International Academic Institute for Science and Technology

International Academic Journal of Science and Engineering
Vol. 5, No. 2, 2018, pp. 43-58.
ISSN 2454-3896

International Academic Journal of Science and Engineering

www.iaiest.com

Metro Tunnel Behavior Based on Near and Far Fault Districts (Case Study of Isfahan-Iran Metro Line 3 Tunnel)

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Abstract

In this study, to investigate the behavior of metro tunnels under the near-fault field disturbances, part of the Isfahan-Iran metro line 3 tunnel with numerical modeling in finite difference software has been investigated. It is generally assumed that the recorded movements are less than 20 km from the site of the disaster and the earthquake focal points, near the mappings of the region. The results of the numerical analysis in this study show that the displacement of the horizontal tunnels of the near-selective area is far greater than that of the distant domain, and the displacement changes in the near-fault earthquakes occur in less time, which is a matter of selecting the behavioral parameters of the materials must be carefully considered. Also, acceleration response in near-field earthquakes is more than the response of the earthquake acceleration in the distant domain, and the variation in the near-range region is more volatile than the far-field, while the acceleration response in the districts of the districts is more uniform. Shear stress variations are performed in an earthquake far from fault faster than an earthquake near the fault. This also shows that the choice of resistance parameters should be considered in proportion to the earthquake.

Keywords: Metro tunnel ,Earthquake ,Fault

1. Introduction

Analysis and modeling of underground structures like tunnels is an inevitable pre-run. Today, with the advancement of technology and relative ease in the excavation and construction of underground structures and the limitations of surface spaces for the implementation of civil projects, the attention of many countries to the construction of underground structures has been devoted. Considering the increasing development of underground structures and the high cost of their construction, and their importance in transportation and the danger that their lives are causing to the people, it is necessary to consider their sustainability against the dangers and, given the importance of speed and reduction Costs for implementing projects and the consequences of possible damage The choice of methods that can provide the most accurate response possible from the tunnel status in the shortest time period can be very helpful. In this study, in order to investigate the behavior of metro tunnels under near-fault zone faults, a part of

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

the Isfahan-Iran metro line 3 tunnel with numerical modeling in finite difference software will be investigated.

The first strong evidence of seismology for the near-fault phenomenon was reported by Bonif (1955) in explaining the intensity patterns observed in the Kernn County (1952) earthquake. Bennif showed that the release of fault failure, such as a moving fountain, could lead to various types of vibrations at the other end of the rupture area "with higher intensities and higher frequencies in the direction of diffusion and lower intensity and lower frequencies in the opposite direction." Also, he moves the vibrating spring Along a straight line and its effects on the amplitude and shape of the waves.
In general, the characteristics and specifications of earthquake mapping of the near field are completely different from the characteristics and characteristics of distant earthquakes. Despite the awareness of this difference, due to lack of information, few studies have been conducted on the characteristics of near-earthquakes and their impact on structures in recent decades. The most dramatic examples of these earthquakes are the Northridge earthquake, the Kobe, the Chinese earthquake in Taiwan, and the special effects that Such earthquakes are characterized by the behavior of structures with different vibration periods, have developed specialized views in order to explain and revise the methods and parameters of analysis and design in seismic engineering. Changes in earthquake response in distant domains are mainly due to changes in the dynamic properties of alluvial deposits. In the near field, the situation is completely different. In this area, the intensity of changes in effects caused by the source of the earthquake and the direction of motion of the waves increases. If the response of the point shakes differed from the other point, then this difference can not be due solely to the dynamic conditions of all of its alluvial dangers, and the factors associated with the source of the earthquake and the wave paths also contribute to this problem. In this regard, several researcher's comments on the earthquake are mentioned:
Bard and his colleagues believe that the micro-zoning studies can only be limited to a time when the condition of the earthquake is limited to a relatively remote distance. Seyed and Edris believe that: in severe local earthquakes, which cause relatively high frequencies in the rocky bed, large changes in the dynamic conditions of the alluvium will not lead to significant changes in potential failure. The above issues do not make any sense of local significance. Frequently, earthquake waves are crossed by alluvial layers reinforced and maximized on the surface of the earth more than the maximum acceleration rate on the bedrock. The magnitude of the earthquake wave amplification by the alluvium with the maximum acceleration of the cluster, and thus the distance from the center of the earth, is closely related. If the distance from the center is too small or the maximum acceleration of the clamping factor is high, then the behavior of the nonlinear aliquots decreases and, as a result, the mean value of the reinforcement decreases. For this reason, the amplitude of the waves in the near and near the earthquake is different. In this research, by numerical modeling in the FLAC2D finite difference software, we will examine the behavior of the Isfahan metro tunnel under the near-fault field disturbances.

2- The rules of various regulations on the design of structures near the fault against earthquakes

Studies on recent close records such as Nortridge (1994) and Kobe (1995) made it difficult for the fault to be introduced as a major criterion for designing structures against earthquakes, including the UBC 97 regulations. In 1991, the UBC regulations provided a simple correction factor based on the distance from the fault, but in 1997, the Na and Nv coefficients were considered as correction of acceleration in the near-fault field. These coefficients, as shown in Table 1, have different values based on different distances from the fault and the type of period of the proposed structure. Given these coefficients, the response rates in some areas are corrected to some extent.

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

Table 1. Correction coefficients for near-fault conditions

N_a			
Seismic Source	**Closest Distance to Known Seismic Source**		
Type	2km≤	5 Km	10Km≥
A	1.5	1.2	1
B	1.3	1	1
C	1	1	1

N_v				
Seismic Source	**Closest Distance to Known Seismic Source**			
Type	2km≤	5 Km	10 Km	15Km≥
A	2	1.6	1.2	1
B	1.6	1.2	1	1
C	1	1	1	1

3. Definition of near-field earthquakes

Although the definite distance can not be clearly defined for near-field earthquakes, it is generally assumed that the movements recorded at a distance of less than 20 km from the site of the earthquake's disaster and the focal point are near-field mappings. By increasing the distance mentioned as the effect of other parameters, such as magnitude and conditions The site of the site increases the characteristics of the registered movements, the impact of the inherent characteristics of the near-earthquake on the recorded movements decreases. Therefore, as noted above, determining a precise focal point for defining the scope of a task is very difficult and irrational. In general, what is important in these earthquakes is the existence of some characteristics different from the distant earthquakes. Therefore, while using the distance criterion in defining these earthquakes, the existence of some of their different characteristics in their mapping can be a more appropriate criterion for classifying these earthquakes.

The characteristics of the near-field movements are directly related to the mechanism of the seismic spring, in order to break the fault relative to the site and the direction of the fault slip. The most distinctive features of the near-field movement are pulses due to the effect of orientation and the effect of permanent displacement. These types of motion pulses are generally one Or several distinct pulses in the history of acceleration, speed, and change of location, and often in the history of time. A pivot point in speed records is the existence of large pace of growth that will be triggered by long-range pulses. An illustration of these effects is the formation of large fluctuations that are also recorded in the Earth's displacement record. The large parameters justifying the motion of the earth near the fault have been characterized by other major earthquake records such as Northridge, Kobe, and Chichi earthquakes. . The features are one of the most prominent characteristics recorded for the near-fault field earthquakes (with a low focal point to the site).

