An attenuation equation based on Hormozgan province (Southern Iran) strong motion data

M. Kavei[1,2], S.D. Gore[3], N.J. Pawar[4], K. Ahmadi[3], P. Malekzadeh[3]

Abstract

This manuscript presents an attenuation relationship of peak ground acceleration (PGA) derived from Hormozgan strong motion data for hard rock, soft rock, soil and soft soil sites and an acceleration map of Hormozgan province (Southern Iran) on this data. For this purpose 370 records in Hormozgan Province (Southern Iran) between 1973 and July 2007 are selected. The database is compiled for earthquakes having body wave magnitude (M_b) and PGA values ranging between 3 and 7, and 5 and 748 gal respectively, and distances to epicenter are between 2 and 279 Km. From the regression analysis of the data, an attenuation equation for PGA, considering hard rock, soft rock, soil and soft soil conditions is developed. In this study, We have suggested an equation for prediction of PGA values. In addition, an equation between body wave magnitude and surface wave magnitude (M_s) and also a relationship between faults rupture length and surface wave magnitude of Hormozgan Province data is developed.

Keywords*: Attenuation relationship; Peak ground acceleration; Strong motion database; Hormozgan province*

[1] Department of Physics, Hormozgan University, Bandarabbas, Iran
2. Department of Environmental Sciences, Pune University, Pune, India(Email: kavei2562000@yahoo.com)
3. Department of Statistics, Pune University, Pune, India
4. Department of Geology, Pune University, Pune, India

1. Introduction

In seismic hazard analyses the quantitative description of the ground motions are very important. One of the ground motion parameters commonly used in geotechnical and structural engineering analyses is peak ground acceleration (PGA). Therefore, estimation of this parameter in a precise manner has a prime importance in engineering design. Major initiatives to instrument seismically active regions around the world were undertaken in the twentieth century, and these instruments have provided a large inventory of recordings. Data from this inventory are used to develop empirical strong motion attenuation relationships to estimate earthquake ground motions based on some characteristics of the earthquakes and local geology. PGA is the simplest strong-motion parameter and hence more than 120 attenuation equations have been derived in the past to predict it (Douglas, 2003, 2004). However, these equations were derived for different earthquake regions and fault types, and interplate versus intraplate. In addition, their data selection criteria are different, and some of them pertain to only a single ground type such as rock or firm soil. As a result of their nature, differences among the estimated PGA values from the existing attenuation relationships from one region or country to another result in a limitation in their use. Therefore, the use of attenuation relationships derived from the records of a region, where the predictive equations are considered, shows an increasing tendency between the associated engineering communities.

In Iran, the seismic hazard zonation map was published by the Building and Housing research center (BHRC, 2005). Based on this map, Iran is divided into four subclasses of seismic zone: high risk, risk, moderate and low risk for zones ranging from I to IV, respectively.

The seismic hazard in Iran has been expressed using different seismic quantities such as the macroseismic intensity (Berberian and Mohajer-Ashjai 1977; Mohajer-Ashjai and Nowroozi 1978; Berberian 1981; Ahmadi and Nowroozi 1981) and peak ground acceleration (Bozorgnia and Mohajer-Ashjai 1982; Nowroozi and Ahmadi 1986; Tavakoli and Ghafory-Ashtiany 1999; Moinfar et al. 2000, Khademi 2002 and Campbell et al. 2003). In this study, an attempt was made to derive an attenuation equation of PGA for hard rock, soft rock, soil and soft soil in Hormozgan Province. The data base, employed in this study included the records from the earthquakes M>= 3 between 1973 and July 2007. Among all the peak ground acceleration records, 370 records were selected for regression analysis, and effects of the site conditions were also considered. From the regression analysis of data, the equation to predict PGA for the sites underlain by hard rock, soft rock, soil and soft soil were established. The PGA values estimated from the equation developed in this study and those from some previous domestic attenuation equations and some imported models based on worldwide data were compared. In addition, using the proposed attenuation equation and considering the epicenters of the earthquakes and the known active faults of Hormozgan province, PGA values were calculated.

2. Data selection criteria and database

The Iran Strong Motion Network, which its accelerographs installed in different cities and villages throughout the country and run by BHRC (Building and Housing Research Center), is started its activity since 1973. This network first consisted of Kinemetrics SMA-1 analog instruments (1975-1989) and is complemented by numerous of SSA-2 digital instruments after the Manjil earthquake of 1990. By the end of 2003, the number of the instrument was reported to be 1100 stations. Fig. 1 represents the location of Iran. Location of the accelerometer sites in Hormozgan province corresponding to the data selected in this

study are shown in Fig. 2. The stations are mainly installed within cities or villages for safety, easy maintenance and faster data retrieval. Exclusion of records based on minimum PGA has been proposed as selection criteria and they are reviewed by Douglas (2003). In this study, we have used from 370 records belong to Hormozgan province and also, the acceleograms with a PGA>= 5 gal were selected considering the criterion by Campbell (1981) to avoid bias in trigger threshold.

