WHY WEREN'T SEISMIC HAZARD MAPS SUCCESSFUL IN PREDICTING NEXT EARTHQUAKE OCCURRENCES?

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ABSTRACT

Seismic hazard analysis is an efficient tool used to evaluate the potential seismic hazard in an area. Different seismic hazard maps propose various types of ground motion or intensity information to their users, however, after some recent destructive earthquakes, several questions were raised on the reliability of local, national and worldwide seismic hazard zoning maps. Experience of some destructive earthquakes such as the 2002 Bam (M_w=6.5), 1978 Tabas (M_w=7.4) and 2017 Ezgeleh (M_w=7.3) earthquakes indicates that in several cases, such hazard maps have clearly failed to predict the actual hazards. Such events indicate the importance of the accuracy of the input datasets, uncertainty treatments, and the level of the knowledge about seismic source parameters in the study regions (e.g. fault geometry and mechanics, return periods of large and destructive earthquakes, maximum magnitude, seismicity rates, etc). In this study, some challenges ahead of the seismic hazard studies and the necessity to revise the hazard maps are investigated.

Keywords: *Seismic Hazard; Earthquake Prediction; Seismic Map; Iran.*

1. INTRODUCTION

Earthquake hazard analysis for seismically active regions is an efficient effort for the earthquake resistant design of civil structures. In this respect, it is essential to have the fullest possible understanding of earthquake hazard by preparing detailed seismic zoning maps in terms of intensity, peak ground motion parameters, spectral accelerations and etc.

Iran is considered as one of the most seismically active regions in the world. This region experiences different earthquake magnitudes each year, some of them may reach M_w8 (e.g. 27 November 1945 M_w8.1 Makran earthquake). During the last century, many destructive earthquakes with magnitude≥7.0 have occurred in this country such as the 1909 Silakhor (M_w.7.3), 1930 Salmas (M_w.7.1), 1962 Bou'in-Zahra (M_w.7.1), 1968 Dasht-e-Bayaz (M_w.7.4), 1978 Tabas (M_w.7.4), 1990 Manjil (M_w.7.4),1997 Ghaen (M_w.7.3), 2003 Bam (M_w.6.6), 2013 Savaran (M_w.7.8) and 2017 Ezgeleh (M_w.7.3) earthquakes. Considering the active tectonic situation with the existence of major faults associated with large earthquakes, it is necessary to analyze the seismic hazard and revise the zoning maps continuously. Therefore, seismic hazard analysis and estimation for the constructions of human structures has become an enforcement for which several research studies as well as seismic codes have been determined.

During the last for decades (from the mid-1970s until 2017), many researchers have attempted to provide seismic hazard maps for Iran using different data, parameters and methods. The first coherent efforts are related to the works concentrated on the 'intensity' assessment as the hazard parameter (e.g. Neghabat and Liu, 1977; Berberian and Mohajer-Ashjai, 1977; Mohajer-Ashjai and Nowroozi, 1978;

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Berberian, 1981). Then, Since 1982, researchers started to calculate the probable ground motion parameters especially peak ground acceleration (PGA) and spectral acceleration (SA) using the PSHA method (Bozorgnia and Mohajer-Ashjai, 1982; Nowroozi and Ahmadi, 1986; Tavakoli and Ghafory-Ashtiany, 1999; Moinfar et al., 2002; Mäntyniemi et al., 2007; Gholipour et al., 2008; Iranian seismic code for buildings, 4th edition in 2012; Zaré, 2012; Hamzehloo et al., 2012; EMME project, 2014; Mousavi-Bafrouei et al., 2014; and Karimiparidari et al, 2014 (Fig. 1). Despite the many different seismic hazard studies, there is still a need to prepare and revise hazard maps because some of them clearly fail to predict some significant large earthquakes. In this respect, it is tried to explain some of the events in Iran that have challenged such hazard maps.

