EARTHQUAKE REGIONALIZATION OF IRAN

by
F. Neghabat[I] and S. C. Liu[II]

SYNOPSIS

A comprehensive earthquake microzonation analysis of Iran is carried out. Four overlapped seismic regions including the Zagros folded belt, the Rezaiye-Esfandazheh Orogenic belt, the Central Southeast Persia and Alborz ranges are analyzed independently. The statistics describing the earthquake occurrence and its local effects are obtained from the seismological, geological, and tectonic data of the region. Regional isoseismic contour maps in terms of intensity with periods from 20 to 1000 years are constructed and synthesized into an earthquake hazard map of Iran. The map can be used to establish the earthquake design criteria of structures.

INTRODUCTION

Iran is a country of high seismicity and during the last several centuries various regions in the country have experience destructive earthquakes. Major life loss and severe property damage has resulted from these earthquakes throughout the country, particularly in the rural areas where most old village and community houses were made of hazardous adobe construction with brick or mud walls and heavy roofs.

To establish a reliable earthquake risk environment to guide future structural design on construction of Iran, a microzonation analysis is undertaken in this study. The process of the study starts, naturally, from a complete and thorough review of the existing literatures concerning Iran seismicity, geology, and tectonics. The data is validated, synthesized, and cast in a form for subsequent microzonation analysis. The results are presented in terms of contour maps of Modified Mercalli intensity for various return periods.

GEOLOGICAL REGIONS

Geologically, Iran can be divided into the following four regions(Fig.1):

(1) The Zagros Folded Belt: This region includes the Zagros thrust zone and folded foothills and foreland extended southwestward to the northern shore of the Persian Gulf. The Zagros thrust zone extends over 1300km and has a remarkably straight alignment in Persia, bending toward the west in northern Iraq, and finally extending westward into Turkey where it joins with the Taurus ranges. At its southern extension, the thrust zone bifurcates north of Bandar Abbas; one branch goes east toward Pakistan, and the second branch bends south toward Oman. Southwest of the thrust zone lies the folded foothills and the foreland in which conformable sedimentation continued from Cambrian to Pliocene time.[1] The entire folded belt is the most active seismic zone in Persia. The most active region is in the vicinicity of Lār where the trend of the Zagros thrust changes. Major earthquakes in this region included shocks occurring at Lār (24 April 1962,

I Director, Building and Housing Research Center, Tehran, Iran
II Program Manager, Earthquake Engineering Program, National Science Foundation, Washington, D. C.

M = 6.9, killed, and 11 June 1961, M = 6.9, 60 killed), near Bastak (31 October 1956, M = 6.4, 255 killed), and many historical destructive earthquakes at or near Shiraz, Quislm Island, and in the Persian Gulf.

(2) The Rezaiye-Esfandagheh Orogenic Belt: This belt runs parallel to the Zagros and separates from it by a narrow zone of deep thrusts and reverse faults. It joins the Taurus Orogenic belt in Turkey. The seismic activity in the belt has been generally low.

(3) The Central and Southeast Persia: This zone covers an area south of Doruneh fault zone to the Persian Gulf and east of Rezaiye-Esfandagheh belt to the eastern mountain ranges of Persia. The northern limit is characterized by the boundaries of the Lut and Tabas blocks, and by the Doruneh, Ferdows, and Kuhbanan faults. The southwest limit of this zone is marked by a major fault running from Nain to northeast of Esfandagheh. The northwest limit is marked by a fault running from Nain to north Kashmar to the south Mashhad area. The seismicity of this region is primarily associated with the boundaries of Lut and Tabas blocks, the Doruneh, Ferdows, and Kuhbaban faults, and the East Persian ranges. The Lut block is bounded in the north by the Ferdows fault and its extension in the north, and by the Kuhbaban fault in the west. The major Dasht-Bayaz earthquake (M=7.2) of 1968 occurred on the Ferdows faults. Destructive shocks associated with Kahbaban fault took place at Kashanan in 1903 (209 killed) and at Torbat-e Heidariyeh in 1925 (nearly 2000 killed). The left lateral Doruneh fault[2] lies about 300km north of the Ferdows faults and extends for about 700km from the central Dasht-e Kavir desert to the eastern frontiers of Iran. The eastern section of the Doruneh fault is presently active and the movements along it are essentially in the vertical direction.[3] Two destructive earthquakes with moderate magnitude (M=6.4, 5 May 1933 and M=6.5, October 1940) were connected with this fault.

