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A Seismic Microzonation Study with Geotechnical Aspects on the New Construction Sites in Ardabil, Iran

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ABSTRACT: Due to development of constructions in Ardabil city in northwest of Iran and placement of it on the alluvium, seismic and geotechnical hazards assessment on the construction sites are needed. It specifies areas with a high seismic and geotechnical hazards that will ultimately lead to the development of urbanity codes. Hence, the most significant faults in the vicinity of city within circle with radius of 150 km collected. Through the deterministic risk analysis, the design acceleration is obtained. In this paper, according to the geotechnical boreholes and tests to a depth of 40 meters in different parts of the city, beside deterministic risk analysis, ground response analyses using appropriate acceleration time histories based on Iranian seismic code 2800 for the construction sites of the city are performed. Using the data from geotechnical measurements, soil types in the different areas are designated. The soil types in the most parts of studied area are classified as type III of the standard 2800 classification. Comparison of the obtained acceleration with the proposed peak ground acceleration of 0.3g of standard 2800, showed that almost 40% of the grid elements exhibit PGA values of 0.3 g to 0.4 g and 25% exhibit PGA values of more than 0.4 g. The dense granular alluviums and some with high stiffness experience the lowest PGA of about less than 0.3g.

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INTRODUCTION

Permits are the way a city regulates construction. This is designed to ensure that all construction sites in the city are safe. The safety of the occupants of buildings is the primary reason for having construction and urbanity codes. The city of Ardabil in northwest of Iran has not adopted state and local urbanity codes. Obtaining the permit should be based on a criterion. One possibility is to develop a micro zonation map. Hence, beside seismic hazards assessment, it is necessary to analyze geotechnical hazards in order to develop microzonation maps.

Seismic microzonation specifies areas with a high seismic and geotechnical hazards that will ultimately lead to the development of mi crozonation maps and urbanity codes. It has generally been recognized as an important component of urban planning and disaster management. So, it should evaluate all possible hazards due to earthquake and represent the same by spatial distribution. This paper presents a microzonation map which has been generated based on location of study area and possible associated hazards. Some studies have been conducted in this area. For example: The study on seismic microzoning of the Greater Tehran area in Iran (2001) by the Japan International Cooperation Agency (JICA) and site effect microzonation of Qom by Kamalian et al. (2008). The seismic microzonation in this study is composed of the following four main phases. In the first phase, the earthquake source and the faults characterization for the study area needs to be determined with respect to the seism otectonic structure. This is used for seismic hazard analysis to determine the required parameters at rock level. In the second phase, a detailed site characterization is carried out using geotechnical data. This is very essential for the assessment of site dependent seismic hazard parameters. In the third phase, analysis and interpretation of the accumulated data in the above two stages is used in detailed estimation of site specific effects which includes shear wave velocity, peak ground acceleration on the surface of the alluvium and etc. This analysis could be utilized for urban planning and thus for earthquake risk mitigation purposes. Finally, the seismic microzonation map is prepared with respect to the required seismic hazard parameters.

Seismotectonic structure and seismicity of Ardabil

Iran is one of the most seismic countries of the world. It is one of those countries which have lost many human lives and a lot of money due to occurrence of earthquakes. The seismotectonic conditions of the Ardabil region are under the influence of the condition of Iranian tectonic plate in the Middle East. In order to understand the seismotectonic role of the region under study, the conditions of the tectonic plate of Iran should be studied. Several studies have been done on the

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seismotectonic structure of Iran in the past. Stocklin (1968), Takin (1972), Berberian (1976) and Nowroozi (1976) have suggested simplified divisions consisting of nine, four, twenty-three regions or seismotectonic provinces respectively (Ghodrati Amiri et al., 2003). Tavakoli (1996) proposed a new model of seismotectonic provinces using a modified and updated catalogue of large and catastrophic Iranian earthquakes. He has divided Iran into 20 seismotectonic provinces (Figure 1). The city of Ardabil is located in Area 16.

Province No.	Span of time	Beta	M_{max}	Lambda (M_s=4.5)
16	1900-92	1.68 ± 0.17	7.6 ± 0.17	0.14

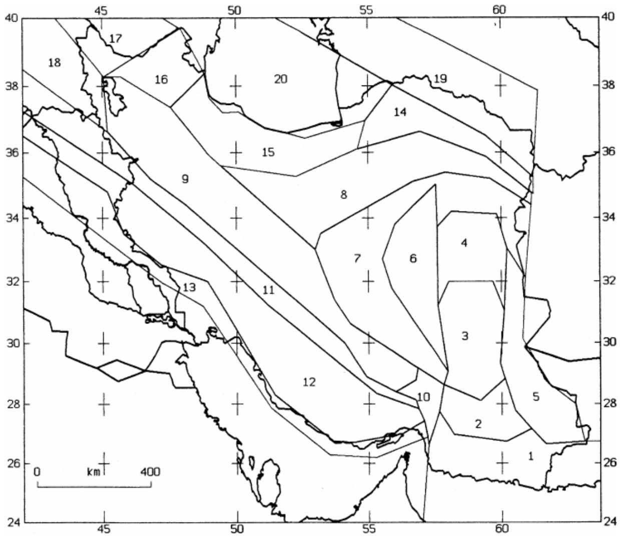


Figure 1. Seismotectonic provinces of Iran (Tavakoli, 1996) and estimated hazard parameters for Ardabil (Area No. 16)

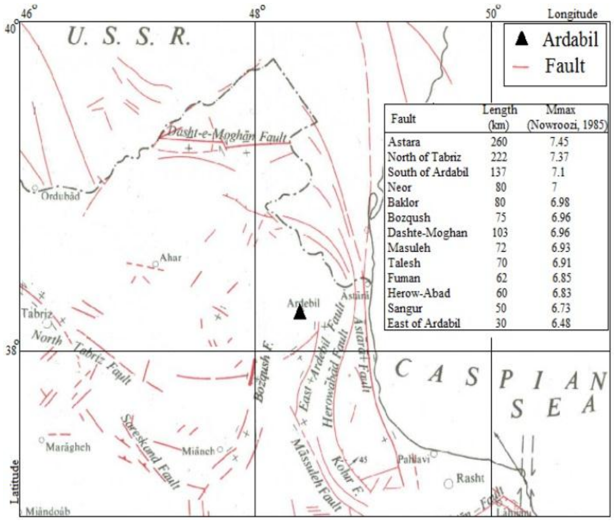
The most significant faults in the vicinity of Ardabil those which fully or partially located within circle with radius of 150 km collected using Berberian (1976) map and local geological organization maps such as Geological and Mining Survey of Iran (NGDIR, 2011) and major active faults map of Iran of International Institute of Earthquake Engineering and Seismology of Iran (IIEES, 2007). The location of these faults can also be seen in Figure 2 within study region. Note that M_{max} in this figure is calculated based on Nowroozi's relation (1985) to convert L (rupture length in meter) to M_s.

The results of investigations by Ambraseys and Melville (1982) and Berberian (1994) which are about historical earthquakes (before 1900) and IIEES (International Institute of Earthquake Engineering and Seismology of Iran), ISC (International Seismological Centre) which are about historical earthquakes (before 1900) and IIEES, ISC which are about instrumental earthquakes (1900-2012) were studied. These results show that a total of 16 earthquakes with magnitudes greater than M_s=5.3 were reported over the time span of the studied catalogue, the maximum of which occurred in 1721 and 1990 with a magnitude of M_s=7.7 and recently Sarein, 1997 with a magnitude of M_s=6.1. The epicentre of this earthquake was in the Southwest of Ardabil, with 3000 casualties more than three villages were destroyed completely.

Seismic hazard assessment

A veriety of parameters are available for description of strong ground motions. Some of these parameters describe ground motion amplitude. Commonly used amplitude parameters include peak acceleration, peak velocity, and peak displacement. The peak acceleration provides a good indication of the high-frequency component of a ground motion.

Seismic hazard analyses involve the quantitative estimation of ground motion characteristics at a particular site. They may be conducted deterministically or probabilistically. Deterministic seismic hazard analysis (DSHA), used in this paper, involves the assumption of some scenario -the occurrence of an earthquake of a particular location- for which ground motion characteristics are determined. When applied to structures for which failure could have catastrophic consequences such as nuclear power plants and large dams and constructions, DSHA provides a straightforward framework for evaluation of worst-case ground motions (Kramer, 1996).



Fault	Length (km)	Mmax (Nowroozi, 1985)
Astara	260	7.45
North of Tabriz	222	7.37
South of Ardabil	137	7.1
Neor	80	7
Baklor	80	6.98
Bozqush	75	6.96
Dashte-Moghan	103	6.96
Masuleh	72	6.93
Talesh	70	6.91
Fuman	62	6.85
Herow-Abad	60	6.83
Sangur	50	6.73
East of Ardabil	30	6.48

Figure 2. Active faults of Ardabil and its vicinity (Berberian, 1976)

One of the most important parts of seismic hazard assessment is attenuation relationship. Attenuation relationship describes decrease in the ground motion as a function of distance and magnitude. Many factors affect the attenuation relationships which are: the geology effects of the site, source specifications, magnitude, fault mechanism, reflection and refraction, etc. Since peak acceleration is the most commonly used ground motion parameter, in this paper, four peak acceleration attenuation relationships were used.

The DSHA procedure, used in this paper, can be described as a four-step process (Reiter, 1990) consisting of:

- Identification and characterization of all earthquake sources
- Selection of a source-to-site distance parameter (*R*) for each source zone
- Selection of the *controlling earthquake* (*M*) expessed in terms of some ground motion parameter, at the site
- The hazard at the site is defined. Peak ground accelereation is commonly used to characterize the seismic hazard

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Source characterization includes definition of each source's geometry (the source zone) and earthquake potential. The most significant faults in the vicinity of Ardabil those which fully or partially located within circle with radius of 150 km were collected (Figure 2).

Fault rupture length has often been used to estimate earthquake magnitude (controlling earthquake) in each fault. In this paper, three fault rupture length relationships are used. The first two relationships come from Nowroozi (1985) and Zare's work (1999) that belongs to Iran and the other relationship comes from Wells et al.'s work (1994) that is obtained according to the type of fault. The earthquake magnitude (M) for each seismic source was calculated as mean.

The hazard would be taken as that which result from South-of-Ardabil Fault with a magnitude M_w=7.14 earthquake occurring at a distance of 20 km. This motion would produce a peak acceleration of 0.32g calculated by four attenuation expressions below (Douglas, 2011): Zare and Sabzali (2006), Ambrasey et al. (2005), Ghodrati Amiri (2007) and Akkar and Bommer (2007). This source (South-of-Ardabil Fault) would produce the design earthquake in DSHA approach. So, the PGA, Magnitude and Dirtance for the design earthquake is 0.32g, M_w=7.14 and R=20 km respectively, which is 6% higher than that proposed by Building Design Codes for Earthquakes - Standard 2800 (0.3g).

Ground response analysis

Site characterization along with site response studies can be used together for the seismic microzonation. As part of the site characterization, experimental data should be collected. Here, an attempt has been made to characterize study area using geotechnical data. About 70 collected geotechnical borehole information with standard penetration "N-spt" values are used for site characterization. Most available reports on geotechnical site investigations conducted by national and local governments and public corporations were collected. These comprised approximately 70 boreholes having limited depth (usually less than 30 m according to Japanese TC4 Zoning Manual) and being unequally distributed in the investigated area in a grid of 1×1 km^2 elements. The methodology of site effect microzonation adopted in this study falls into the category of Grade-3 zoning methods of Japanese TC4 Zoning Manual (1999).

Out of the available 70 borelogs, 25 bore logs were carefully selected in the new construction sites of the city. Figure 3 presents the locations of the selected geotechnical data. For the 25 boreholes, the overburden thickness varies from 15m to about 40m. Subsurface profile information like unit weight, ground water level, SPT values (Figure 4) are thus obtained and compiled for the above selected bore holes and used for the shake analysis using NERA (stands for Nonlinear Earthquake Response Analysis) program. In this approach, first, a known time history of bedrock motion is represented as a Fourier series, usually using the Fast Fourier Transform (FFT). Second, the Transfer Functions for the different layers are determined using the current properties of the soil profile. The transfer functions give the amplification factor in terms of frequency for a given profile. In the third step, the Fourier spectrum is multiplied by the soil profile transfer function to obtain an amplification spectrum transferred to the specified layer. Then, the acceleration time history is determined for that layer by the Inverse Fourier Transformation in step four.

The rock motion obtained from 8 selected time histories are assigned at the bedrock level as input in Nera to evaluate peak acceleration values and acceleration time histories at the top of each sub layer. The acceleration time histories, according to Iranian seismic code 2800, shall have magnitudes and fault distances that are consistent with those that control the design-basis earthquake. So, the selected ground motion records were recorded during earthquakes with approximately the same magnitudes and distances, as estimated by deterministic aproach for controlling earthquakes of well-defined seismic sources affecting the study area. Other factors such as the site condition (rocky sites) and faulting mechanism were also considered. All selected acceleration time histories were normalized to the peak rock acceleration estimated by Deterministic Seismic Hazard Analysis (DSHA).

