AUT Journal of Civil Engineering

AUT J. Civil Eng., 2(1) (2018) 2938
DOI: 10.22060/ajce.2018.14494.5479

Probabilistic Seismic Hazard Assessment and Geotechnical Seismic Micro-zonation of Kangavar with Ambient Vibration and Electrical Resistivity Analysis

I. Ashayeri[1*], M. Biglari[1], S. B. Shamoradi[2], H. Rashidi Gouya[3]

[1] Civil Engineering Department, