IJE TRANSACTIONS C: Aspects Vol. 25, No. 2, (June 2012) 159-165

International Journal of Engineering

Journal Homepage: www.ije.ir

The Use of Monte-Carlo Simulations in Seismic Hazard Analysis in Tehran and Surrounding Areas

A. Yazdani*, A. Shahpari, M.R. Salimi

Department of Civil Engineering, University of Kurdistan, P.O. Box 416, Sanandaj, Iran

ARTICLE INFO

Article history:
Received 3 February 2011
Received in revised form 9 April 2012
Accepted 19 April 2012

Keywords:
Probabilistic
Hazard
Monte-Carlo
Design earthquake

ABSTRACT

Probabilistic seismic hazard analysis is a technique for estimating the annual rate of exceedance of a specified ground motion at a site due to the known and suspected earthquake sources. A Monte-Carlo approach is utilized to estimate the seismic hazard at a site. This method uses numerous resampling of an earthquake catalog to construct synthetic catalogs to evaluate the ground motion hazard and its uncertainties. The method has been tested for peak ground acceleration and spectral response accelerations of 0.2 and 1.0 sec for sites in Tehran and the surrounding area. The disaggregation technique of seismic hazard provides relative contribution to hazards from sources of different magnitudes, M, distance, R and a measure of the deviation of the ground motion from its median value, ε, as predicted by an attenuation relationship. In different sites in Tehran, the major contribution comes from moderate and large magnitudes, at close distances.

doi: *10.5829/idosi.ije.2012.25.02c.9*

1. INTRODUCTION

Quantitative estimation of earthquake ground motion at a specified site may be carried out by deterministic or probabilistic approaches. If the earthquake loads for an engineering project at a particular site are estimated using deterministic seismic hazard analysis (DSHA), one or more earthquake scenarios are defined as part of the process. The DSHA consist of a postulated occurrence of a controlling earthquake taking place at a specified source-to-site distance. The probabilistic seismic hazard analysis (PSHA) includes one or more independent variables based on earthquake statistics and probabilistic numerical calculations. Probabilistic concepts allow the uncertainty in the timing, location, and magnitude of future earthquakes to be explicitly considered in the evaluation of seismic hazard. In the PSHA, the contribution over all possible earthquake occurrences and ground motion around the site are integrated to calculate the ground motion that has a particular probability of not being exceeded at that place during some period of time. A principal advantage of the probabilistic method stems from the nature of Cornell’s scheme [1] that systematically combines the contributions to hazard from all the earthquakes generated by the seismic sources of engineering significance to the investigated area. One major weakness of PSHA, which results from the integrative nature of this approach, is the impossibility of directly calculating parameters characterizing a design earthquake [2]. Probabilistic seismic hazard disaggregation techniques introduced and formulated over the previous decades could be an answer to these technical problems. Disaggregation is a process that allows the identification of individual earthquake scenarios that contribute to a hazard for a given ground motion parameter at a selected annual frequency of exceedance (AFE). A first, application of disaggregation was introduced by McGuire and Shedlock [3] to perform sensitivity analysis on models and parameters in hazard computations. Successively, Ishikawa and Kameda [4], Stepp et al. [5], and Chapman [6] introduced new applications of the disaggregation procedure to select ground-motion time histories compatible with the hazard calculated using probabilistic methods. But, these approaches are not satisfactory as they do not address the problem of uncertainties in the attenuation. In 1995, McGuire [7] introduced a disaggregation method that finds an earthquake, the “beta earthquake”, as a representative of the disaggregated uniform hazard-response spectrum. Bazzurro and Cornell [8] analyzed possible choices for disaggregation computation with particular attention to their relevance and their influence on the computed results.

*Corresponding author: Email- *a.yazdani@uok.ac.ir*

One of the main tasks in Monte-Carlo (MC) approach is the generation of random numbers from prescribed probability distribution to incorporate the uncertainty. The use of MC simulation to compute hazard involves taking a standard seismic source model and using it to generate a large number of synthetic earthquake catalogues representing possible future outcomes of regional seismicity in a period representing the lifetime of the structure being designed [9]. However, a realistic probability distribution is required to fit each uncertain variable. Previous studies to estimate seismic hazard in other areas showed that the MC approach has many advantages over conventional PSHA [9-13]. Application of MC simulation in seismic hazard analysis is rooted in actual earthquake occurrence within each synthetic catalogue.

