SIMULATION OF GROUND MOTIONS FOR THE CITY OF IZMIR

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SUMMARY

A complete seismic design of structures require linear and nonlinear time-history analysis. There are not enough recorded time histories in many part of the world, therefore a number of techniques and computer programs have been developed either to completely synthesize an accelerogram or modify a recorded accelerogram. Both of these methods require uniform hazard spectrum (UHS) as a target spectrum to generate the artificial time histories. This spectrum could be obtained from probabilistic or deterministic seismic hazard analysis. The city of Izmir is lying in the first seismic zone of Turkey. Unexpected large earthquakes can occur in this region, potentially leading to severe damages and losses. A uniform hazard response spectrum (UHRS) is constructed and ground motions are simulated for the city. To achieve this objective, the recorded earthquake database from different references is used. Future events are then modelled by using the past records with a point source model. After constructing the uniform hazard response spectra for 10% and 2% probabilities of exceedance over the next 50 years, 10 ground motions are selected which best fit the UHRS.

Key Words: *Seismic Design; Uniform Hazard Spectrum;Seismic Hazard; Point Source Model*

1- INTRODUCTION

Modern Building Codes allows two basic approaches to the earthquake-resistant design of structures: a static approach in which the effects of ground motions are represented by static lateral forces, and a dynamic approach in which the response of the structure is determined by response spectrum analysis or by time-history analysis. Hence, design ground motions can be specified in terms of design response spectra or design ground motion time histories. The characteristic of the design ground motion at a particular site are influenced by the location of the site relative to potential seismic sources, the seismicity of theose sources, the nature of rupture at the source, travel path effects between the source and the site,and the local site effects (1).

In many places on earth, there are not avaible earthquake records of enough quality to be used as directly an input motion to the structural analysis. This reason stems from the instrumental errors as well as the complex fault conditions. Therefore, there is a need for artificial and/or scaled records of similar earthquake regions. The main challanges in their development is to ensure that they are realistic and consistent with the target parameters. Many motions can appear reasonable in time domain but not when examined in frequency domain. In addition, trying to account for source-to-site effects, such as basin, near-source, and directivity effects, becomes increasingly complex. This study concerns the related issues and comes up with an alternative approach, in which previous records are used to estimate the possible future earthquakes using a point-source simulation method originally developed by Boore. For the purpose of this approach, a uniform hazard response spectrum (UHRS) is first constructed for probabilities of exceedance of 10% and 2% in 50 years, and then select ground motions having their acceleration response spectrum closely fitting to the constructed UHRS .

The current study contributes to previous studies by providing extensive information on the seismicity and seismic hazard in Izmir and its surrounding region. First, the historic and instrumented era earthquake records currently avaible in the international databases were taken into consideration. These records are then combined together for predicting future possible earthquake epicenters and moment magnitudes. These data, with the appropriate seismological parameters, were combined to evaluate seismic hazard in the city of Izmir.

2. STUDY AREA AND THE SEISMICITY OF THE REGION

Izmir is located in a very active seismic region in Western Anatolia (Figure 2.1). Earthquakes in the Aegean Graben System and the Aegean Trench dominate the seismicity of the region. The probabilistic evaluation of the earthquake hazard analysis lies in determination of the important fault zones for the city/place of interest. The sophistication of this approach can vary between a single areal source models to very detailed multi-source models (3). In areas with active seismicity and complex tectonic formations, it may be realistic to assume a single tectonic areal source with a fixed radius around the investigated area (4). Due to the complexity and interlacing of the fault zones in the region, almost none of the seismic sources could be defined exactly in the form of well-defined, distinct fault lines (5).

Furthermore, due to the shallow dip angles of the most of the fault zones, earthquake epicenters associated with a given fault zone varied in the latitude-longitude coordinate system for different focal depths. Therefore, accounting all the facts discussed so far, a simple single areal source model was adopted to estimate the regional earthquake hazard for the city of Izmir.

