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Research Article

A PRELIMINARY STUDY FOR SEISMIC HAZARD ASSESSMENT OF THE ANAR FAULT OF CENTRAL IRANIAN PLATEAU THROUGH DETERMINISTIC APPROACH

***Mohammad Yousef Mahmoodi[1], *Ahmad Nourbakhsh[2], Shoja Ansari[3] and Sara Rokni[4]**
[1]*Department of Civil Engineering, Larestan Branch, Islamic Azad University, Laresta, Iran*
[2]*Department of Earth Sciences, College of Sciences, Shiraz University, Shiraz, Iran,*
[3]*Geological Survey of Iran, Tehran*
[4]*Department of Earth Sciences, College of Sciences, Shiraz University, Shiraz, Iran*
**Author for Correspondence*

ABSTRACT
We investigate the seismic hazard assessment imposed by the Anar fault to the surrounding areas. The Anar fault is a strike-slip fault that disrupts the morphology and the structure of the Central Iranian Plateau. Based on the previous studies this fault approaching to the end of its seismic cycle and the surrounding populated cities could be under the threat of a destructive earthquake in the near future. We have calculated the horizontal and vertical components of the acceleration due to the activation of the Anar fault. Estimation of horizontal and vertical components of acceleration from the seismic sources that may produce a certain magnitude is critical for design of structures to resist earthquakes. Based upon calibrated relations for the earthquakes of the Iranian Plateau the Ms equals to 7.8, Mo equals to 9.21*1027 dyne-cm and Mw equal to 7.3 are expected for the future probable earthquake. Also, The Peak Ground Horizontal (PGH) acceleration of 1347 cm/s^2, 1665 cm/s^2, 2058 cm/s^2 and 2545 cm/s^2 for hard rocks, hard rocks and thin layer of soft-top soil, gravel and sandy soils and soft soils are expected, respectively. For the Peak Ground Vertical (PGV) accelerations the results show 621 cm/s^2, 688 cm/s^2, 763 cm/s^2, and 846 cm/s^2 for hard rocks, hard rocks and thin layer of soft-top soil, gravel and sandy soils and soft soils, respectively. We believe that the nearest areas along the strike of the Anar fault will experience the intensity of 10 in the future earthquakes if the entire of the fault could move.

Keywords: *Peak Ground Acceleration, Attenuation of Earthquake Intensity, Seismic Hazard, Anar Fault, Central Iranian Plateau*

INTRODUCTION
Refineries, ports, factories, power stations, bridges, roads, hospitals, schools, universities and many others facilities can be made safer by estimating the probable accelerations at their sites and retrofit the facilities to be safe at higher acceleration. In addition, acceleration attenuation relations may be used in calculations for seismic mitigation, and deterministic and probabilistic approaches to seismic risk and hazard analysis (Nowroozi, 2005).
Seismic hazard analysis requires an assessment of the future earthquake potential in a region. It is, therefore, necessary to estimate the maximum earthquake magnitude that might be generated by a particular active fault. The most common uses of more detailed geologic data have been to constrain maximum earthquake magnitude using empirical relationships between fault length, earthquake rupture dimension and magnitude (Tavakoli and Ghafory-Ashtiany, 1999).
Iran has the high degree of seismic activity. Estimation of horizontal and vertical components of acceleration from the seismic sources that may produce a certain magnitude is critical for design of structures to resist earthquakes. Acceleration attenuation relations for a given magnitude are essential for construction of safe houses and other public edifices, complex industrial structures that are essential for economical well-being of the nation. In addition, acceleration attenuation relations may be used in calculations for seismic mitigation, and deterministic and probabilistic approaches to seismic risk and hazard analysis (Monalisa *et al.,* 2004; Nowroozi, 2005; Ganapathy, 2010; Panza *et al.,* 2011; Shukla and Choudhury, 2012).