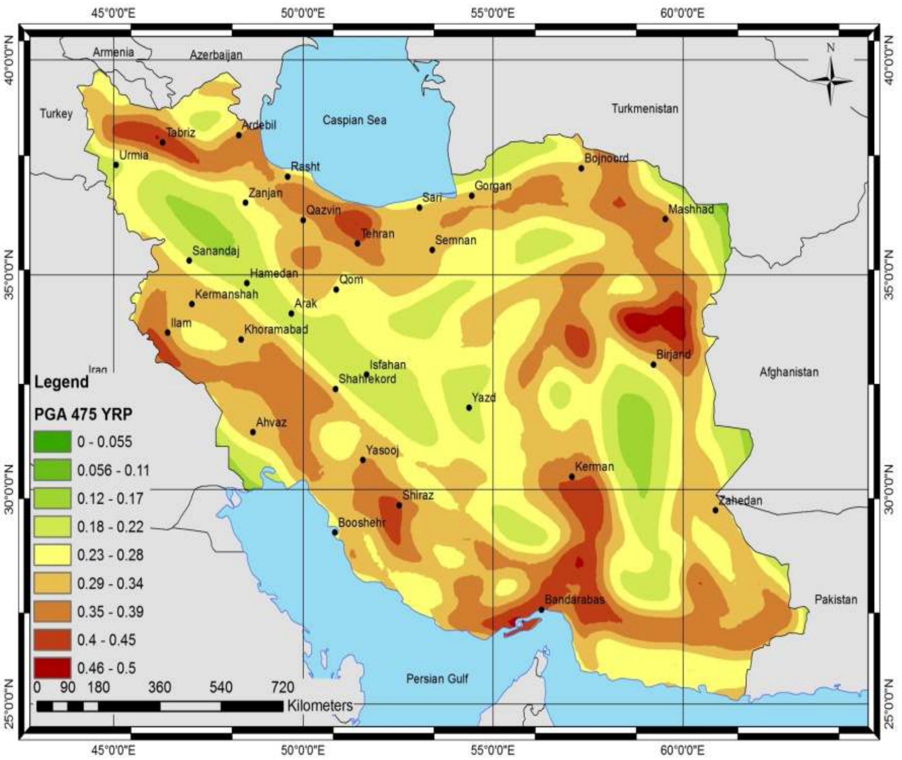

Figure 1. Seismic hazard zoning map of Iran in terms of PGA_{475} by Karimiparidari et al., 2014

2. CASE EXAMPLES

Scientific model's predictions should be continuously validated by observations. After some earthquake (such as the 1978 M_w7.4 Tabas earthquake, 2003 M_w6.5 Bam earthquake and 2017 Ezgeleh earthquake), several questions have been raised on the reliability of the seismic hazard zoning maps and on the comparison between the recorded and previously assessed ground motions.

A number of factors by which errors may appear in seismic hazard maps have been mentioned by Stein et al (2012) including bad physics, bad assumptions, bad data and bad luck. Although there are fairly good recorded historic and instrumental data in Iran and good researches on some critical active faults of the Iranian Plateau (e.g. studies on paleoseismic, GPS and seismicity rate of North-Tehran, North Tabriz and Mosha faults; Ritz et al., 2012), more investigation such as paleoseismic investigation and evaluation of seismic capacity of other active faults as well as identification of blind faults are still a matter of concern. There are still ongoing challenges in hazard analysis such as the detailed evaluation of M_{max} and seismic potential and gaps of seismic sources, soil effects and etc. Here, some of the most important seismic events in Iran are explained for which the hazard assessments failed to predict the real situation.

The first example of such incorrectly predicted situation was the September 16, 1978, M_w7.4

Tabas earthquake in which about 15,000 people were killed. A big challenge related to this earthquake was that, before the earthquake, the causative fault which could generate such a great catastrophic event, was unknown. Therefore, the earthquake ruptured the unmapped and unknown Tabas foothill-front reverse fault at the western Neogene foothills of the Shotori Mountains (Berberian, 2014) (Fig. 2). Such example draws our attention to the importance of the accuracy of the input dataset and the level of knowledge of the seismic source parameters in the study regions (fault geometry and mechanics, return periods of large and destructive earthquakes, etc).