4. Definition of near-field earthquakes

4.1 Modeling

In this research, a finite difference method is used to model and analyze the tunnel.

4.2 Model Specifications and Boundary Conditions

In general, for analysis of a tunnel, one has to analyze the sensitivity and modeling of different dimensions of the model and the boundaries of the boundary. Different research has been used for dimensional sensitivity analysis, some of which are listed in Table 2.

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

As shown in Table 1, the boundary line used in tunnel analysis is defined on the basis of the latest papers in the world about 5 times the diameter of the tunnel from each side.

Table 2. Proposed border dimensions based on various internal and external papers

Boundary	Journal
5D	Sharif University of Civil Engineering
5D	Scientific and Research Journal of Analytical and Numerical Methods in Mining Engineering
5D	Amir Kabir Scientific and Research Journal (Civil and Environmental Engineering (
4D	Soil Dynamics and Earthquake Engineering
6D	Soil Dynamics and Earthquake Engineering
5D	Tunnel Technology Engineering Technology and Underground Space

Considering the above studies on optimal dimension selection, in order to determine optimal geometry dimensions, models with dimensions of 5, 6 and 7 times the diameter of the tunnel in the FLAC2D finite difference program were created and tunnel crown changes were analyzed. Considering the results of the sensitivity analysis to determine the dimensions of the model as well as the studies done, we can say that the best dimensions for modeling is 5 times the diameter of the tunnel from each side. Therefore, given the diameter of the tunnel, the dimensions shown in Fig. 1 are chosen for the model geometry.

In this study, in order to bring the modeling conditions closer to real conditions at the lateral boundaries, horizontal displacement in both directions x and y is not allowed. While their movement is free in the vertical direction. In the horizontal boundaries of the model, the soil can only have a horizontal displacement, and its vertical displacement is limited to zero.

4-3-Mesh

The mesh is used in dynamic analysis with the mesh used for static analysis. Generally, the mesh in dynamical mode should be such that the wave can move in the model and move from one mesh to the next mesh. If the dimensions of the mesh are large enough that the wave in one step of analysis can not cover the length of the mesh, the frequency of the earthquake will be lost and the analysis will be wrong. Therefore, in the dynamic mode, mesh sizes can not be considered too big. Independent of the type of software used to perform dynamic analysis, to ensure that the wave passes through the meshes, the size of the meshes should be considered smaller than the value defined in equation 1, which is referred to as the criterion of wave transmitted.

$$\Delta x \le \frac{\lambda}{10} = \frac{C_s}{10\,f} \qquad (1)$$

In the above relation, Δx is the maximum mesh length, λ is the earthquake wavelength, Cs is the wave velocity, and f is the frequency of the earthquake.

As has been said, in the static analysis, the boundary conditions, which in fact create infinite no earth, were introduced. In the dynamic analysis of the model, first, the static boundary condition should be assigned to the model as the system is in a static state before being subjected to dynamic loading like an earthquake, then we assign the dynamic boundary conditions to the model. When the earthquake's force hits the side borders, it constantly reflects, while in reality it is not, and the earthquake passes through and passes through the ground after it has been created on the ground. For this purpose, one of the methods in numerical modeling is that the dimensions of the boundaries are considered to be large, that the waves will be amortized after encountering the boundaries and reflecting until reaching the desired structure, but the disadvantages of this method increase the analysis time due to enlargement over Model size. Another

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

method is to use elements at the boundaries of the model that the earthquake waves are absorbed and not reflected after collision. In the term of such boundaries, the boundaries are called absorbent. Figure 2 shows the creation of boundary conditions and geometry made in the finite difference program.

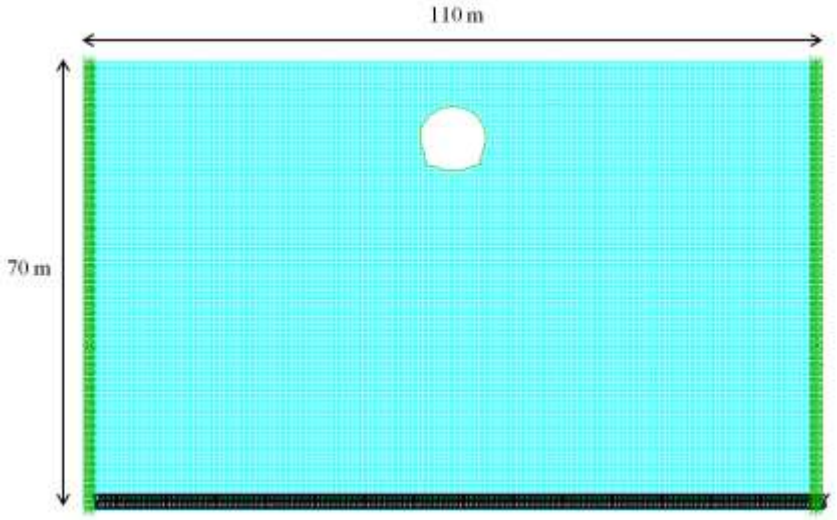


Figure 2. Creation of adsorbent boundaries in the model under study

4-4. Specification of materials

Given that in this research the tunnel section of Azadeh station has been studied, geotechnical information of the ground at this station is presented in Table 3. In this research, the Moher-Columbian Behavioral Model will be used to study the behavior of materials. At the Free Station, groundwater level is located at a depth of 4 meters from the ground.

Table 3. Introduction of materials specifications at Azadi Metro station in Isfahan

Azadi Station				
Density (gr/cm^3)	**Cohesion (KN/m^2)**	**Friction (Degree)**	**Young Modules (KN/m^2)**	**Poisson Ratio**
2.2	100	40	1e8	0.42

4-5 Specifications for the tunnel lining

The tunnel lining specification is presented in Table 4.

Table 4. Introduction of tunnel lining specifications

D (cm)	**Thickness (cm)**	**$E_{concrete}$ (MPa)**	**C (MPa)**	**υ**
Wall	40	2.5e4	25	0.3
Base	50	2.5e4	25	0.25

4-6. Select accelerated mapping

In order to perform dynamic analysis in the present study, at first eight accelerations from different earthquakes in the world were selected in two groups of close and distant field earthquakes and the behavior of the tunnel under these accelerations was compared. The maximum distance from the seismic spring for the mapping of the area near 12 km and the minimum distance from the earthquake focal point for the mapping of the 26 km long districts. In this study, earthquakes with a distance of more than 22 km

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

were used for earth faults near the fault. The important features of the near-field earthquake are the presence of long-period pulses in their mapping, which has a higher pace in time histories. Also, in spite of distant earthquakes in which the earthquake energy is distributed in the entire time of the Earth's movement, it is located in earthquakes near the total earthquake energy in one or more pulses. In general, it has been tried to consider the various mappings of these features even as a result.

