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A study of the earthquakes occurrence distribution in probabilistic seismic hazard analyses method (Case study: Zagros fault, Iran)

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ABSTRACT

Iran undergoes enormous financial and physical damages caused by the occurrence of multiple earthquakes and is among the countries with a very high possibility of earthquake hazard. For this purpose using methods with greater precision in order to control and reduce the damages caused by the earthquake is essential. One of the assessment methods is probabilistic seismic hazard analysis (PSHA); which in this method we have used the assumption of constant risk of earthquake along the fault whereas given the lack of equal energy in various parts of the earth, this assumption is contrary to fact. In this study we have tried to display the errors of this method using numerical programming method (MATLAB) by performing a case study on Zagros fault in Iran. Results suggest that the distribution of earthquake probability is different for each point of Zagros fault. And that the probability of seismic risk is low in some parts of the fault and significantly high in others.

1. Introduction

By the study of the past earthquakes in Iran and also the tectonic studies of the earth we can conclude that Iran is among the countries that have a very high risk of earthquake. Due to the exposure of Iran on the seismic belt and the presence of major and active faults all over it, controlling and reducing the seismic risk in different parts is essential. Seismic risk means the probable consequences of the earthquake risk which is equal to the increase in social and economic impacts and losses of earthquakes more than the value set for the available capital in one or more regions within a specified time (Ghafouri Ashtiani, 2000).

The definitive method of determining the probability of earthquakes is a conservative approach and is the basis of calculating the design levels of earthquakes and is rarely used in the seismic design of some special structures like dams and power plants. Over the past few decades, possibilities concepts and considering the uncertainty in measurement, location and the extent of seismic events and the changes in the characteristics of the earth movements, probability analysis of earthquakes for different time periods have been provided (Karimiparidari, 2007; Ram and Wang, 2013). Seismic hazards are examined in a definitive way when a certain earthquake is considered and in a probable way when the size, time and location of the earthquake are not conclusive (Naeim, 2001; Giorgio Iervolino, 2016). In the following both of these methods will be reviewed briefly and their shortcomings are noted. After that we'll review and evaluate the earthquakes occurred in the past few years along the Zagros fault and then obtained results are presented (Azarafza et al., 2014).

The presence of a fault can't represent the occurrence of an earthquake itself and the issue of fault activity in years is important and debatable. Although there is a general consensus that the term active fault indicates the hazard of earthquake and the term inactive fault indicates the impossibility of repeating the last earthquakes, but still there is no certain way to express how faults perform and different organizations all over the world presented different definitions about faults. For example, Cluff has suggested six groups of fault activity (and five subgroups) according to features like sliding velocity, slip in any incident,

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failure length, earthquake size and earthquake intervals (Cluff and Cluff, 1984). The historical calculations of the ground shaking effects may be used to emphasize on the occurrence of past earthquakes and estimate and the geographical distribution of their intensity. With enough information, we can determine the intensity of the earthquake and hereby estimate the epicenter and size of the earthquake. Although the accuracy of determining the location of the earthquake in this method depends heavily on the intensity and the repetition rate of the earthquakes, but a geographical pattern of historical earthquakes' epicenter can be a sign of the existence of zones of the earthquake source. Since earthquakes' historical records also include the time of the earthquake, we can also use them to estimate the repetition rate of earthquakes or seismicity in special areas (Krammer, 1996).

In most cases, to analyze the seismic risk, uniform distribution of the probability of an earthquake is assigned to each source which means that earthquakes with equal probability occur at any point in the source zone. In deterministic seismic hazard analysis method it is assumed that the probability of an earthquake in various locations of the nearest source to the study area is one and zero in other locations and in probabilistic seismic hazard analysis method we'll assume a uniform distribution for one source which is the fundamental weakness of this method and causes errors in seismic calculations, especially in studies related to important structures. In this article, we have provided the non-uniform distribution of the probability of an earthquake on Zagros fault in order to overcome the shortcomings of the previous methods and modify the uniformity assumption of the earthquake probability distribution. It is worth mentioning that for a given earthquake source, it is generally assumed that earthquakes will occur with equal probability at any location on the fault which means it should be possible to consider non-uniform distributions for future earthquake locations (Baker, 2013).