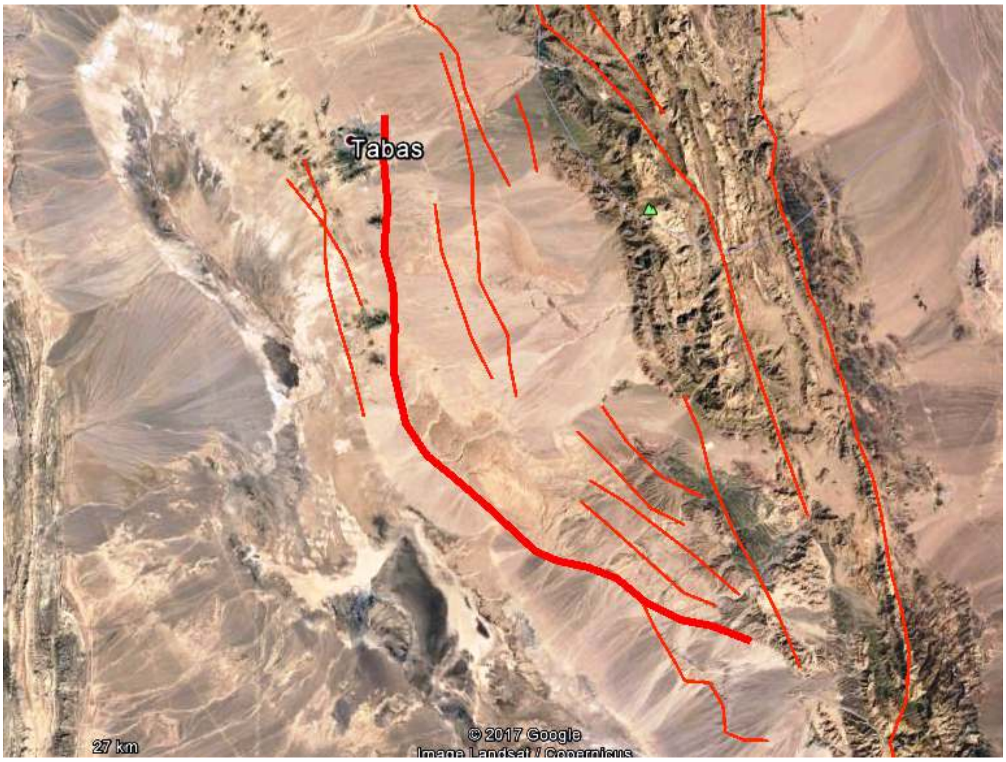

Figure 2. Tabas fault (thick red line) which was unmapped and unknown before the 1978, M_w7.4 earthquake.

Another important example that can be mentioned as a challenge is the December 26, 2003 (M_w6.5) Bam earthquake, indicating the failure of the Iranian seismic hazard zoning map. Before the 2003 Bam earthquake, the region was classified as a zone with an average hazard in the seismic hazard zoning map of Iran in the Iranian building code (Standard No. 2800). On the other hand, based on the available data in historic and modern seismic catalog as well as with respect to stability the Arg-e Bam castle (the largest adobe building in the world located in the city of Bam) for more than 2,500 years, no major earthquake and no significant seismicity trend were determined before the 2003 earthquake. Therefore, it seems that the 2003 Bam earthquake has ended a seismic gap along the Bam fault (Fig. 3). In addition, the strong motion record obtained in the Bam station shows the greatest PGA of 0.8g and 0.7g for the east-west horizontal and north-south horizontal components, respectively, and 0.98g for the vertical component (all non-corrected values). The preliminary observations on the strong motion record obtained in the Bam station, as well as the observed damages in the region shows a vertical directivity effect. This expected effect can be assigned to the Bam earthquake fault rupture, while a strong fault-normal (east-west) motion was created during the mainshock as well. The demolished walls and building of Bam are representative for such effects in the up-down (vertical) (Fig. 4) and east-west directions (fault-normal). The Bam residents that survived the quake explained to the reconnaissance team members that they felt strong up-down displacements during the mainshock (Eshghi and Zare 2003).