Tehran is a large, rapidly growing and important city located at the foothills of the Alborz Mountains and is bounded by several active faults [14]. The existence of several active faults [15] and destructive historical earthquakes associated with active faults near Tehran [16] all indicate the necessity of the evaluation of the severity of earthquake occurrences. Previous PSHA studies have calculated values for design-basis acceleration at greater levels than the value suggested by the seismic code [17-21]. Nateghi [22] demonstrated that a 0.35g scenario could produce a dramatic outcome in Tehran, with extensive damage of buildings and significant numbers of deaths and injuries. Some efforts have recently been made using the DSHA for the simulation of expected earthquake scenarios that affect Tehran [23, 24]. Their results encourage the application of the DSHA as a supplementary tool for region-specific ground motion prediction in the Greater Tehran area.

The objective of this study was to take advantage of the MC simulation in preparation of seismic hazard maps in Tehran and surrounding areas for three different ground motion parameters. These are peak ground acceleration (PGA), 0.2, and 1.0 sec response spectral acceleration (SA) for ground motion having 10% probability of exceedance in 50 years. This level earthquake produces the most commonly used values in the probabilistic approach for specifying a design basis earthquake (DBE), and it is the criterion used for the Iranian seismic code [25] in terms of the design basis acceleration. Then, we include the effect of uncertainties in the hazard estimates and show the contribution of the earthquake magnitude, *M*, and distance, *R*, to the seismic hazard at a site from disaggregation studies based on Monte-Carlo simulation.

2. MONTE-CARLO PROBABILISTIC SEISMIC HAZARD ANALYSIS

For the same local soil condition, the intensity measure of the ground shaking at the site (*Y*) depends mainly on the magnitude, *M*, and source-to-site distance, *R*, of the causative event. For the same *M* and *R* values, however, empirical recordings have shown a great deal of scatter. Such variability is captured by a (standardized Gaussian) variable called *epsilon, ε*, which is defined here as the number of (logarithmic) standard deviations by which the (logarithmic) ground motion deviates from the median value predicted by an attenuation relationship given by *M* and *R*. The procedures for conducting a PSHA are summarized as follows [26]. First, a probability density function is created that uses the distance from the rupture to the site to quantify the earthquake's location, and conditions for the source property (magnitude) are defined. Second, for each seismic source, the probability density function of magnitude is characterized to parameterize the earthquake source. The temporal distribution is modeled using recurrence relationships; in general, a Gutenberg–Richter relationship is used for sources, and a characteristic earthquake model is used for active faults. Third, an evaluation of seismic hazard requires an estimate of the expected ground motion, an attenuation relationship, at the site of interest. Mathematically, based on the aggregated hazard from *N* sources located at different distances and capable of generating events of different magnitudes, the PSHA methodology allows computation of the mean annual frequency of exceedance, $\lambda_{Y>x}$, at a site of a specified level *x* of *Y* [8]:

$$\lambda_{Y>x} = \sum_i v_i \iiint f_M(m)\, f_R(r)\, f_\varepsilon(\varepsilon) \qquad P[Y>x|m,r,\varepsilon]\, dm\, dr\, d\varepsilon \quad (1)$$

where v_i is the mean annual rate of occurrence of earthquakes generated by source *i* with magnitude greater than some specified lower bound. Functions of $f_M(m)$ and $f_R(r)$ are the probability density of earthquake-site distance and earthquake-magnitude, respectively. It should be observed that ε is stochastically independent of *M* and *R*, and then $f_\varepsilon(\varepsilon) = (1/\sqrt{2\pi})\exp(-\varepsilon^2/2)$ represent the standard Gaussian distribution. $P[Y>x|m,r,\varepsilon]$ is an indicator function for the *Y* of a ground motion (generated by source *i*) of magnitude *m*, distance *r*, and ε standard deviations away from the median with respect to level *x*.

