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THE PRESENTATION OF A FLOWCHART TO SELECT NEAR AND FAR-FAULT EARTHQUAKES FOR SEISMIC DESIGN OF BRIDGES AND BUILDINGS BASED ON DEFENSIBLE ENGINEERING JUDGMENT

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ABSTRACT: The seismic design of structures depends on the selection of suitable earthquakes according to the realistic conditions of the structure and its site, which is not possible except by accurately recognizing the characteristics of the earthquakes. For this purpose, in this paper, the characteristics of near and far-fault earthquakes have been studied in detail in order to the seismic design of the structures. Directivity, fling-step, asperity, types of the faults, the duration of strong ground motion and its maximum values (PGA, PGV, and PGD) are some characters of the earthquakes which are investigated in this study. At the end, a flowchart based on the characteristics of the earthquakes in order to select them for the design of structures according to the realistic conditions of the structure and its site is presented.

KEYWORDS: Fault, Directivity, Fling-Step, Asperity, Magnitude.

1 INTRODUCTION

Examining the seismic damage that has occurred in recent decades around the world, it is clear that most of the existing structures are vulnerable to earthquakes for various reasons. In order to the seismic design of structures, it is necessary to have a comprehensive knowledge of the characteristics of earthquakes [1].

One of the important divisions in the discussion of recognizing the characteristics of the earthquakes is the division of earthquakes into two groups, including near-fault earthquakes and far-fault earthquakes. The basis of this division is the distance between the structure and the fault. Different references introduced different distances for this division, including 10, 15 and 25 km, but most references introduced a distance of less than 15 km to the near-fault earthquakes. Recently, many different studies have been conducted on the effects of the near and far-fault earthquakes on the seismic response of bridges and buildings. For instance, Shome et al. [2] and Shome and Cornell [3] showed that the estimation of the seismic response of the structures depends significantly on the acceleration spectrum at the period of the structures. Ghaem Maghamian and Khalili [4] showed that the characteristics of the near-fault earthquakes were strongly affected by divergent faulting on the fault surface.

Mansouri et al. [5] by examining a highway bridge and a railway bridge showed that in order to select earthquakes for the seismic design of structures, it is very important to pay attention to PGA, PGV and PGD. Seyed and Mortezaee [6] stated in their studies that it is difficult to consider a criterion for selecting the records in order to obtain to the desired results and it is necessary to test a group of the records. Akbari and Nazari studies [7] showed that the selection of accelerometers in the standard 2800 is based only on strong ground motion, while in the probabilistic method, the earthquakes selection is based on minimizing the standard deviation and according to the structural characteristics that ultimately the choice of accelerograms will be optimal. Mansouri [8] showed that Iranian Standard 2800 and ASCE code for scaling earthquake have introduced the magnitude parameter, and do not discuss on considering the effects of the maximum values of strong ground motions (PGA, PGV, and PGD) that are crucial in the estimating of the response of the structures. The results of his studies showed that there is no direct and constant relationship between the magnitude of the earthquakes and the seismic response of structures. Abdollahzadeh et al. [9] focused on comparing hysteretic energy and inter-story drift in steel frames with V-shaped brace under near and far-fault earthquakes. They showed that the amount of hysteretic energy in a structure could be an index of its damage level or its malleability. Their paper carried out a nonlinear dynamic analysis on steel buildings with a V-shaped (Chevron) brace, hence surveying hysteretic energy distribution as well as maximum inter-story drift in the stories of these buildings, under the influence of equalized near and far-fault records. The results showed that the inter-story drift need for equalized near-fault records was more than the far-fault ones. Also the results showed hysteretic energy caused by near-fault records that were more than the far-fault ones. The study of Shahbazi et al. [10] focused on the seismic response of the steel moment frames considering simultaneous excitations of the vertical and horizontal components. In their paper, the behavioral seismic differences of these frames have been evaluated in two states. First, under the simultaneous excitation of the horizontal and vertical constituents of near-field earthquakes that have fling-steps in their records. Second, under simultaneous excitation of the horizontal and vertical constituents of far-field (FF) earthquakes. Considering that the simultaneous effects of the horizontal and vertical constituents of near-field earthquakes were subjected to a fling-step resulting in an increased inter-story drift ratio, the horizontal displacement of stories, an axial force of columns, created the moment in columns, base shearing of the structure, and velocity and acceleration of the stories. Wu et al. [11] studied the effects of the seismic performance evaluation of building-damper system under near-fault earthquake. In their paper, by taking into account near-fault earthquakes, the seismic performance of the building-damper system and damper failure's influence were evaluated systematically. A 9-storey steel building was designed by the Chinese seismic code as the benchmark model, and five typical dampers, including buckling-restrained brace damper (BRB), friction damper (FD), self-centering damper (SCD), viscous damper (VD), and viscoelastic damper (VED), were adopted. It was found that the building-damper systems showed a large response and possible damper failure under the near-fault earthquake excitations. Subsequently, by introducing the artificial near-fault earthquake excitation, the influences of different pulse parameters, such as pulse velocity amplitude, pulse period, and the number of significant pulses, were studied. It showed that the pulse velocity amplitude and pulse period obviously affect the seismic performance, while the number of significant pulses presented little influence.

Despite all the researches that have been done, some of which have been mentioned, so far there is not a worthy study in case of the investigating of the characteristics of near-fault earthquakes and far-fault earthquakes and also compared them with the cases raised in the regulations of the seismic design of structures. Therefore, in this paper, after reviewing and comparing the characteristics of near-fault earthquakes and far-fault earthquakes, these characteristics are compared with the items mentioned in standard 2800 for selecting earthquakes in order to the design of the structures. At the end of the research, a flowchart is presented to select the earthquakes for the seismic design and the seismic retrofit of buildings and bridges.

2 THE STUDY OF THE PARAMETERS OF STRONG GROUND MOTION IN THE FAR AND NEAR REGIONS OF THE FAULTS

2.1 The general concepts

According to Figure (1), by examining the records related to the Tabas earthquake in stations in far and near areas of the fault, it is clear that with increasing distance from the epicenter, the maximum values of the strong ground motion decreased dramatically, but an amount of the magnitude was considered for each earthquake. This issue indicates that in the selection of the earthquakes for the seismic design of structures, only considering the magnitude parameter of the earthquake is not enough and also other parameters are vital.

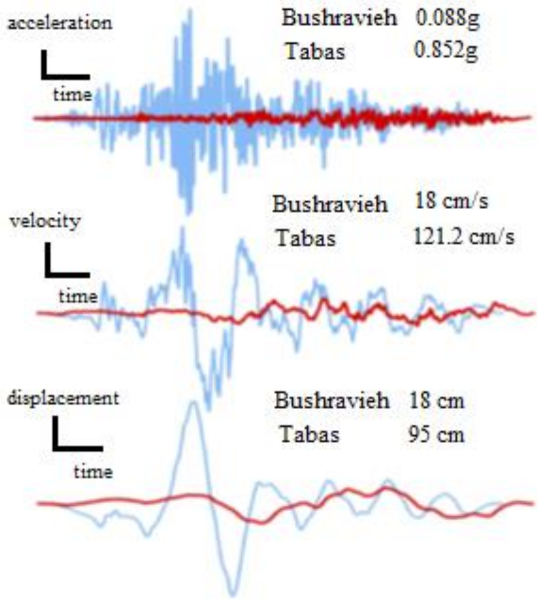

Figure 1. The comparison of perpendicular-to-fault components in Tabas earthquake in 1978, closest distances of Tabas and Bushravieh stations from the fault were 2.55 and 28.79 km, respectively [12]

In far areas from the faults, structures are usually designed against only acceleration, but in near areas from the faults, in addition to the acceleration (PGA), other characteristics of the earthquakes including the velocity (PGV) and the displacement (PGD) are also vital in the seismic design of structures. For this reason, more details will be provided in the following sections of this paper.

In addition to PGA, PGV and PGD, the duration of strong ground motion is a factor influencing the seismic response of structures and in most cases has significant effects on the rate of the inelastic deformations of the structure.