2. Material and Methods

2.1. Deterministic seismic hazard analysis

In the early years of seismic geotechnical engineering, the application of deterministic seismic hazard analysis (DSHA) has been common. A deterministic seismic hazard analysis method is related to the determination of the specific seismic scenario according to which the risk assessment of the motion of the earth is carried out. This scenario includes an estimate of earthquake with a certain size and a specific location. An example of deterministic seismic hazard analysis with a four-step method is expressed as follows (Reiter, 1990):

- Identification and characterization of all the earthquake sources in location that is able to produce strong ground motions. By identifying these sources we mean defining the geometry of earthquake source and its seismic capability,
- Selecting the parameter of the distance of the source to the specified location for each source zone, that in most cases of deterministic seismic hazard analysis methods we choose the closest distance between source zone and the location of the study,
- Choosing the reference earthquake (the earthquake that will produce the most severe vibrations) which is usually determined in terms of a number of ground motion parameters in location,
- Risk of earthquake in location is usually defined in terms of movements of the earth by the conductor earthquake. We usually use maximum acceleration, maximum speed and response rage to specify the risk of earthquake.

When the method is used for the evaluation of large structures (like nuclear power plants and giant dams), it provides a clear framework to search for the most sever motions of the ground, but doesn't give us any information about the possibility of the reference earthquake, the location of the occurrence, the expected vibration during a specified time (including the useful life of a building or particular facility) and finally the effect of uncertainty at various stages required for the calculation of specifications due to the movement of the earth and this is the fundamental shortcoming of this method that is partly resolved in probabilistic seismic hazard analysis methods.

2.2. Probabilistic seismic hazard analysis

During the past 20 to 30 years, using the concepts of probability has led to the consideration of uncertainty in size, location, the speed of earthquake repetition and also changing the specifications of earth movement by the magnitude and location of the earthquake explicitly in the evaluation of earthquake hazards. Probabilistic seismic hazard analysis (PSHA) offers a framework in which uncertainties are identified and are combined quantitatively and in a regular procedure in a way that draws a more complete picture of the earthquake. Understanding the concepts and structure of this method, requires familiarity with some terms and basic concepts of probability theory (Krammer, 1996). Here PSHA method is the same as the method determined by Cornell in many ways (Cornell, 1968). Furthermore, PSHA will be a four-step method which is somewhat similar to DSHA method at each stage of the process (Reiter, 1990).

The first step which includes the identification and specification of earthquake sources is similar to the first step in previous method, except that in this method we should also determine the probability distribution of failure potential position within the seismic source zone. In most cases, the uniform probability of earthquake distribution will be allocated to each source meaning that earthquakes occur with equal probability in each point inside the source zone. Then these extensions will be combined with the earthquake source geometry in order to achieve the probability distribution from the source to the location. On the other hand in DSHA we assume that the probability of an earthquake in various locations of the nearest source to the study area is one and in other areas it's equal to 0 while in PSHA we'll consider a uniform distribution for the source and this assumption is the shortcoming of this method and causes errors in seismic calculations specially in the study of important structures. In this article we have demonstrated this shortcoming (Mahbobi et al., 2012).

The next step will be the identification of seismicity or the temporal distribution of earthquakes repetition. At this stage in order to specify the seismicity of each source zone we have used a good replication relationship by which we'll determine the average speed that an earthquake with specific size may exceed.

In this step we must determine the motion of the earth in the study area by earthquakes that might occur within the source zone with any size and in any location, using predictive relations. In the last stage, we'll combine the uncertainties obtained including the size of the earthquake and the estimates of ground motion parameters, in order to obtain the probability that an earthquake with a certain size and a certain time interval might exceed.

Uncertainties relating to the earthquake site in the first step, uncertainties relating to the size and distance in the second step and the probability distribution of a specific event in the third step are all combined so that we can obtain the probability that a specific event like acceleration exceeds a certain value (Ang and Tang, 1975). All the stages above suggest that in order to analyze the earthquake risk in an area we need the history of the earthquakes occurred on a fault so that we can calculate the distribution related to different probabilities.