(4) The Alborz: This region includes the Alborz mountain ranges in northern Iran and a parallel zone to the south of the mountains, extending to the province of Khorasan in the east. The southern extent of the Alborz structure is marked by the Shahrud fault. A number of destructive earthquakes occurred in this region during the historic time. Major earthquakes in recent decades occurred at Torud (1955), Alborz (1957), Hamadan (1957, 1130 killed), and Buin-Zahra (1962, M=7.2, 12,000 killed). It is noticed that most of the major earthquakes in Persia occurred on the boundaries of the Persia plate.[4] For example, the Torud and Alborz earthquakes were associated with the Shahrud fault which marks the northern boundary of the Persian plate; the Hamaden and Buin-Zahra earthquakes were associated with the northwestern boundary of the plate; and the recent Dasht-e Bayaz earthquake of 1968 occurred on the eastern boundary which separates the Persian plate and the Lut block.

SEISMICITY

Although Iran has been known as an active earthquake country, the seismic history of the region is not very well known. There exists very little published records about Iranian seismicity prior to 1900, and only incomplete documentation exists after 1900, Banisadr[4] has collected the available seismic information for the period 1900 to 1969 and constructed an epicentral map. Nowroozi[5] has superimposed the epicentral locations of Iran earthquakes for the period of 1950 to 1965 on the Iran fault map. These studies show that most of the activity is spread around the periphery of the country. Two major seismic bands are clearly identifiable, one starting from the north-east and extending towards the north-west along the Alborz mountain and the Caspian sea coasts. The second band starts from the northwest and extends towards the western and southern part of Iran along the Zagros range. As expected, these two bands of seismic activity align with existing faults and fault zones in the area.

MICROZONATION ANALYSIS

The actual earthquake environment that a specific structure must survive is a function of its geographic location and the geological and seismological conditions at the site. A microzonation analysis method[6] is employed here to define the earthquake environment of Iran. In general, a microzonation study results in a probabilistic characterization of the earthquake environment at a site. It combines historical earthquake data and seismological and geological information with a sound statistical model to determine the expected design environment. This information may be presented in terms of contours that there is a specified probability that the indicated contour acceleration or intensity levels will not be exceeded during the service life of the structure.

Basic Procedure: The basic approach that is employed in the microzonation analysis is as follows: (i) Subdivide the seismically active areas of Iran into four overlapping regions as shown in Fig. 2, (ii) Microzone each of the four regions separately and determine intensity contours for various return periods, and (iii) Developed the 50-yr to 500-yr return period intensity or peak acceleration contours for the entire country by synthesizing the results of the four regions.

Analytical Procedure: The analytical and computational procedure[6,7] employed in this microzonation study can be summarized as follows: (i) Each of the four regions in Fig. 2 is divided into an appropriate number of subregions. Each of these subregions is considered an earthquake source area. In this particular study there are 48 source areas for each of the four regions. (ii) The earthquake history of each region is used to develop the recurrence relationship, arrival rates, and average focal depths for each of the 48 source areas in that region. The 70-yr (1900-1970) earthquake history of Iran[4] is used as the data base of the analysis. All pre-shocks and after-shocks are eliminated from the data and only earthquakes with Richter magnitude greater than or equal 4.0 are included. Earthquakes with magnitudes below this level are not considered to be significant for risk and damage analyses of structures. The recurrence relationship for a region as described by $\ln(n)=a+bm$ where n is the number of earthquakes with magnitude exceeds and equal to m, is developed by examining existing earthquake data. It indicates the distribution of earthquake occurrences with respect to their magnitude. In general, lower values of $-b$ reflect a history of the occurrence of more larger magnitude earthquakes. A value $b=6.7$ is obtained[8] for Iran which is comparable to that of Alaska and reflects the potential for large earthquakes. This constant is assumed to be the same for the entire country, since b is generally quite stable within large areas. The arrival rate depicts how earthquakes occur in time and it is assumed that the number of occurrences of large shocks is random in time and follow a Poisson probability distribution, i.e. $p(n,t)=e^{-\nu t}(\nu t)^n/n!$ In this study an arrival rate ν= earthquakes per year is assigned to each of the 48 source areas in each of the four regions of Fig. 2. These rates are determined by employing the data discussed above and the results should that they vary from 0 to 0.36.