Analytically, the effects of all earthquakes of different sizes, occurring at different locations within different earthquake sources and having various frequencies of occurrence, are integrated into a single seismic-hazard curve that shows the frequencies of different levels of ground shaking being exceeded at a site during a specified period of time. The MC simulation uses randomly generated points in the simulation of stochastic processes to cover the range of values that enter into a calculation. The technique has the advantage of being relatively easy to implement on a computer and allowing uncertainty in the input parameters to be dealt with in a very powerful way by the generation of random numbers. The essence of the MC simulation is the generation of (pseudo) random numbers from a prescribed probability distribution to incorporate the uncertainty. Figure 1 schematically represents the application of MC simulation in PSHA [11]. Each hypocenter location within the source fault is determined randomly so that the possible range of source-site distance will be $R_{min} < R < R_{max}$ for each fault; as a result, any location within the fault has a seismic equal probability.

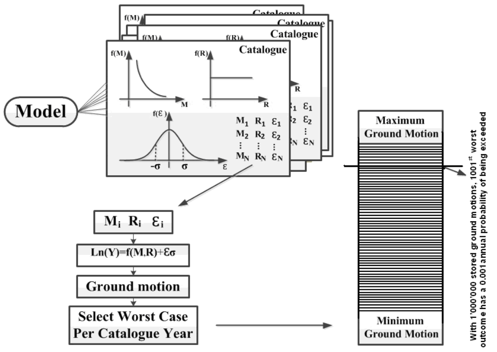


Fig. 1. A typical model of Monte-Carlo seismic hazard assessment

Yazdani and Kowsai [27] examined a range of time- and magnitude-dependent earthquake occurrence models. They found that the Poisson model is adequate since the last earthquake occurrence exceeds the mean recurrence interval and the fault exhibits a very regular interval of earthquake occurrence. It is assumed that earthquakes, with a probability of occurrence described by the Gutenberg-Richter relationship, can occur anywhere. For each fault, the seismic recurrence relationship shows that the range of possible magnitudes will be $M_{min} < M < M_{max}$. The use of Monte-Carlo simulation to compute hazard involves taking a standard seismic source model and using it to generate a large number of synthetic earthquake catalogues representing possible future outcomes of regional seismicity in a period representing the lifetime of the structure being designed [9]. An attenuation relationship is a mathematically-based expression that relates specific, strong motion parameters to one or more seismological variables of an earthquake. For each earthquake, the ground motion at site can be simulated from knowledge of the attenuation and the scatter of the attenuation. From observation of the effects of a very large number of simulations, probabilities can be calculated by merely counting the number of results exceeding a critical value [11]. As a simple illustration, when the highest ground motion value from 1000000 generated data is sorted by size, one can determine the ground motion value with a 10^{-3} annual probability of being exceeded by just picking the 1001st value in the sorted list.

The disaggregation of hazard results, which shows the calculation of different magnitude distance pairs, allows the identification of individual earthquake scenarios that contribute to the hazard for a given ground motion parameter at a selected annual frequency of exceedane [7-10]. The disaggregation based on MC simulation is rooted in actual earthquake occurrence within each synthetic catalogue to calculate design ground motion at the sites. By performing any sort of analysis on the resulting earthquake set, the characteristics of the earthquake most likely can be determined.

3. SEISMICITY PARAMETERS OF TEHRAN

3.1. Tectonic Setting Alborz is an active, EW trending mountain 100 km wide and 600 km long, which was formed when a piece of the Gondwana collided with Eurasia in the Late Triassic. The Alborz range is bounded by the Talesh Mountains to the west and by the Kopet Dagh Mountains to the east [28]. Several active faults affect the Central Alborz [28-30]. Tehran is an important city located in the southern foothills of the Alborz Mountain range. In the south of the Alborz range, the main active faults are the North Tehran, Mosha and Niavaran faults. The North Tehran fault clearly appears as a thrust fault and the other two have behaved as left-lateral strike slip faults during the Quaternary [31, 32]. To the south of Tehran, the Kahrizak, Garmsar, North and South Ray, and Pishva faults also exhibit mostly oblique–reverse left-lateral motion [31]. The locations of the most significant faults in the vicinity of Tehran can also be seen in Figure 2.