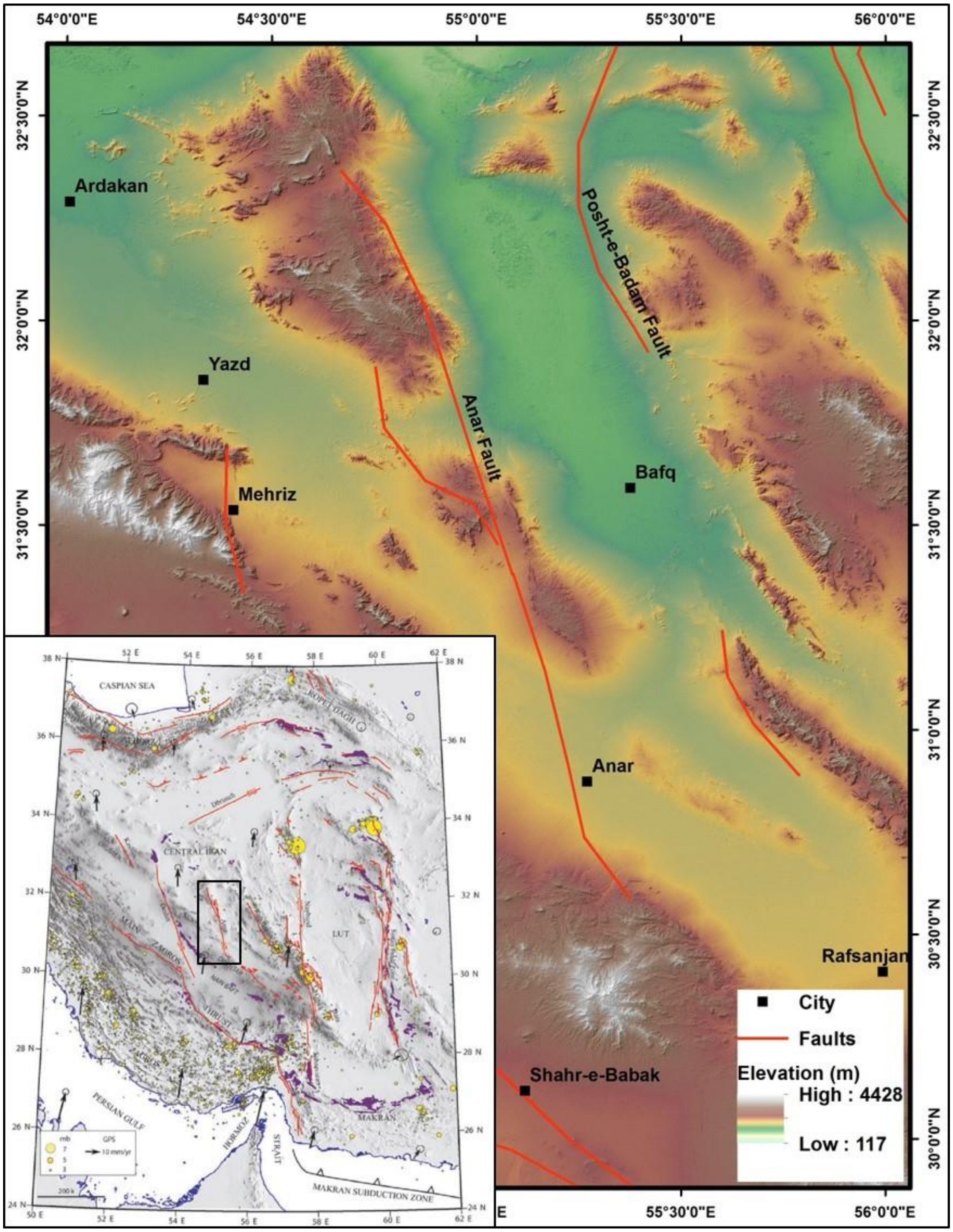

Figure 1: Location of Anar Fault in the Iranian plateau

The palaeoseismic study performed on the Anar fault (Figure 1) shows that this right-lateral fault hosted large earthquakes during the Holocene or possibly Uppermost Pleistocene for the older one. The preferred age of the more recent event suggests that the fault is approaching the end of its seismic cycle and the surrounding populated cities could be under the threat of a destructive earthquake in the near future (Foroutan *et al.*, 2012). Nearly 820,000 peoples live within populated cities (e.g. Yazd capital city with more than 500,000 populations) that are located around the Anar faults with less than 100km distance (Table 1).

Table 1: Name of the cities that are located around the Anar Fault with less than 100km distance. The population data provided by the Statistical Center of Iran: http://www.amar.org.ir/Default.aspx?tabid=133

Name of the city	Population	Approximate distance from the Anar fault (km)
Anar	13089	3
Bafq	33882	35
Yazd	486152	55
Mehriz	28483	60
Shahr-r-Babak	45265	60
Rafsanjan	151420	65
Ardakan	56776	70

In this work an attempt has been undertaken to predict the probable high acceleration components and attenuation of intensities for a future earthquake due to the Anar fault in the Central Iranian Plateau. In this area due to low seismicity during the last few decades, seismic data is scanty, specific seismic studies are not available and ground motion measurements are not at all available, and the deterministic study is more useful to assess the hazard in the event of occurrence of seismic activity by the Anar Fault.

Geological Setting

The Central Iranian Plateau is a wide region experiencing low GPS deformation rates and is commonly described as a rigid block (e.g., Jackson and McKenzie, 1984; Vernant *et al.*, 2004). This region appears aseismic during the last few millennium based on instrumental and historical seismic records. Nevertheless, it is sliced by several strike-slip faults that are hundreds kilometers-long. These faults display along-strike, horizontal offsets of intermittent gullies that suggest the occurrence of earthquakes in the Holocene (Foroutan *et al.*, 2012).