Table 5. Specifications of the accelerated fields of the selected area for dynamical analysis of the tunnel

Earthquake	Station	M (Rich)	R (Km)	Vs (m/s)
Kocaeli-Turkey	Yarimca	7.51	1.38	297
Kobe	Port Island	6.9	3.31	198
Chi-Chi	TCU055	7.62	6.34	359.13

Table 6. Specifications of the accelerated fields of the selected area for dynamical analysis of the tunnel

Earthquake	Station	M (Rich)	R (Km)	Vs (m/s)
Imperial Valley	Delta	6.53	22.03	242.05
Loma Prieta	Gilroy Array #7	6.93	22.35	333.85

In dynamic analysis, according to the type of analysis (linear or nonlinear equivalents), behavioral models in modeling should be used to consider the shear modulus parameters and the shear strain and the damping is also introduced in the model. In this research, Riley damping is used to deplete earthquake force. Riley's damping affects energy depreciation in an object to the matrix of difficulty and mass, and its value is obtained from equation 2:

$$[\mathrm{C}] = \alpha[M] + \beta[K] \quad (2)$$

In the above relation, the mass matrix and the hard matrix are both symmetric, α is the mass ratio matrix and β is the coefficient of fit of the hard matrix. The relationship between critical damping ratio (ξi) and angular velocity (ωi) is defined as:

$$\alpha + \beta\omega_i^2 = 2\omega_i\xi_i \quad (3)$$

In relation 3, ωi, the frequency of the mode i and ξi is also the damping ratio of the mode i.
In Fig. 3, the normalized damping ratio is shown against the angular velocity. As you can see, there is a curve in the form of three. The state = 0β relates to the state in which the only component of the mass of the damping matrix is considered. The state = 0 α is related to the state where only the hardness component of the damping matrix is considered.

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

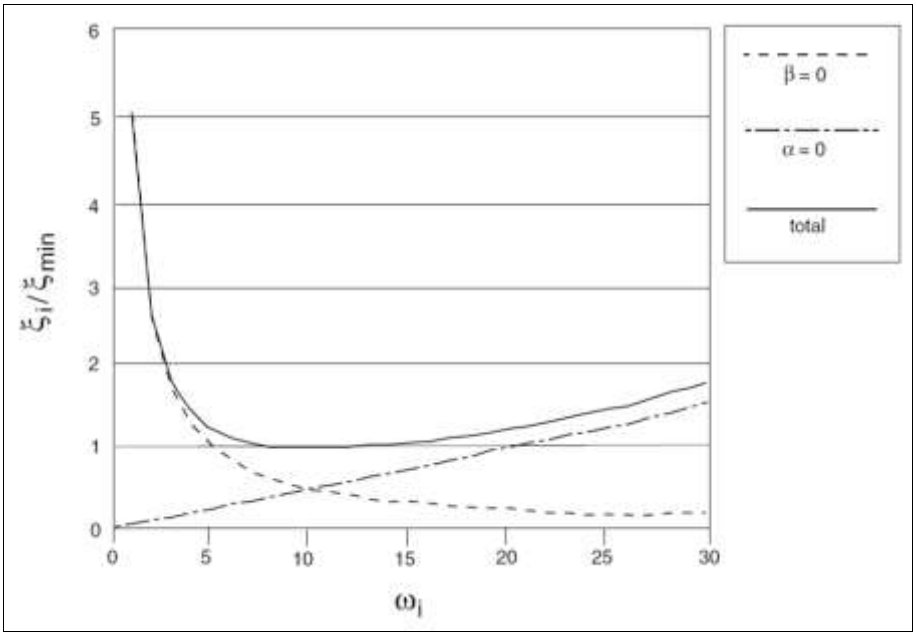


Figure 3. Normalized damping ratio versus angular velocity

As shown in Fig. 3, the role of mass-dependent damping is dominant at low angular velocities, while hard-wearing damping over high angular velocities dominates the other. The general curve, which consists of the sum of the two components, reaches its minimum in the following values:

$$\xi_{min} = (\alpha\beta)^{0.5} \quad (4)$$

$$\omega_{min} = (\alpha / \beta)^{0.5} \quad (5)$$

Therefore, by determining the prevailing frequency and also having a critical attenuation for at least one material, Riley's damping coefficients can be calculated using the above relations.

5-results

5.1 Changing crown tunnels

In Figs. 4 and 5, horizontal displacement of the tunnel crown is shown under the earthquake and near-critical disturbances. As the graphs show, the horizontal displacement of the near-selective canal tunnel is far greater than that of the distant domain. What is to be seen from the comparison of these two charts is that changes in displacement in faults near earthquakes occur in less time, which should be carefully considered when choosing the behavioral parameters of the materials. Comparison of horizontal displacement during the earthquake with horizontal displacement in static state indicates that the occurrence of earthquakes causes a lot of deformation that is not considered in the static design of the tunnel. Therefore, the proper mechanism for tolerating this change in the tunnels should be seen. The vertical displacement of the tunnel corridor for the critical earthquake in the near and far field is shown in Figures 8 and 9, respectively. In these two diagrams, noteworthy is the trend of vertical displacement changes in the two distant and nearer areas. According to these diagrams, there is a rising trend in earthquakes near the fault zone. This is despite the fluctuating trend in earthquakes in the districts. The reason for this may be the nature of the earthquake as near or far from the fault. Comparison of Figures 5 and 8 shows that the trend of horizontal and vertical displacement in seismic distances from the fault

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

follows the same form, but this conclusion is not true for earthquakes in the near field. Therefore, as a summing-up, it can be stated that during static design, the horizontal displacement of the earthquake should not be ignored, and appropriate measures should be taken. Also, the choice of the type of earthquake also has a significant impact on the behavior of the tunnel.