These records were logged by Building and Housing Research Center, that available in BHRC's website (BHRC, 2005). Based on the database for a total of 370 events in Hormozgan province occurred between 1973 and July 2007, the numbers of the magnitudes given by BHRC in M_b and M_s Scales are 370 and 72, respectively. In other words, M_s Values are not available for all events. So using data sets of 72 between M_b and M_s, the relationship and conversion equation derived between M_b and M_s are given in Fig. 3. This relationship yielded considerably high correlation coefficients greater than 0.9 by 370 M_b versus 72 M_s magnitudes in this study
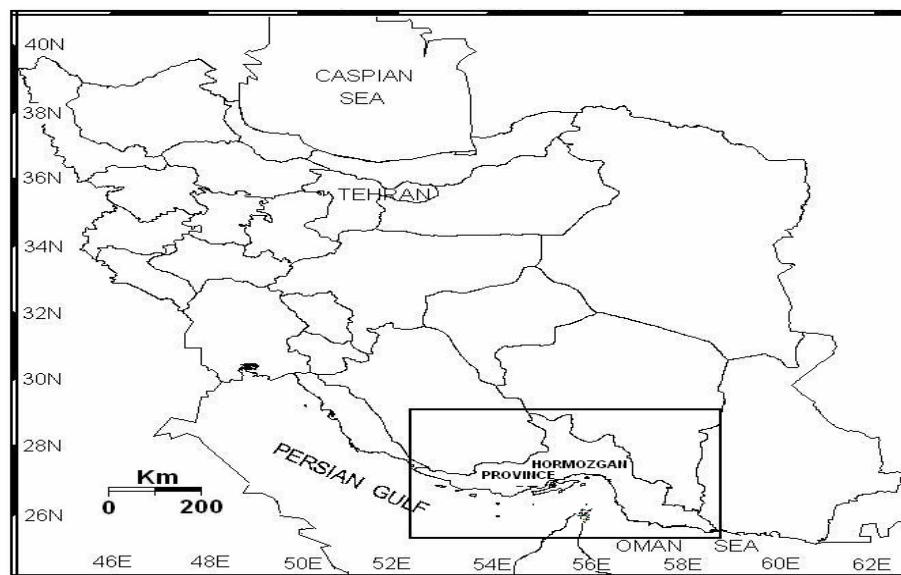

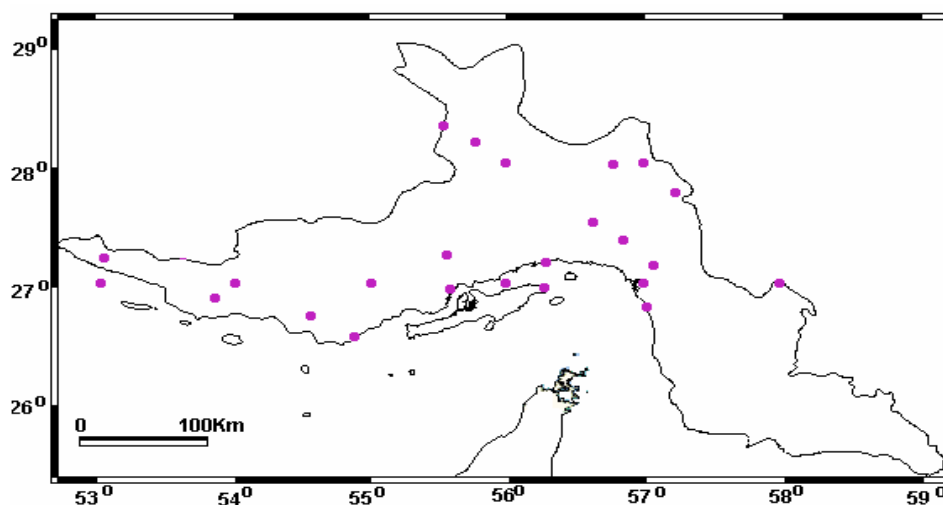Fig. 1. Map of Iran and location of Hormozgan province, Southern part of Iran.

Fig. 2. The locations of the strong ground motions stations of Hormozgan Province employed in this study.

In addition the correlation between the reported M_b and M_s Values for Hormozgan province shows that this equation (Eq. 1 and Fig. 3) can compare with equation 2 for Zagros region by Mirzaei et al. (1997):

$$M_b = 1.94 + 0.678M_s \quad 3.0 \le M_b \le 7.0 \quad (1)$$

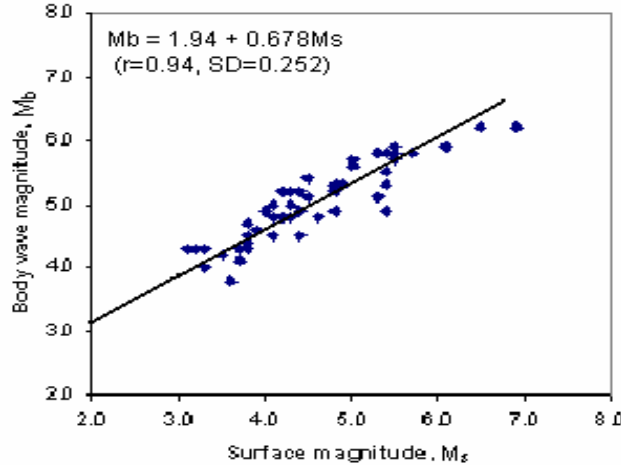$$M_b = 2.41 + 0.558M_s \quad 4.0 \le M_b \le 6.2 \quad (2)$$

Fig. 3. Correlation between the reported M_b and M_s values for Hormozgan province earthquakes(r: correlation coefficient; S.D.: standard deviation)

