Fuzzy-Logic Tree Approach for Seismic Hazard Analysis

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Abstract—**This study presents an approach for seismic hazard analysis based on logic tree and fuzzy sets theory. To accomplish seismic hazard analysis in the framework of fuzzy sets theory, all of the variables are first converted into fuzzy sets using α-cut method. Calculations have been made for various combinations of them and also applying logic tree approach. Extracted output in the framework of fuzzy are defuzzified using mean of maxima method. The method is applied to Tehran site and the hazard curve is obtained. Peak ground accelerations are estimated to be 0.17g and 0.34g for 10% and 63% probability of exceedance in 50-year, respectively. Outcomes of this study would contribute for the quick and better estimation of the seismic design of structures.**

Index Terms—**Fuzzy method, logic tree, probabilistic approach, seismic hazard analysis.**

I. Introduction

Iran is one of the most seismic countries of the world. In this country, a destructive earthquake occurs every several years due to the fact that it is situated over a seismic zone. Tehran city, the capital of Iran, has its special features including highly dense population (more than 10 million people), as well as political and economic centralization, that make it prone to more severe earthquake damage here will affect the whole country, and therefore, the evaluation of the severity of earthquake occurrence is indeed very necessary.

The existence of the active North Tehran thrust, the active faults like Mosha and North and South Rey, the alluvium deposits of Tehran plain and Rey city, and the occurrence severe past earthquakes, all indicate the high seismicity of this region and they have caused the probability of occurrence of severe earthquakes with magnitudes over 7 to be very high [1].

The seismic hazard assessment of this region is of great importance to minimize the seismic risk and to predict earthquakes accurately. Seismic hazard may be analyzed using an empirical-statistical approach, which is based on historical data, or a deterministic approach, when a particular scenario is assumed, or a probabilistic approach, in which uncertainties in earthquake size, location, and time of occurrence are explicitly considered.

Based on, logic tree approach and fuzzy set theory, the present study analysis the probabilistic seismic hazard for the Tehran site and peak ground acceleration over bedrock for 10% and 63% probability of exceedance in 50 years are estimated for it.

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II. Tectonic Setting

During a quarter of century, from the pioneering works of Stöcklin [2] and Nowroozi [3-5] to Berberian [6], [7], Jackson and McKenzie [8, 9], Baker et al. [10], Priestley et al. [11], Jackson et al. [12], [13], Talebian and Jackson [14], Tatar et al. [15], Walker and Jackson [16], and Copley and Jackson [17], considerable efforts have been made to understand the active tectonics of Iran and neighboring regions.

Mirzaei et al. [18] divided the territory of Iran into five major seismotectonic provinces (Fig. 1), which we used in this study. Our study area, encompassed by the 49.5–53.5°E longitudes and 34–37°N latitudes, is located in two of these main seismotectonic provinces: Alborz-Azarbayejan and Central- East Iran. In order to understand the seismotectonic of the region under study, the conditions of these two seismotectonic provinces are briefly discussed.

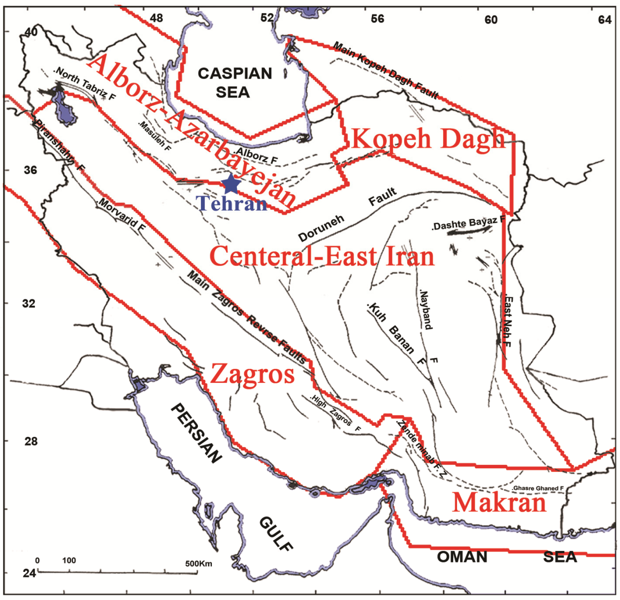

Fig. 1. Major seismotectonic provinces of Iran [18].