2.2 The investigation of the characteristics of near-fault earthquakes

2.2.1 The general concepts

The earthquakes in near and far areas of faults have different characteristics from each other. The criteria set in most regulations in the world are for the seismic design of structures in far- region of the faults. In this case, it is assumed that the vibrations of strong ground motion are applied to the structures in the form of numerous cycles in a relatively long period and the structures have sufficient opportunity to deal with them. While a significant number of cycles of these vibrations in near region of the faults are applied to the structures in the form of strong pulses. If special measures are not taken to counteract with these pulses, the structures will suffer significant seismic damages. Usually, the evaluation of the seismic behavior of structures and their design against near-fault earthquakes have been reviewed in research articles and studies, and a few regulations have provided sufficient criteria for the design of structures in near region of the faults.

Figure (2) shows how seismic waves reach buildings at different distances from the seismic sources. In building (A), which is near to the epicenter, the records have pulses. Examining the records applied to buildings (B) and (C), it is clear that with increasing distance from the epicenter, the records are applied to the structures almost cyclically.

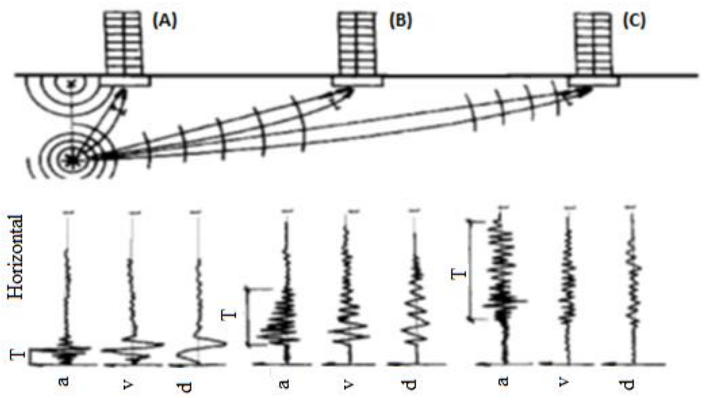

Figure 2. How applying histories of the acceleration, the velocity and the displacement to buildings located at different distances from the seismic source [13]

Earthquake records in near region of the faults have a variety of the characteristics, such as directivity and fling-step and asperity. Each of these features will be described below.

2.2.2 Directivity

Depending on the location of the site, the faults rupture propagation direction and the slip on the faults, directivity is divided into three types, including forward directivity, backward directivity and neutral directivity. These features will be described in the following.

2.2.2.1 Forward directivity

If the rupture propagation direction of the fault is towards the site and the direction of the slip of the fault is in the same direction, the ground motion in this site has feature of forward directivity.

Usually, the structures that are not in the direction of the fault rupture do not suffer devastating effects of near-fault earthquakes, while these structures have little distance to the fault.

Figure (3) shows the time histories of three components of acceleration-time and velocity-time for Bam earthquake in a near station of the fault. Carefully in the form of horizontal records of velocity-time related to Bam earthquake, it is clear that both horizontal components of velocity-time of this earthquake have pulses at the beginning of their motions, but the pulses are reported to component of –NS2W (EW) are much larger than the pulses of –NSE (NS) component.

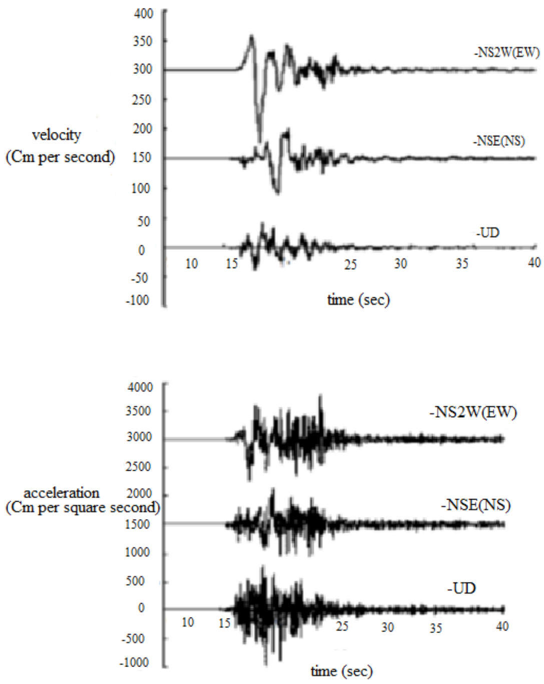

Figure 3. The acceleration-time and the velocity-time records, Bam earthquake [4]

