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Technical Note

INFLUENCE OF SITE AND SOIL CHARACTERISTICS ON UNIFORM HAZARD SPECTRA OF ANDIMESHK SITE

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ABSTRACT

Evaluating strong ground motion propagation in soil is one of the issues in geotechnical engineering which has caused heated debate among engineers and it is utilized for computing ground surface motions. This paper, presents analyses to acquire hazard curves and uniform hazard spectra for Andimeshk site considering the influences of the site and soil characteristics. Several recorded accelerograms of the past earthquakes at the abovementioned site and adjacent zone (radius of 200Km) are used to determine the region-specific source parameters. Seismic hazard curves are first acquired by using the Crisis software based on the records of Andimeshk catalog and then uniform hazard spectra obtain considering site effects by modeling the soil profile of Andimeshk and performing the nonlinear analysis in time domain by DeepSoil software. The results are compared to Iranian Seismic Code and significant differences are shown. Moreover, this paper provides further suggestions for using new spectrum (2/3 of 2% in 50 years) for engineering design purposes.

Keywords: Site effect; hazard spectrum; ground surface motions.

1. INTRODUCTION

Recent investigations have been carried out to retrofit buildings under seismic motion and to predict the effect of an earthquake according to characteristics such as distance from the source of energy release or the effect of area soil. The design of structures requires specific methods and approaches which may include modifying the spectra, applying specific coefficients to computations and specific recommendations for design in those fields.

Evaluating ground response has caused heated debate among geotechnical engineers because ground response analysis is used to predict ground surface motion. Records from previous earthquakes have shown the influence of local site conditions in the propagation of ground motion. Strong ground motion from earthquakes such as the 1999 Chi-Chi, 1989

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Loma Prieta, and 1994 Northridge events indicate significant differences exist between soil site and nearby rock site responses. Investigation of the 1985 Mexico City earthquake has shown that the existence of soft soil can result in significant amplification of ground motion, even at large distances from the earthquake source and cause severe damage.

Analysis to predict site response is usually performed using a site response model. The accuracy of prediction depends on several factors, the most important of which is representation of soil behavior during a seismic event. Site effects are vital for prediction and evaluation of seismic hazard at the ground surface [1]. Probabilistic seismic hazard analysis (PSHA) can be used for a given location in a given future time period to predict earthquake ground motion and probabilistic models of earthquake occurrence can be used to estimate specified levels of earthquake ground motion. A seismic hazard curve for a specific site and a seismic hazard map for a specific area are the preferred results of the PSHA for practical application of seismic hazard maps [2].

PSHA has revealed that it is desirable to use a single conditioning period for spectral acceleration, since a direct link to a ground motion hazard curve (for spectral acceleration in a single period) is beneficial to probabilistic assessments [3;4]. Records obtained from earthquake ground motion at a site can be the basis for a more accurate evaluation of site effects. Deviation of calculated acceleration spectra of observed records from those estimated using a reference empirical attenuation equation can properly determine site effect [5]. Sokolov et al. [6] evaluated site-dependent seismic hazard in Romania. Their results act as a cornerstone for probabilistic seismic hazard assessment in terms of peak ground acceleration (PGA), peak spectral acceleration and Medvedev-Sponheuer-Karnik intensity using Fourier amplitude spectra for exceedance probabilities or average return periods. Their investigations revealed that the distribution of earthquake ground-motion parameters throughout Romania was considerably influenced by geological factors.

A series of modified equivalent linear analyses were carried out by Park and Hashash [7] to describe the effect of rate-dependent soil behavior on site response. They found that rate dependence had a relatively limited effect on soil behavior, causing up to 20% difference in the calculated response for very weak ground motion, and less than 10% for higher amplitude motion.

Nowroozi [8] and Berberian [9] have given an account of seismicity of Iran. Previous studies on seismic risk in Iran include. Since 1978, there have been at least five earthquakes of magnitudes greater than 6 that produced substantial faulting (Nowroozi and Mohajer-Ashjai [10]). In fact, Iran is one of the most seismically-active regions of the world [11].

A specific barrier model using stochastic modeling and calibration for up-to-date strong-motion data has been used in Iran to evaluate the relationship of earthquake ground motion and rock and soil sites. A strong-motion network with more than 1000 stations extends throughout the country; its location in a seismically-active region makes Iran a rich source of data. Observations from this seismic region total more than 7500 records that have been compiled in an enriched catalog of strong motion in the Iranian plateau [12].