3. The origin of the study

Iran is one of the world's large countries that are neighbors with Armenia, Azerbaijan, Turkmenistan and the Caspian Sea from north, Turkey and Iraq from west and Persian Gulf and Gulf of Oman from south. This country is in the range of 25 degrees and 3 minutes to 39 degrees and 47 minutes north latitude and 44 degrees and 5 minutes to 63 degrees and 18 minutes eastern longitude. Iran is among the countries that have a relatively high risk in terms of the phenomenon of earthquake in most areas. Alp belt puts Iran among countries that are in danger of earthquake which has a considerable impact on society and the economy. Iran's plane is located between Turan's plane and Arabia's plane. Arabia's plane goes under Iran's plane 3 centimeters every year. This motion leads to Iran being a high-risk country in terms of seismicity. Bam earthquake that occurred in 1382 (2003) is an instance with 30000 deaths and 40000 injuries. For this purpose further and wider researches are necessary to reduce seismic risks in different parts of the country.

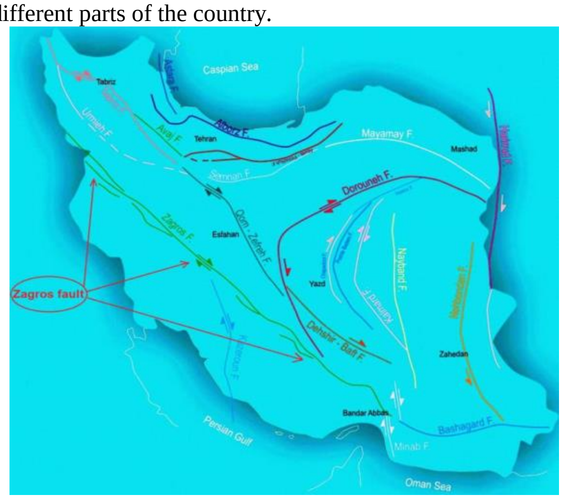

Figure 1. The map of major faults in Iran

The origin of the study in this article is Zagros fault that is known as the biggest and most important fault in Iran. In this study, the possible distribution of earthquake and the seismic risk of Zagros fault that passes through major cities of Iran will be reviewed and the results of this method are provided to express the probability distribution of earthquake risk. In the figure below Zagros fault zone is identified and shown. In Figure 1, the position of Iran's faults especially Zagros fault is displayed in green.

4. Results and discussions

As explained, in probabilistic seismic hazard analysis (PSHA), the probability distribution of all points are assumed with uniform distribution within the source zone, meaning that earthquakes will occur with equal probability at each point within the source zone and this is considered one of the disadvantages of this method. In this article for the probabilistic seismic hazard analysis (PSHA), the non-uniform distribution of earthquake is considered at any point within the seismic source. Meaning that considering the size and the number of earthquakes occurred within each fault, we can obtain the probability distribution function at that point. The basis of this method is the use of energy ratio released at each point in a certain zone around the fault to the total released energy of the fault in the long-term period. After determining the location and the circumstance and number and size of the earthquakes happened within the fault range, and after the classification of the fault, the number of earthquakes is determined due to their size per piece and according to the following equation, energy released at every point can be achieved (Gutenberg and Richter, 2016).

$$\log(E) = 11.8 + 1.5M \qquad (1)$$

where M is the magnitude of each earthquake and E is the amount of energy released. Eventually, the ratio of the function of the energy released at every piece to total energy of the parts (the entire fault) is obtained and is provided as the energy probability distribution function curve. Considering this non-uniform probability distribution function for Zagros fault, the calculations will be more accurate in the next steps of the probabilistic seismic hazard analysis (PSHA).

4.1. Main Zagros fault earthquakes distribution assessment

Zagros main thrust extends from north of Bandarabbas to Marivan area over 1350 kilometers. In Marivan the fault enters Iraq and from Sardasht enters Turkey. Zagros fault has a significant effect in the seismicity of Iran (Azarafza et al., 2014). This fault consists of two main and young parts that parallel to each other and sometimes these two faults join each other. The mechanism of main Zagros fault is thrust-pressure and its young fault is a reverse dextral fault.

In order to assess the distribution of the earthquake first we've identified the status and the location of main Zagros fault according to Figs. 2 and 3. This fault's equation is estimated by the following equation in which X and Y are latitude and longitude respectively. According to the distribution of the earthquakes occurred in the last 30 years in the area surrounding the fault, a suitable region is selected to do the calculations according to Fig. 4.