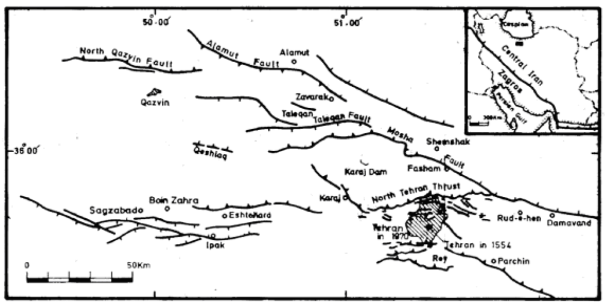


Fig. 2. Active faults in the vicinity of Tehran [15]

3.2. Seismicity Parameters The seismic assessment is based on data on the earthquake occurred in the concerned region (the historical earthquakes, occurred before 1900, and instrumentally recorded earthquakes, after 1900). Usually, the earthquake catalogue in a radius of 200 km is gathered and processed, assuming that the earthquake follow a Poisson distribution. Historical earthquakes in Iran have been reviewed by Ambraseys and Melville [16] and Berberian [28]. Historical earthquakes were ascribed magnitudes that were computed on the basis of a simple linear relationship between intensities and magnitudes [33]. Early (pre-1964) and recent (after 1964) instrumentally recorded events are collected from Moinfar et al. [33] and the global seismological networks [34] for the period 4th BC to 2011. The final collective catalog in this study was prepared by eliminating aftershocks, foreshocks [35] and incorrect reported events from the data. The cleaned and updated catalog contains earthquake magnitudes given in several scales. Surface-wave magnitude (Ms), and body-wave magnitude (mb) and Richter local-magnitude scales are converted to the moment magnitude (Mw) according to the relationships proposed by Utsu [36]. Due to the lack of sufficient recorded data, it was not possible to assign the occurrence of the earthquakes to their causative sources; as a result, estimating the seismicity parameters for individual fault was not possible and was obtained in an area with a radius of 200 km around Tehran. The Gutenberg-Richter recurrence relationship has been calculated using maximum likelihood regression for the sources of background seismicity employing events of magnitude $4.5 < M_w < M_{max}$ from 1900 to 2011 from the catalog. The study area for seismicity parameters is confined to 33°50-´37°50´ N and 49°-53°50´ E. The a and b values were calculated for the whole area and were found to be 2.25±0.05 and 0.55±0.04, respectively [20]. The maximum earthquake magnitude (M_{max}) is determined based on maximum historical earthquake and fault rupture length procedures, for which the most commonly used empirical relationships are relationships provided by Wells and Coppersmith [37]. In this study, the maximum magnitude was found to be equal to 7.8 and 7.5 for the North and South Tehran faults, respectively.

4. HAZARD ANALYSIS AND DISAGGREGATION OF RESULTS

In this section, the procedure for generating ground motions at multiple sites of Tehran for a range of AFE using PSHA and MC simulation are presented. At each site within this study, and at each AFE of interest, the PSHA results would need to be disaggregated for the identification of a few earthquake scenarios that contribute to the hazard level for given ground motion parameters. According to the Monte-Carlo method, the seismic source of the area surrounding Tehran can be considered to construct different earthquake catalogs. In order to produce more accurate results, the area of greater Tehran is divided into one hundred subareas, and the seismic hazard is evaluated for each subarea. An earthquake catalog for Tehran region spanning 10,000 simulations of 100 years of data has been generated using Monte-Carlo simulation, and we include in the calculation all possible sources of earthquakes that may occur within a region surrounding the site. The data is generated using the MC simulation coupled with the Latin Hypercube Sampling (LHS) technique. The ground motions from all the simulations were sorted by size from the largest to the smallest for each site. As a result, hazard curves can be produced for each site. Musson [11] showed that, in a MC simulation, the results with very low AFE may not be accurately represented and that by performing a large number of simulations this disadvantage can be overcome. In this study, two ground-motion attenuation relationships [38, 39], developed for the area of Alborz are used in hazard analysis and disaggregation. Hazard data depicting the peak ground acceleration (PGA) seismic map over bed rocking with a return period of 475 years is presented in Figure 3. These results based on MC approach is comparable with a hazard map produced by Ghorati-Amiri et al. [18] in their PSHA study of Tehran based on conventional approach, and the two produce consistent results, with slight difference, mainly due to the fact that the two studies use different attenuation relationships and different maximum earthquake magnitudes. Figure 4 indicate the 5% damped response for important periods of 0.2 and 1.0 sec spectral acceleration seismic map over bed rock with a return period of 475 years.