Obviously, for the same recurrence constant b, a higher arrival rate ν implies a more severe earthquake hazard for the area. (iii) The attenuation function $I = c_1+c_2m-c_3\ln r$ which relates focal distance r to intensity I for a given Richter magnitude earthquake is required in the application of the seismic risk equations. The relationship and the resulting attenuation constants $c_1=7.8$, $c_2=1.7$, and $c_3=3.0$ are assumed to be the same for the entire country.[9] (iv) Each source area is approximated as a series of equally spaced point sources. In this study 35 point sources are used for each source area. (v) The seismic risk methods developed by Cornell[6,7] are employed to determine the probability of the maximum earthquake intensity being less than or equal to some level I at a location due to shock at a point source "j" at r_j distance away:

$$F_j(I) \simeq 1 - (1-\Theta)\nu - \Theta\nu \exp(-\beta I/c_2)\ CG$$
$$\text{where } \beta = -b \ln 10, \quad C = \exp[\beta(c_1/c_2+m_0)], \quad G = (r_j)^{-\beta c_3/c_2}, \text{ and}$$
$$\Theta = [1-e^{-\beta(m_1-m_0)}]^{-1}. \qquad (1)$$

In the above equation, m_1 and m_0 are the largest and smallest earthquakes that are allowed to occur in the region and have an important effect on the expected seismic environment. In this study the minimum magnitude level is assumed to be $m_0 = 4.0$. This is consistent with the data base and the fact that earthquakes with Richter magnitudes less than 4.0 are hardly of any engineering significance. The maximum allowable earthquake is taken as $m_1 = 7.5$. This is based on the general seismicity of Iran and a statistical fit of Gumbel's distribution of the maximum Richter magnitude with a return period up to 500 years for Iran's historical earthquake data. Assuming each source is independent, the cumulative distribution of the maximum site intensity at the location of interest due to all point sources within a radius of $r_I = \exp(c_1+c_2m_1 - I/c_3)$ is given by

$$F_{I,max} = \prod_{j=1,N_T} F_{j,max}(I) \qquad (2)$$

where N_T is the total number of point sources within radius r_I of the location of interest. The probability that the maximum intensity exceeds I is given by $1-F_{I,max}$. The average return period of an earthquake of intensity I at the location of interest is, therefore,

$$T_I = (1-F_{j,max})^{-1} \qquad (3)$$

Equations (1) to (3) are employed to develop a general computer program which generates iso-intensity contours for a rectangular study area.

Intensity Contour Maps: Application of the procedure and basic data previously described has resulted in the 50-yr, 100-yr, 200-yr, 400-yr and 500-yr intensity contour maps respectively. Isoseismic intensity levels of V to X are obtained and the patterns of risk distribution for various return periods are consistent. Upon synthesizing these contours maps and the Iran geological epicenter maps, a composite isointensity contour map which depicts the Iran earthquake hazard is developed in Fig. 3. From Fig. 3 it can be noticed that the highest intensity levels occur in the northeastern section of the country near the city of Mashad. An examination of seismicity data indicates that although this particular area has a history of earthquake activity, some other regions near the Persian Gulf have had more earthquakes. The reason for the higher expected intensity levels near Mashad is due to the relatively shallow focal depths, i.e. approximately 15km, in this region. Therefore, in light of this the results are not unexpected. The second highest risk regions are along the Persian Gulf, the northwest corner of Iran near Turkey, and the area surrounding the high risk Mashad region. These results are consistent with the historical data. The lowest risk areas occur basically in three places, i.e. the northwest between Tehran and Tabriz; the central part of the country including Kashan, Esfahan, Yato and Bafq; and the southeastern portion of the country between Bam and Pakistan. These results are also consistent with the historical data.