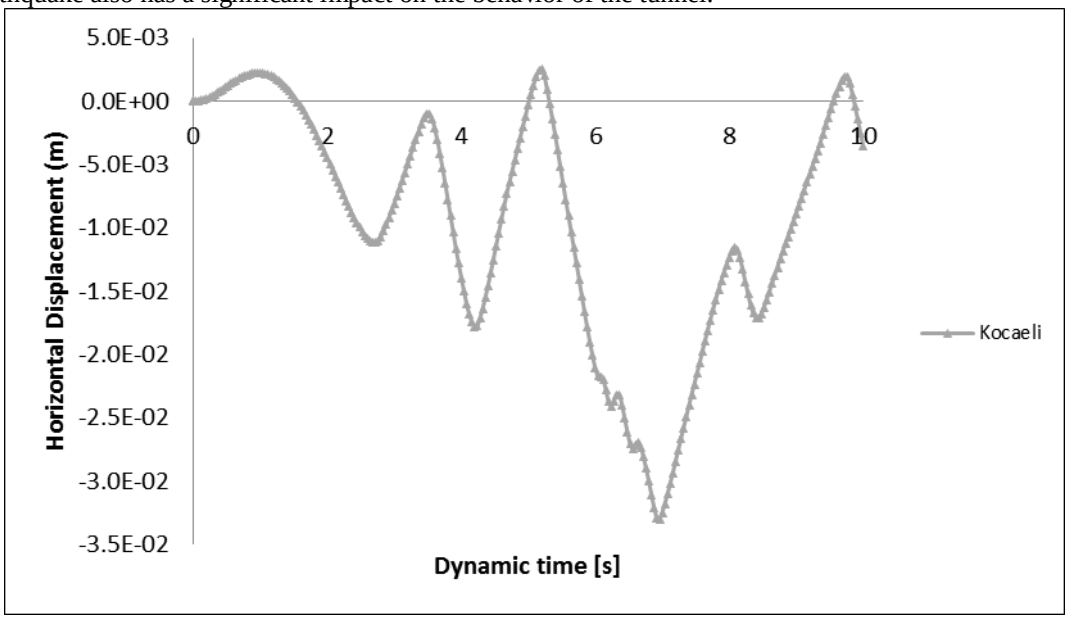


Figure 4. Horizontal displacement of the tunnel crown under the earthquake near the Kocaeli fault zone

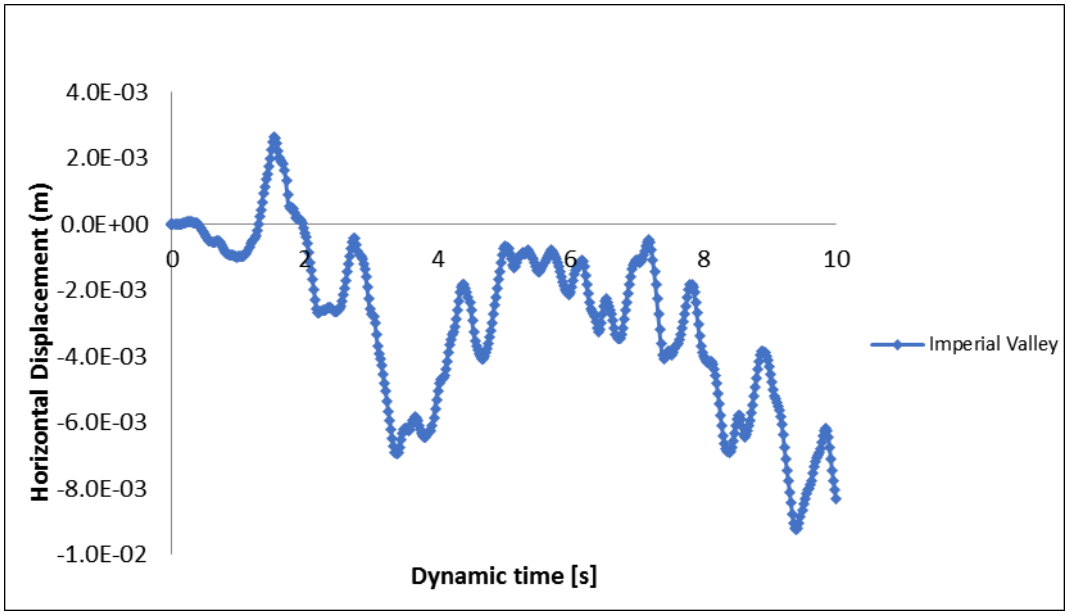


Figure 5. Horizontal displacement of tunnel crown under Imperial Valley fault zone

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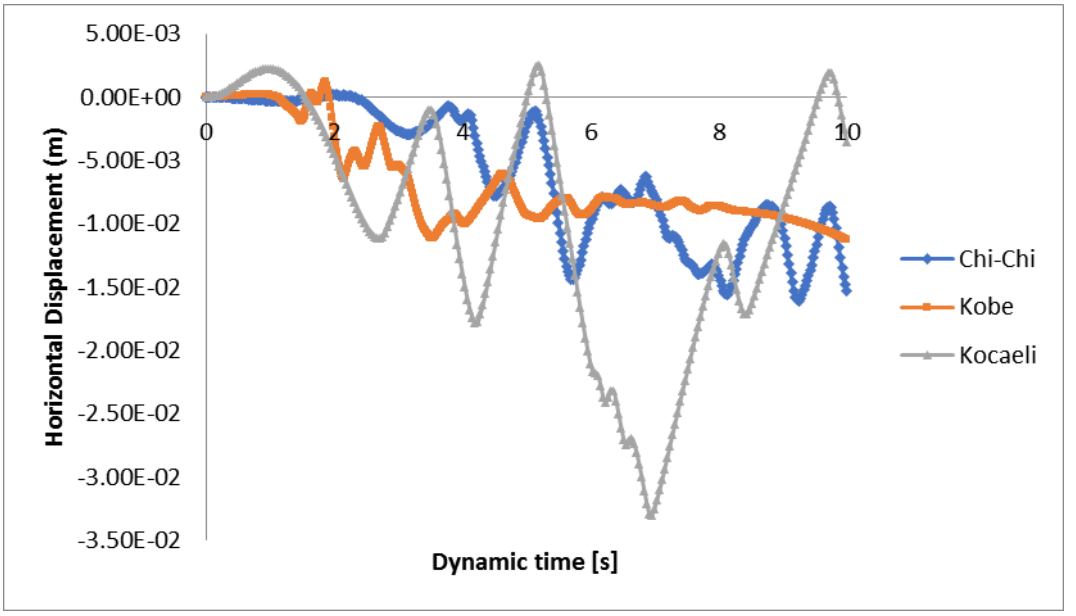


Figure 6. Horizontal displacement of the tunnel crown under earthquakes near the fault zone