The Anar fault zone is a strike-slip fault involving two distinctive portions that disrupt the morphology and the structure of the Central Iranian Plateau that is parallel to the Dehshir fault to the east. The Anar fault is a 200-km-long strike-slip fault with minimum slip rate of 0.8±0.1mm/yr (Meyer and Le-Dortz, 2007; Foroutan *et al.*, 2012) located within the Central Iranian Plateau between 30.6°N–55.3°E and 32.3°N–54.8°E, north of the Zagros. It is the shortest of a series of northerly trending, right-lateral fault system slicing Central and Eastern Iran. The northern portion is located within the mountains with several closely spaced splays cutting across the relief of the Kuh-e-Kharanaq range. The splays merge southward extending into a single fault trace. The southern fault strand runs along the Kuh-e-Bafq range over a 20-km-long distance, and cuts right across the western piedmont of the range and across the Anar Salt flat. Further south, the fault bends eastwards, to reactivate a thrust fault to the north of the Urumieh Dokhtar magmatic arc. The total dextral offset is outlined by the displacement on the order of 20–30 km of a Lower Cretaceous sandstone unit (Walker and Jackson, 2004; Meyer and Le Dortz, 2007; Le-Dortz *et al.*, 2009).

The Anar fault is likely to be active from its trace in Quaternary alluvium (Berberian, 1976; Walker and Jackson, 2004). The southern end of the Anar fault and the western end of the Rafsanjan fault are linked through the mountains by a narrow linear valley, which follows a geological. It appears likely that the two faults link together across this geological fault. However, it is difficult to determine whether the fault within the mountains is active in the Quaternary as no Quaternary sediments are present (Walker, 2006).

The Anar fault current slip rate is evaluated 1.2 ± 1.3 mm/yr of right-lateral slip on the fault and 1.3 ± 1.0 mm/yr of shortening across its strike. The lateral slip rate might rather be in the range 1.2–2.7 mm/yr (hence 2.0 ± 0.7 mm/yr) and both lateral and across-strike slip rates increase from south to north (Walpersdorf *et al.*, 2014). Over geological times, the Anar fault is taken to have slipped laterally by a minimum of 30 km over the last 20 and more likely 12 Ma (Walker and Jackson, 2004; Meyer and Le Dortz, 2007). From the measurement and dating of offset stream risers, a minimum Holocene slip rate of 0.8 mm/yr is inferred at one central site of the fault (Le Dortz *et al.*, 2009). The long-term and Holocene slip rates on the Anar fault might thus range between 0.8 and 1.5 mm/yr.

The palaeoseismic study performed on the 200km-long, NS striking Anar fault shows that this right-lateral fault hosted three large (M≈7) earthquakes during the Holocene or possibly Uppermost Pleistocene for the older one. These three seismic events are recorded within a sedimentary succession, which is not older than 15ka, suggesting an average recurrence of at most 5ka. The three earthquakes have occurred within following time intervals: 4.4±0.8ka, 6.8±1ka and 9.8±2ka. The preferred age of the more recent event, ranging between 360yrs and 5200yrs, suggests that the fault is approaching the end of its seismic cycle and the surrounding populated cities could be under the threat of a destructive earthquake in the near future (Foroutan *et al.*, 2012).

MATERIALS AND METHODS

Method

By definition, seismic hazard describes a natural phenomenon associated with an earthquake, such as ground shaking, fault rupture, tsunami, liquefaction rockfall, landslide, etc. It is generally quantified by three parameters: (a) the level of severity expressed by intensity I, magnitude M, and peak ground acceleration and (b) spatial (occurrence site) and (c) temporal (occurrence frequency) characteristics (Mourabit *et al.*, 2014).

Seismic hazard analysis is the description and/or the evaluation of the effects of a possible future earthquake on human activities, is the research area in seismology which has the strongest impact on society. The deterministic approaches are transparent, their input and output parameters are easy to understand. Also, the deterministic output is very useful in the definition of various hazard scenarios (Orozova and Suhadolc, 1999).

A deterministic hazard study should firstly identify the reference earthquakes that will be expected to affect a particular area in the future, and then apply a reliable seismological model to predict the ground motion. The estimated ground motion in the selected area is called a deterministic scenario (Reiter, 1990; Ameri *et al.*, 2008). For seismic design and retrofits, deterministic scenarios are useful if they have been derived from magnitude and distance deaggregation (McGuire, 1995; Bazzuro and Cornell, 1999). Deterministic scenarios may also be useful to check worst-case events, e.g. the largest magnitude at the closest distance. Insurance/reinsurance decisions are likewise highly quantitative and deserve analyses that consider all possible events. These decisions also benefit from identification of a `maximum foreseeable loss', which is a deterministic event defined by some criterion as the worst possible. If the system is a lifeline that crosses an active fault, a deterministic approach would be appropriate that examines the effect on the system of fault movement (McGuire, 2001).