2.2.2.2 Backward directivity

If the site is in a location that the fault rupture propagation direction away from it, the seismic waves reach the site slowly. This phenomenon is called backward directivity. In this case, the highest rate of displacement, velocity and acceleration of the earth's motions are far less than mode of the forward directivity.

Figure (4) shows how the seismic waves propagate. On the one hand, the rupture velocity of the fault is approximately equal to the propagation velocity of the seismic waves and the rupture direction of the fault is towards site A, because of these reasons, the seismic waves reach this site in a short time and the concentration of the seismic waves occurs which leads to a strong pulse in this site. On the other hand, the seismic waves reach site B in a relatively long time and strong pulses do not occur in this site. This issue indicates that all near regions of the fault are not under the influence of the forward directivity hazard. With the help of extensive analysis and defensible engineering judgment, the rupture direction of fault can be detected with high probability.

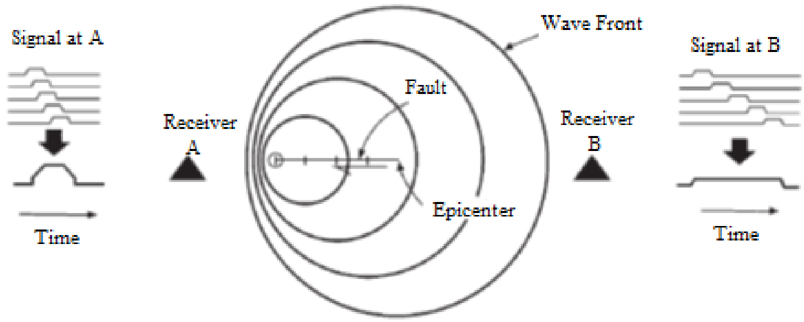

Figure 4. Forward directivity occurs in site A and backward directivity occurs in site B [14]

2.2.2.3 Neutral directivity

The neutral directivity occurs in case that the site is in a location where the rupture propagation of the fault does not move away from it or towards it.

2.2.3 Fling-step

The fling-step depends on the permanent and relative deformation of the fault edges at the time of the fault rupture. In this case, the motion of the earth in parallel-to-fault is including the effect of fling-step and a one-way velocity pulse.

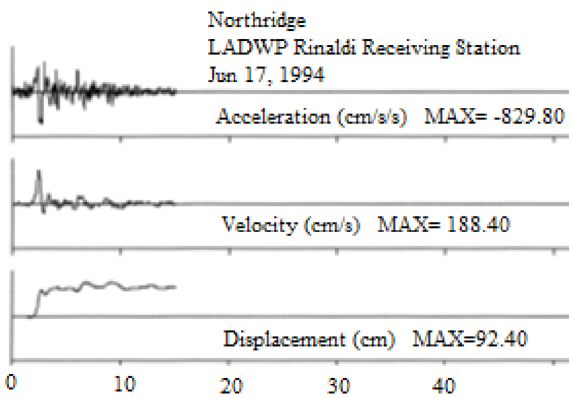

Figure 5. Time histories of the acceleration, velocity and displacement of Northridge earthquake, 1994 [15]

Figure (5) shows the time histories of the acceleration, velocity and displacement of the Northridge earthquake which recorded at the LADWP Rinaldi Receiving Station.

There is a large pulse in the acceleration–time record. There is a one-way velocity pulse in the velocity-time record which its PGV is equal to 188.4 cm/s. When a half-pulse occurs in the velocity-time record, as a result, in the displacement-time record, a permanent displacement occurs which is equal to 92.4. The effect of fling-step can be particularly dangerous for long bridges and energy or water transmission lines.