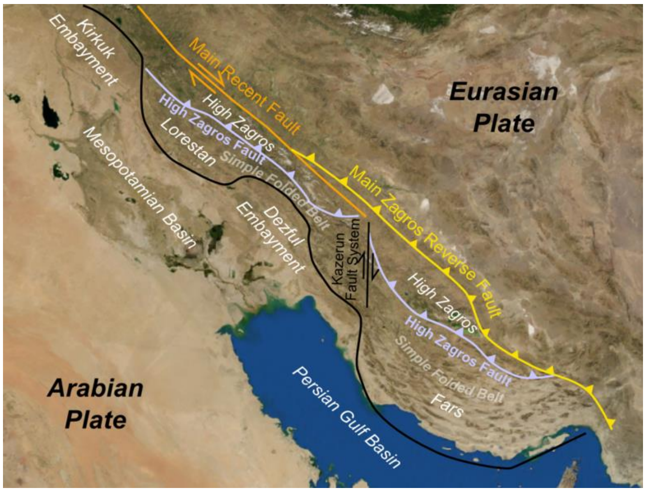

Figure 2. The position of main Zagros fault in Iran

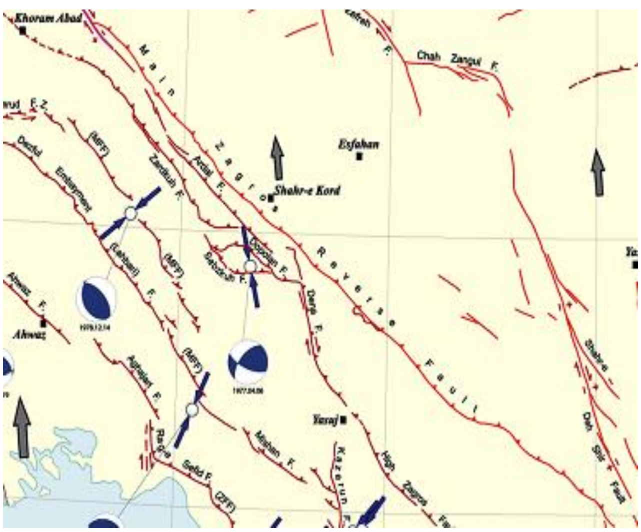

Figure 3. The position of main Zagros fault

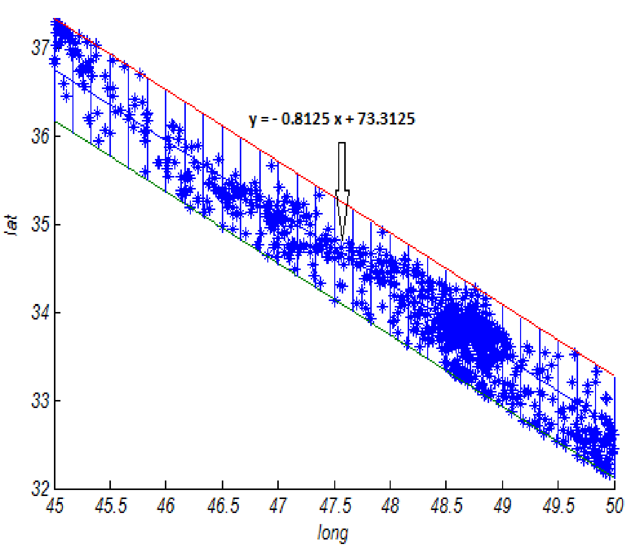

Figure 4. The distribution of the earthquakes occurred around the main Zagros fault

According to figure 4, the area under study is specified at a distance of 25 kilometers around each fault and the distribution of the earthquakes that occurred in this region in last 30 years is displayed. At the end, the energy probability distribution function of each part of the fault to its whole is presented considering the non-uniform distribution and based on the magnitude of each earthquake. As can be seen, earthquake distribution along the Zagros fault with a length of 1350 kilometers isn't the same and according to the results obtained in Figs. 3 and 2, Zagros fault in longitude of 48.5 to 49 has the highest energy probability distribution function and in other words has the highest seismic hazard (Figs. 5 and 6).