The deterministic approach basically requires the determination of the maximum magnitude of a causative fault or seismotectonic zone. Then, an empirical relationship regarding the unelastic attenuation of seismic energy with respect to the distance from the energy source is employed. Once the maximum magnitudes that each fault zone can generate are determined through the empirical relationship, the next step is the selection of an appropriate attenuation equation of strong ground motion (Panza *et al.*, 1999; Radulian *et al.*, 2000; Kayabali and Akin, 2003; references therein; Naik and Choudhury, 2015).

In the deterministic seismic hazard analysis, the source causing the highest hazard at any location is considered to be the causative source that gives a maximum ‘‘threat’’ for that particular location One of the basic elements in assessing seismic hazards is to recognize seismic sources that could affect the particular location at which the hazard is being evaluated. Defining and understanding seismotectonic sources are the major part of a seismic hazard analysis and requires knowledge of the regional and local geology, seismicity and tectonics (Tavakoli and Ghafory-Ashtiany, 1999; Naik and Choudhury, 2015).

The potential earthquake source is the 200km-long NS striking Anar fault. An approximate magnitude and seismic moment of this earthquake could have been estimated prior to the event. Nowroozi (1985) developed empirical relations between fault length, L, seismic moment, Mo, and the surface wave magnitude Ms. These equations are

$$M_S = 1.259 + (1.244 * \operatorname{Log} L), \quad (1)$$

and

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$\text{Log } M_0 = 14.354 + (1.733 * M_S)$, (2)
Where L is in meters and Mo is in dyne-cm.
For Iranian earthquakes Nowroozi (2005) and Nowroozi (2010) reported on relations between Ms Magnitude and fault length, L, in meters. By transferring those equations to Mw it follows:
$M_W = 2.7887 + (0.858 * \text{LogL})$, (3)
and
$M_W = (0.69 * M_s) + 1.92$, (4)
Where the results of the two relations are similar.
The probability of earthquake ground accelerations is complex, often experts' opinions on source areas, seismotectonic provinces, thus magnitude frequency relation, appropriate attenuation of ground accelerations, upper bound magnitude, site conditions and method of calculations may differ (Reiter, 1990; McGuire, 1993; Nowroozi, 2010).