The distance to epicenter is the easiest measure to use because the epicenter is the location information given for all earthquakes. For small earthquakes, the use of distance to epicenter in hazard analysis is reasonably straightforward because easily available catalogues of previous epicenters can be used as the future sources or if line or surface source zones are used then epicenters can be distributed on these source zones (Douglas, 2003). For large magnitude earthquakes, the closest distance measures are generally preferred over the point source distances, such as distance to the surface projection of the rupture (e.g. Joyner and Boore, 1981) or rupture distance(Campbell, 1981), at least for records from earthquakes with M>6. However, for most of the events, particularly for small events that have occurred in Hormozgan province, rupture surfaces have not been defined clearly, and these distances are more difficult to estimate. In this study the majority of distances to epicenter are less than 100 Km (Fig. 4).
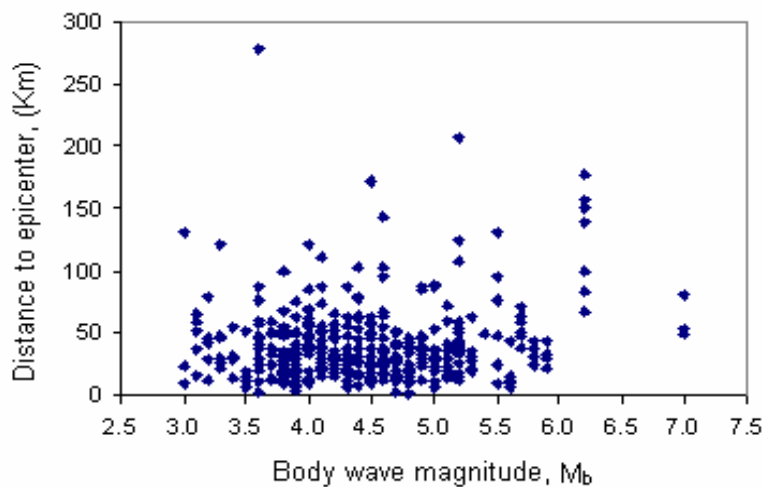

Fig. 4. The distribution of events in the database employed in this study in terms of body wave magnitude and distance to epicenter.

One of the other distance measures that are available for most earthquakes is hypocenter distance. However, accurate measures of focal depth are often difficult, and therefore, estimation of hypocentral distance is affected from this limitation. Most damaging earthquakes occur within a shallow region of the crust (about the top 30 Km) and hence hypocentral distance and distance to epicenter become equal at intermediate and large distances (Douglas, 2003).

In this study distance to epicenter is preferred to be used as site-source distance in PGA estimation relation. Minimum and maximum distance criteria are sometimes applied. A minimum distance criterion of 2 Km was applied by Wang et al. (1999) because 2 Km is the minimum error in epicentral locations and hence including records from smaller distances may give errors in the results. As mentioned by

Douglas (2003), only records associated with reliable measures were used by some investigator (Campbell, 1981; Sabetta and Pugliese, 1987) by including only earthquakes with locations (epicenters or rupture distance) known to within 5 Km or less. On the other hand, in the majority of the strong ground motion relations suggested for tectonically active regions (e.g. Boore et al., 1997; Campbell, 1997; Sadigh et al., 1997) the upper bound for site-source distance is taken 100 Km, which is the range where ground motions have engineering significance. Therefore, 5 and 100 Km were taken as the lower and upper bounds of the distance to epicenter, respectively, and records, for which the distance to epicenter does not fall into this range were omitted. However in this study the majority of focal depth are less than 30 Km (Fig. 5)
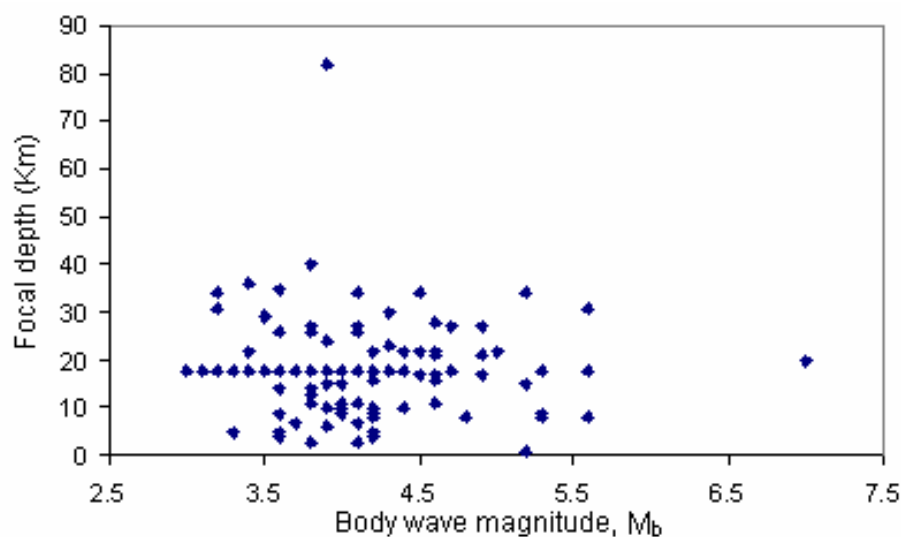.

Fig. 5. The distribution of records in the database employed in this study in terms of body wave magnitude and focal depth.

