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Analyzing the Reaction of Metal and Concrete Structures near Earthquake Centers

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Abstract

Movements recorded near active faults have different characteristics compared to normal movements recorded far from the fault due to the effects of progressive directionality and permanent displacement. Among the most important distinguishing features of these movements are the presence of long period pulses in the time history of acceleration, velocity, and displacement, a large ratio of maximum speed to maximum acceleration in the time history, the high-frequency content of the map, and short duration in the component perpendicular to the fault map. Pointed out each of these features has different effects on different structures. Also, in such earthquakes, the accumulation of energy in a short period and a pulse can cause shock-like movement. A case study of three steel structures and their responses to earthquakes produced by the Green's function method. Three steel structures are selected and modeled for analysis. Then, these structures are analyzed under the earthquake produced near the fault and their response is analyzed and investigated.

Keywords: Earthquake Consequences, Metal and Concrete Structures, Vicinity to the Vibration Point.

Introduction

The increase in the population of cities close to active faults (such as Tehran, Tabriz, Los Angeles, and Tokyo) doubles the probability of an earthquake with huge casualties shortly. This issue stems from the fact that an earthquake near the fault can impose a greater seismic demand on the structure compared to an earthquake far from the fault, and as a result, it has caused a lot of damage in past earthquakes (Aghazadeh, M. et al., 2018). This issue shows that investigating the seismic behavior of structures under earthquakes near the fault is very important. Some of the features that distinguish an earthquake near the fault from an earthquake far from the fault include the directional effect, the permanent displacement effect when the fault rupture direction is towards a particular site and the fault rupture speed is close to the propagation speed of shear waves, in that site has a directional effect (MM Norouzian & N Gheitarani, 2023).

In this case, a significant share of energy is transferred to the site in a short period. A large amount of incoming energy in a short period causes a separate pulse in the time history of the earthquake speed. This effect can often be seen in the component perpendicular to the fault (Norouzian & Gheitarani, 2023). The presence of this pulse causes the scale of response spectrum intensity (Sa) to increase in periods close to the pulse period. Therefore, the response of structures under a pulsed earthquake will be different compared to an earthquake away from the fault. In addition to the above feature, the maps recorded during recent near-fault earthquakes, such as the Kokaeli earthquake in Turkey (1999) and the Chi Chi earthquake in Taiwan (1999), contain large amounts of permanent ground displacement, which is called permanent displacement (Norouzian M. M., et al., 2024).

This deformation occurred during the sliding time in the direction of the fault slip and therefore it is generally visible in the parallel component of the fault. Therefore, in most cases, it is not combined with the effects caused by directionality (Naghibi Iravani, S., et al., 2024 -c). The response of multi-degree-of-freedom structures under an earthquake near a fault has special characteristics. Unlike the response of the structure under a normal earthquake, the distribution of requirements in the height of the structure for an earthquake near the fault is completely non-uniform. These special characteristics for the response of structures under near-fault earthquakes make the study of the behavior of structures under these earthquakes worthy of further scrutiny (Khanian, M., et al., 2013). The development of design guidelines for structures close to active seismic springs requires a proper understanding and perspective of the response and performance of structures under such earthquakes (Zakerhaghighi et al., 2015).

One of the problems in examining the seismic response of structures under near-fault earthquakes is that the number of earthquake records that have characteristics of near-fault earthquakes has been recorded so far. In areas where information about past earthquakes is not available, this problem is double. One of the solutions for these areas is the use of artificial earthquakes (Ghadarjani et al., 2013- a). There are many ways to generate artificial earthquakes for a particular region. In general, these methods can be divided into probabilistic methods and deterministic methods. Probability methods can be divided into two general methods: point source and wide source (Dizaji, A. et al., 2023). Since the earthquake away from the fault has a probabilistic nature, probabilistic methods are used for such earthquakes. Earthquakes near the fault have a different nature from earthquakes far from the fault, and deterministic methods are used to simulate these earthquakes (Norouzian & Gheitarani, 2024).

Hisada and Bilak presented an efficient method based on the kinematic spring model, which is well able to simulate the effects of an earthquake near a fault, including the effects of directionality and permanent displacement. In this method, the earthquake source is modeled as a surface fault and the characteristics of the fault as well as the characteristics of different soil layers are also modeled (Sadigh Sarabi, M., et al., 2024. -a). Finally, by solving Green's functions, the earthquake map can be calculated at the desired site. In this study, we are going to investigate the seismic response of structures under an earthquake near the fault. For this purpose, we use the earthquake produced for the site, especially near the fault, and examine the seismic response of the structure under this earthquake. Finally, we will compare the seismic response of the structure under the earthquake near the fault with velocity pulse and also the earthquake without pulse (Aghazadeh, M. et al., 2019).