Site effects are crucial for evaluation of seismic hazard at the ground surface. The present study determined the acceleration response spectra using a hazard curve obtained from earthquake catalogs for the city of Andimeshk to produce seismic hazard maps at the ground surface and to estimate site effects. The objective of the present study was to evaluate the influence of site effects using uniform hazard spectra (UHS). A UHS was produced at the ground surface for all periods with 2% and 10% probability of return for periods of 50 years using acceleration response spectra according to the Iranian Seismic Code.

2. REFERENCE MODEL

2.1 Seismicity parameters

To estimate the seismicity parameters of the city of Andimeshk and its surrounding region, the area was divided into grids 1° × 1° in size along the northwest direction. Past earthquake data in a control region with a radius of 200 km were assembled to quantify seismicity around each grid point. Fig. 1 shows the distribution of the fault sources. The databases used for this study were subsets of the updated PEER strong motion database (http://peer.berkeley.edu/nga), the International Institute of Earthquake Engineering and Seismology (http://www.iiees.ac.ir), and the United States Geological Survey Earthquake Hazards Program (http://earthquake.usgs.gov).

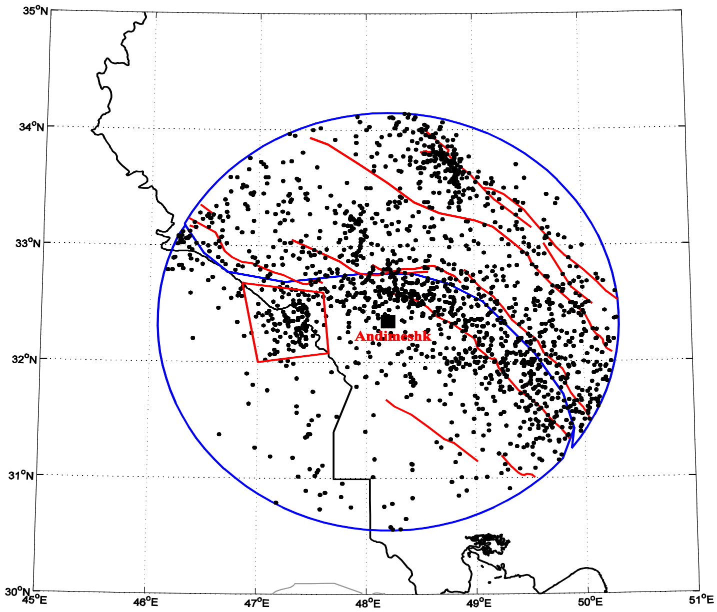

Figure 1. Earthquake catalog grids for Andimeshk in the northwest direction

Tectonic studies require modern seismograph networks compiled into earthquake catalogs, which are significant products of seismology. A graphical user interface called ZMAP was used to help analyze the catalog data. ZMAP is primarily a set of tools suited to evaluate catalog quality and to address specific hypotheses; however, it can also be useful in routine network operations [13]. The earthquake data was first evaluated for its completeness using ZMAP. From the combined historical and instrumental data, the seismicity parameters of b-value, λ, and maximum expected magnitude (M_{max}) were obtained using the methodology proposed by Kijko and Sellovel [14].

Estimating strong ground motion from probable earthquakes plays a pivotal role in evaluating site-specific seismic hazards. The magnitude, tectonic environment, source-to-site distance and source type applied for the estimation of PGS using attenuation relationships have been major research topics for seismic hazard estimation. Zafarani et al. [12] applied 171 strong motion accelerograms recorded from 24 earthquakes at distances of up to 200 km with moment magnitudes of 5.2 to 7.4 Mw to determine region-specific source parameters of attenuation relationships. The attenuation equation (Eq. (1)) is]12]:

$$Y(M,r,f) = E(M,f).P(r,f).G(f).I(f) \tag{1}$$

where ***M*** is seismic moment, ***f*** is frequency and ***r*** is distance.

2.2 Site effects

The site effects were determined as the geometrical average of the ratios of acceleration response spectra calculated from site records (Table 1) to those estimated by Eq. (1). The UHS were obtained using site effects from soil profiles and records from Andimeshk using nonlinear analysis in the time domain using DeepSoil software.