One of the extremely difficult items in determining the site condition coefficient of the attenuation relationships is the ground conditions. Local site conditions at an acceleograph station can affect the strong motion recorded. Therefore, attempts have been made in most ground estimation relations to model the effect of near-surface ground conditions or strong

motion. Data selection criteria, which seek to limit the acceleograms used to those recorded at stations with similar local site conditions, are the simplest techniques. While the widely accepted method quantitatively defines the near-surface material based on shear wave velocity, V_s, beneath the station. However, without consistent site classifications for the

attenuation relations, it is often difficult to know how to apply the relations to a specific site. But information on V_s is currently lacking for the stations in Hormozgan province. In brief, Building and Housing Research Center (BHRC)

divided soil groups for whole Iran. Based on BHRC, four site conditions, namely hard rock, soft rock, soil and soft soil were considered (Table 1).

Table 1. Soil classification (after BHRC, 2005).

Soil Type	Description
1	Hard Rock ($V_s >= 750$ m/s)
2	Soft Rock (375m/s $<= V_s <= 750$m/s
3	Soil (175m/s $<= V_s <= 375$m/s
4	Soft Soil ($V_s <= 175$m/s)

Among all accessible records, 370 earthquakes occurred between 1973 and July 2007 following the data selection criteria outlined above (PGA>= 5 gal, M>= 3, and distance between 2 and 279 Km). The data set employed in this study

is given BHRC (2005) and distribution of all records with respect to body wave magnitude, distance to epicenter and site condition is shown in Fig. 6. Based on this set of data, body wave magnitude of the earthquakes ranged between 3 and 7.
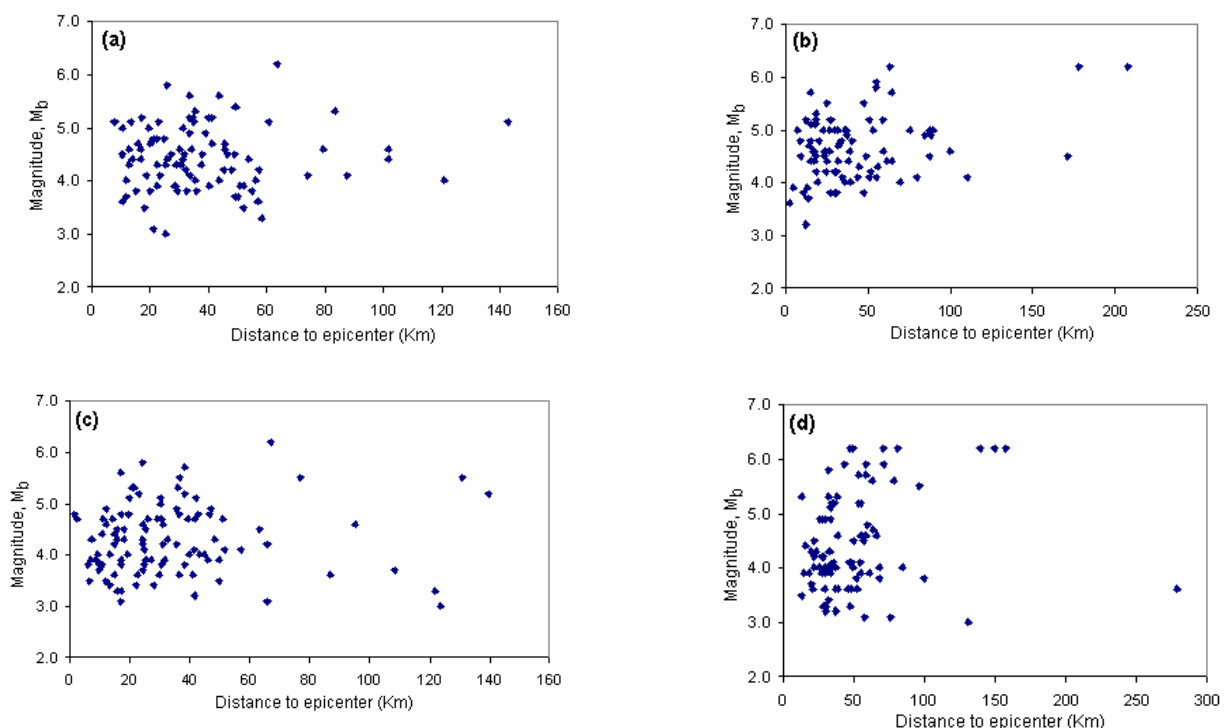

Fig. 6. The distribution of records in the database employed in this study in terms of magnitude, distance to epicenter and site conditions: (a)= Hard rock, (b)= Soft rock, (c)= Soil and (d)= Soft soil.

3.An attenuation relationship for PGA

In the development of the attenuation relationship, body wave magnitude(M_b),

distance to epicenter(E_d), site conditions (S_1, S_2, S_3 and S_4; where $S_1 = S_4 =1$ and $S_2 = S_3 = 0$ for hard rock sites, $S_2 = S_4 =1$ and

$S_1 = S_3 = 0$ for rock sites, $S_3 = S4 = 1$ and $S_1 = S_2 = 0$ for soil sites ,$S_4 = 1$ and $S_1 = S_2 = S_3 = 0$ for soft soil sites) and recorded longitudinal component PGA value of each station were employed. A total of 99 hard rock sites, 87 rock sites, 93 soil sites and 91 soft soil sites were considered in the analyses. In this analysis by multiple regressions, the following attenuation relationship was obtained (Eq. 3).

$$PGA = 28.4\,M_b - 0.537\,E_d + 101\,S_1 - 17.4\,S_2 - 19.2\,S_3 - 51.8\,S_4 \qquad (3)$$