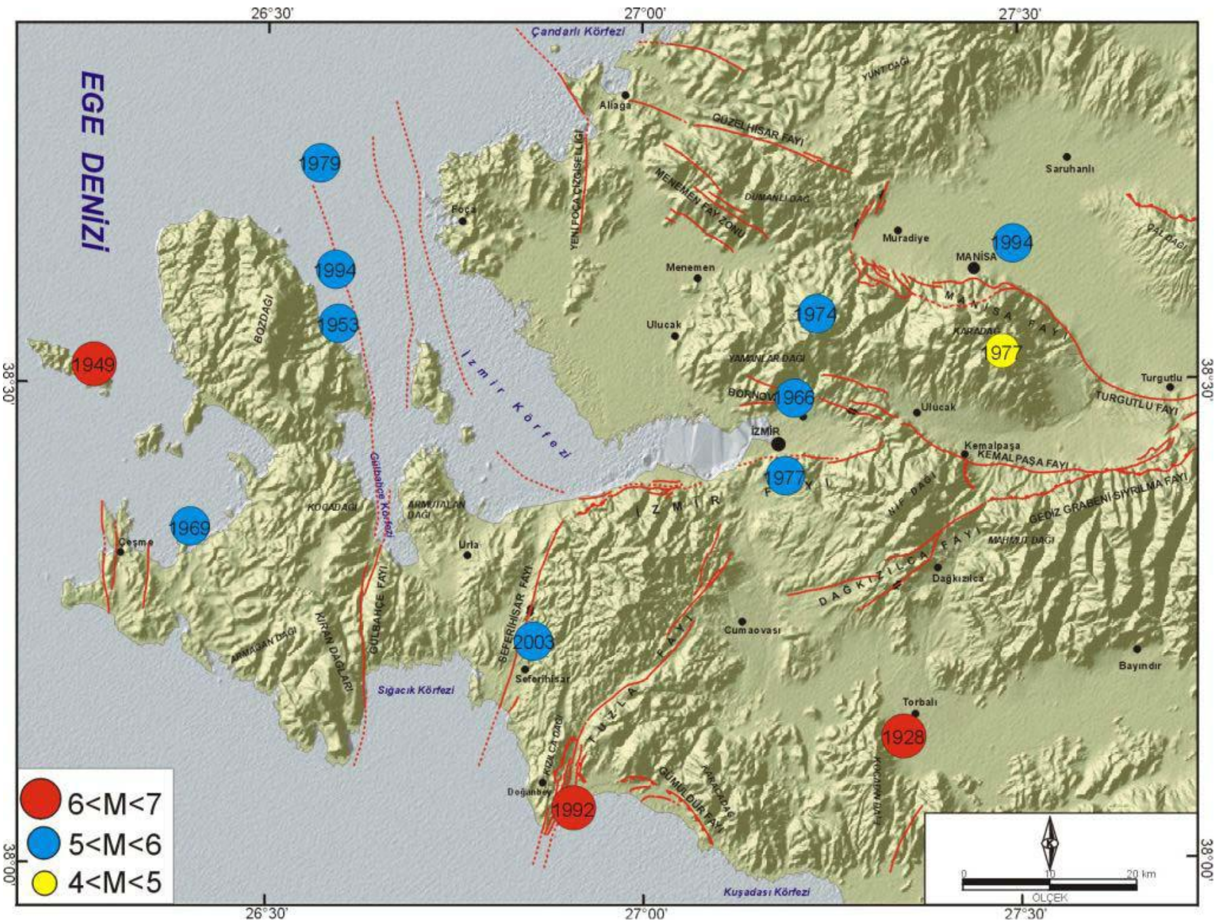

Figure 2.1 Main Highlights of the Earthquakes and related fault zones in Izmir Region.

2.1. Earthquake Catalogue

The first stage in probabilistic seismic hazard analysis is the estimation of the probable earthquake magnitude based on seismological and geological data for the region. The effective zone is taken to be a circular area with a radius of 100 km centered at the given city center. Earthquake records for the historical era (approximately between 1654 and 1899) with intensity Io >V, for Izmir region were compiled based on available earthquake catalogues (6,7, 8). Since the records for this period are in terms of intensities, the relation developed for Turkey by Ansal (9) is used;

$$M = 0.594\, Io + 1.36 \tag{2.1}$$

This method of evaluation is not without some drawbacks. To mention some, for instance, the historical data compiled for a longer time interval may not be very accurate with respect to the given epicenter locations, dates, and intensities. Using the instrumental records, hovewer, will not represent the tectonic regime going on for millions of years. The result of this earthquake database evaluation is the occurance intervals given in Table 2.1, each with the occurance times constrained with the earthquake magnitudes. Table 2.2, gives the database results as a function of occurance and probability distribution.