DeepSoil is a site response analysis program that performs 1D nonlinear and 1D equivalent linear analyses and features an intuitive graphical user interface. DeepSoil incorporates the pressure-dependent hyperbolic model developed by (Matasovic, 1993 [15]) based on the hyperbolic model by (Konder and Zelasko, 1963 [16]). It adds the additional parameters of $\boldsymbol{\beta}$ and ***s*** to adjust the shape of the backbone curve β:

$$\tau = \frac{G_{mo}\gamma}{1+\beta\left(\frac{G_{mo}}{\tau_{mo}}\gamma\right)^{s}} = \frac{\mathrm{G_{mo}}\gamma}{1+\beta\left(\frac{\gamma}{\gamma_{\mathrm{r}}}\right)^{s}} \tag{2}$$

where G_{mo} is initial shear modulus, τmo is shear strength, γ is shear strain, and *β, s*, and *γr* are model parameters. There is no coupling between the confining pressure and shear stress [17]. The Masing criteria define the unloading-reloading criteria and behavior under general cycle loading [18] as illustrated in Fig. 2. Earthquake ground motion records at Andimeshk site were selected to determine the site effects and obtain the UHS for the ground surface.

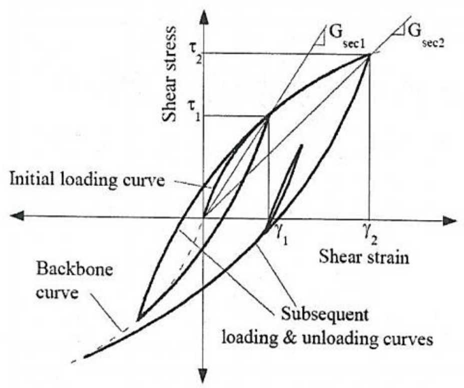

Figure 2. Hyperbolic, non-linear soil model with extended Masing rule to define loading and unloading behavior [18]

Table 1: Earthquake records from Andimeshk bedrock

Record	PGA (cm/s^2)			Database number	Event time	
	T	V	L		time	date
1	28	6	10	4932	00:36:04	2009/01/30
2	12	6	12	1506.11	05:51:46	1994/09/20
3	12	5	17	1848	07:05:18	1997/04/29
4	23	11	21	2070.01	15:05:17	1998/05/19
5	24	15	11	2070.02	22:42:37	1998/12/01
6	33	13	51	1506.02	05:19:12	1994/07/31
7	21	6	4	2302.02	15:27:58	1999/08/08
8	17	9	11	2438	04:09:04	2000/01/04
9	12	8	7	3651.01	00:22:54	2004/02/29
10	9	4	12	3651.02	18:39:16	2004/03/04
11	12	4	14	2302.01	12:22:33	1999/02/24

Tables 2 and 3 list the features of the soil profile and bedrock, respectively.

Table 2: Soil profile model

No.	Layer Name	Thickness (m)	Unit Weight (kN/m^3)	Shear Velocity (m/s)
1	1	5	17	370
3	2	10	17	450
2	3	15	18	630

Table 3: Bed rock properties of model

Rigidity	Half-space
Shear velocity	800 (m/s)
Unit weight	22 (kN/m^3)
Damping ratio	5%

3. EVALUATION AND COMPARISON OF UHS

The uniform hazard response spectrum is a range of probabilities in which all parts are the same at different periods. The UHS contrast with spectra scales based on the PGA such as the Iranian Seismic Code [19]. Unlike scaled spectra PGA, UHS are not constant. The form and amounts of the spectra depend on earthquake magnitude and the distance and probability of an earthquake; however these parameters generally do not affect scaled spectra, while UHS directly apply them. UHS are used to estimate the response and force of an earthquake in a more logical way than that of scaled spectra [20].

Andimeshk site was selected as a zone with high seismicity in Iran and probabilistic seismic hazard analysis was used to provide hazard curves and UHS (2%, 5% in 50 yr) using the Andimeshk earthquake catalog. Crisis software was used to compute the seismic hazard using a probabilistic model that considers the rates of occurrence, attenuation characteristics and geographical distribution of earthquakes (Fig. 3). The hazard curves at 0.36g and 0.52g (PGA) for 10% and 2% probability, respectively, were then compared with the Iranian Seismic Code at 0.3g (PGA of Andimeshk) and their probabilities were investigated.

