Attenuation Laws of Iranian Earthquakes

H.R. Ramazi
Department of civif engineering
Amirkabir University of Technology

Abstract

On of the main elements required for seismic hazard assessment is the attenuation law, specifying the strong ground motion attenuation as a function of earthquake magnitude, site geology and epicentral or hypocentral distance and or distance to the earthquake source (causative fault). Peak ground acceleration (PGA) is one of the most important parameters specified by attenuation law. There are several empirical relationships to determine PGA in a given point. Among them the relations offered by Ramazi and Schenk(1994) are extracted by using Iranian strong ground motion data. In this paper it has been tried to review the predicted results and compare them to the real data recorded by Iranian accelerographs network during the recent destructive Iranian earthquakes. Finally, the results are compared to the predicted PGA by a few equations presented by other researchers. It is concluded that the Ramazi and Schenk's attenuation laws have the best fitting to the recent real data.

Key words

Earthquake, Attenuation law, Strong ground motion, PGA, Iran

Introduction

Three destructive earthquakes occurred in 1997 and 1998 in north and east of Iran. A large number of accelerograms were recorded by the accelerographs network of Iran during these earthquakes. For example, the Zirkoh Qaenat (E. Iran) was recorded by 39 triaxial SMA1 and SSA2 accelerographs. Here it is tried to analyze the records and to compare the recorded to the predicted PGA by some empirical attenuation laws, including the relations presented by Ramazi & Schenk 1994, Campbell & Bozorgnia 1993, Ambraseys 1995 and Abrahamson & Litehiser 1989. The last three equations are chosen because of involving some of the Iranian strong motion among the input data, which have been applied to determine the laws.

Recent Iranian Destructive Earthquakes

Garmkhan (north Bojnurd, NE. Iran) earthquake of 4.Feb. 1997

In Feb. 4, 1997 an earthquake having surface wave magnitude of 6.7 shook the northern part of Khorasan province NE. Iran, leaving about 100 of people perished and two thousands injured. Several Villages were totally destroyed and dozens were severely damaged. Analyses of observed collapses, damages and others intensity data indicates a maximum intensity of VIII in MSK scale. Strong ground motion due to the quake was recorded by 14 accelerographs erected in the region. The highest recorded PGA belongs to the Bojnurd station located about 23 Km far from the macroseismic epicenter [1].

Ardebil Earthquake of Feb.28 1997

On February 28, 1997, an earthquake with a surface wave magnitude of 6.1 shook south east of Ardebil province located in western coast of Caspian sea, NW. Iran. This quake totally destroyed some villages, damaged tens of others and caused about 900 people perished and more than 2000 injured. The quake was continued by thousands of aftershocks adding to the damage. The maximum estimated intensity according to field observation was about VIII in

MSK scale. Main shock of this earthquake was recorded by 19 triaxial accelerographs established over the region [2].

Qaenat Earthquake of May 10 1997

On May 10, 1997, at 7,57', 29" GMT (12,27', 29" Local time) an earthquake having a magnitude (Ms) of 7.1 struck the eastern part of Qaenat, in E. of Iran and caused great losses and casualties. Hadjiabad, Ardekul, Esforogh, Fakhrabad, Bashiran and Kalateh Villages were thoroughly destroyed. Abiz and Esfaden Pishbar Villages were greatly damaged and a number of some other villages faced considerable casualties and damages. The earthquake was recorded by a set of 29 SSA-2 and SMA-1 accelerographs in the region, nearest of which to the epicenter was Hadjiabad. The accelerograph in this station was buried under the debris, so, its record of the main shock was disrupted [3].

The earthquake was associated with a surface refaulting of more than 80 km, which is clearly observed on the ground from the north Karizan to the south Ardekul. There are also some questionable traces of surface refaulting at east Ahangaran heights. The overall direction of this fault is north-west to south-east (N20-25W). The fault has a right-lateral strike slip main vector, where displacements in different points along the fault trace are varied between 20 to 100cm. The vertical displacement mechanism is complicated. But generally, it may be said that the lateral block of west-southwest of the fault is relatively elevated. Izo-intensity curves indicate that the main stress concentration has occurred between Hadjiabad and Ardekul, and the rupture of this part of the fault was the main cause of the earthquake. But, the same shock caused a removement at the northern part of the fault between Hasjiabad and Karizan. This part of the fault has had a refaulting during the previous destructive earthquake in the area in 1979. Therefore, no great energy was needed for displacing it (as required for the southern part of the fault). This was the main cause of the surface refaulting of the earthquake, being considerably longer than 50km, which is expected for an earthquake with a magnitude of 7.1[3].