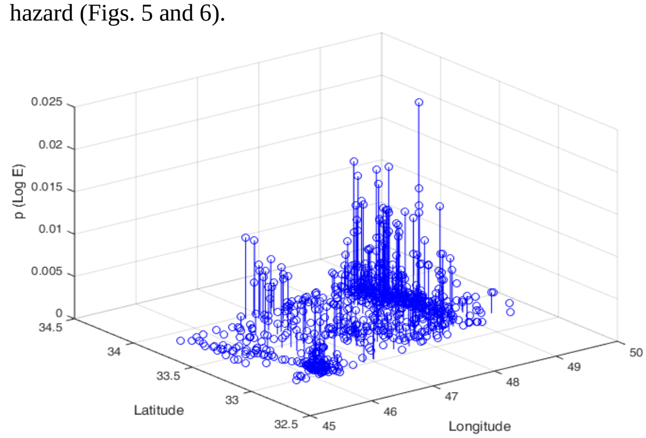

Figure 5. The three-dimensional display of energy probability distribution function for Zagros fault

4.2. High Zagros fault

In this section we'll study the high Zagros fault that according to the following figure is below the Zagros main fault and given that it's in the north of Shiraz and close to it. High Zagros fault is driven to south-west over some discrete parts. The penetration of Hormoz formation salts along various parts of high Zagros fault is indicative of its deep faulting (Berberian et al., 1984). In Figs. 7 and 8 you can see the status and location of the fault. The following earthquakes occurred due to high Zagros fault becoming operational (Gutenberg and Richter, 1956):

- Zor city earthquake on November 18th 1226 with the magnitude of M_w = 6.4 and intensity of VII=10,
- Zor city earthquake in 1310 with the magnitude of M_w = 5.3 and intensity of VII=10,
- Marvdasht earthquake in 1623with the magnitude of M_s > 5.5 and intensity of VII<10,
- Darian earthquake in 1865 with the magnitude of M_w = 5.9 and intensity of VII=10,
- Kharameh earthquake on February 26th, 1894 with the magnitude of M_w = 5.8 and intensity of VII=10,
- Hormozgan earthquake on November 6th, 1990 with the magnitude of M_s = 5.7.

Energy probability distribution function of each spot of the fault of the total, considering the non-uniform distribution and based on the magnitude of each earthquake is provided in Fig. 9. As can be seen, High Zagros fault along 51.3 to 51.45 degrees has the highest energy probability distribution function and in other words has the highest seismic hazard and in other spots, earthquake distribution is low and sometimes even ZERO.