Table 2.1 Earthquake Occurance Intervals

TIME	Number of Earthquakes Nm with M>m,						
PERIOD	4	4,5	5	5,5	6	6,5	7
Nm	370	201	86	61	27	9	2
λm	1,06	0,57	0,25	0,17	0,08	0,03	0,01
	290						

Table 2.2 Earthquake Epicenter Distributions and Probabilistic Evaluation of Data

Epicenters	Number of Earthquakes Nm with M>m,									
Epicenters	1;10	10;20	20;30	30;40	40;50	50;60	60;70	70;80	80;90	90;100
Number of Occurance	17,00	20,00	16,00	24,00	37,00	65,00	63,00	36,00	52,00	38,00
λ4	0,05	0,06	0,05	0,07	0,11	0,19	0,18	0,10	0,15	0,11
	5,00	15,00	25,00	35,00	45,00	55,00	65,00	75,00	85,00	95,00
P(i)	0,05	0,05	0,04	0,06	0,10	0,18	0,17	0,10	0,14	0,10
Fλ(i)	0,05	0,10	0,14	0,21	0,31	0,48	0,65	0,75	0,89	1,00

2.2. Prediction of Future Earthquake Parameters

For the evaluation of earthquake hazard, the possible future earthquake moment magnitudes and epicenters are defined using the avaible earthquake magnitude and epicenter records mentioned in the previous section. The procedure for predicting future earthquake magnitudes and epicenters starts with determination of the cumulative distribution of both the magnitude and epicenters of historically investigated data. Based on the past earthquake data and occurance rates, 1050 earthquakes will be generated for the next 1000 years in the aerial limit of Izmir center. Therefore, a set of uniformly distributed 1050 random numbers is generated from 0 to 1, which represent both the $F_M(m)$ and F_λ (k) for the future 1000 years. A statistical analysis in MATLAB was conducted for this purpose by assuming that all epicentres of past earthquakes are possible epicentres for future earthquakes (10, 11). A magnitude and epicenter corresponding to these cumulative distribution values are then used for earthquake simulation parameters. For instance, in Figure 2.2, a randomly selected cumulative distribution function of 0.6 corresponds to the magnitude of 4.75.

Using the data in Table 2.1, the resulting probability distribution of magnitude for the Gutenberg-Richter law with lower bound is expressed in terms of cumulative distribution function (CDF):

$$F_M(m) = P\{M < m | M > m_0\} = \frac{\lambda_{mo} - \lambda_m}{\lambda_{mo}} = 1 - e^{-\beta(m - m0)} \tag{2.2}$$

Probability density function (PDF) is defined in Eqn. 2.3. below

$$f_M(m) = \frac{d}{dm} F_M(m) = \beta e^{-\beta(m-m0)} \tag{2.3}$$

Cumulative distribution function of earthquake magnitudes is given in Figure 2.2 based on the Gutenberg-Richter formulation.