Theoretical

Directional effect. Orientation causes certain changes in the amplitude and duration of the earthquake time history around the fault (R≤10km) and also the difference between the components parallel and perpendicular to the fault. The results of the studies show that the presence of a directional pulse in the earthquake record increases the amplitude of the spectral acceleration, especially at about 0.6 seconds and above (Gheitarani, N., et al., 2013- a). The propagation of the fault towards the building with a speed close to the speed of the shear wave (Vr≈0.8Vc) causes most of the energy from the fault to reach the building in a big impact, which appears at the beginning of the earthquake's time history (Zaker Haghighi et al., 2014).

In other words, if we assume that every part of the length of the fault breaks in a certain period, the amplitude of this pulse depends on the direction of propagation of the fault relative to the location. If the fault rupture propagates towards the desired location, because the propagation speed of the fault is almost equal to the propagation speed of the shear wave, the waves reach the location in a short period and cause a pulse with a large amplitude of a short period, which leads to this phenomenon is called progressive directivity effect. Now, if the failure is in the direction away from the place, the waves will reach there in a scattered form and this phenomenon is called retrograde directivity effect (Sadigh Sarabi, M., et al., 2024. –d).

In the case that the orientation of the failure is such that it is neither close to the place nor away from the place, it is called the effect of neutral orientation. Pulsating movements can also be produced by the permanent displacement of the ground caused by a surface fault (Karimimansoob et al., 2024- b). This pulse is different from the pulses caused by progressive directivity. What has been studied in this article is the pulse effect caused by progressive directivity, which according to the results of previous research, causes the most damage to the structures.

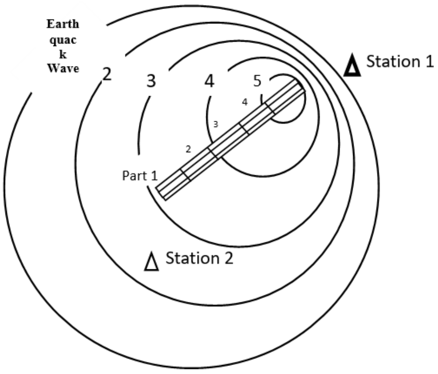

Figure 1. Waves resulting from faulting and production are directional.

Directional impact for strike-slip faults is observed in the direction perpendicular to the fault, and in the direction parallel to the fault, the amount of this effect is much less. In the direction parallel to the fault, the effect of tectonic displacement is also observed. This is while for normal and reverse faults, orientation and tectonic displacement are observed in the direction perpendicular to the fault (Aghazadeh, M. et al., 2017). Also, the destructive effects of earthquakes near the fault were mainly observed in the 1994 Northridge and 1995 Kobe earthquakes. In each of these earthquakes, the maximum speed of the ground movement was reported to be about 175 cm/sec, and the pulse period in the record was in the range of 1 to 2 seconds. This period range is close to the natural period of bridges and medium-height structures, and as a result, these types of structures suffered a lot of damage in these earthquakes (Norouzian, M. M., 2024).

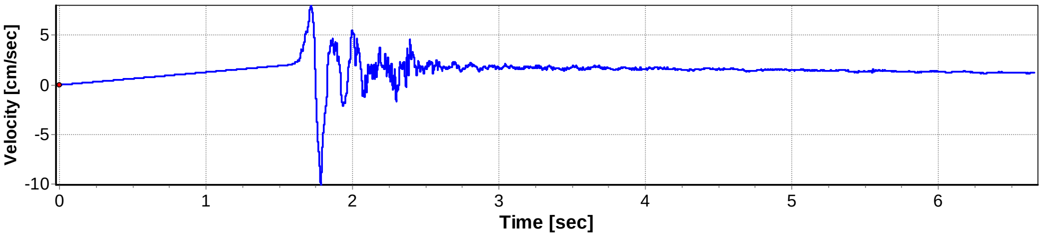

Figure 2. The pulse in the speed record in the Bam earthquake

Figure (2) shows the velocity component recorded in the 1989 Loma Prieta earthquake at different sites, as well as the geometric image of the fault that caused the earthquake. As can be seen, near the center of the earthquake and also at the left end of the fault, the earthquake records lack directional pulses. Meanwhile, at the right end of the fault, the earthquake records have large pulses caused by the directional effect. Permanent displacement effect. The first seismological evidence of the phenomenon of permanent earthquake displacement was reported by Benioff in 1955.