The variation of PGA with distance to epicenter for hard rock, rock, soil and soft soil sites with respect to different values of M_b are shown in Figures 7, 8, 9 and 10 respectively.
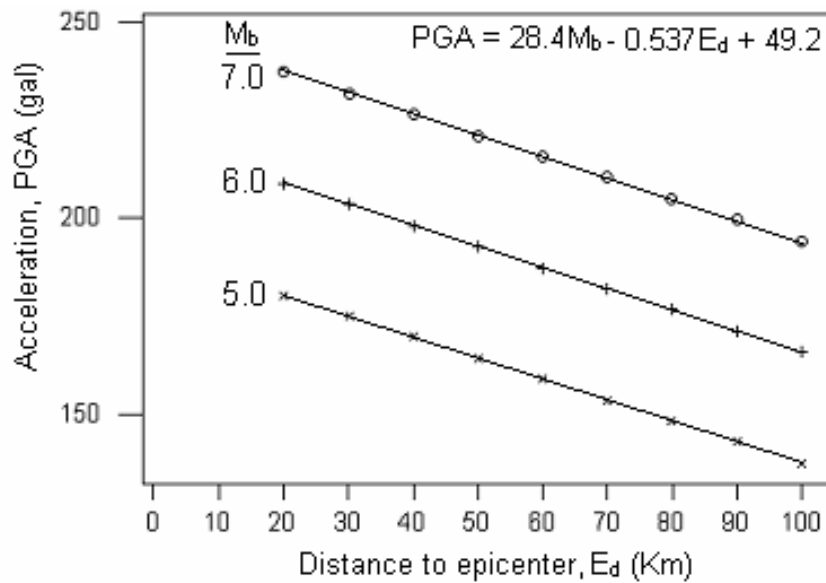

Fig. 7.Relationship between PGA and distance to epicenter for various magnitudes and site condition (hard rock) based on BHRC (2005) and Equation 3
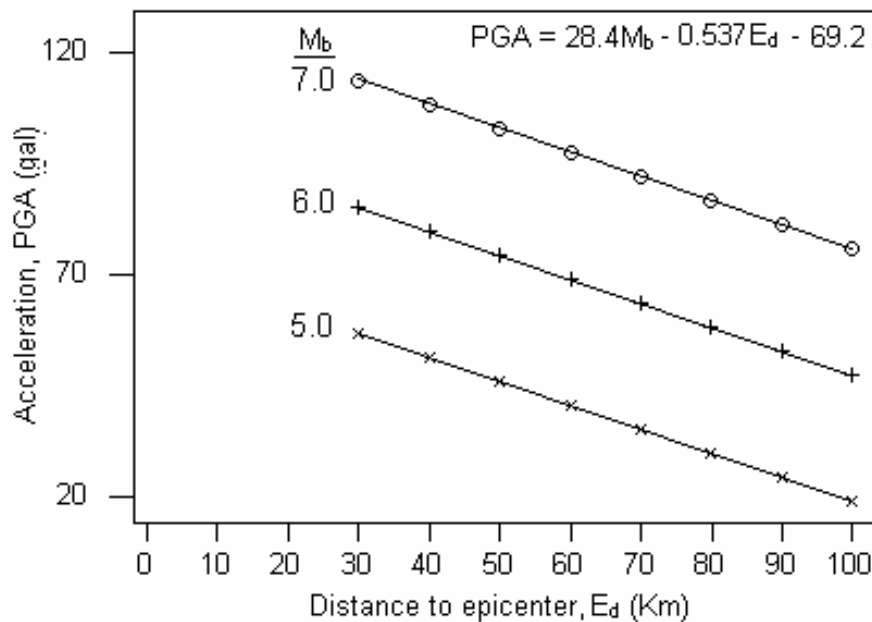