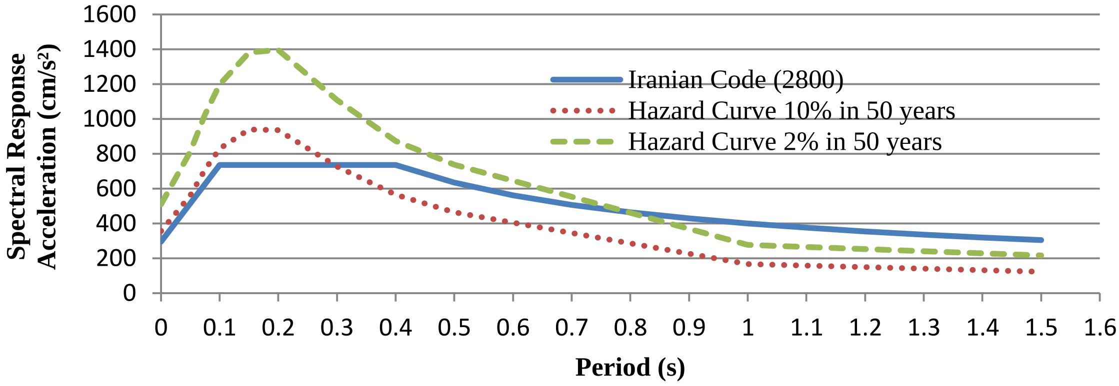

Figure 3. 2% and 10% hazard curves with a return period of 50 yr for Andimeshk vs. Iranian seismic code spectrum

Previous studies have shown that site effects have a noticeable effect on hazard curves. The present study produced UHS based on site effects using the soil profile and 11 records from the bedrock of Andimeshk for spectra of 10% and 2% probability in 50 yr, respectively, as shown in Figs. 4 and 5.