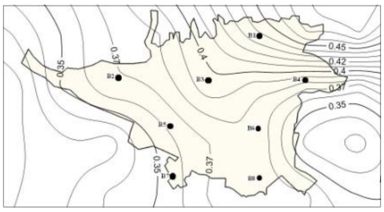
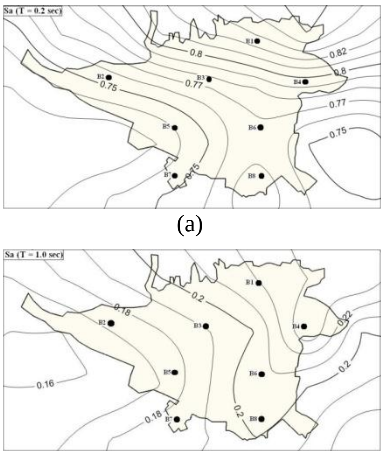


Fig. 3. Seismic zoning map of PGA over bedrock in Tehran and its vicinity for 475 year return period



(a)

(b)

Fig. 4. Seismic zoning map of spectral acceleration over bedrock in Tehran and its vicinity for 475 year return period at a) 0.2 sec, and b) 1.0sec

Seismic hazard disaggregation has two major objectives: the first one is to elicit the contribution to a fixed hazard level in terms of fundamental quantities and the second is to provide seismological parameters describing the earthquakes that contribute most to a fixed hazard value. Subsequently, these parameters can be used to guide the selection of scenario events in the site of interest. In this study, we consider return periods of 475 years for a specific earthquake at a 10% probability of exceedance in 50 years. This level earthquake criterion is the criterion used for the Iranian seismic code in terms of the design basis acceleration. To provide further insight into the contribution to hazard, we disaggregate the hazard results by magnitude *M*, distance *R*, and ground-motion deviation ε. The magnitude-distance-epsilon triple giving the largest contribution to a predetermined level of hazard is the most common result computed by disaggregation analysis. It can be used to select representative time histories or to generate hazard-compatible synthetic signals. The dominant scenario is usually determined by either the mean or the mode of the deaggregated result. The mean has the advantage in that it is defined unambiguously and does not depend on the bin size. The disadvantage is that it may correspond to a scenario that is not realistic if there are two or more sources with significant contribution to the hazard. The mode is the most likely scenario group. It corresponds to the scenario group that has the most probable parameters. The mode has the advantage that it always corresponds to a realistic source [40]. The interval sizes used here (0.1 on magnitude, 1 km on distance, and 0.1 on epsilon) appear to work well. Table 1 illustrates the most likely *M*, *R*, and ε for combinations causing the exceedence of the 475 year ground motion for PGA, 0.2, and 1.0 sec spectral acceleration in different blocks (B1-B8) as demonstrated in Figures 3 and 4. The major contribution comes from moderate and large magnitude at close distance and high values of epsilon. The contribution of the scatter to the hazard is notable. Table 1 carries values for epsilon above the expected value of the hazard-consistent ground motion. There is considerable difference between the design values for different blocks. As might be expected, there is reasonable agreement between the values for PGA and 0.2 sec, and as it is expected the values for 1.0 sec would not agree so well.

TABLE 1. Disaggregation of the Sa with 10% probability of exceedence in 50 years

	PGA			*Sa (T=1.0)*			*Sa (T=0.2)*		
	$\hat{M}$	$\hat{R}$	$\hat{\varepsilon}$	$\hat{M}$	$\hat{R}$	$\hat{\varepsilon}$	$\hat{M}$	$\hat{R}$	$\hat{\varepsilon}$
B1	6.4	7.5	2	6.2	12.5	1.3	6.2	7.5	1.2
B2	6.4	7.5	2.1	6.6	12.5	0.7	6.2	7.5	1.5
B3	7	12.5	1.1	6.6	12.5	1.1	7	12.5	0.7
B4	6.2	12.5	0.7	6.2	12.5	1	6.2	12.5	0.5
B5	6.2	12.5	-1.1	6.4	17.5	1.1	6.2	12.5	1.2
B6	6.6	12.5	1.4	6.2	12.5	0.7	6.6	12.5	1
B7	6.6	7.5	-1.3	6.2	12.5	1.6	6.6	12.5	1.3
B8	6.2	7.5	-0.9	6.4	7.5	1.2	6.2	7.5	1.6