CONCLUSION

A statistical method of analysis for seismic microzonation has been developed and is used to identify the earthquake environment of Iran. The method yields a meaningful quantitative description of seismic regionalization in terms of both the size and occurrence frequency information of historical shocks. The results have synthesized into a general hazard map for return periods of 20 to 2500-years. The hazard map can be implemented to determine regional design environments for earthquake-resistant structures in Iran.

REFERENCES

1. Takin, M. "Iranian Geology and Continential Drift in the Middle East," Nature, Vol. 235, January 21, 1972, pp. 147-150.

2. Wellman, H. W., "Active Wrench Faults of Iran, Afghanistan, and Pakistan," Geological Rundsch, Vol. 55, 1966, pp. 716-735.

3. Tchalenko, J. S., Berberian, M. and Behzada, H., "Geomorphic and Seismic Evidence For Recent Activity on the Doruneh Fault, Iran," Tectonphysics, Vol. 19, 1973, pp. 333-341.

4. Banisadr, M., "The Seismicity of Iran, 1900-1969," Ph.D. Thesis, Imperial College of Science, University of London, 1969.

5. Nowroozi, A. A., "Focal Mechanism of Earthquakes in Persia, Turkey, West Pakistan, and Afghanistan and Plate Tectonics of the Middle East East," Bulletin Seismological Society of America, Vol. 62, No. 3, 1972, pp. 823-850.

6. Liu, S. C. and DeCapua, N. J., "Microzonation of Rocky Mountain States, "Proceeding of U.S. National Conference Earthquake Engineering, Ann Arbor, Michigan, June 1975, pp. 128-135.

7. Cornell, A. C., "Engineering Seismic Risk Analysis," Bulletin of Seismological Society of America, Vol. 58, October 1968, pp. 1583-1606.

8. Technical Report, Dox-IRN-A29.

9. Goudarzi, K. M. Hossain-Javahera, J., and Riahi, M. A., "Seismic Zoning of the Iranian Plateau, Part I - Shiraz, Journal of Earth and Space Physics, 1972, Vol. 1.