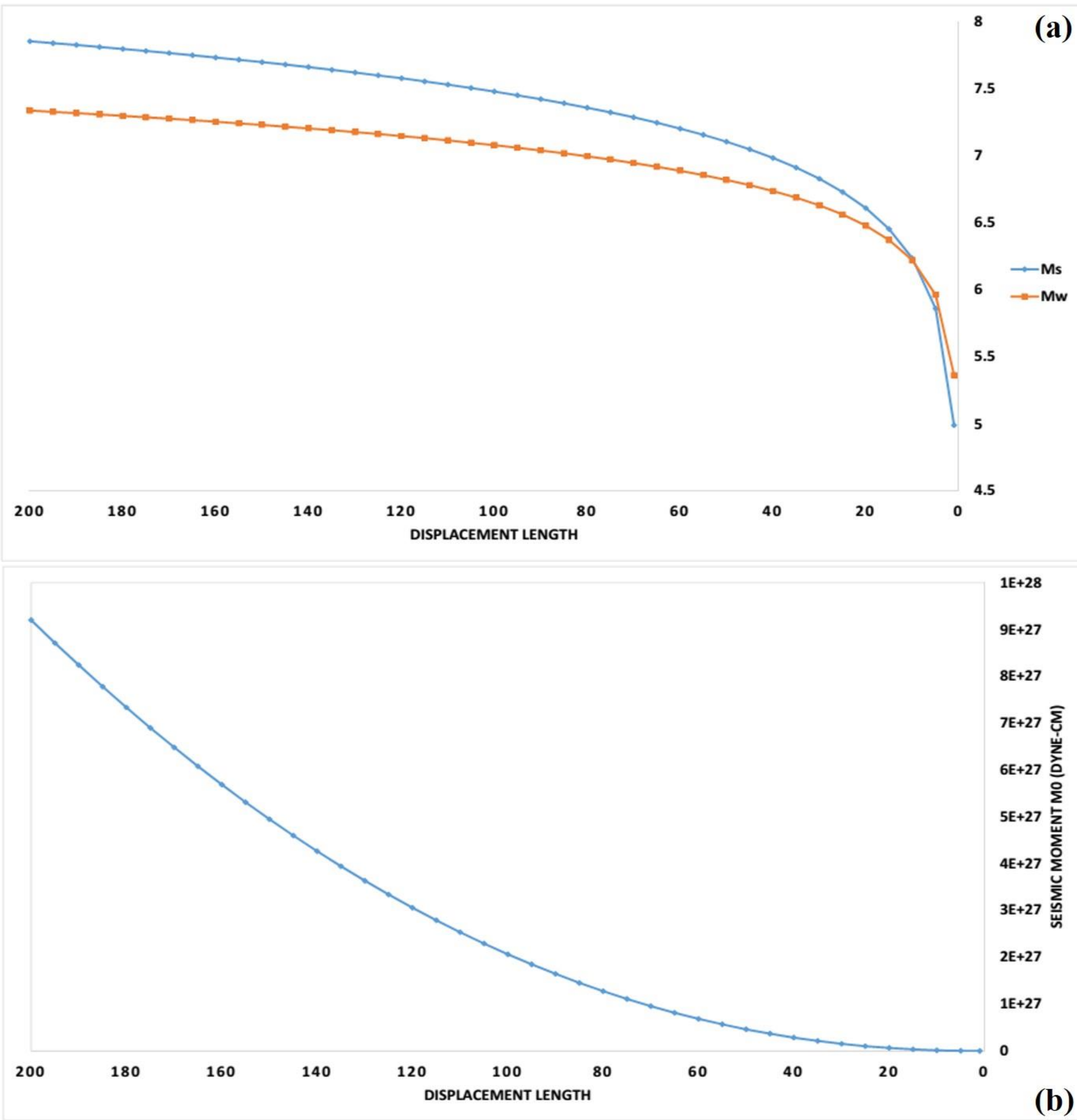

Figure 2: Decrease of Ms,Mw and Mo with decreasing in displacement length of the fault during an earthquake

Two empirical relationships presented by Nowroozi (2010) for the assessment of PGH and PGV based on the Iranian accelerometers data bank that are calibrated for the Iranian Plateau. Those are

$$\mathrm{Ln(PGH)} = 8.283 + [1.255 * (\mathrm{M_W} - 6)] - \left[1.142 * \left(\mathrm{Ln}\sqrt{\mathrm{EPD}^2 + \mathrm{h}^2}\right)\right] + (0.414 * \mathrm{S}), \quad (5)$$

And

$$\mathrm{Ln(PGV)} = 7.416 + \left(1.231 * (\mathrm{M_W} - 6)\right) - \left[1.101 * \left(\mathrm{Ln}\sqrt{\mathrm{EPD}^2 + \mathrm{h}^2}\right)\right] + (0.214 * \mathrm{S}), \quad (6)$$

Where parameter S can assume value 1 for hard rock, 2 for hard rock and thin layer of soft-top soil, 3 for gravel and sandy soil and 4 for soft soil. In above equations PGH, PGV are peak ground horizontal and vertical accelerations in cm/s2, Mw, EPD and h are moment magnitudes, epicentral distances in km and focal depth in km respectively.