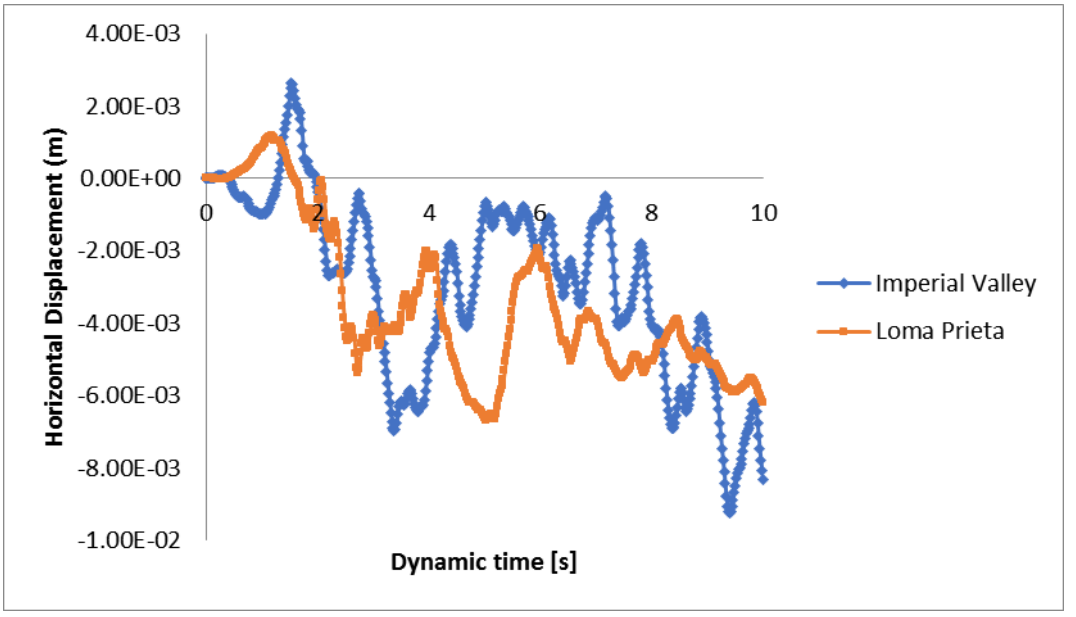


Figure 7. Horizontal displacement of tunnel crown under fault disturbing earthquakes

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

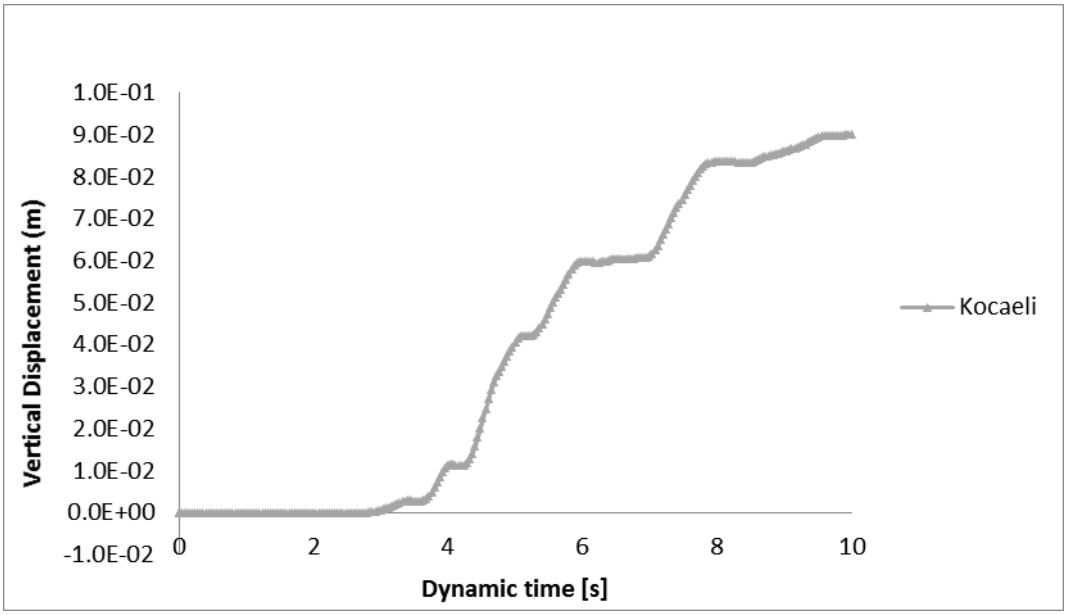


Figure 8. Vertical tunnel displacement under the earthquake near the Kocaeli fault

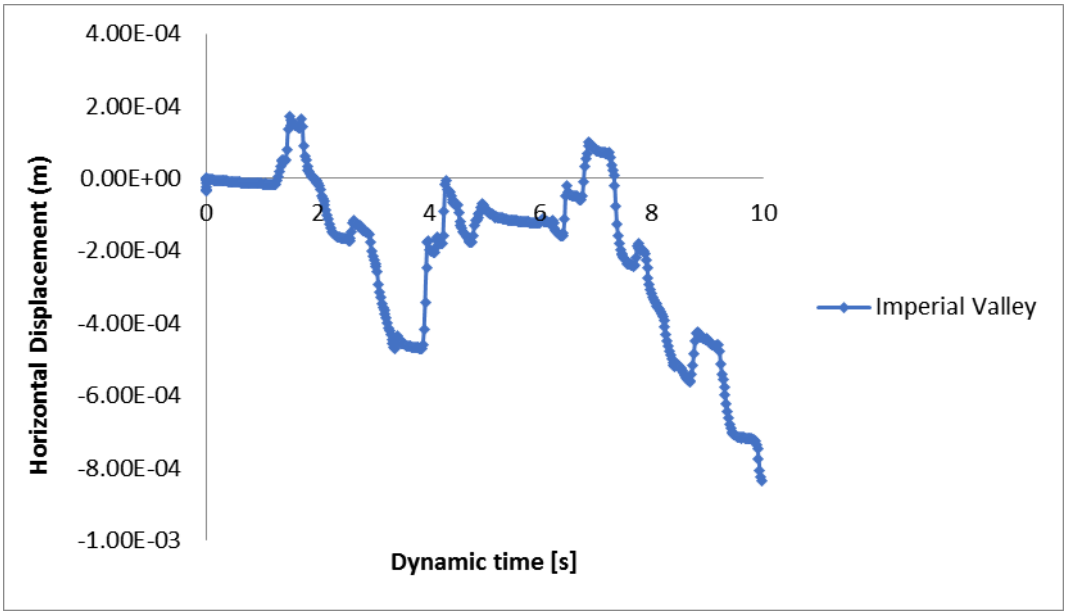


Figure 9. Comparison of the vertical displacement of the tunnel crown under the critical earthquake in the Imperial Valley fault domain

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

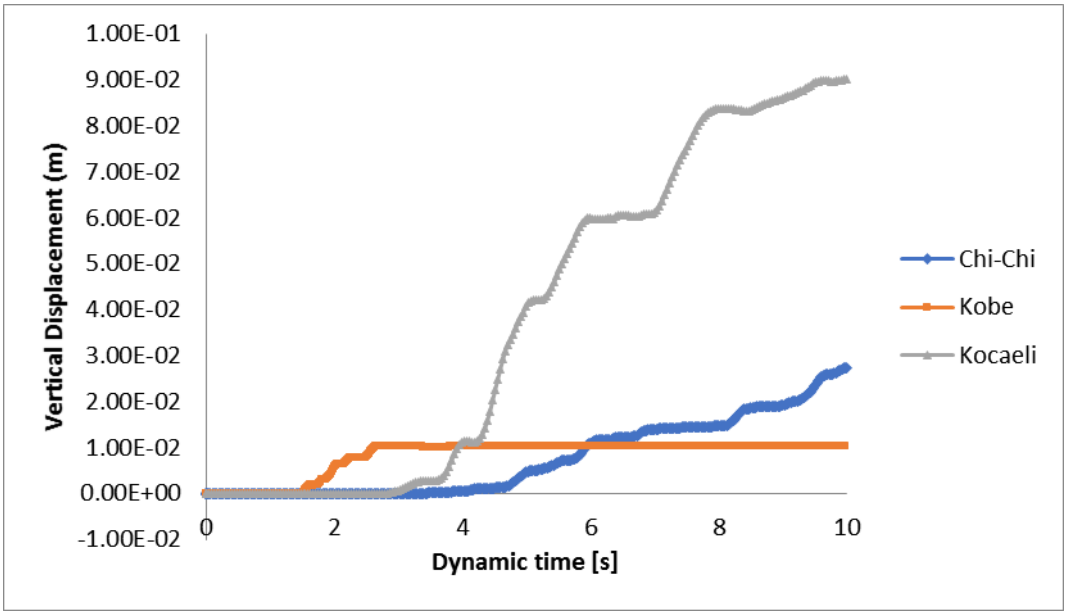


Figure 10. Vertical tunnel displacement of the tunnel under earthquakes near the fault zone