The area of the maximum intensity covers a prolate ellipsoid with the large axis of about 50km. and small axis of about 10 km, which is extended from south-west of Ahangaran to south of Abiz at the large axis. The intensity of the earthquake in this area is estimated about IX in MSK scale, which according to the distance from the causative fault and the site effects in different villages of the area, the intensity is varied between IX^- and IX. The maximum intensity is observed in Ardekul village, located at about 200 meters to the fault. It should be mentioned that site effects influenced Ardekul and topographical conditions has also contributed to the increased intensity. Single-storey concrete buildings of the village were totally damaged and most of them demolished. According to macroseismic observations, the epicenter of the earthquake is located at some point between Hadjiabad and Ardekul, 33.55 N, 59.98 E. The earthquake was considered as shallow, and its focal depth was estimated about 10km [3].

Strong Ground Motion Attenuation Laws

A large number of strong ground motion attenuation laws are now in use in engineering seismological practices and earthquake hazard analyses. Primarily, the choice of an attenuation relation requires the engineer to have an understanding of the way in which such laws are extracted. He or she should also be in a position to use his/her own judgment about their suitability and sufficiency for utility in a particular region and site. Minimum requirements for the acceptance of an attenuation law include both the seismological (earthquake parameter), seismotectonic and strong motion input data.

Some of these relationships are extracted by using a worldwide data others by regional data and even some are based on data belonging to a seismotectonic province. From another point of view, some laws are used to predict strong motion of earthquakes in a given point based on the distance from the source and others consider focal distance, epicentral distance or distance from the refaulting exposure of the causative fault. Therefore, the criteria and input parameters are different in equations. Here the chosen attenuation laws are reviewed.

The relation proposed by Campbell and Bozorgnia (1993)

Campbell and Bozorgnia derived an attenuation relation using accelerograms generated by earthquakes in USA, Canada, Alaska, Iran, India, Chile, Mexico, Turkey, Nicaragua and the former USSR [4].

$$\mathrm{Ln}(a) = -3.512 + 0.904M - 1.327\mathrm{Ln}(R^2 + (0.149e^{0.67})^2) + (1.125 - 0.112\mathrm{Ln}R - 0.096M)F + (0.440 - 0.171\mathrm{Ln}R)S_{sr} + (0.405 - 0.222\mathrm{Ln}R)S_{hr}$$

Where;

M is the greatest magnitude of Ms or M_l, R is the distance in Km, measured as a straight line from the station to the closest point on the effective rupture surface and requires knowledge of the non-seismogenic depth. F is a variable, which takes a value 1 for faults with a reverse component and 0 otherwise.

S_{sr} and S_{hr} are two site variables, S_{sr} is equal to 1 for soft sites and S_{hr} is equal to 1 for hard sites and both equal to 0 otherwise.

The Equation Suggested by Ambraseys (1995)

Ambraseys used a set of data records combined from earthquakes in Albania, Algeria, Bulgaria, Greece, Iceland, Iran, Israel, Italy, Pakistan, Portugal, Romania, Spain, Turkey, Yugoslavia and the former USSR, and has derived an equation as follows [5]:

$$\mathrm{Log}(a_h) = -1.43 + 0.245M - 0.786\mathrm{Log}\sqrt{R^2 + 2.7^2} - 0.001\sqrt{R^2 + 2.7^2}$$

Where;

R is the distance to the fault rupture in Km

The Attenuation Laws Suggested by Ramazi and Schenk (1994)

This study included a systematic analysis of accelerograms recorded by the Iranian accelerograph network during destructive earthquakes. The results of the research are presented as attenuation laws of horizontal PGA, vertical PGA and horizontal PVA for conditions of site geology, hard sites and soft sites. The equations are derived based on the nearest distance from the refaulting exposure of the causative fault. Another equation has also been presented by using the focal distance. Here, the relations determined by using the closest distance to the refaulting exposures are presented [6]:

$$a_h = 4000(20 + R + H)^{-2.02} e^{0.80M}$$
$$H = |16M - R|^{0.63}$$

For soft sites

$$a_h = 4000(20 + R + H)^{-2.11} e^{0.79M}$$
$$H = |16M - R|^{0.63}$$

For hard sites

Where;

R is the nearest distance in Km from the refaulting exposure(s) of the causative fault. Soft sites include the site geology conditions defined according to the seismic code of Iran as site conditions III, VI. Shear wave velocities of these sites to a depth of 30 meters, are less than 360 m/s. Hard sites cover local conditions type I, II having shear wave velocities greater than 360 m/s.