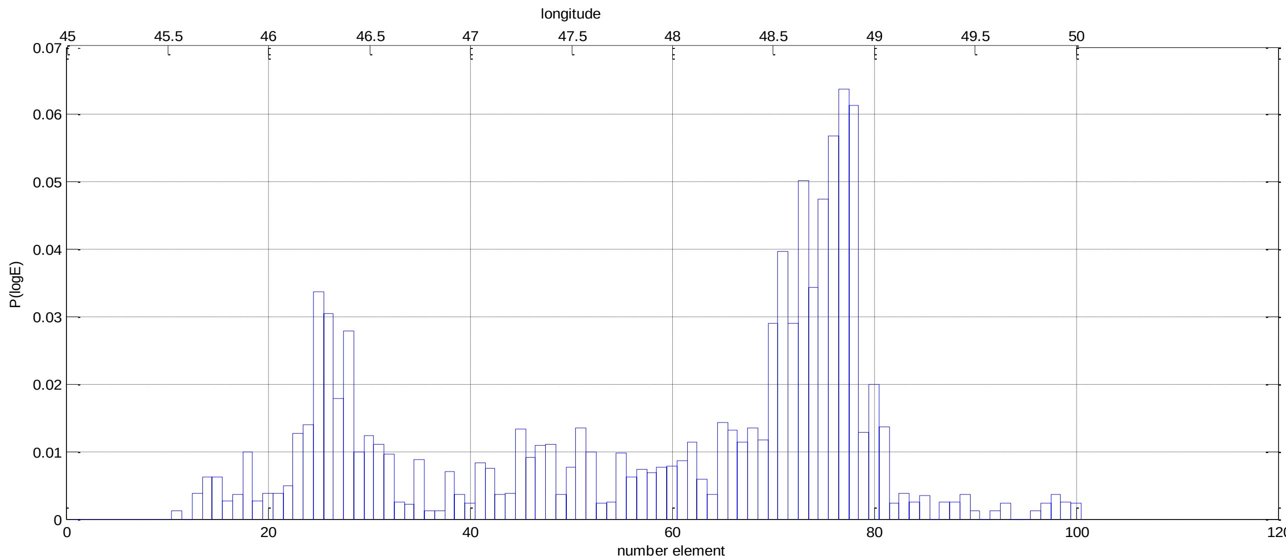

Figure 6. Energy probability distribution function graph for Zagros fault

Figure 7. High Zagros fault location

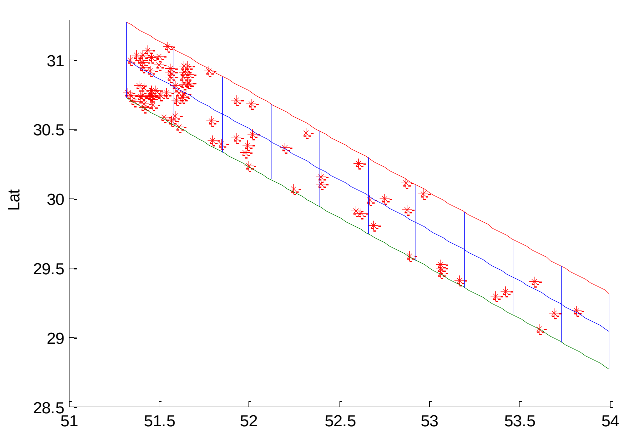

Figure 8. The distribution of the earthquakes occurred around the fault

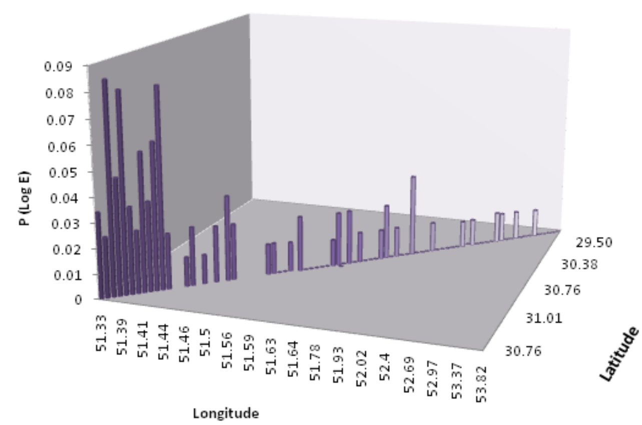

Figure 9. The three-dimensional display of energy probability distribution function for high Zagros fault

According to the information obtained from the history of earthquakes occurred around Zagros fault during the last thirty years, as you can see explicitly in Figs. 5, 6 and 9, the probability distribution of earthquake is non-uniform and in most parts the probability of earthquake is low and in some parts has the maximum value. This hasn't been included in the investigations performed by probabilistic seismic hazard analysis (PSHA) yet, that ultimately leads to error in calculations and the results of the analysis.

5. Conclusion

Based on the results obtained on main Zagros fault, while identifying the weaknesses of earthquake hazard probabilistic methods, we observed that the amount of energy probability function for each part of the fault to the whole is different. Considering the non-uniform distribution of Energy in main Zagros fault with a length of 1350 kilometers, the Earthquake distribution isn't the same and according to the results in longitude of 48.5 to 49 has the highest energy probability distribution function. Also, high Zagros fault along 51.3 to 51.45 degrees has the highest energy probability distribution function and in other spots, earthquake distribution is low and sometimes even zero. This indicates that in some parts of the fault, energy probability function and seismic risk to the whole is low and sometimes even zero, but in other parts is significantly high. Eventually with regard to the results obtained, it is suggested that in order to maximize accuracy and check the studied formations of the fault properly, instead of considering the earthquake hazard uniform probability distribution in all parts of the fault (according to PSHA), the distribution is applied non-uniformly for the analysis. So that we can obtain a more logical and consistent answer with the behavior of earthquakes in nature.

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