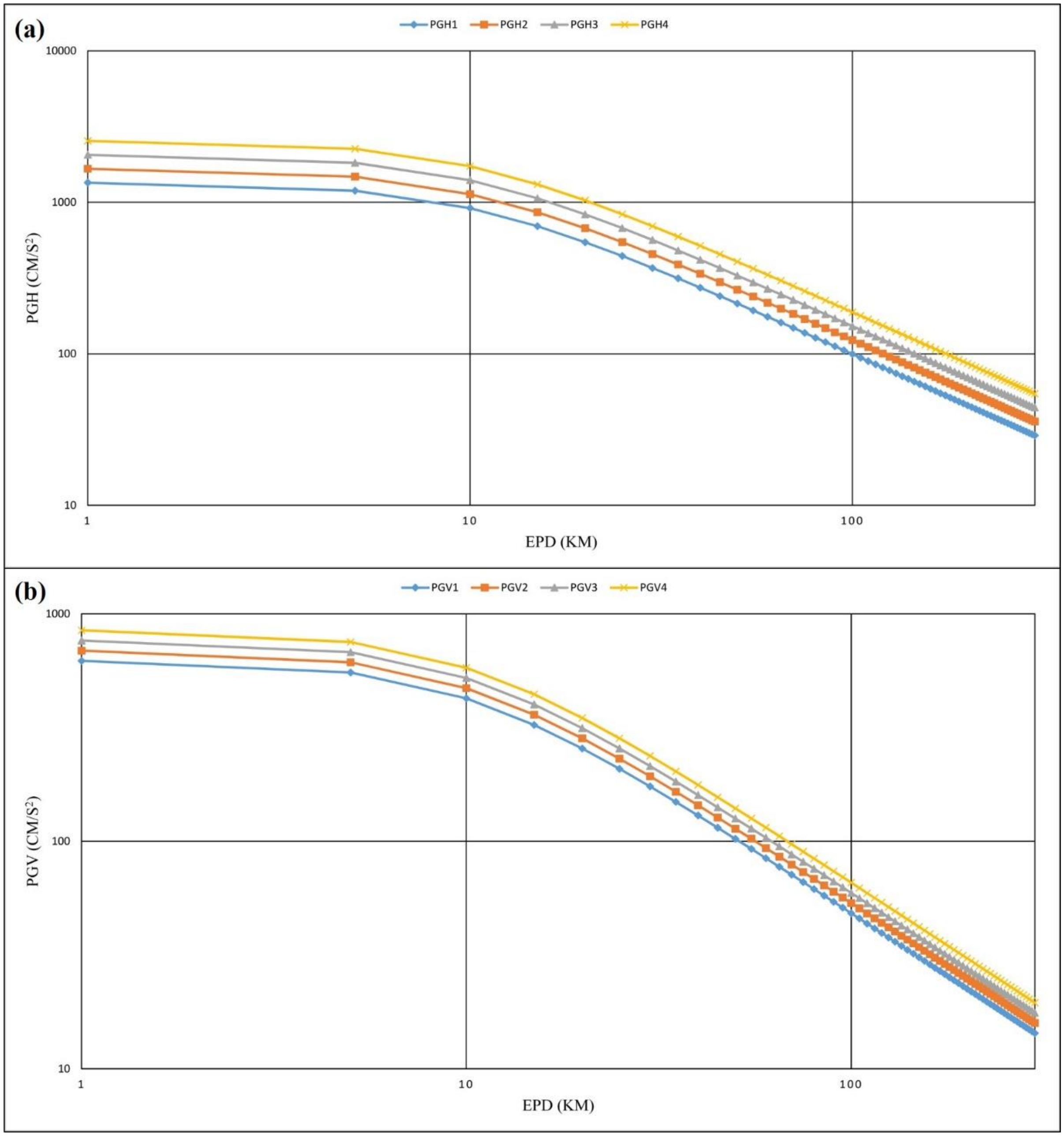

Figure 3: Decrease of PGH (peak ground horizontal acceleration) and PGV (peak ground vertical acceleration with decreasing in EPD (epcentral distance)