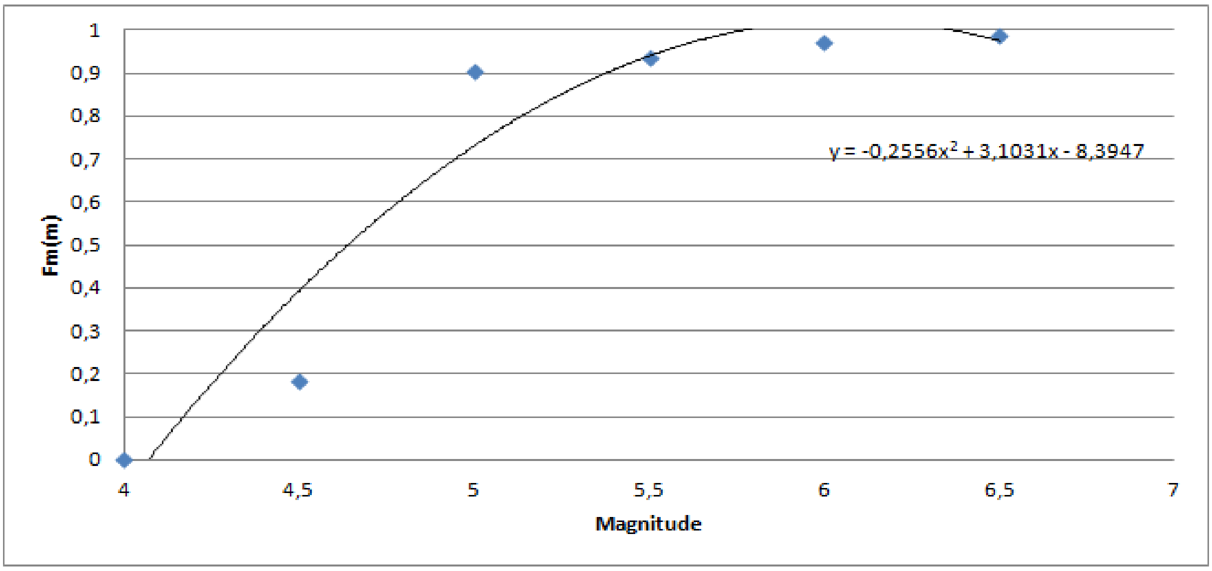

Figure 2.2 Gutenberg-Richter evaluation of moment magnitude v.s. fm(m).

The possible earthquake epicenters of future events are generated using cumulative distribution probability F_λ(i) is evaluated in Egn 2.4 and given in Figure 2.3.

$$F\lambda(i) = \sum_{i=1}^{ki} P_{ki} \tag{2.4}$$

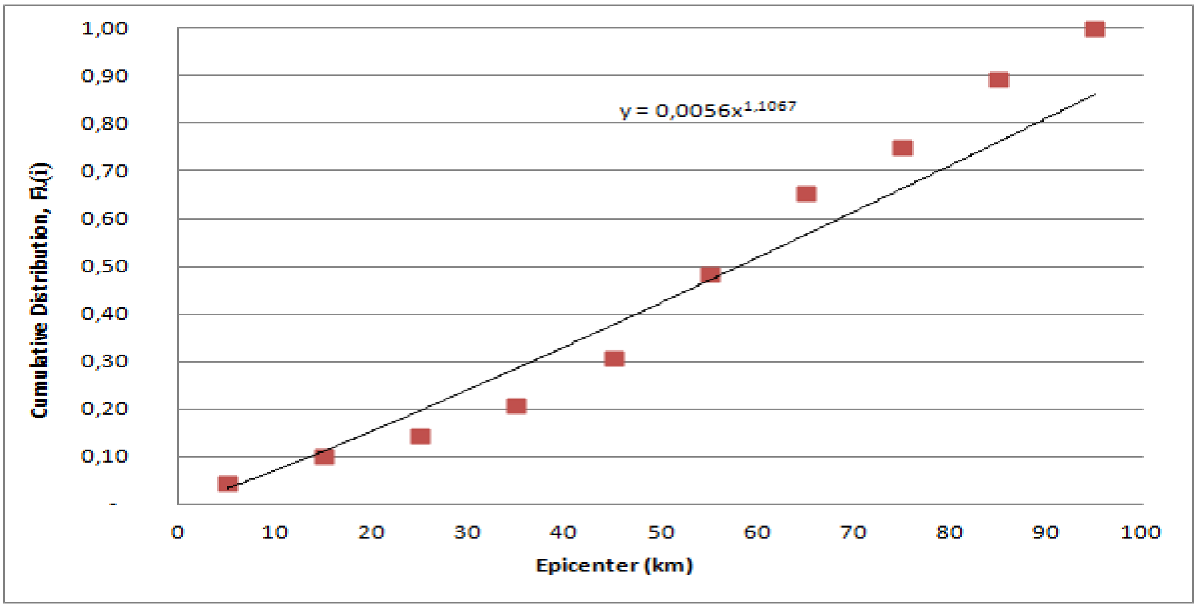

Figure 2.3. Cumulative distribution function of possible future earthquake epicenters

3. PROBABILISTIC SEISMIC HAZARD ANALYSIS

As the time of occurance, magnitude and location of future earthquakes are not known with certainty, seismic hazard analysis may be performed in a probabilistic manner. The key steps of the probability-based seismic hazard analysis are stated as below (Fig. 3.1)

- determination of the seismic sources,
- assesment of the earthquake occurance characteristics for each seismic zone,
- selection of the appropriate ground motion prediction model including attenuation and local site effects
- identification of the site characteristics.

