with E=12.5x104 (KN/m2) and earthquake action

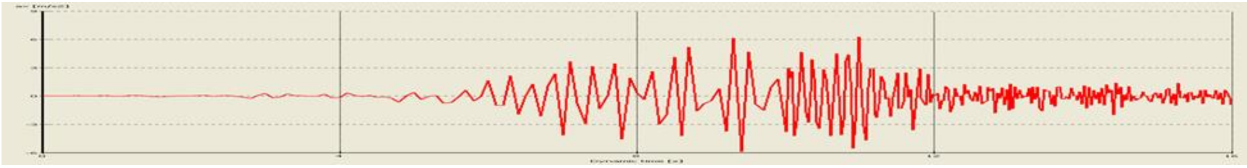

Figure 3. Acceleration, a point on the earth's surface with E=10.1×104 (KN/m2) and earthquake action

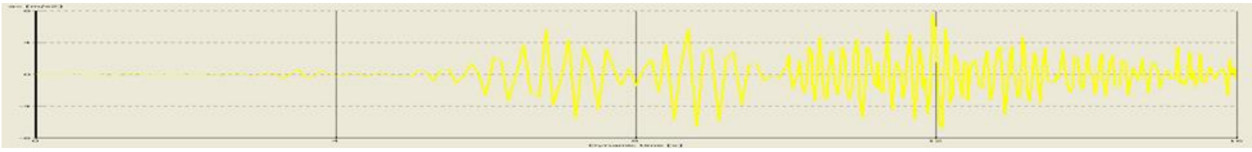

Figure 4. Acceleration, a point on the earth's surface with E=8.077×104 (KN/m2) and earthquake action

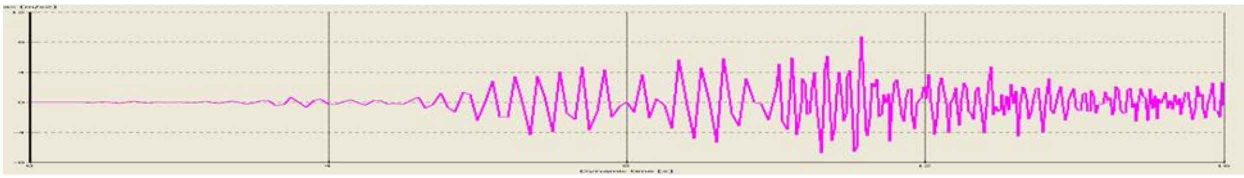

Figure 5. Acceleration, a point on the earth's surface with E=6.9×104 (KN/m2) and earthquake action

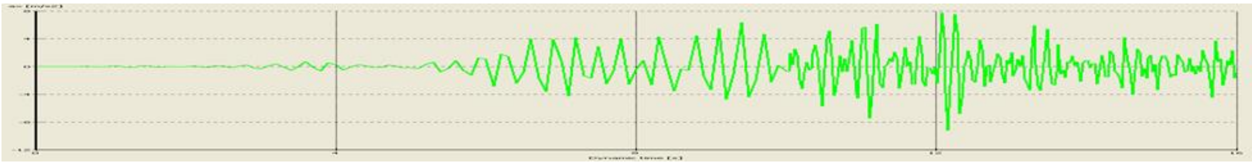

Figure 6. Acceleration, a point on the earth's surface with E=5.2×104 (KN/m2) and earthquake action

4. Conclusion

Horizontal acceleration recording the acceleration of the earth during an earthquake is the best way to detect the earth's response to an earthquake. By applying an earthquake with a magnitude of 4.9 on the Richter scale, in the upper part of the earth, the place where the earthquake wave propagates, the amount of acceleration generated will vary between 0.5 to 0.7 (m/s2), has been calculated. The maximum acceleration is entered at the bottom of the tunnel and the wall, and this acceleration is low and is rejected by the tunnel.

Applying the history of the acceleration map of the magnitude 5.9 earthquake, the acceleration value in this earthquake is 0.8 to 0.7 (m/s^2). It increases near the surface of the ground at the top of the tunnel up, and with an earthquake of magnitude 7.7 on the Richter scale, the acceleration value in this earthquake is between -5 to 5 (m/s2), is at the bottom of the tunnel and near the ground, the amount of acceleration increases, (figure 7).

In the dynamic mode, because all parameters depend on time, acceleration was obtained. In static and quasi-static mode, due to no relationship with time, the created acceleration value is zero. By increasing the accelerogram, the amount of acceleration created and the displacement increases. Because the damage of underground structures is definitely dependent on the parameters of the earthquake. These damage can be related to the peak ground acceleration (PGA), peak ground velocity (PGV), moment magnitude (Mw) and the epicenter of the earthquake. The time of the maximum acceleration created during an earthquake is different from the time of the maximum acceleration of the environment. Because as the time of the strong ground motion the earthquake becomes longer, the ruptures due to the fatigue of the materials increase and significant deformations are created.

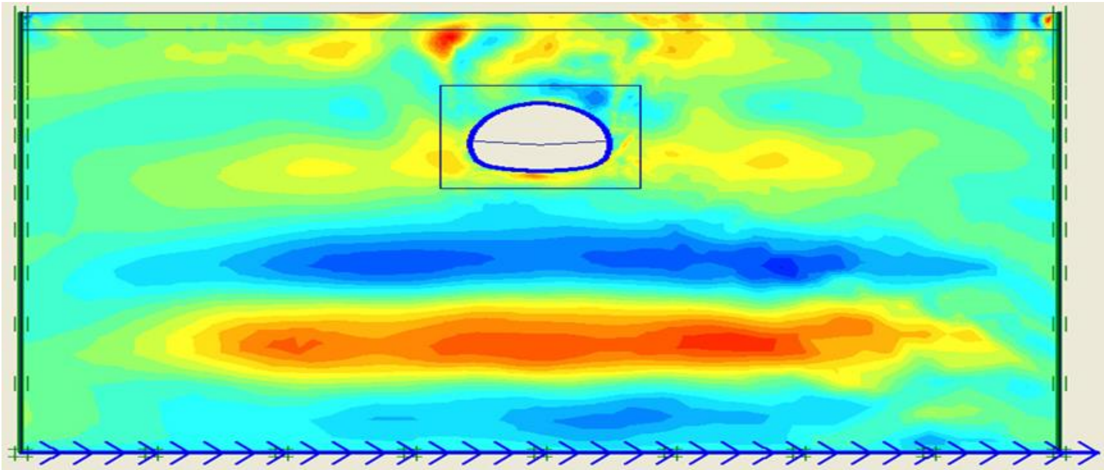

Figure 7: The final acceleration after the maximum earthquake by numerical method

Stress Considering that the earthquake frequency is low and the number of stress periods is high, the number of oscillations of the structure during an earthquake creates tension around the tunnel, this tension causes the amount of damages around the tunnel. Earthquake causes rearrangement of stresses around the dug tunnel, which causes the tension and pressure of the tunnel. The tunnel in the rock mass is related to many complex issues due to the uncertainty of the rock mass's response to the earthquake. Determining the stress in the stability of the tunnel is very important. If the stress around the tunnel is high, it will change the shape around the tunnel.

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