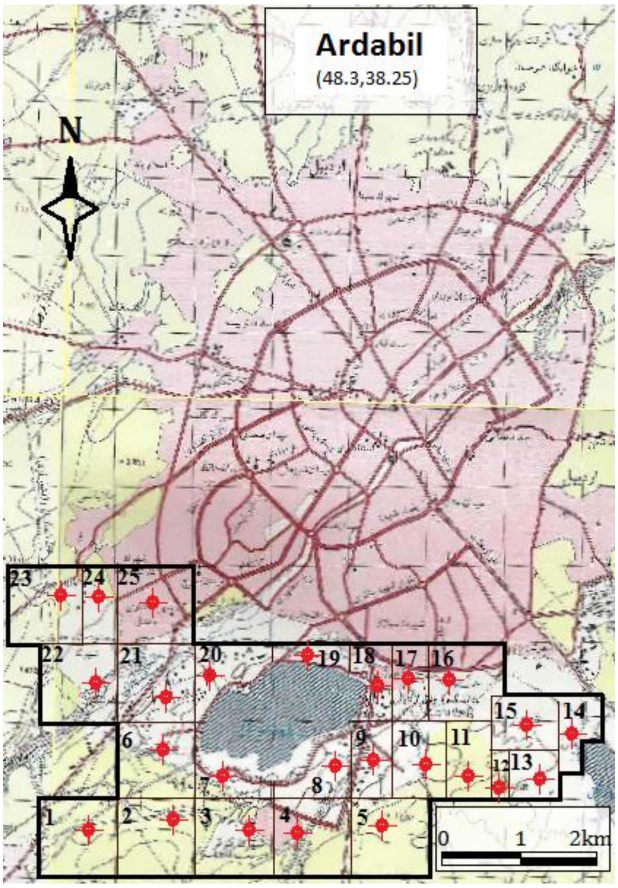

Figure 3. Location of geotechnical boreholes

In order to determine the soil type based on shear wave velocity in the area, the average velocity has been calculated using the equation given below.

$$\bar{V}_s = \frac{\sum d_i}{\sum \left(\frac{d_i}{V_{si}}\right)} \quad (1)$$

Where d_i and V_{si} are the thickness and shear wave velocity in each layer respectively. Reliable experimental relationships as well as physical and

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mechanical properties of soil may be used to evaluate V_{si} as an input for Nera. In the present study, four equations were used (Jafari et al., 2002, Lee, 1992, Baziar et al., 1988, Hasancebi and Ulusay, 2006).

The average shear wave velocities show that whole study area falls into soil type II and III as Code 2800 classification.

A soil property of each layer is modeled by using modulus reduction (G/G_{max}) and damping (β) versus shear strain curves. The degradation curves used for the present work are those proposed by Seed and Idriss (1984).

Microzonation map development

Seismic microzonation is defined as the process of subdividing a potential seismic or earthquake prone area into zones with respect to some geological and geophysical characteristics of the sites such as ground shaking, liquefaction, etc. Microzonation provides the basis for site-specific risk analysis, which can assist in the mitigation of earthquake damages (Tuladhar et al., 2004). In most general terms, seismic microzonation is the process of estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface (Finn, 1991).