5. CONCLUSIONS

The Monte-Carlo hazard maps demonstrated that hazard, PGA, 0.2, and 1.0 sec spectral acceleration, in greater Tehran decrease from the northeast of the interested area in both southern and western directions. The seismic hazard map of PGA on bedrock indicated that, given the same input data, MC simulation techniques produce the same output as conventional PSHA methods. The MC simulation has the advantage that it is easy to isolate the contributions of different parameters in the analysis in the estimation of the uncertainties in the seismic results. Because a simple model was used for the seismic hazard analysis in this method, most of the uncertainty in the analysis would be categorized as an aleatory uncertainty [41]. In the MC approach, the simulation of long earthquake catalogs and the use of large sets of generated ground motions can give an estimate of the size of the inherent aleatory uncertainty in the seismic hazard values. The PGA ranges from 0.34g to 0.47g for a return period of 475 years, which is more than the PGA values presented in Iranian seismic code. The minimum acceleration values are expected in the south of Tehran where soil deposits are thick while maximum acceleration values are expected in the northeast of Tehran where soil deposits are thin.

The MC approach also has the advantage that it allows the contribution of individual earthquakes to the hazard to be calculated explicitly, making the disaggregation quite simple. The disaggregation results show the location and the size of the postulated earthquakes to calculate design ground motion at the sites. To determine the corresponding parameters at the surface of the sites, local site effects play an important role in earthquake resistant design. The seismic hazard analysis carried out in this paper was based on the assumption of an ideal bedrock case and therefore no influence of local soil condition is taken into consideration.

6. ACKNOWLEDGMENT

The authors would like to thank anonymous reviewers for comments which helped to improve the manuscript.

7. REFERENCES

1. Cornell, C.A., "Engineering Seismic Risk Analysis", ***Bulletin of the Seismological Society of America,*** Vol. 58, (1968), 1583-1606.
2. National Research Council (NRC), "Probabilistic Seismic Hazard Analysis, Report of the Panel on Seismic Hazard Analysis", National Academy Press, Washington, D.C. (1988).
3. McGuire, R.K. and Shedloek K.M., "Statistical Uncertainties in Seismic Hazard Evaluations in the United States", ***Bulletin of the Seismological Society of America,*** Vol. 71, (1981), 1287-