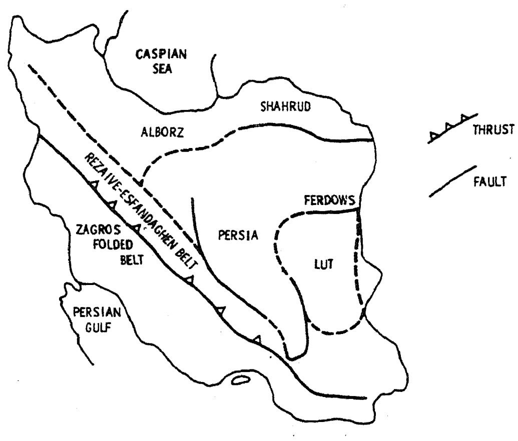

FIG. 1 SCHEMATIC OF IRANIAN GEOLOGICAL DIVISIONS

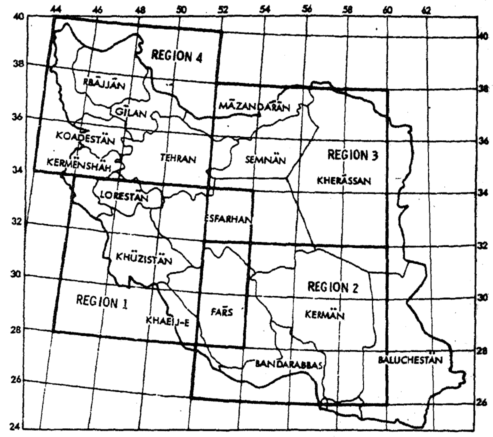

FIG. 2 MICROZONATION REGIONS

RETURN PERIOD (YRS)	CONTOUR 1	CONTOUR 2	CONTOUR 3
20	VI	VII	VIII
100	VII	VIII	IX
500	VIII	IX	X
2500	IX	X	XI

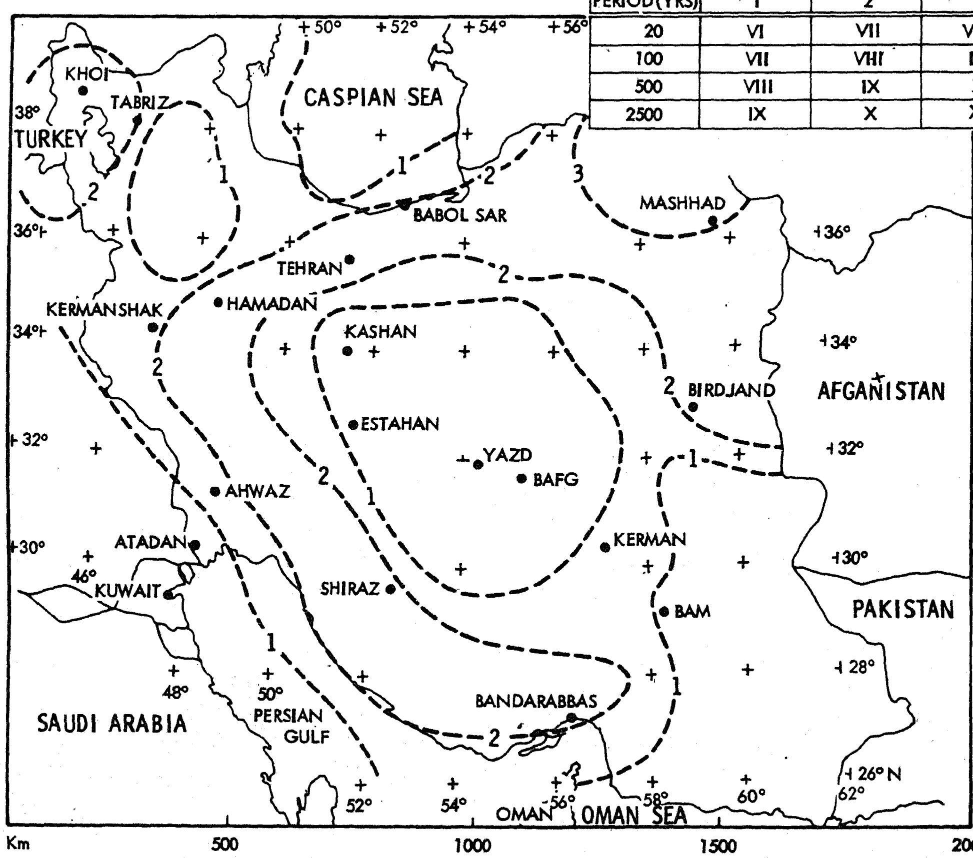

FIG. 3 EARTHQUAKE INTENSITY CONTOUR MAP OF IRAN

DISCUSSION

M. Barberian (Iran)

You mentioned that "The seismic history of Iran is not well known", for your information it would like to add that the seismic history is well known and the data is published by the Geological Survey of Iran 2 months ago (Report No.39, contribution to the Seismotectonics of Iran).

L.S. Cluff (U.S.A.)

Your paper indicates that the area of lowest seismic risk in South Eastern Iran near the Pakistan border. Recent geologic studies along the Makran coast in south eastern Iran show that the Makran area is the area of greatest potential earthquakes up to magnitude 8 + . This shows how erroneous conclusions come from only using historical seismic data. Regional geologic data must be taken into account to give a realistic evaluation of the earthquake hazard which will lead to a better estimate of earthquake risk.

I.N. Gupta (U.S.A)

Seismic risk maps are generally very sensitive to the spatial attenuation relationship used in the analysis. How did you obtain the attenuation formula used in your study ?

Author's Closure

With regard to the question of Mr. Barberian, we wish to state that the author is well aware of Report No. 39, which is based on the seismic history of Iran. Same data was published previously, and used in our analysis prior to the distribution of the seismotectonic map of Iran. It is true that seismic data are available to certain degree, but the statement of it not being well known is true only from statistical point of view.

With regard to the question of Mr. Cluff, we wish to state that the using historical seismic data which is well adaptable to mathematical models, is a common practice among researchers. There is no doubt that if the model could further consider the effect of regional data, a more realistic conclusion could be reached. However, the authors are not aware of any known methodology that can incorporate the effect of all factors involved.

With regard to the question of Mr. Gupta, we wish to state that the references mentioned in the paper give adequate account of how attenuation formula is derived at.