There is a possibility of occurrence of directivity phenomenon in strike slip faults and dip slip faults. Forward directivity in strike slip faults occurs in a relatively large area that has forward directivity conditions. Forward directivity in dip slip faults occurs in a relatively small and limited area where the fault rupture propagation direction is towards the site and also the slip direction is in the same direction with the site movement. The geometry of the fault and the slope angle of the fault affect the amount and location of the forward directivity effect. Figure (6) shows the effects of forward directivity and fling-step for strike slip faults and dip slip faults.

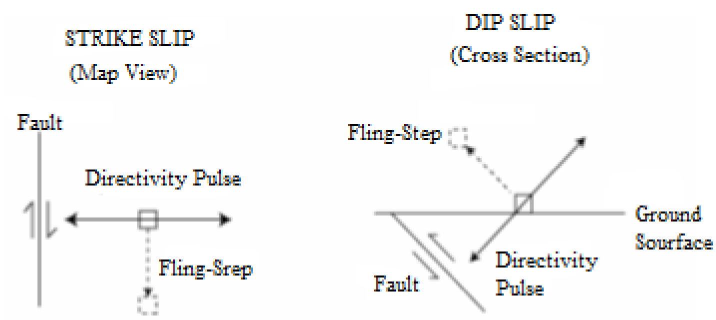

Figure 6. The effects of forward directivity and fling-step for strike slip faults and dip slip faults [16]

2.2.4 The effect of asperity

The area on the fault surface has the higher displacement than the average displacement is defined as asperity phenomenon. Figure (7) shows the non-uniform distribution of landslides on the fault surface in the Bam earthquake, which is prepared in accordance to far the seismic waves. In this figure, three asperities are observed on the surface of the fault.

In the seismic design of important structures can use asperity spring model in order to prevent very damages to structures in near areas of the fault. The asperity spring model can provide realistic conditions for simulating strong ground motions.

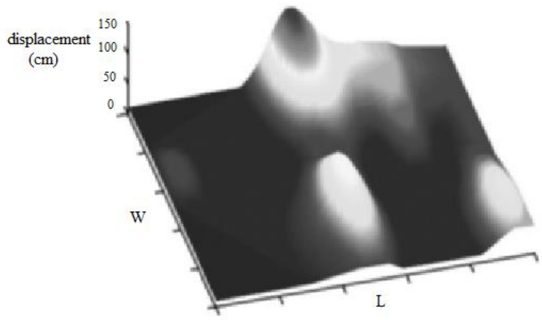

Figure 7. The non-uniform distribution of landslides on faults surface in the Bam earthquake [4]

2.2.5 The effect of the fault slope angle

The fault slope angle has a significant effect on the seismic response of the structures located in near regions of the fault. The effects of the slope angle of the fault are especially important for buildings with large length and width as well as for long bridges located in near area of the fault.

2.3 The investigation of near-fault earthquakes

The seismic waves are applied to the structures in far region of the fault in the form of numerous cycles. In other words, the energy of an earthquake is divided between different cycles of the seismic waves (according to the shape of its records).

In far area of the fault, the acceleration-time records are cyclic-shaped and in near area of the fault, the acceleration-time records are pulse-shaped. Near-fault earthquakes have records with fewer cycles and larger amplitudes than far-fault earthquakes.

2.4 The comparison of parameters of strong ground motions in near and far areas of the faults

Table (1) presents the values of parameters PGA and PGV for Chi-Chi, Kocaeli and Imperial Valley earthquakes. According to data of this table, it is clear that with increasing distance from the epicenter, rates of PGA does not change much, but rates of PGV significantly reduced. This issue indicates that among parameters PGA and PGV, only the parameter PGA is most important for the structures in far area of the fault, but both of them are very crucial for the structures in near region of the fault. It is necessary to mention that the same magnitudes were expressed for each earthquake. It is easy to understand that the magnitude parameter alone cannot be a suitable factor for selecting an earthquake for the seismic design of bridges and buildings.