He showed that the rupture propagation of the fault as a moving source leads to different earthquakes on both sides of the fault zone with a large difference in the frequency content of the records. The permanent displacement phenomenon can cause a half-pulse in the time history of the earthquake velocity (Sadigh Sarabi, M., et al., 2023- a). Regarding the phenomenon of permanent tectonic displacement, it is important that the position of the building about the direction of the fault has nothing to do with the intended displacements, and only the type of fault and the distance from the fault surface are considered effective factors in the number of permanent displacements (Naghibi Iravani, S., et al., 2024 -a).

This means that at distances greater than 5 km from the fault surface, the effect of this phenomenon is reduced to a large extent due to the increase in the distance. Permanent tectonic displacement is visible in the parallel component of the fault and has a static nature (Dehghan S. et al., 2024). The difference between this phenomenon and the directional phenomenon is that the directional phenomenon occurs in the perpendicular component along the fault and has a dynamic nature. The most important effects of the permanent tectonic displacement phenomenon are specific displacement along the fault, inhomogeneous settlement, earth distortion, earth cracking, and the creation of compressive and tensile strains in the earth.

Among these cases, heterogeneous displacement and earth strains are among the most destructive permanent tectonic displacement effects. Permanent tectonic displacement is the result of a static displacement in the ground, and the main feature is the existence of a unidirectional pulse (half pulse) in the time history of the earthquake speed, and a uniform step in the time history of the earthquake displacement (Farrokhirad & Gheitarani, 2024).

Methodology

An efficient technique for simulating acceleration mapping in the near-fault domain. Hisada and Bilak (2003) presented an efficient mathematical method to calculate the strong ground motion in the near-fault domain in a layered semi-infinite environment, where special attention is paid to the static permanent displacement due to surface faulting. Also, the simultaneous effect of permanent and directional displacement in powerful earth movements is included in this technique (Gheitarani, N., et al., 2020). This method can calculate the displacement related to the strong ground motion for three components in the area near the fault and the low-frequency range. Notably, this method has been improved for cases where the observation point (wave recorder) is near the fault plane. The basis of this method is based on representation theory (Karimimansoob, V. et al., 2024- c). In this theory, the displacement component at the point of observation and time is calculated from the following relationship:

Ошибка! Текст указанного стиля в документе отсутствует.$\boldsymbol{U}_{\mathbf{m}}(\mathbf{y},\mathbf{t}) = \int_{-\infty}^{\infty} \mathbf{dt}' \iint_{\Sigma} \mathbf{D}(\mathbf{X},\mathbf{t}') \,.\, \mathbf{T}^{\mathbf{m}}(\mathbf{X},\mathbf{t}-\mathbf{t}';\mathbf{y})\mathbf{d}\Sigma$

Where the slip function in the spring is the vector related to the Green's functions and the fault plane. Because solving this equation in the time domain is very time-consuming, this equation is often expressed in the derivative domain:

$$U_k(Y;\omega) = \int_{\Sigma} T_{ik}(X,Y;\omega) D_i(X;\omega) d\Sigma$$

Where U¬k is the kth displacement component at the observation point Y, X is the source point on the fault plane, ω is the angular frequency and Σ is the fault plane. Tik is the effect of Green's function and Di is the i-th slip component on the fault plane. The Green's function of the semi-infinite space is calculated by the integral of the wave counter in the form of the following equation:

$$T_{ik}(X,Y;\omega) = \int_0^{\infty} t_{ik}(X,Y;\omega,k)dk$$

The dependent variable is Green's function. Hisada and Biak presented a modified form of the representation theory relation in the frequency domain, with a special approach to permanent displacement and directional effect, in which the singular points of the original Green's function are removed by subtracting and summing the static Green's function to the form of the following relation (Kahvand, M., et al., 2015).

$$U_k(Y;\omega) = \int_{\Sigma} \{T_{ik}(X,Y;\omega) - T_{ik}^{s}(X,Y)\} D_i(\mathrm{X};\omega) d\Sigma + \int_{\Sigma} T_{ik}^{s}(X,Y) D_i(X;\omega) d\Sigma$$

Therefore, with this separation, the directional effect (first integral) and permanent displacement effect (second integral) can be well modeled. The mentioned method has been implemented in the form of three FORTRAN codes by Professor Hisada. The results of various studies show that this method has a suitable efficiency for earthquake modeling in the area near the fault. Uncertainty in future probable earthquake production parameters. One of the biggest design challenges in earthquake engineering is the wide variability of seismic excitation characteristics that a particular structure can experience (Naghibi Iravani, S., et al., 2024 -b).