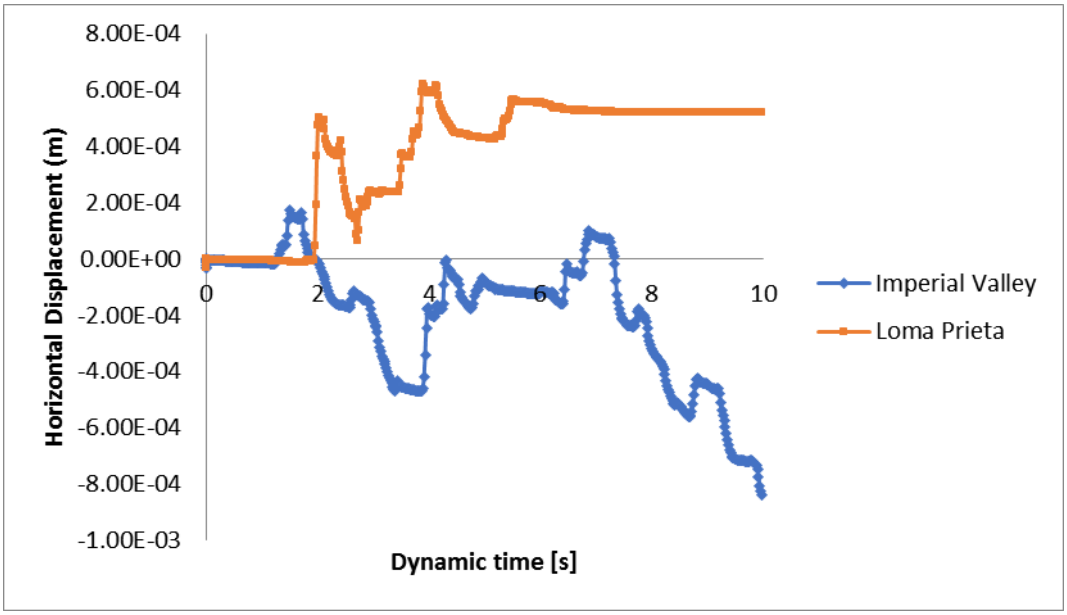


Figure 11. Vertical tunnel displacement under tunnel faults

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

5.2 Changes in tunnel crown acceleration

The first result of the time histories of the response of the upper right acceleration in the near-field area is that the accelerated response response graphs are almost complete. Another consequence of this is that the acceleration response in the near-field earthquakes is more than the response of the earthquake acceleration of the distant domain. And also the rate of change in the near-range region is more volatile than the far-field, while the acceleration response in the districts of the districts is more uniform. Also, the critical time in earthquakes far from fault is less than earthquakes near the fault. This will have a significant impact on tunnel behavior by changing tensile conditions before applying the main force of the earthquake.

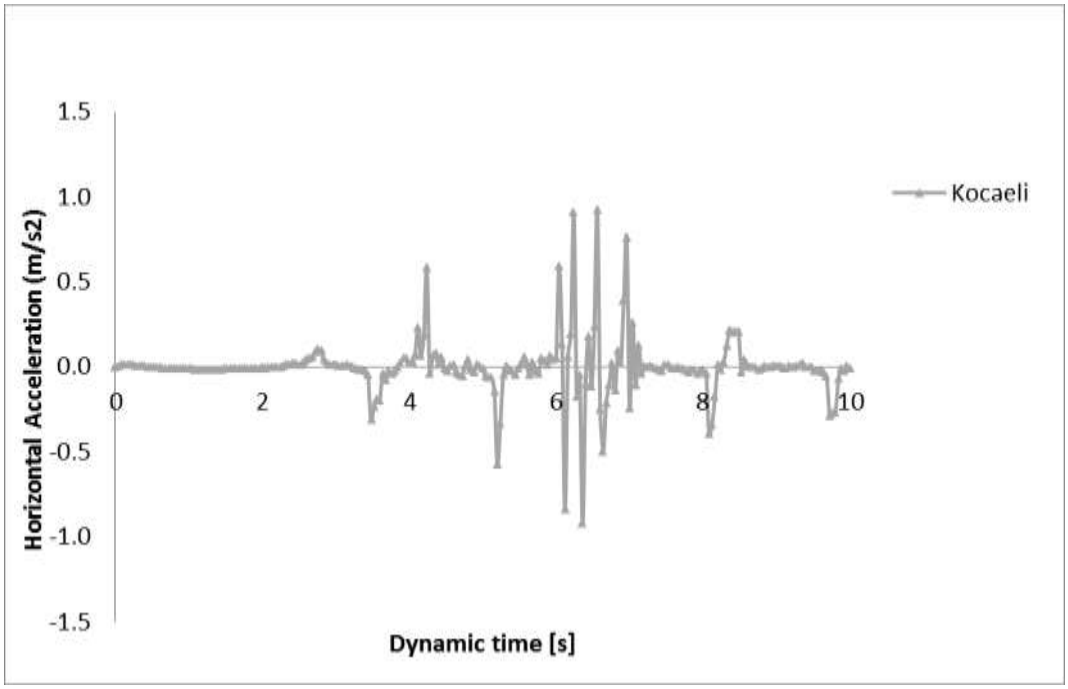


Figure 12. Horizontal acceleration of the tunnel crown under the critical earthquake near the fault zone