3 THE PRESENTATION OF A FLOWCHART

The parameter PGA is only relevant to a specific moment and cannot be a suitable criterion for determining the intensity of the earthquake or its selection. Also, at the beginning and end of an acceleration-time record, there are usually times that motion of earth is so weak that can be ignored. The "duration" and "Average acceleration intensity" of strong ground motions have a significant effect on the seismic response of structures. With ignoring parameter PGA which only belongs to one moment and with ignoring times of a record which ground motions at those moments have no significant effect on the seismic response of the structures, the average acceleration intensity of strong ground motions (AGA) and their duration (T) are introduced as two very effective parameters in determining the seismic response of the structures. In the following, Tables (2) and (3) provide some the classifications of the average acceleration intensity of strong ground motions (AGA) and their duration (T). In order to the select of the earthquakes in different sites in far areas from faults, it is important to consider both factors AGA and T.

In addition to these two parameters, considering the characteristics of strong ground motions in near areas of the fault for structures located in this area are very vital. In the following, according to the flowchart provided, the appropriate accelerations can be selected according to the characteristics of the sites and the structures. Figure (8) provides a flowchart for selecting near and far-fault earthquakes for the seismic design of the structures based on defensible engineering judgments.

Table 1. Properties of selected near-fault and far-fault ground motion records [17]

Ground motion	Earthquake	Station	PGA (m/s^2)	PGV (m/s)	PGA/PGV	M_W	Distance to fault (km)
Near fault	Chi-Chi	TCU060	0.20g	36.3	0.18	7.6	9.50
Far fault	Chi-Chi	TCU060	0.20g	11.8	0.06	7.6	48.68
Near fault	Kokaeli	IZT180	0.15g	22.6	0.15	7.8	4.8
Far fault	Kokaeli	FAT090	0.16g	0.09	0.06	7.8	64.50
Near fault	Imperial Valley	H-BRA225	0.16g	35.9	0.22	6.9	8.50
Far fault	Imperial Valley	H-CMP285	0.15g	9.5	0.06	6.9	32.60