1308.
4. Ishikawa, Y. and Kameda H., "Probability-based Determination of Specific Scenario Earthquakes", in Proc. ***4th Int. Conf. Seismic Zonation***, 3-10, (1991).
5. Stepp, J. C., Silva, W.J, McGuire, R.K. and Sewell R.T., "Determination of Earthquake Design Loads for a High Level Nuclear Waste Repository Facility", Proc., ***4th DOE Natural Phen. Haz. Mitig. Conf.***, Atlanta, 651-657, (1993).
6. Chapman, M.C., "A Probabilistic Approach to Ground Motion Selection for Engineering Design", ***Bulletin of the Seismological Society of America,***Vol. 85, (1995), 937-942.
7. McGuire, R.K., "Probabilistic Seismic Hazard Analysis and Design Earthquakes: Closing the Loop", ***Bulletin of the Seismological Society of America,*** Vol. 85, (1995), 1275-1284.
8. Bazzurro, P. and Cornell C.A., "Disaggregation of Seismic Hazard", ***Bulletin of the Seismological Society of America,*** Vol. 89, (1999), 501-520.
9. Musson, R.M.W., "Design Earthquake in the U.K.", ***Bulletin of* Earthquake Engineering,** Vol. 2, (2004), 101–112.
10. Musson, R.M.W., "Determination of Design Earthquakes in Seismic Hazard Analysis through Monte Carlo Simulation", ***Journal of Earthquake Engineering***, Vol. 3, (1999), 463–474.
11. Musson, R.M.W., "The use of Monte Carlo Simulations for Seismic Hazard Assessment in the UK.", ***Annali di Geofisica***, Vol. 43, (2000), 1–9.
12. Ebel j.E. and Kafka A.L., "A Monte Carlo Approach to Seismic Hazard Analysis", ***Bulletin of the Seismological Society of America,*** Vol**.** 89, (1999), 854-866.
13. Tavakoli, B. and Monterroso, D., "Monte Carlo Seismic Hazard Maps for Northern Central America, Covering El Salvador and Surrounding Area", ***Natural Hazard in El Salvador,*** Geological Society of America, Special paper 375, (2004).
14. Tchalenko, J.S., Berberian, M., Iranmanesh, H., Bailly, M., Arsovsky, M., "Tectonic Framework of the Tehran Region", Geological Survey of Iran, Report No. 29, (1974).
15. Berberian, M. and Yeats, R.S., "Contribution of Archaeological Data to Studies of Earthquake History in the Iranian Plateau", ***Journal* of Structural *Geology*,** Vol. 23, (2001), 563– 584.
16. Ambraseys, N.N. and Melville, C.P., "A History of Persian Earthquakes", Cambridge University Press, Cambridge, Britain, (1982).
17. Boland Payeh Co. "Seismic Hazard Analysis for Milad Tower", Tehran, Iran, (1998), (in Persian).
18. Ghodrati Amiri, G., Motamed, R. and Rabet Eh-haghi H., "Seismic Hazard Assessment of Metropolitan Tehran, Iran", ***Journal of Earthquake Engineering***, Vol. 7, (2003), 347-372.
19. Nowroozi, A.A., "Probability of Peak Ground Horizontal and Peak Ground Vertical Accelerations at Tehran and Surrounding Areas", ***Pure* and *Applied Geophysics,*** Vol. (167), (2010), 1459-1474.
20. Yazdani, A. and Abdi, M.S., "Stochastic Modelling of Earthquake Scenarios in Greater Tehran", ***Journal of Earthquake Engineering***, Vol 15, (2011), 321-337.
21. Yaghmaei-Sabegh, S. and Lam, N.T.K., "Ground Motion Modeling in Tehran Based on the Stochastic Method", ***Soil* Dynamics and *Earthquake Engineering,*** Vol. 30, (2010), 525–535.
22. Nateghi, F., "Earthquake Scenario for the Mega-City of Tehran", ***Journal of Disaster Prevention and Management,*** Vol. 10, (2001), 95-101.
23. Japan International Cooperation Agency (JICA), "The Study on Seismic Microzoning of the Greater Tehran Area in the Islamic Republic of Iran", Final report to the Government of the Islamic Republic of Iran, Tokyo, Japan (2000).
24. Zafarani, H., Noorzad, A., Ansari, A. and Bargi K., "Stochastic modeling of Iranian Earthquakes and Estimation of Ground Motion for Future Earthquakes in Greater Tehran", ***Soil Dynamic and Earthquake Engineering,*** Vol. (29), (2009), 722-741.
25. Iranian Code of Practice for Seismic Resistant Design of Building, Standard No. 2800, Third Revision, Building and Housing Research Center, Tehran, Iran, (2006) (in Persian).
26. McGuire, R.K., "Seismic Hazard and Risk Analysis", Earthquake Engineering Research Institude, Mno-10, (2004).
27. Yazdani, A. and Kowsari, M., "Statistical Prediction of the Sequence of Large Earthquake Engineering", ***International Journal of Engineering,*** Vol (24), (2011), 325-336.
28. Berberian, M., "The Southern Caspian: a Compressional Depression Floored by a Trapped, Modified Oceanic Crust", ***Canadian Journal of Earth Science,*** Vol. 20, (1983), 163–183.
29. Berberian, M., Ghoraishi, M., Shoja-Taheri, j. and Talebian, M., "Seismotectonic and Earthquake-Fault Hazard Investigations in the Semna Region", Geological Survey of Iran, Publication No. 63, (1996).
30. Allen, M.B., Ghassemi, M.R., Sharabi, M., and Qoraishi, M., "Accomodation of Late Cenozoic Oblique Shortening in the Alborz Range, Northern Iran", ***Journal* of Structural *Geology*,** Vol. 25, (2003), 659– 672.
31. Ashtari, M., Hatzfeld, D. and Kamalian, N., "Microseismicity in the Region of Tehran", ***Tectonophysics***, 395, (2005), 193-208.
32. Ritz, J.F., Balescu, S., Sleymani, S., Abbassi, M., Nazari, H., Feghhi, K., Shabanian, E., Tabassi, H., Farbod, Y., Lamothe, M., Michelot, J.L., Massault, M., Che´ry, J.F, and Vernant, P., "Geometry, Kinematics and Slip Rate Along the Mosha Active Fault, Central Alborz, Nice", France, EGU-AGU-EUG Joint Assembly, Abstract EAE03-A-06057, (2003).
33. Moinfar, A., Mahdavian, A. and Maleki, E., "Historical and Instrumental Earthquake Data Collection of Iran, Mahab Ghods Consultant Engineers, Iran", (1994), (in Persian).
34. ISC: On-line Bulletin. Thatcham, UK. *Available at:* http://www.isc.ac.uk
35. Gardner, J. K. and L. Knopof, "Is the Sequence of Earthquake in Southern California, with Aftershocks Removed, Poissonian?" ***Bulletin of the Seismological Society of America,*** Vol. 64, (1974), 1363-1367.
36. Utsu, T., "Relationships between Earthquake Magnitude Scales", ***Bulletin* of the *Earthquake Research Institute,*** Vol. 57, (1982), (in Japanese with English abstract).
37. Wells, D.L. and Coppersmith K.J, "New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement", ***Bulletin of the Seismological Society of America,*** Vol. 84, (1994), 974-1002.
38. Ghodrati-Amiri, G., Mahdavian, A. and Manouchehri-Dana, F., "Attenuation Relationships for Iran", ***Journal of Earthquake Engineering,*** Vol. (11), (2007), 469–492.
39. Ghodrati-Amiri G., Khorasanib, M., Mirza-Hessabib, R. and Razavian-Amrei, S.R., "Ground-Motion Prediction Equations of Spectral Ordinates and Arias Intensity for Iran", ***Journal of Earthquake Engineering***, Vol. (14), (2009), 1- 29.
40. Abrahamson, N.A. "Seismic Hazard Assessment: Problems with Current Practice and Future Developments", ***1th Conference of ECEES,*** Switzerland, (2006).
41. Toro, G.R., Abrahamson, N.A., and Schneider, F., "Model of Strong Ground Motions from Earthquakes in Central and Eastern North America: Best Estimates and Uncertainties", ***Seismological Research* Letters,** Vol. 68, (1997), 41–5.