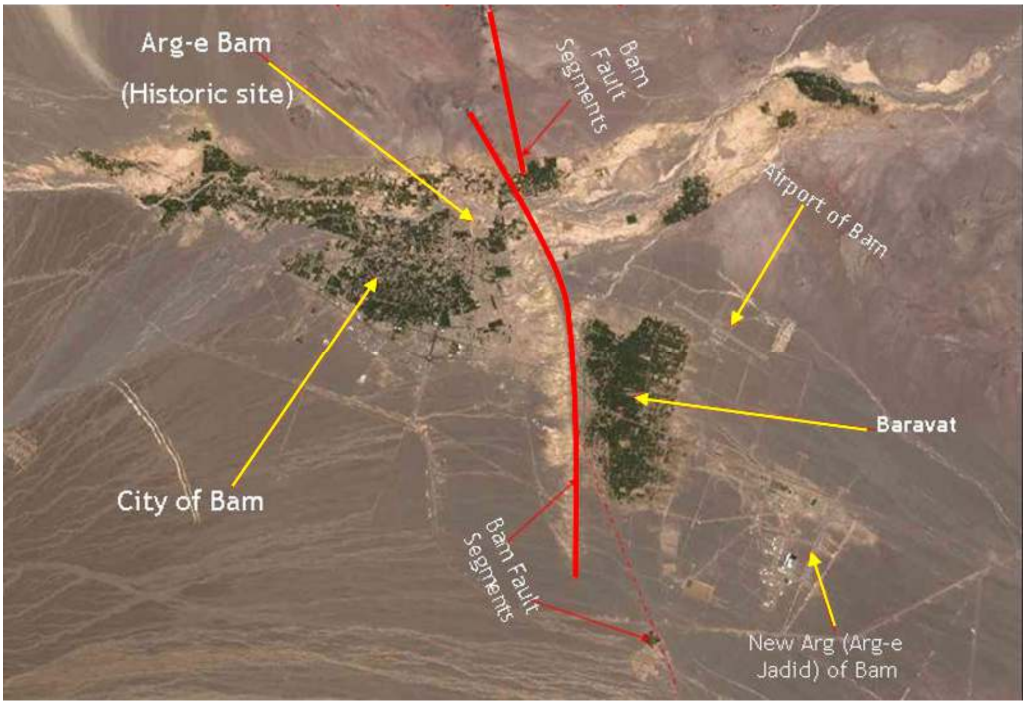

Figure 3. Bam fault in the vicinity of the city of Bam and Arg-e Bam

Figure 4. Collapse of the first floor of a building due to the vertical directivity effect in 2003 Bam earthquake.

The latest challenging example refers to the recent M_w7.3 earthquake in Iran which occurred in Ezgeleh-Sarepole Zahab, Kermanshah region on November 12, 2017. The focal mechanism solutions for this earthquake indicate a fault dipping shallowly to the east-northeast, or on a fault dipping steeply to the southwest. Based on the active fault map of Iran, this earthquake seems to be triggered by the movement of the Zagros Mountain Front Fault (MFF) in Pol-e-Zahab Region (Fig. 5). Despite the records of some large earthquakes in the Zagros Mountains, events with magnitude more than 7 are known to be rare in this region. This area has the highest rate of seismicity in the Iranian Plateau and its frequent seismic events with small to intermediate magnitudes release the energy of deformation within the crust. According to the seismic history and hazard models, it was rarely thought that such a big event with magnitude 7.3 could occur along the folded Zagros in the border of folding and foothill. It should be noted that the strong motion of the November 12, 2017, M_w7.3 mainshock was recorded by 98 stations of the Iran Strong Motion Network (ISMN). Among these records, the highest value corresponds to the Sarepol-e Zahab station with an uncorrected PGA of about 684 cm/s^2 which exceeds the estimated value in the latest seismic hazard maps. Based on the preliminary assessments, the maximum intensities and most of the destructions were also reported in the Sarepol-e Zahab (Fig. 6) and Qasr-e- Shirin cities of Kermanshah Province in Iran. Therefore, the 2017 Ezgeleh showed that we have to revise long return periods in our hazard models and we also need to determine the model validity and seismic hazard uncertainties.