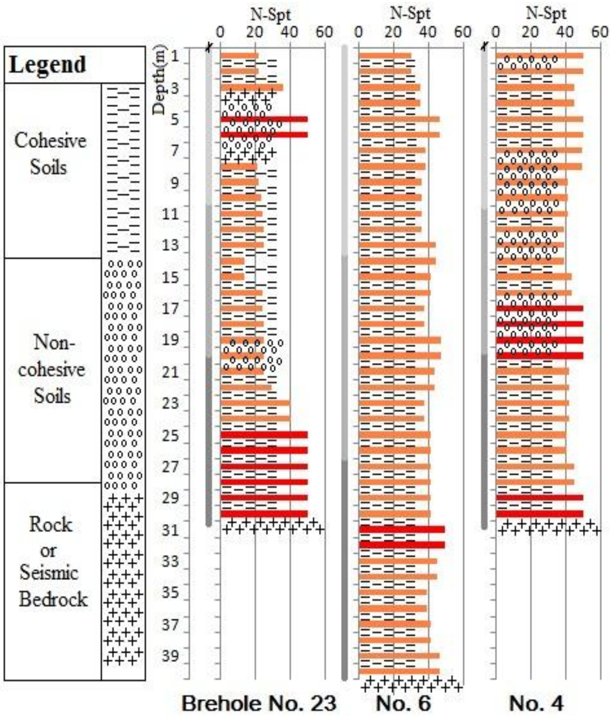

Figure 4. N-Spt values of borehole No. 23, 6 and 4

One of the results of ground response analysis is the peak ground acceleration (PGA) on the surface of the alluvium. The results can be directly used to create a microzonation map for the study area. Microzonation map is produced for city (not for state or country, which is named Macrozonation map), where the data grid is less than 1 km × 1 km. Figure 5 shows the microzonation map of PGA. It shows the distribution of PGA throughout the study area. Almost 40% of the grid elements exhibit PGA values of 0.3 g to 0.4 g and approximately 25% exhibit PGA values of more than 0.4 g because of their considerable amplification potential caused by low to medium dense soil layers. Only 16% of them experience PGA values of about 0.3 g. The dense granular alluviums and some with high stiffness experience the lowest PGA of about less than 0.3g because the amplification potential of such sites is negligible.

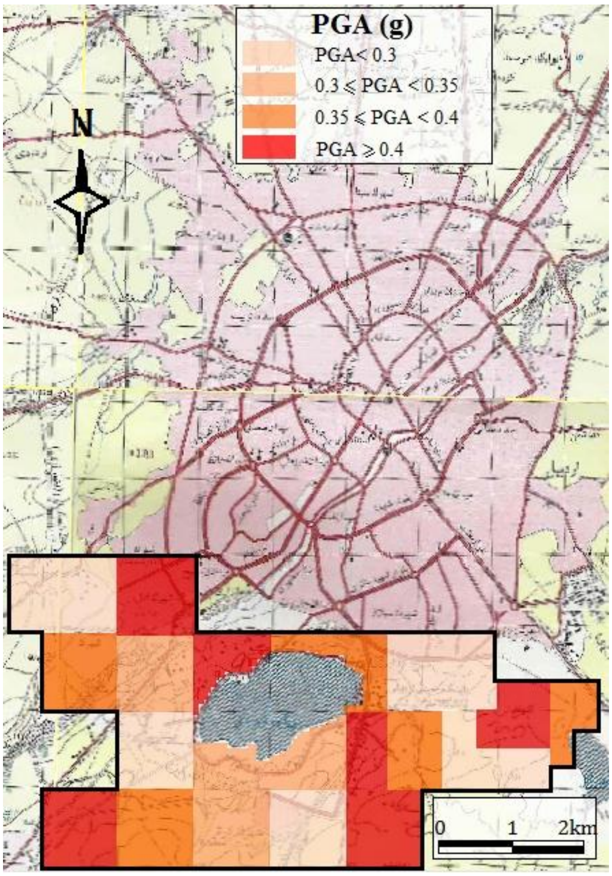

Figure 5. Microzonation map of PGA

CONCLUSION

The methodology of site effect microzonation adopted in this study falls into the category of Grade-3 zoning methods of the Japanese TC4 Zoning Manual (1999). After dividing the study area into a grid of 1 × 1 km^2, the following steps were taken:

• Seismic hazard assessment of the study area and estimation of strong ground motion on bedrock, using Deterministic approach;

Due to the use of new relationships and comprehensive data in this study, the peak ground acceleration (PGA) of 0.32g was determined based on risk analysis which is 6% higher than that proposed by Building Design Codes for Earthquakes - Standard 2800. The PGA is caused by the fault South-of-Ardabil (as the design fault), which is located 20 km from the site. So, the PGA, Magnitude and Distance for the design earthquake is 0.32g, M_w=7.14 and R=20 km respectively.

• Gathering and investigation of the existent geotechnical data of the study area, preparation of representative geotechnical profiles of the city based on the geological and geotechnical data;

For the convenience of Engineers, the soil type of boreholes, according to Iranian seismic code 2800, were determined. The boreholes No. 15, 16 and 17 are of type II and the rest falls into soil type III.

- Estimation of strong ground motion characteristics of surface level using one-dimensional site response analysis of the representative geotechnical profiles;

Almost 40% of the grid elements exhibit PGA values of 0.3 g to 0.4 g and 25% exhibit PGA values of more than 0.4 g. The dense granular alluviums and some with high stiffness experience the lowest PGA of about less than 0.3g.

- Preparation of the final microzonation map of site peak ground acceleration (PGA) of the study area.

This map can serve as a basis to evaluate site-specific risk analysis, which is essential for critical structures and can assist in the mitigation of earthquake damages. It can be used as a means of avoiding the construction of mass residential units in high risk areas and that will ultimately lead to the development of urbanity codes.

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