3.1. Simulation Method And Model Parameters

In this study, a ground motion simulation method based on stochastic approach (12) is used. In this method the ground motion is modeled as band limited finite-duration Gaussian white noise in which the radiated energy is assumed to be distributed over a specified duration (13).
One of the important features of this method is that it puts together the various factors affecting ground motions–source, path, and site factors–into a physically determined algoritm so that it can be used to predict ground motion. Modeling parameters of the point source model for the city of Izmir is adopted from the previous studies (14, 15, 16, 17, 18).

This stochastic ground motion models is widely used in different regions of the world and is proved to be a reliable method for the seismic regions of the world, in where quality strong ground motions can not be gathered easily. To mention, some of these studies are referenced here which were used in various academic and design studies (19, 20, 21, 22).

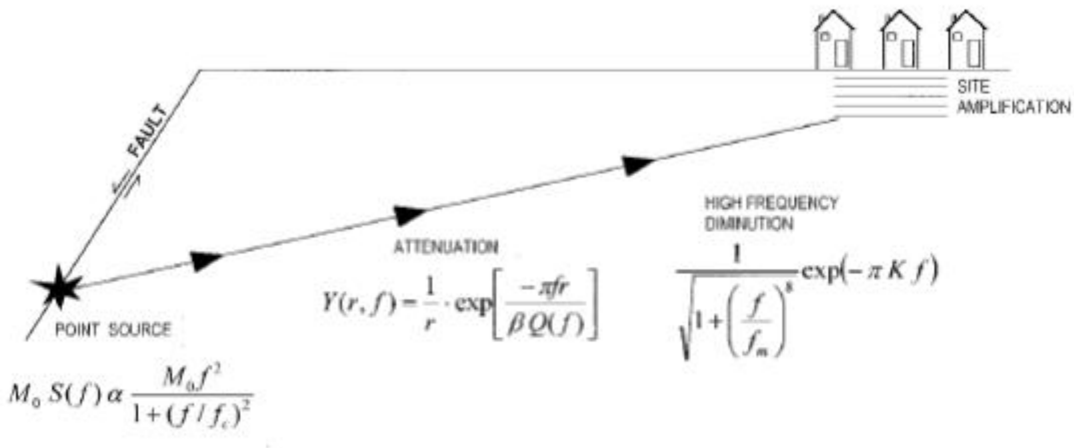

Figure 3.1. Source to Site Modeling of Seismic Motion

The paremeters used in simulations are given in Table 3.1 below. These parameters were used to evaluate the ground motion for the bedrock-engineering rock level (Vs≥750 m/sn). Model involves various phases from the source to attenuation and dimunition. The site amplification effects does not taken into account as the ground motion motion is evaluated for the bedrock level. This motion will then be used for site-specific analysis or dynamic soil-structure interaction analysis (23).

Table 3.1. Parameters and Algoritm Used In The Analysis.

Acceleration Fourier Amplitude Spectrum	A(f,M0,R)=S(f,M0)D(f,R)P(f)
Source Spectrum -*Brune Source Spectrum*	$S(f,M0)=C(2\pi f)^2 M0\frac{1}{1+(\frac{f}{fc})^2}$ $C=R_{\Phi}FV/(4\pi\rho\beta^3 R_1)$ R_{Φ}=0,55, F=2, V=0,71 ρ=2,8 g/cm3
Corner Frequency	$fc=4{,}9*10^6\beta\frac{\Delta\sigma}{M_0}^{1/3}$ β= 3,87 km/s Δσ= 100 bars
Attenuation	D(f,R)=Dg(f,R)D(f)
Geometric Attenuation	Dg(R)=1/R; R<70 km Dg(R)=1/70; 70<R<130 km $Dg(R)=1/70(130/R)^{0,5}$ R>130 km
Q model-Anelastic Attenuation	$Q(f)=220f^{0,52}$
Low-Cut Filter	P(f)=exp(-πκf) κ=0,048 sec- sand κ=0,006 sec-hard rock κ=0,02 sec- soft rock κ=0.04 sec;

In current seismic performance evaluation procedures two different seismic hazard levels are generally used, which are defined by probabilities of exceedance of 10% and 2% in 50 years. For these two levels, annual occurrence rates can be calculated using Poisson process shown in Eq. 3.1:

$$P(S_a > a_j, t = 50 \text{ years}) = 1 - e^{-\lambda(S_a > a_j) x 50} \quad (3.1)$$

The annual occurance rate, $\lambda(S_a > a_j)$ is calculated as 0.0021 and 0.004, corresponding to for 10% and 2% probabilities of exceedance in 50 years ($P(S_a > a_j, t = 50$ years). Thus Sa is calculated for the annual exceedance probabilities of 0.0021 and 0.0004 for each 91 periods. Figure 3.2 shows the spectral accelerations for the 10% and 2% exceedance of probabilities in 50 years at T=0.05 s. After evaluating the same spectrals at each 91 periods, the outcome is the uniform hazard spectrum (See Fig. 3.3).