The Relation Presented by Abrahamson & litehiser (1989)

The relation is determined by using a very large data set from all around the world. The law included two variables, one depending on the fault mechanism and the other variables depending on interplate or interplate regions [7]:

$$\mathrm{Log}(a_h) = -0.62 + 0.177M - 0.982\mathrm{Log}(R + e^{0.284M}) + 0.132F - 0.0008ER$$

Where;
F is equal to 1 for reverse faults and 0 otherwise
E is equal to 1 for interplate regions and 0 otherwise

The Relations Suggested by Ramazi (1998)

Accelerograms (39 three components), recorded during Qaenat earthquake of 1998, have been used to derive attenuation laws for PGA, both horizontal and vertical, for two different site conditions. The results are as fallows [3]:

$$a_h = 4000(25 + R + H)^{-1.93} e^{0.80M}$$
$$H = |16M - R|^{0.63}$$

For soft sites

$$a_h = 4000(20 + R + H)^{-2.15}\ e^{0.79M}$$
$$H = |13M - R|^{0.68}$$

For hard sites

Comparison of the Relations and Fiting to the Recent Data

To derive attenuation laws, different authors have used sets of input data of different qualities and quantities, as well as different definitions of several associate variables. This makes it very difficult to compare the predicted results obtained from the equations suggested by different authors. But, if there are some similarities in variables involved in the laws, they could be compared. Here it is tried to compare the predicted PGA by the described attenuation relations to the real PGA recorded during recent Iranian destructive earthquakes and Manjil earthquake of June 20, 1990,having surface waves magnitude of 7.7.

Conclusion

Prediction of PGA in earthquake hazard practices has a great importance for large earthquakes because of their great influences on the structures, lifelines and so on. In Iran, large earthquakes (M>6) are associated with exposures of refaulting of the causative faults. There fore, use of attenuation laws derived based on the nearest distance to the exposures of refaulting has two advantages. First, it dose not require any knowledge of focal depth which is usually associated with a considerable uncertainty. The second advantage is that the faults are more or less known in each area so that the refaulting zones could be predicted in future earthquakes. Consequently, the PGA could be better estimated according to the distance to the fault in hazard assessments. It should also be said that the recorded data show a greater regression coefficient of correlation when using the distance to the causative fault in comparison to using other measures of distances like focal distance. The comparison of predicted PGA by the described attenuation laws to the data recorded during recent destructive Iranian earthquakes, presented in the figures, show that the attenuation relationships derived by Ramazi and Schenk 1994, has best fitting to the real data. Therefore, they could be suggested for using in earthquake hazard analyses in Iran.

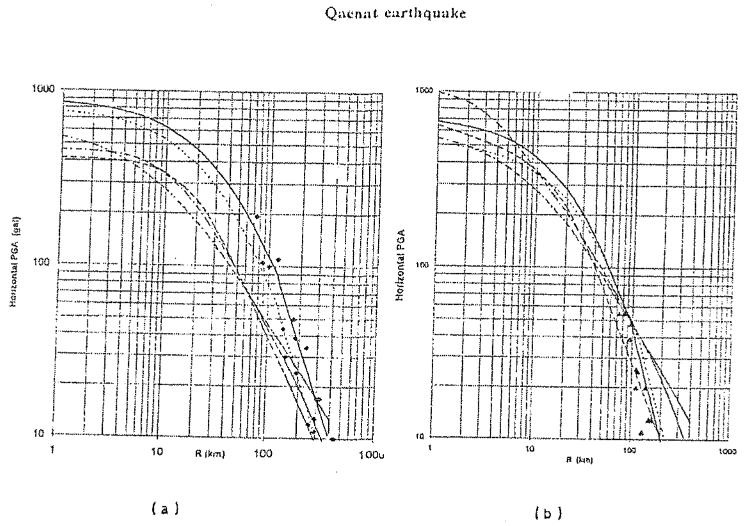

Fig. 1. Comparison of predicted PGA and date recorded during Qaenat earthquake of May 10, 1997 M_s 7.3, (a) Soft sites, (b) Hard sites