Experimental observations have shown that points located at equal distances from the seismic source in a particular earthquake can experience different levels of earthquake intensity (Dehghan S., 2024). Attenuation relationships provide the relationship between a characteristic of seismic excitation at a site, and the magnitude and distance of an earthquake, and can be used to determine the mean as well as the range of variation of a measure of earthquake intensity in a structure. However, these relations only provide a characteristic of earthquake intensity, and therefore the output of such relations cannot be directly used in time history analysis (Gheitarani, N., et al., 2024- b).

In the previous section, an alternative approach was described, which is the generation of the excitation time history according to the building conditions (Khanian, M., et al., 2019). However, the effects of variability in the excitation characteristics are usually neglected in the modeling chain and consequently the design. In this section, the sources of this uncertainty are studied and the methods of its application in the simulation chain are mentioned. In general, the variability (uncertainty) in the simulation of a physical phenomenon such as an earthquake was divided into two types uncertainty in the model and uncertainty in the model parameters (Sadigh Sarabi, M., et al., 2023-b).

Each of these uncertainties has components of cognitive uncertainties as well as inherent uncertainties (Karimimansoob et al., 2024- a). Uncertainty in the model means that if the physical parameters of an event are known, the simulation model of the physical phenomenon does not always provide reality-based results, and therefore this error should be considered in simulation studies. The reason for the non-compliance of the model results with the reality can be caused by the assumptions and simplifications of the model or the inherent difference between the simulation model and the physical phenomenon. Uncertainty of parameters is called uncertainty in the precise determination of model parameters (Norouzian, M. M., & Sarabi, 2023).

Part of this uncertainty can be caused by our lack of correct understanding of the studied parameter (cognitive uncertainty) and part of this uncertainty is caused by the random nature of that parameter (inherent uncertainty). By increasing the awareness of the model or parameter, we will be able to reduce the cognitive uncertainty in it, otherwise the inherent uncertainties cannot be reduced. The simplest example of the inherent uncertainty is balding. The output of this experiment can only be expressed by the probability distribution function, not by a specific number (Sadigh Sarabi, M., et al., 2024. -c). A simple example of cognitive uncertainty is measuring the length of a table with different tools. Contrary to the inherent uncertainty, the output of this test should be a number, even if none of the tools used can provide this number.

In this case, this uncertainty can be reduced by using more data or more accurate data. Simulation of future earthquakes considering spring uncertainty. To evaluate the effectiveness of spring modeling methods in simulating the spring of a probable future earthquake, the 1994 Northridge earthquake is considered a future earthquake scenario (Gheitarany, N., et al., 2013- b). The uncertainty of the earthquake spring is reflected in the calculation process based on the hybrid model described in the previous section. For this purpose, the empirical relations presented by Wong are used, because these relations can include the uncertainty in the various parameters of the spring model in the earthquake estimation process (Gheitarani, N., et al., 2024- a). Table (1). It shows the uncertainty in the various parameters of the earthquake spring model. Using the hybrid spring model, 100 spring models were produced for the 6.7 magnitude earthquake scenario. Figure (3). It shows an example of fountain models made by the hybrid method. Based on the generated spring models, earthquake simulation was done with the help of the Hisada and Bilak method.