A. Alborz-Azarbayejan Seismotectonic Province

Alborz-Azarbayejan major seismotectonic province is a significant belt of seismicity that covers the northwestern Iran and southern margin of the Caspian Sea. The Alborz Mountains, as a northern segment of the Alpine–Himalayan orogenic belt in western Asia, constitute the eastern part of the Alborz-Azarbayejan province across the northern Iran.

They face the depressed South Caspian Block in the north and to the south grade into the plateau of Central Iran. The structure of Alborz is the result of two great orogenies [19]: a Precambrian (Assyntic) orogeny and the Alpine orogeny of Mesozoic–Tertiary.

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B. Central-East Iran Seismotectonic Province

Central-East Iran is an intraplate environment between Zagros and Kopeh Dagh fold-trust border belts. It has undergone several major orogenic phases and is characterized by various syntectonic metamorphic and magmatic events, especially during the Late Paleozoic, Middle Triassic, Late Jurassic, and Late Cretaceous phases along its southwestern margin [6].

Seismicity in Central-East Iran is mainly concentrated on several seismogenic fault zones surrounding relatively stable microcontinental fragments. The eastern part of Central-East Iran shows more intense seismicity, in which major seismic activity is concentrated in few patches on the active fault zones [18].

In its northern border, the Central-East Iran major seismotectonic province is separated from Alborz-Azarbayejan and Kopeh Dagh by a series of active faults, namely, North Tabriz, Ipak, Torud, Meyamey, Sabzevar, and Torbat-e-Jam from east to west, respectively.

Along its eastern edge, the region is bounded by the north– south trending Harirud Fault, which despite its current aseismic character and pre-Jurassic age serves as a boundary between the aseismic zone of western Afghanistan and the highly seismic region of eastern Iran [20].

The southernmost extent of Central-East Iran coincides with the inner ranges of Makran, bounding the Jaz Murian depression from the south. To the west and southwest, Central-East Iran is clearly separated from the Zagros by truncation of intense seismicity and sharp topography change along High Zagros Reverse Fault and Main Recent Fault [18].

III. POTENTIAL SEISMIC SOURCES

In practice, two key assumptions are considered; first, the assumption of earthquake repeatedness, implying that major earthquakes occur preferentially near the sites of previous earthquakes; second, the assumption of tectonic analogy, which implies that structures of analogous tectonic setting are capable of generating same size earthquakes. Preferentially, potential seismic sources are modeled as area sources, in which the configuration of each source zone is controlled, mainly, by the extent of active faults, the mechanism of earthquake faulting and the seismogenic part of the crust [21].

A total of eleven potential seismic sources in Tehran and neighboring regions delineated by Tahernia and Boostan [22] based on available geological, geophysical, tectonic and earthquake data were used in this study as displays in Fig. 1.

IV. SEISMICITY PARAMETERS

The classical description of seismic activity is based on the seismic activity rate, l, which is equal to the number of events with magnitudes equal or greater than a defined magnitude level, say M_0, during a specified time period, T; the parameter b (or β, β=b ln10); and sometimes the max- imum magnitude, M_{max} [23].

Seismicity parameters for these potential seismic sources were evaluated by Tahernia and Boostan [22] using the method developed by Kijko and Sellevoll [24] in which magnitude uncertainty and incompleteness of earthquake data are considered (Table I)

TABLE I: SEISMICITY PARAMETERS OF THE SEISMIC POTENTIAL SOURCES OF STUDY AREA.

Source	M_{max}	β	$\lambda_{4.0}$
1	5.3 ± 0.22	1.57 ± 0.65	0.19 ± 0.04
2	6.3 ± 0.40	1.37± 0.62	0.19 ± 0.03
3	7.3 ± 0.32	1.28 ± 0.31	0.21 ± 0.04
4	6.1 ± 0.72	0.71 ± 0.08	0.14 ± 0.02
5	7.7 ± 0.55	0.76 ± 0.07	0.16 ± 0.02
6	5.5 ± 0.41	1.26 ± 0.46	0.13 ± 0.02
7	6.3 ± 0.57	1.15 ± 0.67	0.16 ± 0.02
8	6.9 ± 0.48	1.21 ± 0.30	0.24 ± 0.05
9	6.8 ± 0.21	0.65 ± 0.05	0.13 ± 0.02

V. BACKGROUND EARTHQUAKE

In the regions in which lack of information does not allow for delineation of potential seismic sources, and even in areas where the active faults are defined, it is necessary to model background earthquake (background seismicity). In the concept of background seismicity, small- and moderate-sized earthquakes may occur in the defined area randomly. We used background earthquake values determined by Mirzaei et al. [25] about 6.0 and 5.5 for studied areas located in the Alborz - Azarbayejan and Central-East Iran provinces, respectively.