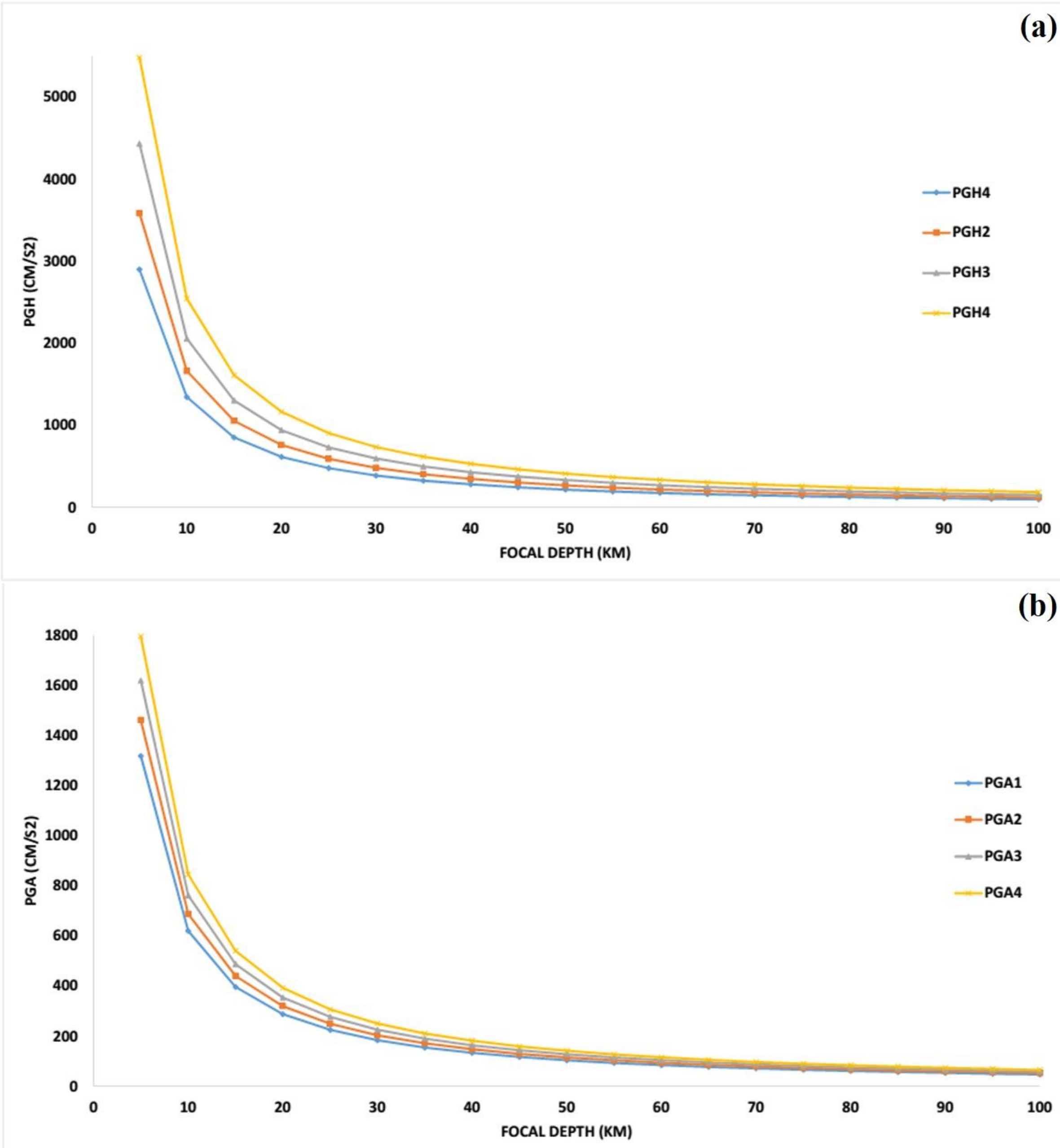

Figure 4: Maximum expectable PGH and PGV with increasing of earthquake focal depth (the epicentral distance is considered as 1 Km)

Number 1-4 are related to hard rock, thin layer of soft-top soil, gravel and sandy soil, soft soil

Three relationships for attenuation of intensities in Iran presented by Siahkali *et al.*, (2004) for the main direction of fault, transverse to it and average attenuation were derived. These are along the main direction of fault,

$I_a = 11.564 + (0.943 * M_S) - [2.508 * Ln(R_a + 33)] \quad R_a < 200km,$ (7)

Transverse to the main direction of fault,

$I_b = 9.469 + (0.717 * M_S) - [2.121 * Ln(R_b + 13)] \quad R_b < 140km,$ (8)

And average attenuation

$I = 11.926 + (0.831 * M_S) - [2.7 * Ln(R + 22)] \quad R < 167km,$ (9).

Where Ms is the surface wave magnitude and I is the intensity at a distance R (km) from the epicenter.

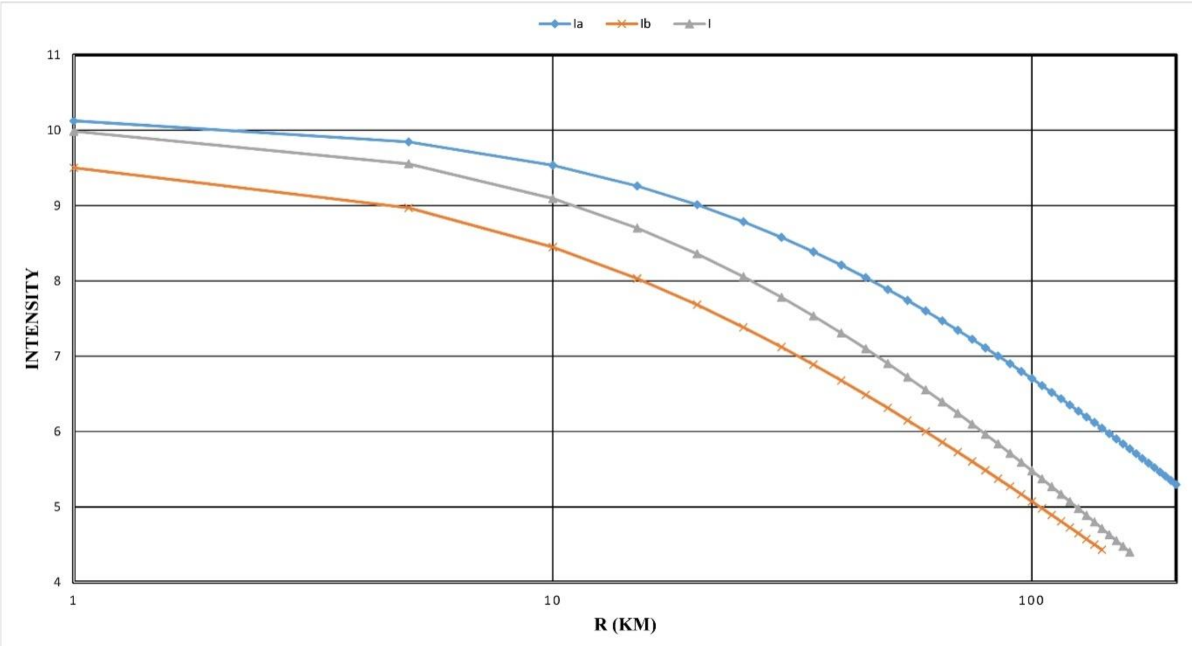

Figure 5: Attenuation of Intensities related to R (distances from the epicenter)