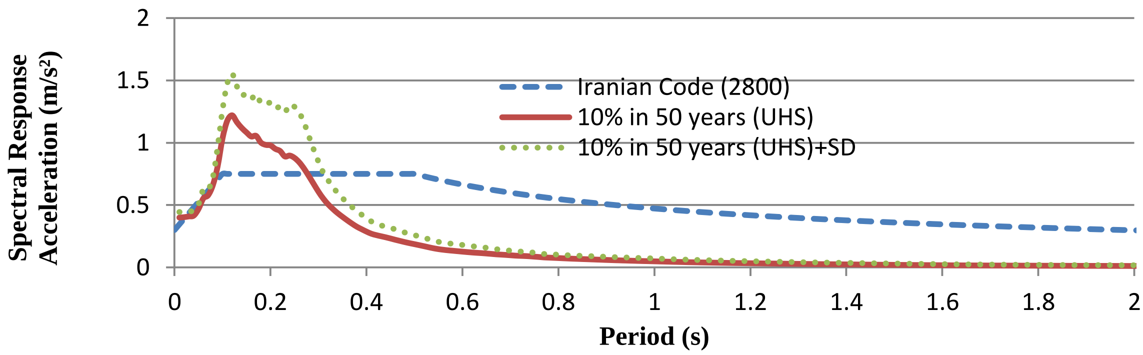

Figure 4. UHS with 10% probability in 50 yr vs. Iranian code

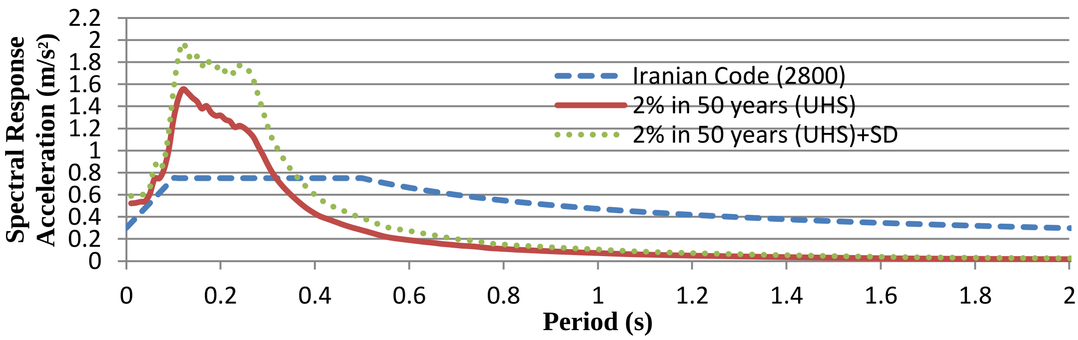

Figure 5. UHS with 2% probability in 50 yr vs. Iranian code

A comparison of the UHS with 5% damping with the spectral response acceleration of the Iranian Seismic Code [19] shows that these spectra do not follow the same trend and are similar only for short periods. The conservatism of the much lower frequencies of structures is evident. This indicates that the seismic forces calculated for average and tall buildings (over 3 floors) will be overestimated.

The rate of change of ground motion versus probability is not constant throughout the spectra and the difference between the 10% and 2% in 50 yr ground motion is remarkable. To clarify, incorporating a hazard level of 10% in 50 yr will not establish a uniform seismic margin throughout the country. It is better to use the maximum considered earthquake hazard level (2% in 50 yr) to prepare a standard design spectrum, as has been done recently for the seismic codes of Canada and the US. To establish a uniform seismic margin throughout the country, acceleration rates with 2% probability in 50 yr have been used as design criteria. Two-thirds of the 2% acceleration in 50 yr was used for the designs. Fig. 6 compares the spectra.

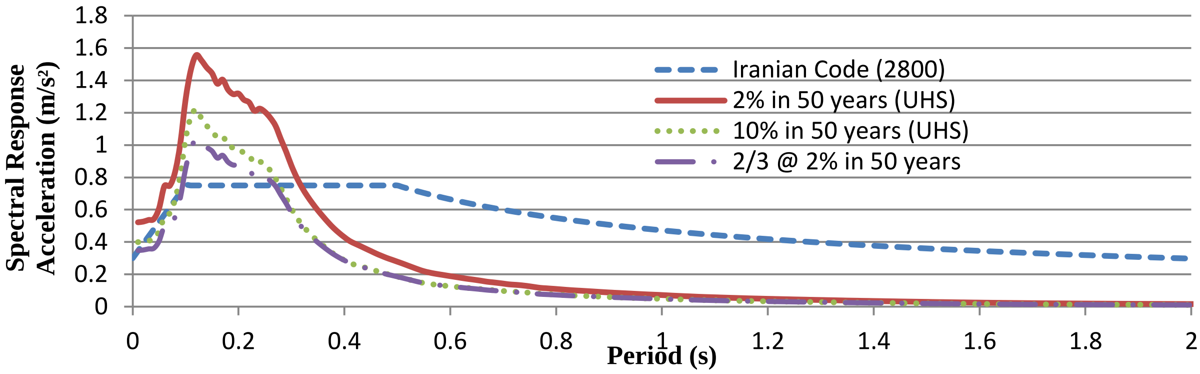

Figure 6. UHS vs. Iranian Code at 2/3 of 2% in 50 yr.

4. CONCLUSION

The current investigation studied the influence of site effects on uniform hazard spectra under earthquake records. Understanding the difference between the Iranian Seismic Code spectral response acceleration and UHS obtained from accurate analyses was the target. The following conclusions were derived from this study:

- It is advantageous in precise response estimation to account for the influence of site effects when predicting the response of a structure subjected to ground motion. The seismic codes of countries such as Canada and the US have specified a spectral acceleration (S_a) at a given location in a given period using a hazard level of 2% in 50 yr for predicting seismic hazard. Instead of the Iranian Seismic Code spectral response acceleration and UHS of 10% in 50 yr, it is preferable to use two-thirds of the 2% in 50 yr spectra acceleration as the specified spectral acceleration for engineering design.
- The probabilities of all parts of the spectra scaled based on PGA, such as the Iranian Seismic Code, are not the same at different periods; conversely, hazard curves follow the

same trend, the periods are comparatively similar, and the estimated responses and forces of earthquakes are closer to real responses.

- For a short period (0.1 to 0.3) or short building, the Iranian Seismic Code spectral response acceleration does not cover design requirements; after a 0.3 period, the margin of safety of the Iranian Seismic Code is greater than the seismic demand. Generally, seismic forces calculated for average and tall buildings (over 3 floors) will be overestimated.
- Taking into account site effects in the analysis is generally sufficient for reliable seismic assessment of structures.

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