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

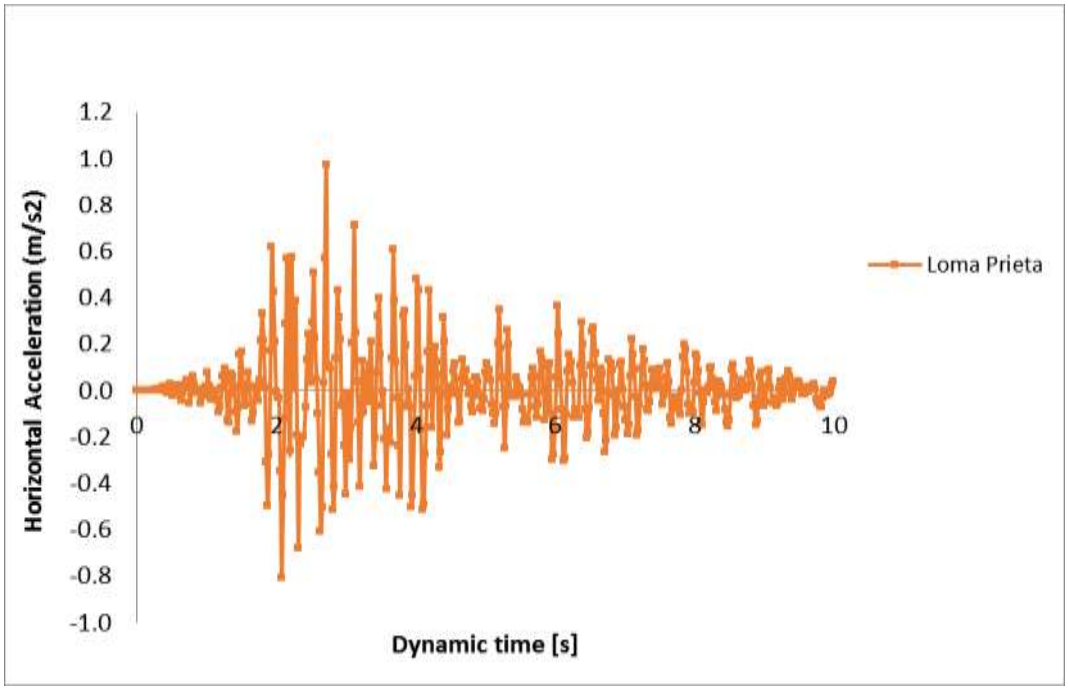


Figure 13. Horizontal acceleration of tunnel crown under critical earthquake in fault zone

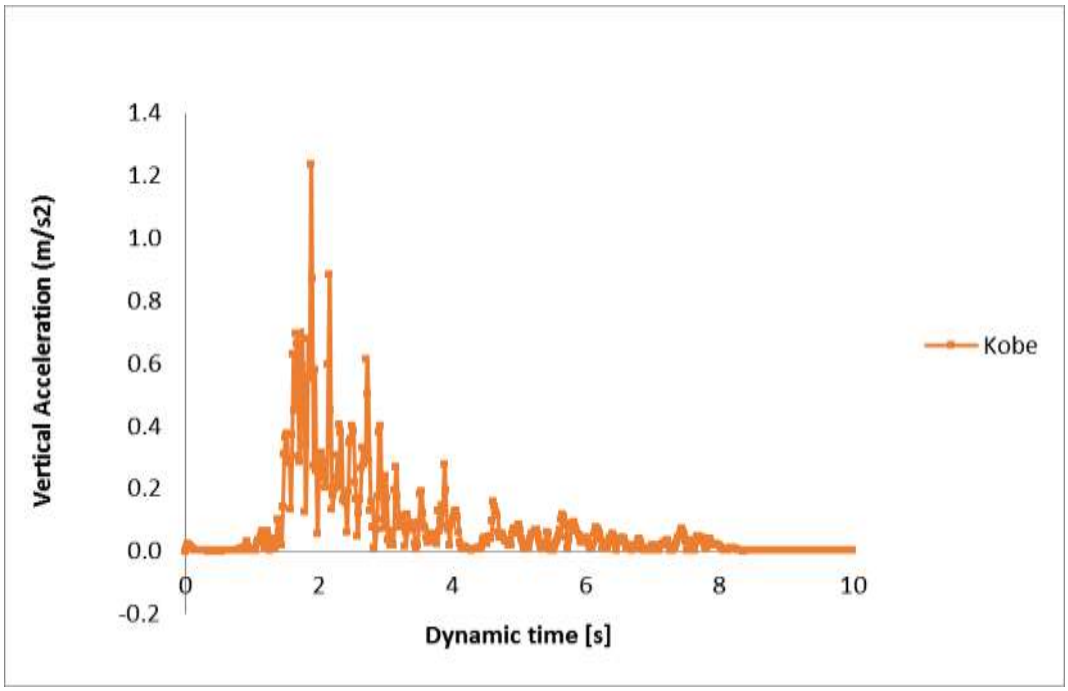


Figure 14. Changes in tunnel crown acceleration under critical earthquake near fault zone

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

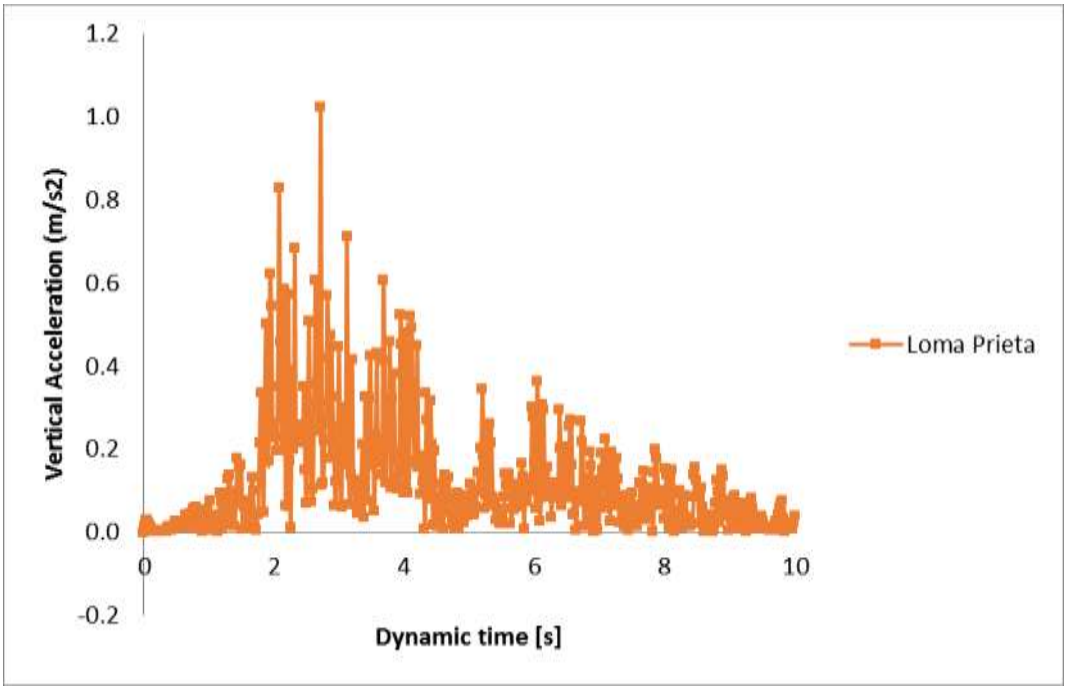


Figure 15. Changes in tunnel crown acceleration under critical earthquake in fault zone

3.5 Shear stress variations

Shear stress variations are shown in Figures 16 and 17. In this form, it is observed that shear stress changes occur in an earthquake far from the fault faster than an earthquake near the fault. This also shows that the choice of resistance parameters should be considered in proportion to the earthquake. Regarding what is mentioned in the review of displacements and the present result, it can be generally stated that the choice of behavioral model as well as its parameters in dynamic analysis of tunnels should be based on the type of earthquake.