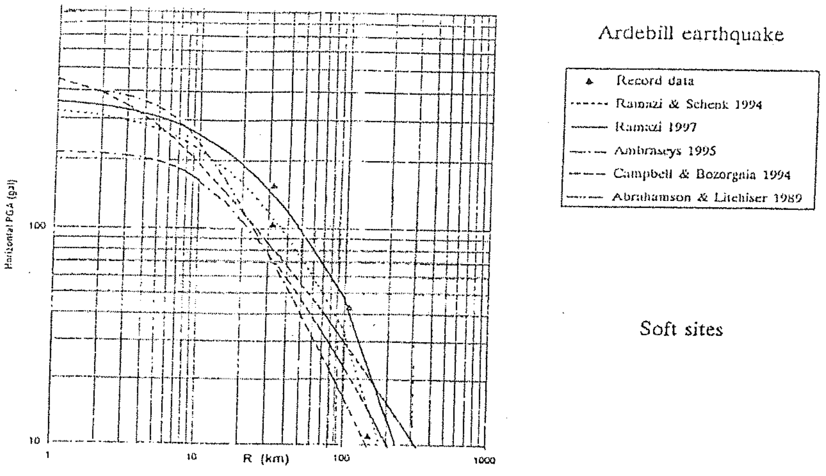

Fig. 2. Comparison of predicted PGA and date recorded during Ardebill earthquake of Feb. 28, 1997 M_s 6.1 (Soft sites)

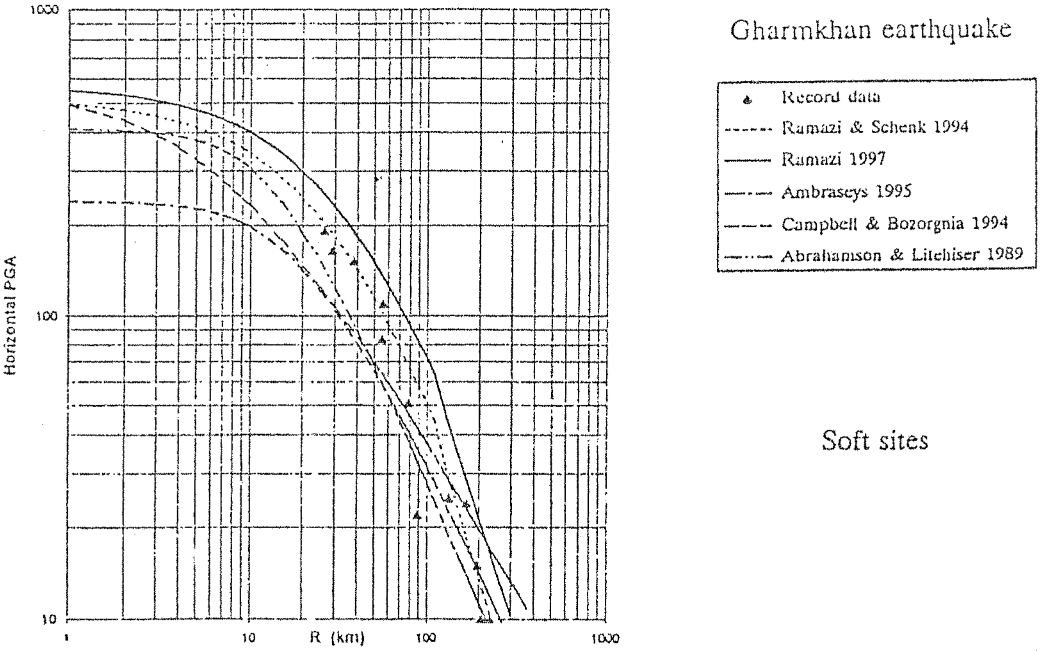

Fig. 3. Comparison of predicted PGA and date recorded during Gharmkhan earthquake of Feb. 4, 1997 M_s 6.7 (Soft sites)