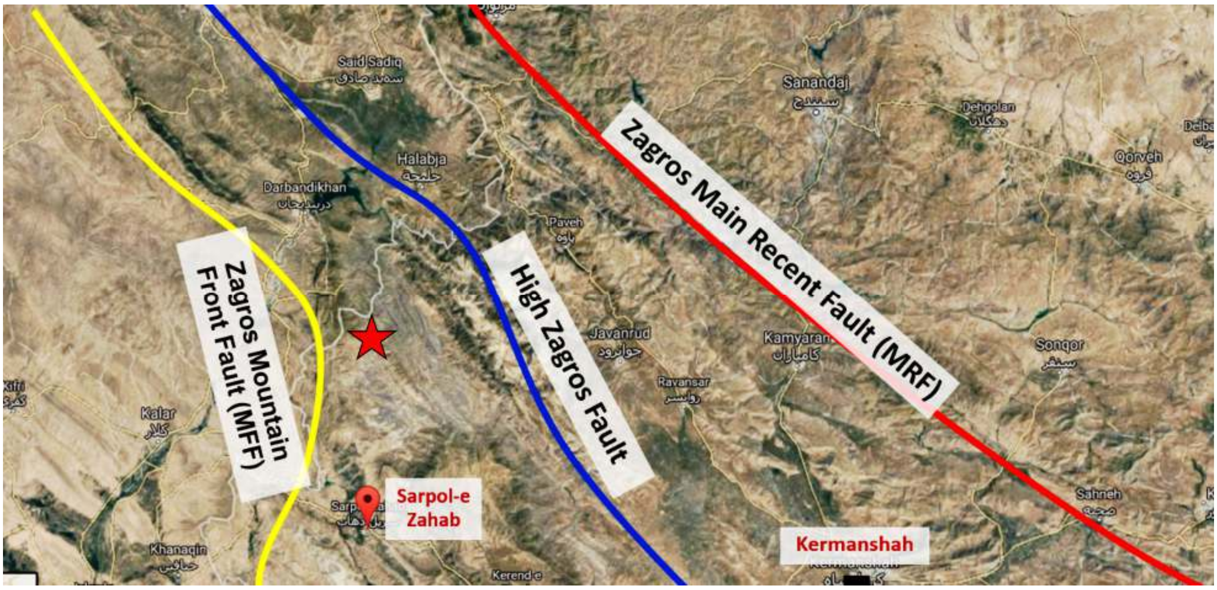

Figure 5. Location of different faults in the Zagros Mountains near the affected area of the 2017 M_w7.3 earthquake (red star).

Figure 6. Collapsed buildings in Sarpol-e Zahab city

3. DISCUSSION AND CONCLUSIONS

As noted, several hazard maps have been developed during the last four decades based on the development of seismic source parameters (e.g. fault geometry and mechanics, return periods of large and destructive earthquakes, paleoseismology data, archaeological information, etc.) and accuracy of seismicity datasets and computational methodologies. However, after some earthquakes in Iran (such as the 1978 M_w7.4 Tabas, 2003 M_w6.5 Bam, 2017 Ezgeleh earthquakes and etc), some discussions have been raised about the reliability of the different existing seismic hazard zoning maps and a comparison between the recorded and previously assessed ground motions. In general, the failure in prediction originates from the uncertainties in data, physical hypothesis, calculation methods or even interpretation. Thus, in case of lack of complete knowledge about different hazard parameters (e.g. long return periods of earthquakes, unknown characteristic of seismic sources, etc), different levels of error are unavoidable.

Although in case of lack of complete knowledge about different hazard parameters (e.g. long return periods of earthquakes, unknown characteristic of seismic sources, etc), different levels of error are unavoidable, it should be also taken into account that many of the seismic hazard maps have been prepared for a special return period on the bedrock and just for ordinary buildings, which do not consider special conditions like site effects, near-field effects (e.g. forward and backward directivity, fling step, pulse-like motions) as well as special structures. Therefore, the difference between the predicted hazard levels with actual hazard levels emphasizes on the necessity of revision and evaluation of the efficiency of the previous hazard maps in order to determine that to what extent these maps are acceptable or to what extent they may contain large errors? In should be also noted that, in seismic hazard assessments, it is a common practice to consider the ‘ground shaking’ which includes the calculation of strong motion at the bedrock level or at the ground surface based on site effects, while the ‘ground deformation’ in terms of secondary earthquake-induced phenomena (e.g., landslides, subsidence, liquefaction, etc.) can also be included as an important factor in the future seismic hazard analysis to improve the results.

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