Fig. 8. Relationship between PGA and distance to epicenter for various magnitudes and site condition (rock) based on BHRC (2005) and Equation 3
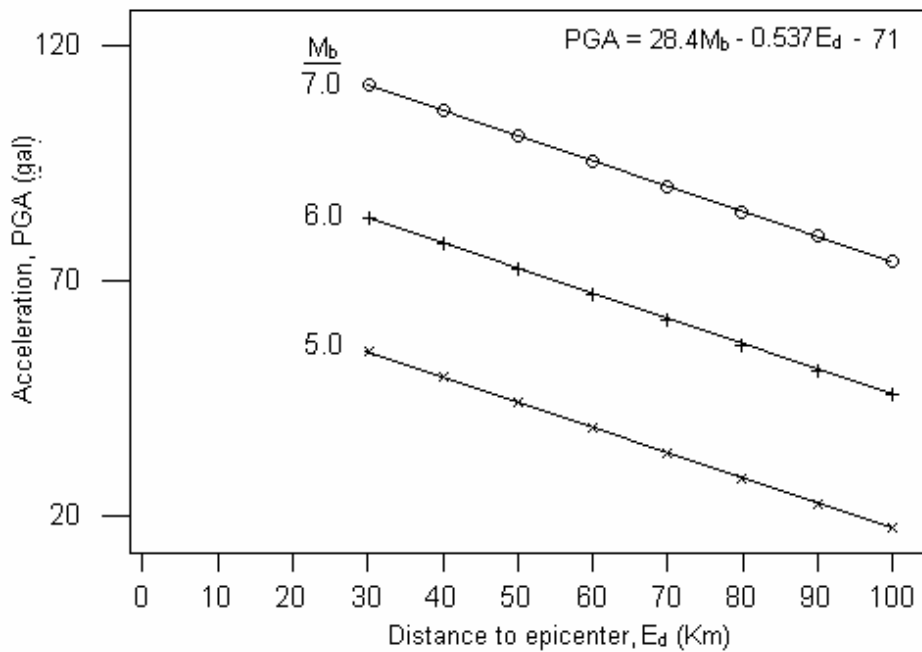
Fig. 9. Relationship between PGA and distance to epicenter for various magnitudes and site condition (hard soil) based on BHRC (2005) and Equation 3.
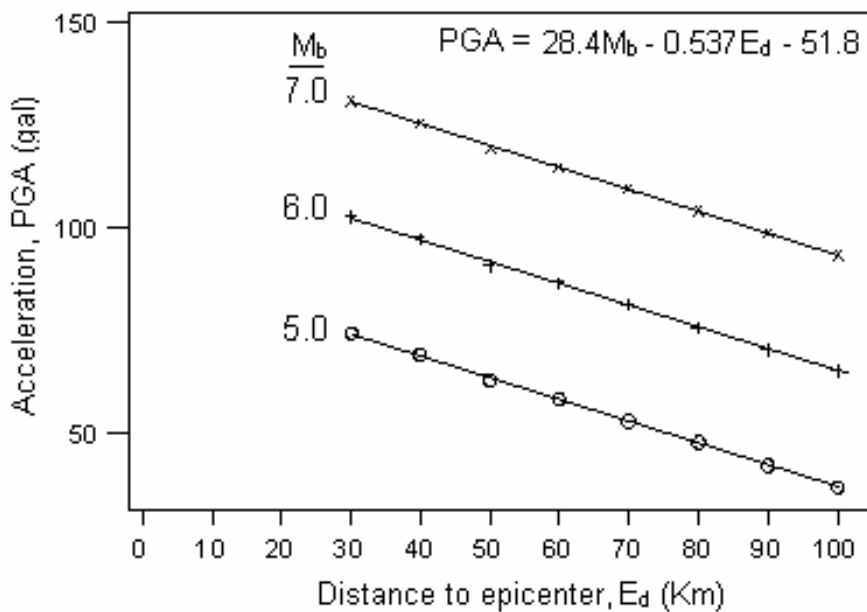

Fig. 10. Relationship between PGA and distance to epicenter for various magnitudes and site condition (soil) based on BHRC (2005) and Equation 3

The general performance of the attenuation equation developed in this study is shown in Fig. 11, where measured PGA values from the database are plotted against predicted PGA values using Eq. (3). As seen from Fig. 11, although a few points fall above and below the lines with 1:0.5 and 1:2 slopes, which indicate some overestimates and underestimates, respectively, most of the predictions are scattered within these lines. Particularly smaller PGA values fall close to the line 1:1. Correlation coefficient and standard deviation corresponding to $PGA_{observed} = PGA_{predicted}$ condition are 0.49 and 31.56, respectively.
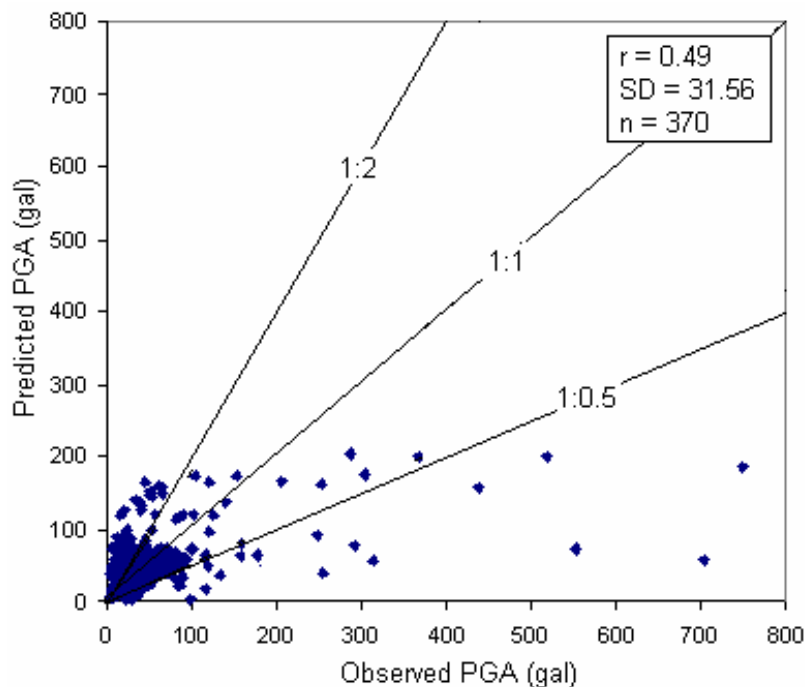

Fig. 11. PGA values predicted from Eq. (3) versus observed PGA values (r: correlation coefficient; S.D.: standard deviation; n: number of data).