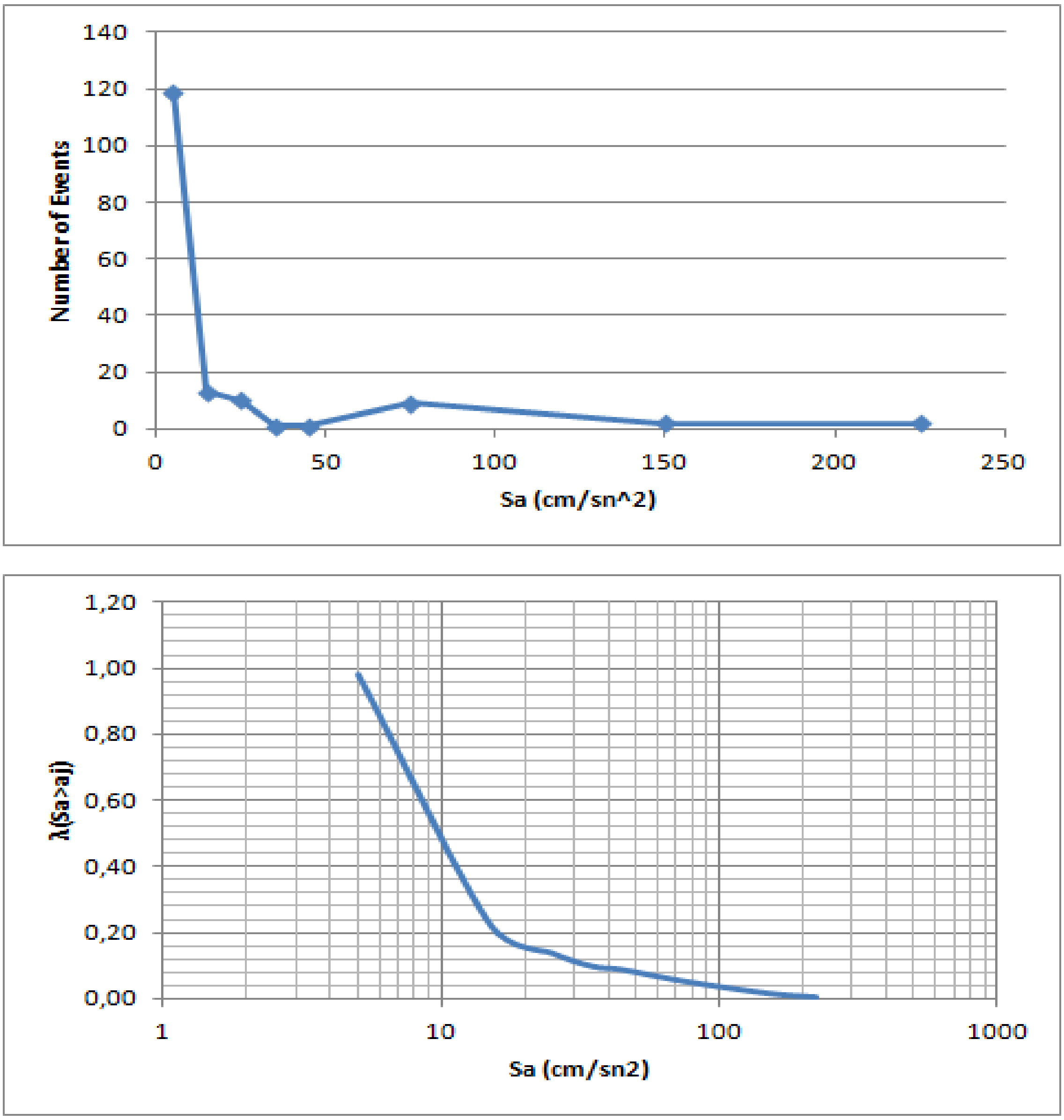

Figure 3.2. Histogram of acceleration response spectrum (T = 0.05 s). (a) Histogram, (b) λ(S_a < a_j).