Received:22 June 2018/Accepted:12 September/Published:19 December 2018

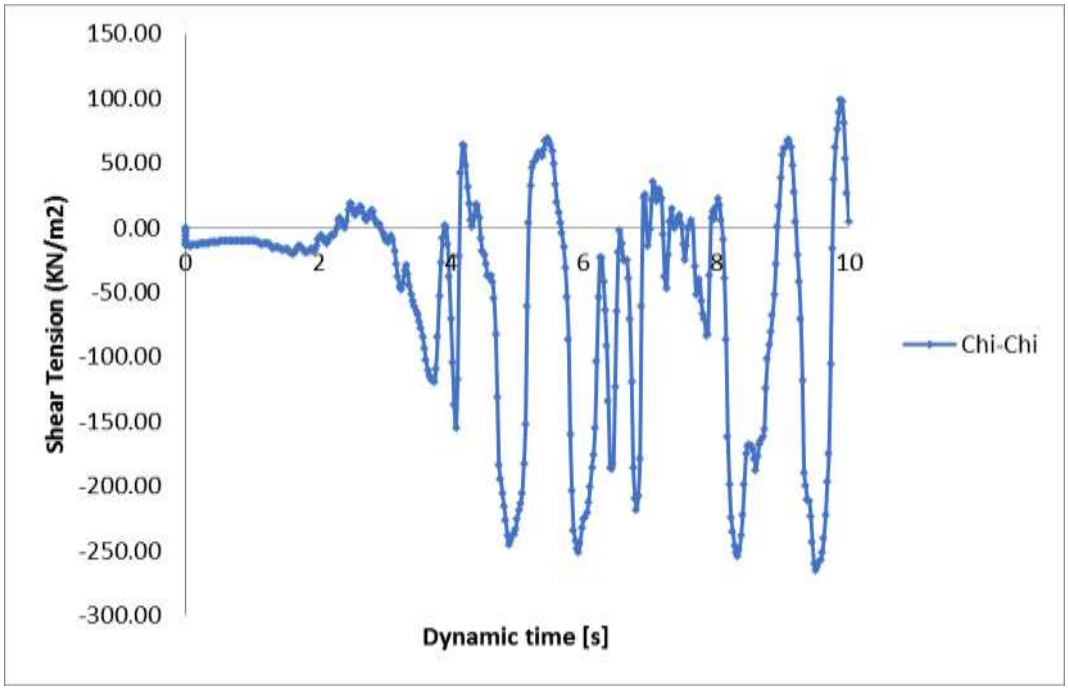


Figure 16. Shear stress variation of tunnel crown under critical earthquake near fault zone

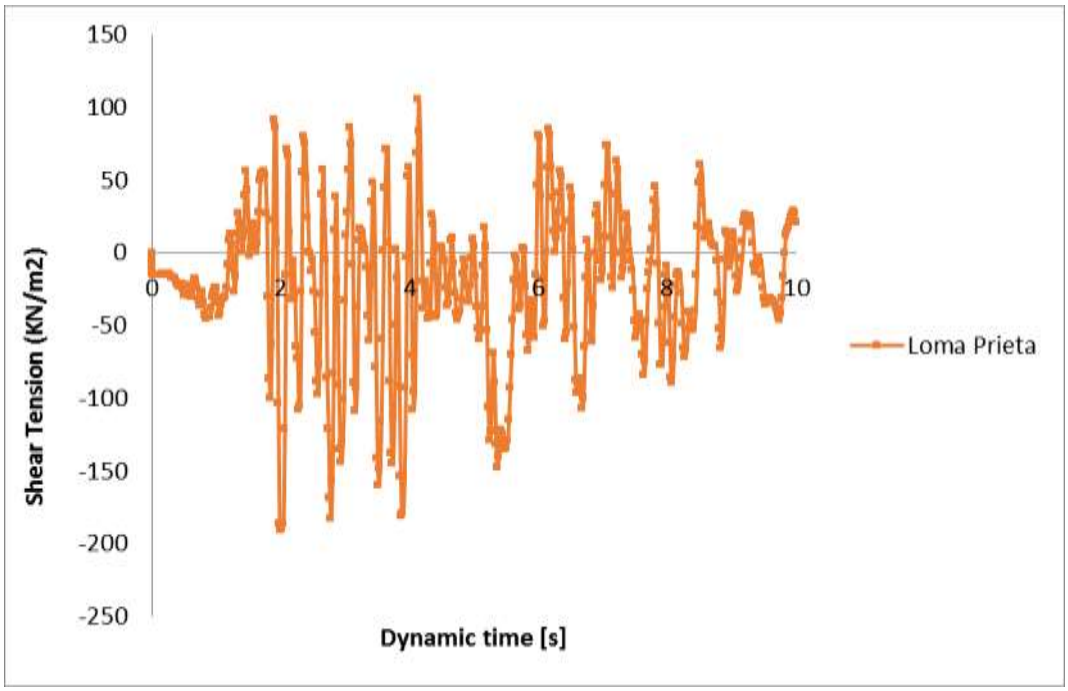


Figure 17. Shear stress variation of tunnel crown under critical earthquake in fault zone

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6-Conclusion

The variation in the horizontal displacement of the near-selected domain tunnel is far greater than that of the distant domain, and the displacement changes in the near-fault earthquakes occur in less time, which should be carefully considered when choosing the behavioral parameters of the materials. Vertical displacement changes in the near-fault field earthquake are ascending as it is, while in the districts of the districts, there is a fluctuating trend. The reason for this may be the nature of the earthquake as near or far from the fault. The trend of horizontal and vertical displacement changes in earthquakes far from faults follow the same form, but this conclusion is not true for earthquakes in the near field. Therefore, as a summing-up, it can be stated that during static design, the horizontal displacement of the earthquake should not be ignored, and appropriate measures should be taken. Also, the choice of the type of earthquake also has a significant impact on the behavior of the tunnel.

According to the results, acceleration response in near-field earthquakes is more than the response of earthquake acceleration in the distant sphere. Also, changes in the near-range region are more volatile than the distant domain, while the acceleration response in the districts of the districts More uniform. Also, the critical time in earthquakes far from fault is less than earthquakes near the fault. This will have a significant impact on tunnel behavior by changing tensile conditions before applying the main force of the earthquake.

Shear stress variations are performed in an earthquake far from fault faster than an earthquake near the fault. This also shows that the choice of resistance parameters should be considered in proportion to the earthquake. Regarding what is mentioned in the review of displacements and the present result, it can be generally stated that the choice of behavioral model as well as its parameters in dynamic analysis of tunnels should be based on the type of earthquake.

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