4. PGA map of Hormozgan Province

A completed form of the active fault map employed in this study is shown in Fig. 12 together with the numbers assigned to the faults. Name, length and type of each fault are listed in Table 2. In addition, Fig. 13 indicates the epicenters of a number of earthquakes, which occurred between 1930 and July 2007, appear in this province. This situation suggests that only the use of distances to the known active faults in the attenuation relationship will result in unrealistic PGA assignments for a series of points selected in such regions. Therefore, in this recent study, the epicenters were also decided to be used as the second group of earthquake source. For fault sources, the magnitude of the upper level earthquake is usually estimated from fault dimensions. Before fault segmentation concepts were developed, usually some fraction of the total length was used to estimate the magnitude of the design earthquake. For example, it was common to use 1/3 to 1/2 of the total fault length for the estimation of maximum magnitudes (Mark, 1977). Fault segmentation studies have replaced this approach for well-studied faults (Abrahamson, 2000). Therefore, in this study, use of fault segments is considered to be more realistic in the prediction of magnitudes, instead of connecting the segments.
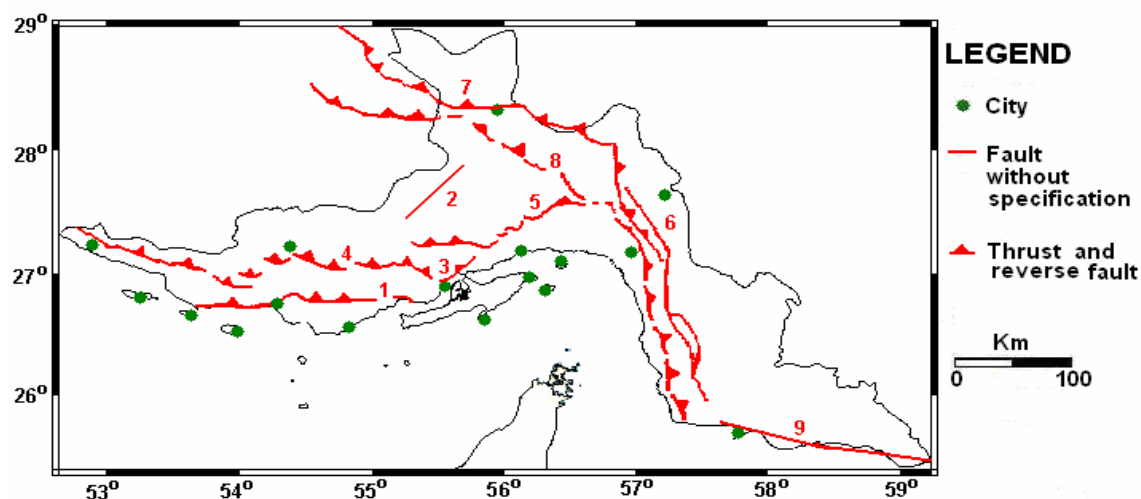
Fig. 12. Major faults of Hormozgan province by GIS soft wares
(Faults after Barzgar et al, 1997 and IIEES, 2003).

Table 2. List of active faults appearing in Fig. 12 and the information associated with the faults
considered in the construction of iso-acceleration map.

Fault number	Fault name	Fault type[a]	Length (Km)	Maximum magnitude (Ms) assigned
1	Charak	T	120	7.5
2	Moran	U	95	7.3
3	Khamir	T	50	7.0
4	Zagros	T	325	8.0
5	Khorgo	T	60	7.1
6	Minab	U	240	7.78
7	Main Zagros	T	250	7.79
8	High Zagros	T	300	7.87
9	Makran	U	205	7.71

a T: Thrust and reverse fault; U: Although shown on the active fault map of Iran(after Barzgar et al., 1997
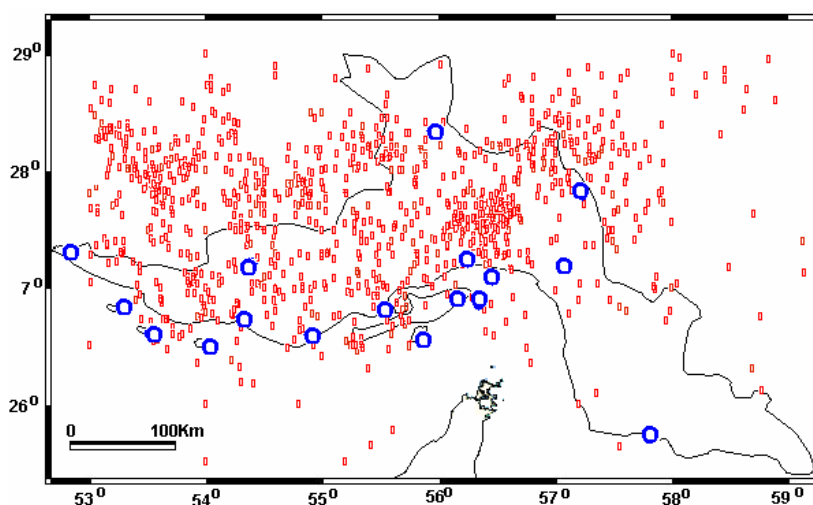and IIEES, 2003), information on fault type is not available.

Fig. 13. 1101 earthquake epicenters of magnitude 2.8 - 7 were located in Hormozgan Province
(1930 - 2007). Rectangles denote the location of earthquake epicenters and circles denote the location
of cities.