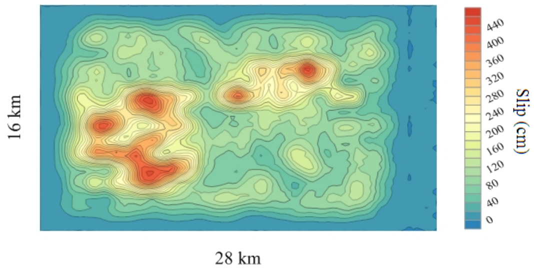

Figure 3. An example of spring models produced for an earthquake scenario

Table 1. Uncertainty in earthquake spring model parameters

Fault model parameters	**Relationship**	**σ**
S/km2 rupture surface	log S= MW - 4.05	0.29
L/km fault length	log = 0.5MW-1.9	0.18
W/ km fault width	W = S / L	-
/cm average slip on the fault surface	log$\overline{D}$ = 0.5 MW -1.35	-0.29
	log Sall= logS – 0.67	0.16
Sall / km2 area of sprites	log Sm= logS – 0.83	0.18
Sm / km2 area of maximum sprite	log Lm= log – 0.44	0.15

Fault model parameters	Relationship	σ
Lm/km maximum length of sprite	log Xm= log – 0.53	0.18
Xm / km position of the maximum sprite in the direction of Strike	log Ym= logo – 0.30	0.2
Ym/km position of maximum sprite along dip	$\log\overline{D}m = \log\overline{D}+0.34$	0.07
m /cm average slip on maximum sprite	$\log\overline{D}0 = \log\overline{D}+0.28$	0.06
	relationship	σ
0 /cm average slip on other sprites	log Xs= log – 0.37	0.24
	log Ys= logW – 0.09	0.17

As can be seen, there is a good agreement between the average spectrum of the simulated earthquakes and the recorded earthquakes at periods higher than 0.5 seconds. The reason for the mismatch of the spectrum in periods less than 0.5 seconds is that the accelerograms produced from the period 0.5 seconds onwards because this interval of the period can include the effects near the fault.

Results

In this research, three structures of 3, 9, and 20 floors with steel bending frame system of SAC project designed in Los Angeles are used for analysis. The structures studied in this research have been widely used by researchers in various researches. The system resistant to side loads in these buildings is the steel bending frame system.

Connecting the beam to the column in the internal frames is an articulated connection, and these frames are only responsible for transferring gravity loads (Ghadarjani et al., 2013- b). The peripheral bending frames are responsible for bearing lateral loads. Modal characteristics of the structures are represented in the table (2). It should be noted that the mass of the structures is concentrated at the level of the floor and therefore the number of degrees of freedom of the structures is equal to the number of floors.

Table 2. Modal specifications of 3, 9, and 20-floor SAC structures

The fifth mode	The fourth mode	The third mode	The second mode	The first mode	Structure period
--	--	0.14	0.30	0.98	3-storey structure
0.21	0.30	0.46	0.82	2/23	9-storey structure
0.41	0.55	0.78	35/1	96/3	20-story structure

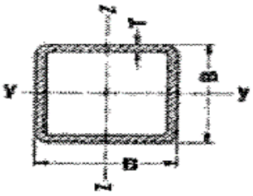

Figure 4. The frame of the 20-story SAC structure.

Table 3. Specification table of columns of rows A and F of the 20-story structure

Section	Length (B) mm	Width (B) mm	Thickness (T) mm
BOX#1	150	150	5
BOX#2	150	150	75
BOX#3	150	150	10
BOX#4	150	150	12.5
BOX#5	150	150	20

Table 4. Specifications of the mass entered into the frame of the structures

Description	Mass (kg)	Position	Structure
The mass added to the frames is without the mass of the steel structure. The mass of the structure is calculated by the software.	413676	First and second-floor	3-storey structure
	407780	roof	
	417305	first floor	9-storey structure
	428191	second floor	
	424109	The third to the ninth floor	
	411408	roof	
	254465	first floor	20-story structure
	263991	second floor	
	260362	3rd to 20th floor	
	253105	roof	

Structure analysis method. The growth of the power of computer technology provides the possibility of accurate calculations, at the same time, the analytical methods have become more complicated. For a long time, different methods have been used to analyze and design structures, which include linear static analysis, non-linear static analysis, linear dynamic analysis, and finally, non-linear dynamic analysis. Therefore, the analyses have undergone a major change and have been upgraded from the elastic analysis mode to the non-linear dynamic analysis (Norouzian & Sarabi, 2023).

The simplest of these methods is linear static analysis, in which the behavior of all members is defined in a linear range, or other words, considering linear elastic behavior for the components of a structure, and all static loads are modeled. In linear analysis, only the main members are modeled and the non-main members are controlled only for the deformations resulting from the analysis, because the non-main members usually have a significant reduction in stiffness and strength under reciprocating loads, and they are quickly removed from the lateral load system (Maleki, M., et al., 2024).