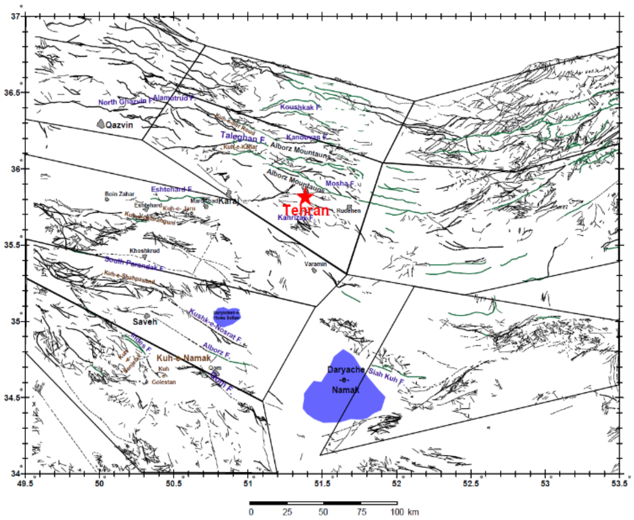

Fig. 2. Potential seismic sources in the Tehran region [22].

VI. ATTENUATION RELATIONSHIP

Since the attenuation relationship highly influences the results of seismic hazard analysis, the choice of a ground motion attenuation model is of great importance. However, because of inadequacy of usable data, there is not a well-constrained attenuation relationship for Iran. Therefore, four attenuation relationships are used in this study. PGA is the most commonly used ground motion parameter for the seismic hazard studies. The present study involved use of the following attenuation relationships developed by Ambraseys et al. [26], Campbell and Bozorgnia [27], Chioua and Youngs [28], and Boorea and Atkinson [29].

VII. Probabilistic Seismic Hazard Analysis

Numerous seismic hazard forecasting models were developed within the last several decades. The simplest widely used model is the Poisson model with the assumptions that seismic events are spatially and temporally independent and the probability that two seismic events will take place at the same location and at the same time approaches zero [30].

Seismic hazard is the expected occurrence of a future adverse earthquake that has implications of future uncertainty. Therefore, the theory of probability is used to predict it [31].

Assuming that the exceedance of ground motion value g follows a Poisson process, we have:

$$P(G_i > g) = 1 - e^{-\nu_g t}, \quad (1)$$

where $P(G>g)$ is the probability of exceeding ground motion value g and υ_g is the rate of exceeding ground motion value g.

υ_g is estimated in the hazard calculations by evaluating the following expression:

$$\nu_g = \lambda \int_{m^-}^{m^+} \int_{r^-}^{r^+} f_R(r) f_M(m) P(G > g|EQ\!: m, r)\, dm\, dr, \quad (2)$$

where, λ is the seismicity rate of earthquakes with magnitudes between m^- and m^+. $f_R(r)$ and $f_M(m)$ denote the probability density function of site-to-source distance, r, and the probability density function of earthquake magnitude, m, respectively. $P(G > g|m,r)$ is the conditional probability of ground motion G exceeding some specified value, g, given the occurrence of an earthquake of magnitude m at distance r.

In the general case of multiple seismic sources, the total hazard can be calculated easily if it is assumed that the sources are statistically independent. In that case, for t=1 year and $\upsilon_{g_i} \ll 0.1$,

$$P_{total}(G > g) = \sum_{i=1}^{n} \nu_{g_i} \quad (3)$$

A plot of the values of P_{total} from equation (3) versus motion parameter, g, is known as a hazard curve. This is a basic result of the hazard analysis. [32].

VIII. Fuzzy Sets

Seismic hazard assessment like many other problems in seismology is a complicated problem, owing to the variety of parameters affecting the occurrence of earthquake. Uncertainty, which is a result of vagueness and incompleteness of the data, should be considered in a rationale way. Herein, fuzzy set theory is used to take into account the inherent uncertainty in the seismic hazard analysis.