The Use of Monte-Carlo Simulations in Seismic Hazard Analysis in Tehran and Surrounding Areas

A. Yazdani, A. Shahpari, M.R. Salimi

Department of Civil Engineering, University of Kurdistan, P.O. Box 416, Sanandaj, Iran

A R T I C L E I N F O

Article history:
Received 3 February 2011
Received in revised form 9 April 2012
Accepted 19 April 2012

Keywords:
Probabilistic
Hazard
Monte-Carlo
Design earthquake

چکیده

تحلیل خطر لرزه ای احتمالاتی تکنیکی است که به کمک آن مقدار احتمال رویداد سالیانه یک مشخصه زمین لرزه در یک ساختگاه مشخص تخمین زده می شود. روش شبیه سازی مونت کارلو بر اساس تولید تعداد زیادی کاتالوگ مصنوعی در منطقه مورد نظر روند مناسبی جهت انجام تحلیل خطر احتمالاتی و بررسی عدم قطعیت های آن ارایه می دهد. نقشه های هم خطر نظیر شتاب ماکزیمم زمین و دامنه طیف شتاب نظیر پریودهای ۰/۲ و ۱ ثانیه بر مبنای شبیه سازی مونت کارلو در کلان شهر تهران محاسبه شده است. با روش تفکیک خطر لرزه ای می‌توان ضرایب مشارکت نسبی مقادیر مختلف بزرگ نمایی، فاصله از گسل و مقدار انحراف مشخصه زمین‌لرزه از مقدار متوسط آن (که به کمک رابطه کاهندگی بدست می‌آید) را در تحلیل خطر محاسبه کرد که به کمک این نتایج می توان محتمل ترین بزرگ نمایی و فاصله جهت تعیین زلزله طرح را مشخص نمود. نتایج نشان می دهد که در نواحی مختلف تهران محتمل ترین حالت، رویداد زمین لرزه با بزرگ نمایی متوسط و بالا در فواصل نزدیک می باشد.

doi: *10.5829/idosi.ije.2012.25.02c.9*