I_a is for along the fault, I_b is for transverse to the main direction of fault
I is average intensity

RESULTS AND DISCUSSION

This study presents ground accelerations for maximum probable magnitude and a range of epicentral distances and site conditions, because priority of all parameters are unknown and estimations are not for a particular site. Calibrated empirical relations of Iranian plateau (Nowroozi, 1985, 2005, 2010; Siahkali Moradi *et al.*, 2004) have been used in this study for estimation the maximum magnitude and ground accelerations due to future earthquake of the Anar fault.

Equations 1 to 4 yield Ms Equals to 7.8, Mo equals to 9.21*10^{27} dyne-cm and Mw equal to 7.3, respectively. These results are predicted if the entire fault length activates during an earthquake, thus, it is the maximum capability of this fault. It is believed that any critical structures that are near the Anar fault ought to be designed for this potential magnitude. However, often only a portion of a strike-slip fault is activated. So, in this work two diagrams are presented that they represent the decrease of Ms, Mw and Mowith decrease in displacement length of the fault during an earthquake (Figure 2). For the equations of (5) and (6) the variables of EPD and h are considered between 1-300 km and 10 km as suggested by Nowroozi (2005) for the strike-slip faults of the Iranian Plateau, respectively (Figure 3). Although, two diagrams are presented that show decrease in the maximum expectable PGH and PGV (the epicentral distance is considered as 1km) with increasing of earthquake focal depth (Figure 4). Also for the equations of (7), (8), and (9) attenuation of intensities plotted on the diagrams that are presented in Figure (5).

The result of calculations based on the above presented relations show that we can expect maximum PGH accelerations of 1347 cm/s^2, 1665 cm/s^2, 2058 cm/s^2 and 2545 cm/s^2 for hard rocks, hard rocks and thin layer of soft-top soil, gravel and sandy soils and soft soils, respectively. Also, for the PGV accelerations the results show 621 cm/s^2, 688 cm/s^2, 763 cm/s^2, and 846 cm/s^2 for hard rocks, hard rocks and thin layer of soft-top soil, gravel and sandy soils and soft soils, respectively. These accelerations are the maximum expectable values along the fault and they will decrease by increasing the distance from the fault. So that, at 300km far from the fault we can expect the PGH accelerations of 29 cm/s^2, 36 cm/s^2, 44 cm/s^2 and 55 cm/s^2 for hard rocks, hard rocks and thin layer of soft-top soil, gravel and sandy soils and soft soils, respectively. This scenario for the PGV accelerations at 300km far from the fault are 14 cm/s^2, 16 cm/s^2, 18 cm/s^2 and 19 cm/s^2 for hard rocks, hard rocks and thin layer of soft-top soil, gravel and sandy soils and soft soils, respectively. The intensity relations show that if the total length of the Anar fault moves during an earthquake the nearest areas to the fault will experience intensities of 10.1 along the main direction of fault, 9.5 transverse to the main direction of fault and 9.98 as an average intensity. The attenuation of intensities based on the presented relations caused to experience of 5.3 at 200 km far from the main direction of the fault, 4.4 at 140km far from the transverse direction of the fault and 4.4 at 167km far from the fault as an average value.

Conclusion

Proper determination of the peak horizontal ground acceleration for designing the earthquake-resistant structures in countries on major seismic belts like Iran bears paramount importance. The almost total absence of strong motion data and the time required for their collection around the Anar Fault lead us to carry out the potential seismic hazard analysis following a deterministic approach. In this area due to low seismicity, seismic data is scanty, specific seismic studies are not available and ground motion measurements are not at all available, and the deterministic study is more useful to assess the hazard in the event of occurrence of seismic activity by the Anar Fault. The present preliminary seismic hazard analysis helps in deciding the location of important and critical structures and other structures as well. The structures can be appropriately planned in less hazard locations if options are available which will reduce the vulnerability and the risk and also ease out the economic burden by reducing costs. The existing structures around the Anar Fault facing a threat can be rehabilitated and upgraded to reduce their seismic risk.

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