Representative ground motions for 10% and 2% in 50 years can also be selected from the ground motions with the least squared logaritmic difference from the target spectrum. This is achieved by selecting ground motions from 1050 ground motions, which have the least sum of the squared logarithmic difference calculated by Eq.3.2 at 91 different periods between their acceleration response spectra and uniform hazard spectrum. This procedure is proposed by (24).

$$d_i = \sum_{j=1}^{91}(\log S_{aj-UHRS} - \log S_{aj})\text{^}2 \quad (3.2)$$

Where d_i is the sum of the squared logaritmic difference of ith ground motion (i=1-1050), $S_{aj-UHRS}$ is the uniform hazard response spectrum at jth period (j=1-91), and S_{aj} is the response spectrum of ith ground motion at jth period.

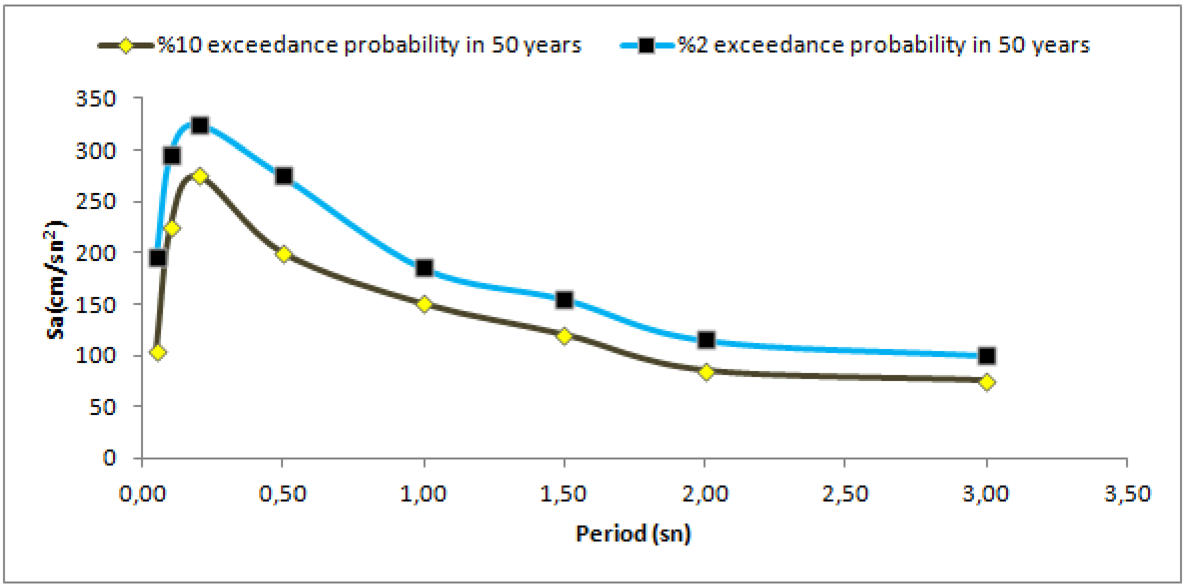

Figure 3.3. Uniform Hazard Spectrum-Bedrock Izmir (UHRS-IZMIR)

4. CONCLUSION

In designing new structures and evaluating seismic performance of existing structures, it is important to construct an accurate uniform hazard response spectrum and to simulate representative earthquake ground motions at a selected site. A uniform hazard spectrum defines the contribution of various source zones, takes into account different range of earthquake magnitudes occuring at various rates and thus directly takes into account the outcome of these complex fault systems. In these type of regions, the areal concept of probabilistic analysis is adopted. From the historical and instrumental records, a probabilistic distribution of the magnitude and epicenters are determined from which the new distributions are determined.

This study simulates future earthquakes defined by magnitudes and epicenters, based historically avaible and instrumental records. Using simulated earthquakes, ground motions are generated at a site using the SMSIM software that can account for attenuation and local site condition. The parameters used for the point source model in the SMSIM software is adopted from a range of literature survey, which best fits the data. As an outcome of the study, a uniform hazard response spectra is constructed for 10% and 2% probabilities of exceedance in 50 years. Ground motions that have the least logarithmic difference between their response spectrum and uniform hazard response spectrum at 91 different periods among 1050 simulated ground motions can also be selected and used in the dynamic soil-structure interaction analysis.

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