Fuzzy sets are groups whose components have grades of membership. It was first presented by Zadeh [33] who extended the classical concept of sets. Information is obtained from data, measurements, or past knowledge; approximations must often be made which in turn introduce uncertainties. Fuzzy sets signify vague information which required in the analysis. The data are fuzzy numbers, i.e., fuzzy variables defined on a real line in a fuzzy environment.

A. A- Cut Technique

Zadeh [33] presented α-cut or α-level set, which is one of the most significant concepts established as a link between fuzzy set theory and traditional set theory.

Let X be a non-empty set, $F(X)$ represents the set of all fuzzy sets of X. A is a fuzzy set in X, where, $A \in F(X)$ and $\alpha \in [0, 1]$. Then the non-fuzzy or crisp set:

$$A_\alpha = \{x \in X | \mu_A(x) \geq \alpha, \quad (4)$$

is called theα-cut or α-level set of A. If above equation is replaced by:

$$A_\alpha = \{x \in X | \mu_A(x) > \alpha, \quad (5)$$

then is called a strong -cut. Any fuzzy set can be collected from a family of nested crisp sets satisfying equation (5), and the problems in the context of fuzzy sets such as decision making could be solved by transforming these fuzzy sets into their families of nested α-cuts and determining solutions to each of them using traditional techniques. Then all the partial results derived in this way are merged reconstructing a solution to the problem in its original fuzzy set based formulation.

In this study four of the input parameters including d, β, λ and M are fuzzily defined by the discrete membership functions μ(d), $\mu(\beta)$, $\mu(\lambda)$ and $\mu(M)$, respectively.

IX. Logic Tree

Input parameters to probabilistic seismic hazard analysis (PSHA) such as fault dimensions, recurrence rates, maximum magnitudes, attenuation relationships, etc. [1]. Often has to be estimated from limited data or determined by subjective judgment. Logic tree is a popular tool used to compensate for the uncertainty in PSHA. Logic tree reflects uncertainty by allowing the analyst to assign each parameter a range of values, along with an assessment of the probabilities that each of these is the correct value [34]. The final result of this process is a logic tree in which each of the value forms a branch. Fig. 3 shows the logic tree that considered the uncertainty in attenuation relationships and sources.

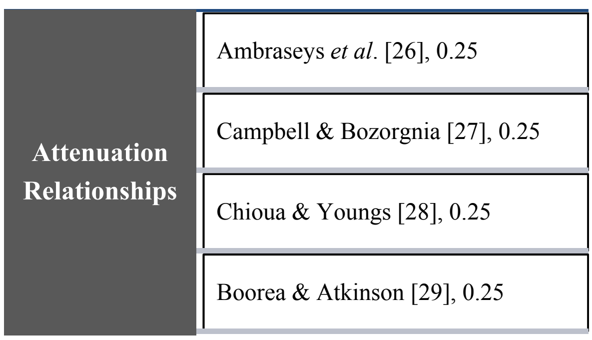

Fig. 3. Elements of logic trees in our PSHA scheme and the assigned weights.

Each branch is weighted by the product of the weight assigned to it. Seismic hazard can then be assessed at each end nod. The reason for using the four different attenuation relationships rather than a single one in this paper is that Iranian data does not have the required accuracy.

Since in many applications of fuzzy logic in engineering problems, most of the decisions by humans or machines (e.g. computers) are to be zero and one, it is necessary to convert the results of fuzzy analyses to classical (typical) numbers. The output is defuzzified using mean of maxima method, one of the most common method to quantify a fuzzy quantity.

The hazard curve for Tehran site are displayed in Fig. 4. This figure shows curve for the study site with applying logic tree and fuzzy set theory approaches.

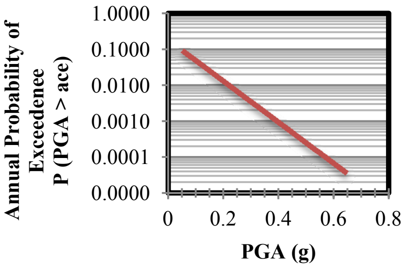

Fig. 4. Seismic hazard curve of Tehran site

X. Conclusion

In this study, we apply logic tree approach and fuzzy set theory to analysis seismic hazard of Tehran site. Calculations have been made for various combinations of variables with applying both fuzzy set theory and logic tree approach. The extracted outputs in the framework of fuzzy are defuzzified using mean of maxima method. Peak ground accelerations are estimated to be 0.17g and 0.34g for 10% and 63% probability of exceedance in 50-year, respectively.

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