Static analysis method. Static analysis methods are suitable when the response of the structure during an earthquake is mainly caused by vibration in the first mode, or other words, the effect of higher modes is not significant. When the effect of modes higher than the first mode is not significant if the building is short and regular, therefore, it is necessary to use dynamic analysis methods for long and irregular buildings (Sohrabi, S., 2024).

In the static analysis method, the following assumptions are made:

The behavior of materials is linear although the force of an earthquake on a structure has a dynamic nature. But in this method, this force is introduced into the structure as a static equivalent load, and finally, the total force of the desired earthquake is calculated as a coefficient of the total weight of the structure. But in reality, the behavior of materials is not linear and elastic, and this issue leads to the use of non-linear methods. In this regard, the incremental nonlinear static analysis method can be mentioned. This is a suitable method for predicting the deformation and force requirements, and all the important characteristics of nonlinear and linear response are presented in it.

In this analytical method, the lateral loads are used in the form of predetermined patterns and show the approximate relative inertial forces in the position of the generalized real masses. Deformations and internal forces are calculated at each level of displacement. These are estimates of the deformation and strength requirements of the structure, which are comparable to the existing capacity (Sadigh Sarabi, M., et al., 2024. -b). This method provides a complete picture of the behavior of the structure from the elastic stage to collapse. However, the static and load-independent nature of this type of analysis and the compatibility of its results with the dominant mode of vibration are among the weak points of this method.

Dynamic analysis method. Due to the dynamic nature of the forces caused by the earthquake, which cannot be clearly expressed in the form of a mathematical function, several methods of numerical dynamic analysis of structures were developed. Since the structures enter the stage of non-linear behavior even in moderate earthquakes, the non-linear behavior of the materials and structure geometry should be considered in their analysis. In dynamic analysis, there are two methods of dynamic analysis, linear and non-linear.

Linear dynamic analysis can be performed in two ways: spectral or time history. The specific assumptions of this method in the range of linear behavior are: The behavior of the structure can be calculated as a linear combination of the states of different vibration modes of the structure that are independent of each other. The period of vibration of the structure is constant in each case during the earthquake. In this method, similar to the linear static analysis method, the response of the structure in an earthquake of the desired risk level is multiplied by the coefficients according to the regulations so that the maximum deformation of the structure corresponds to what is predicted in an earthquake. For this reason, the internal forces in malleable structures that will behave non-linearly during an earthquake are estimated to be larger than the tolerable forces in the structure.

In the non-linear dynamic analysis of structures, deformations, internal forces, and in general the response of the structure are calculated under the effect of one or more specified mapping accelerations. Also, in this analysis, the response of the structure is calculated by considering the non-linear behavior of the materials and the geometry of the structure. In this method, it is assumed that the stiffness and damping matrices can change from one step to the next, but the time intervals of the steps are fixed and the response of the structure under acceleration is considered for each time step, and using methods a number can be calculated. Non-linear time history analysis, which is one of the non-linear dynamic analysis methods, is a complex method and at the same time the most accurate method for evaluating the inelastic needs of the structure under the effect of acceleration of ground motion maps.

In the Fourier spectrum of the map of earthquakes in the near area, instead of the spectral range having a maximum value in a large period range, it has its maximum value in a small range or somehow in a specific period. The existence of such features in the earthquakes of the near area causes the behavior of the structure to go out of the mode state in which one or more modes of the structure determine the behavior of the structure, and become wave-like in this case, the behavior of the structure is caused by the collective The effects of waves passing through the structure.

What was mentioned above as wave-type effects is proof of the effect of movements in the near field on the behavior of tall structures. Regarding these pulses with long periods, it should be said that due to the closeness of the period of these movements with the natural oscillation period of tall structures, the behavior of the structure tends towards the phenomenon of intensification. This causes large changes in the structure. The result of this is the increase of the P-Δ effect in the oscillatory behavior of tall structures. The occurrence of a pulse at the beginning of the record indicates the release of a significant kinetic energy in a short period, caused by the failure of the fault.

In a short period, a large kinetic energy is induced into the structure. This problem is considered one of the most important characteristics of the earth's movement records in the area near the fault. This, in addition to causing the phenomenon of intensification in structures with long periods, also affects the materials used in the construction of structures due to the application of force in the form of impact, and the structure shows a more brittle behavior. On the other hand, since these pulse-like movements enter the structure in a short period, the structure will not have enough time to show the response to the incoming forces.