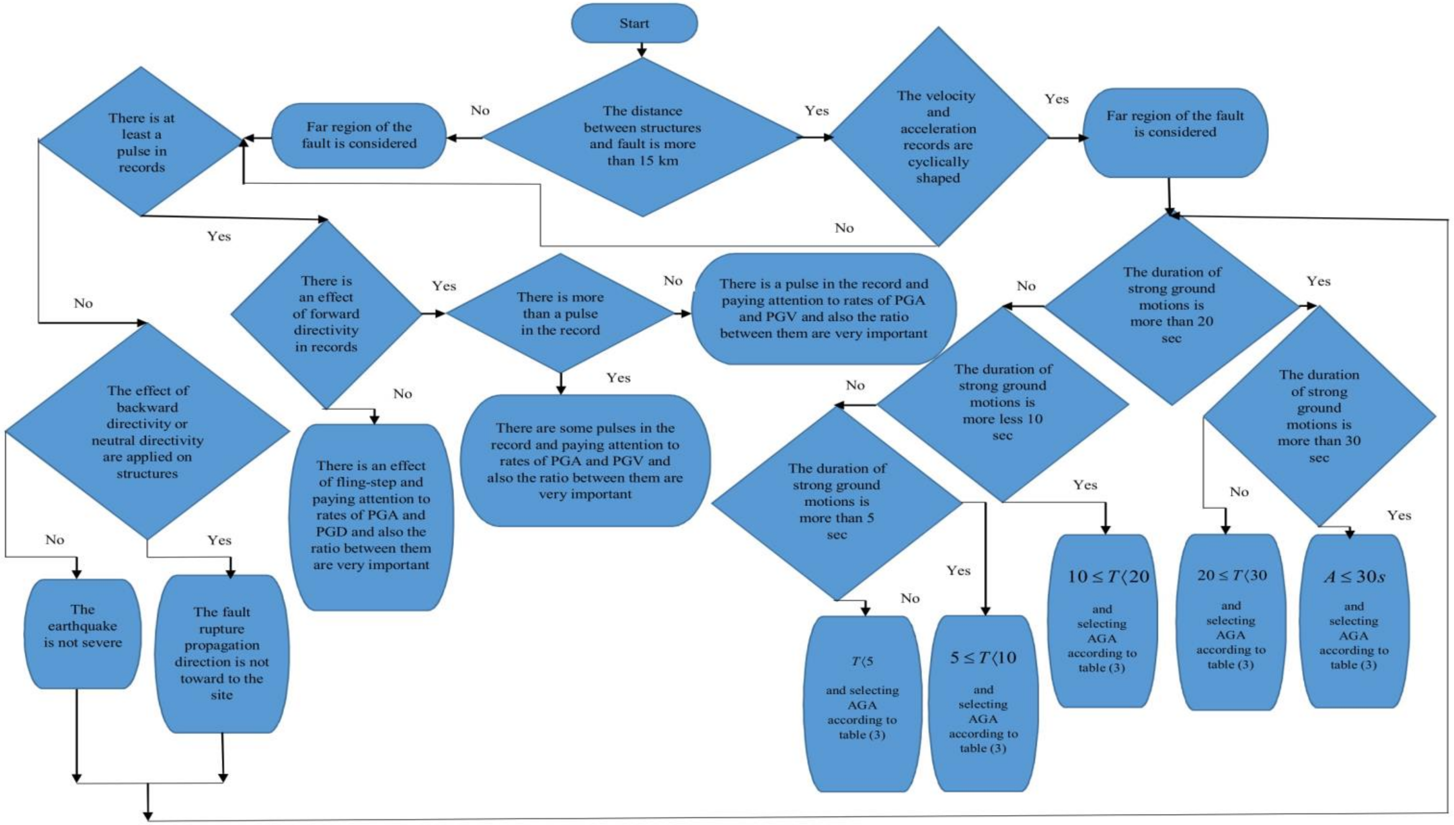

Figure 8. The presentation of a flowchart for selecting earthquake to the seismic design of the structure

Table 2. The introduction of the classifications of the intensity of strong ground motion

Class	**The intensity of strong ground motions**
Great	$0.4 \leq AGA$
Major	$0.35 \leq AGA \langle 0.4$
Strong	$0.30 \leq AGA \langle 0.35$
Moderate	$0.25 \leq AGA \langle 0.30$
Light	$0.20 \leq AGA \langle 0.25$
Minor	$0.20 \langle AGA$

Table 3. The introduction of the classifications of the duration of strong ground motion

Class	**The duration of strong ground motions**
Great	$30 \leq T$
Major	$20 \leq T \langle 30$
Strong	$10 \leq T \langle 20$
Moderate	$5 \leq T \langle 10$
Minor	$T \langle 5$

4 CONCLUSION

The results of the studies indicate that for selecting earthquakes to the realistic seismic design of structures according to the characteristics of the structure and its site, at first, based on a general and qualitative classifications according to the distances of the records from the epicenter, earthquakes were divided into two groups far and near-fault earthquakes based on distances greater and less than 15 km, respectively. Then are studied the characteristics of records and spectra.

For far-faults earthquakes that are applied to structures in form of an irregular cycle (These earthquakes are called cyclic-shaped), it is important to pay attention to the duration of strong ground motions and their intensity (Paying attention to T and AGA parameters).

To select earthquakes in the near area of the fault that are applied in form of an impact on the structures (these earthquakes are called pulse-shaped), it is important to pay attention to the maximum values of ground motion including PGA, PGV and PGD.

There are records with distances more than 15 km from the faults that pulse-shaped and should be applied to the structures like near-fault earthquakes.

There are records with a distance of less than 15 km from the faults that cyclic-shaped and should be applied to the structures like far-fault earthquakes.

It is very important to pay attention to the provided flowchart to identify the characteristics of earthquakes.

Using this flowchart can lead to the realistic seismic design of structures, it also prevents the scattering the estimated responses to a structure by multiple designers.

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