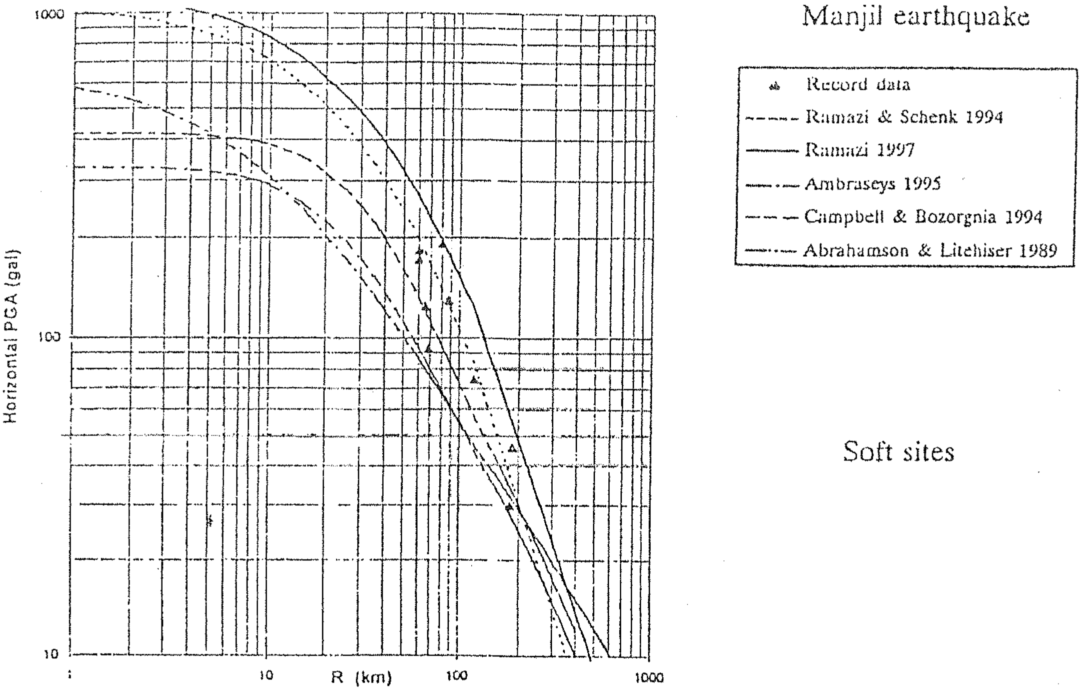

Fig. 4. Comparison of predicted PGA and date recorded during Manjil earthquake of June 20, 1990 M_s 7.7 (Soft sites)

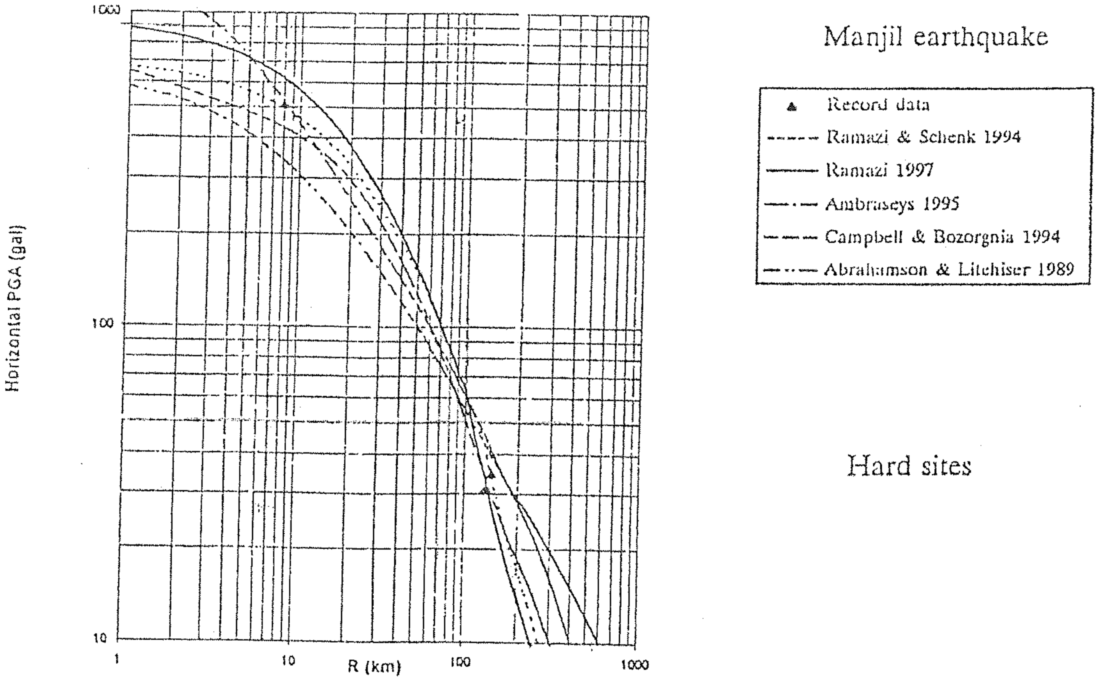

Fig. 5. Comparison of predicted PGA and date recorded during Manjil earthquake of June 20, 1990 M_s 7.7 (Hard sites)

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