For a specific fault, the magnitude of the potential earthquake can be estimated by relating it to the potential rupture length of the fault using the relation proposed by Wella and Coppersmith (1994). However, it was considered that use of a relationship between magnitude and surface rupture

length based on Hormozgan earthquake data would be more realistic. In this study, we have determined relation between surface wave magnitude (M_s) and surface length (L) by the Hormozgan earthquakes (Fig. 14).
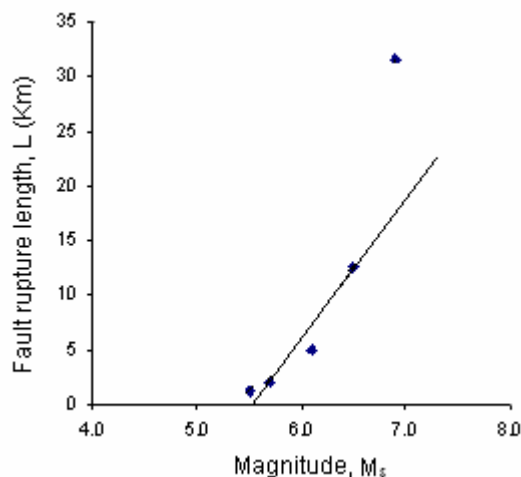

Fig. 14. Relation between surface magnitude (Ms) and surface rupture length (L) based on Hormozgan earthquakes.

A probabilistic seismic hazard map of Iran constructed by Building and Housing research center in Figure 15 (BHRC, 2005). This Figure shows that there are four risk categories in whole Iran. But in recent study, we have located the first map of peak ground acceleration in Hormozgan

province. As can be seen from Fig. 16, higher values of PGA are generally concentrated along the main seismotectonic features of Hormozgan province .
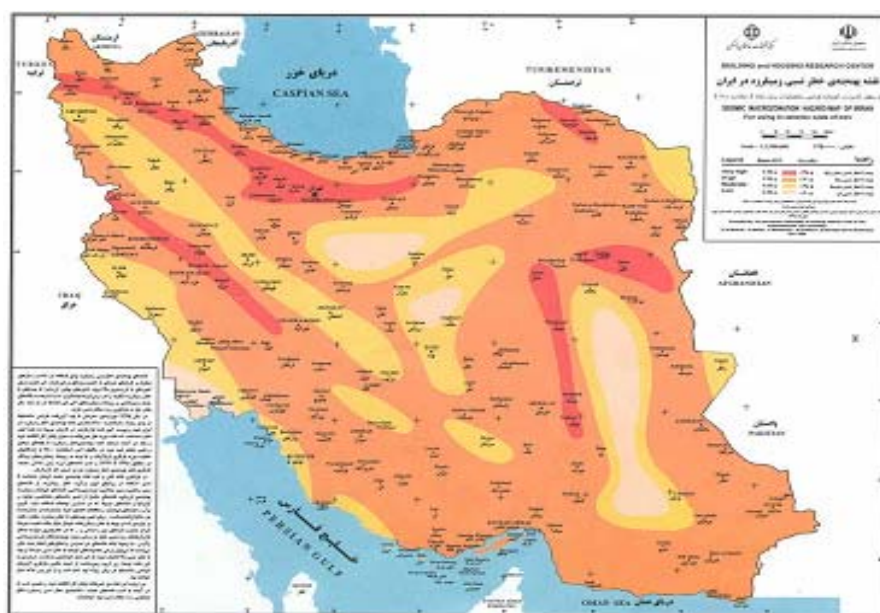

Fig. 15. Seismic macrozonation hazard map of Iran to use in seismic code of Iran (BHRC, 2005)
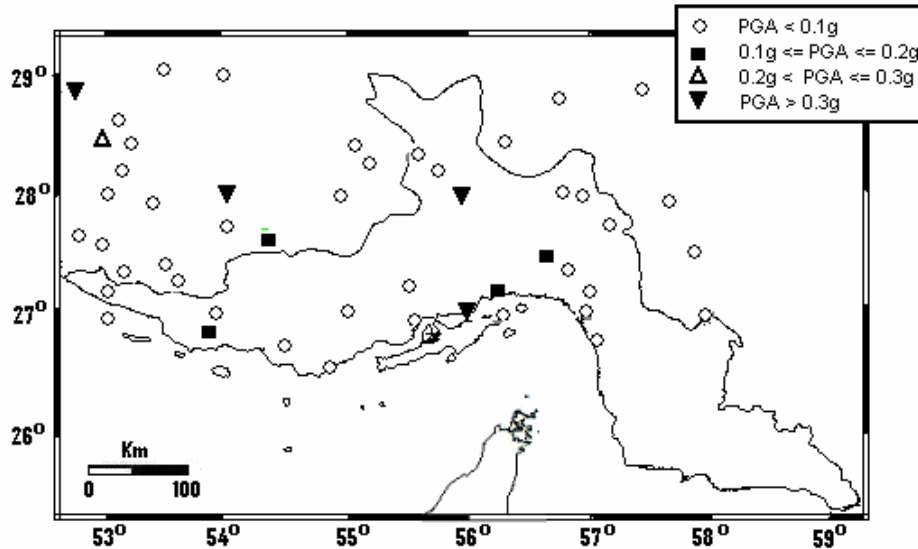
Fig. 16. The amount of PGA of Hormozgan province employed in this study.

5 Conclusions

In this study, a unique attenuation relationship of PGA based on the recent data from Hormozgan province is presented. In this equation, the variation of PGA with distance to epicenter for hard rock, rock, soil and soft soil sites with respect to different values of M_b is calculated. So by this relationship we can predict peak ground acceleration for each earthquake in this zone. In addition, an attempt is made to construct an equation between body wave magnitude and surface wave magnitude. The comparison between the body wave magnitude and surface wave magnitude relationship is suggested and another important relation developed using data from Iran indicates that the relationship of Mirzaei et al. (1997) considerably overestimates the magnitudes [body wave and surface wave] values.

Acknowledgements

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