Due to the phenomenon of intensification in the response of structures with long periods and bridges with large spans, using the response spectrum alone is not enough to express the real behavior of these structures. Therefore, in the areas near the fault, using the spectrum of the structure's response alone for structures, especially tall structures, under the effect of the forces caused by the earthquake is not enough and cannot express the real behavior of the structure under the effect of the forces in the above conditions.

Regarding the parameters recorded near the fault, it has been observed that the values of maximum acceleration (PGA), maximum velocity (PGV), and maximum displacement (PGD) near the fault are more than the values recorded in areas far from the fault. As we get closer to the center of the earthquake, these values increase. PGV, PGA, and PGD parameters have large values in the areas close to the fault, especially for the record recorded along the perpendicular to the rupture.

Introduction of structures. As can be seen, the average values as well as the standard deviation of the seismic demand under an earthquake with a directional pulse are higher than the values obtained under an earthquake without a pulse. This shows the special effect of the near-fault earthquake on engineering structures. The high values of the standard deviation of the seismic demand under directional pulse earthquakes indicate greater uncertainty in estimating the seismic demand of structures in the areas near the fault than in the areas far from the fault. In addition, it can be seen that the seismic demand on the first floors of the buildings under signals with permanent displacement pulses is significantly higher than when the structures are under directional pulses. In general, the effects of higher modes are more prominent in signals with directional effects.

Floor drift ratio. The results showed that the permanent displacement effect on the seismic response of structures is a significant effect and comparable to the directional effect. Although seismic regulations and the fourth edition of Iran's 2800 regulations have tried to include the effects of earthquakes near the fault in the stages of loading and designing engineering systems, the main focus of these regulations is more on the effect of directionality. Considering the significant contribution of permanent displacement pulse effect on the seismic demand of engineering systems especially in the first floors of structures, it seems necessary that more studies should be considered to consider the effect of permanent displacement in the process of analysis and design of engineering structures. It is needed in areas near the fault.

Conclusion

The studies conducted in the near field show that the horizontal maps perpendicular to the fault have pulses with a long period so such maps have more effects on the structures than the maps far from the fault. The obtained results indicate higher values of seismic demand on different floors of structures. Based on the study, the average values and standard deviation of the seismic demand of the studied structures in the analysis mode under the earthquake near the fault are more than the values of the seismic demand under a normal earthquake and without directional pulses and permanent displacement.

The large amount of standard deviation of the seismic response of the structures indicates the existence of high uncertainty in the seismic analysis of the structures under the near-fault earthquake. Also, the results showed that the relative drift of the floors under the earthquake with permanent displacement pulse in the initial floors of the structures is more than the case where the structures are placed under the earthquake with a directional effect. Meanwhile, the contribution of higher modes increases when the structures are subjected to directional earthquakes. Therefore, an earthquake with a permanent displacement effect can cause a lot of damage to the first floors of structures.

The increase in the seismic demand for structures under an earthquake near the fault requires the special design of structures in the areas close to the source of the earthquake. While the regulations of the world as well as the 2800 regulations in their fourth edition try to include the near-fault effects in the analysis and design stages of structures, the main focus of these regulations is on the directional effect and fewer attempts are made to Reflect the effect of permanent displacement in the loading of structures. This is while the results of this study indicate the high contribution of the permanent displacement effect in causing damage to engineering systems in the areas near the fault.

Therefore, it seems necessary to consider the effect of permanent displacement in the calculations in the stages of seismic risk analysis as well as the analysis of engineering systems. The obtained results indicate that under the earthquakes near the fault, the energy concentration in the lower floors was much higher than the records far from the fault and this accumulation of energy will result in the accumulation of damage. Also, despite the uniform distribution of resistance in the height of the floors, the distribution of energy in the floors is completely irregular and non-uniform.

This issue shows that the existing regulations for the seismic design of structures are not sufficient regardless of the distance of the structure from the fault. In this study, to evaluate the effect of an earthquake near the fault on the structures, the earthquake produced by the theoretical Green's function method was used. The results of the study showed that the use of seismological methods such as earthquake simulation can help engineers evaluate the behavior of structures under probable future earthquakes. To consider the uncertainty in the future earthquake spring specifications, spring modeling methods were used. The results showed that the use of new earthquake source modeling methods can well take into account the uncertainty in future earthquake source characteristics. The use of these methods can greatly help engineers in simulating earthquake scenarios required in engineering (such as operational-level earthquakes and design earthquakes).

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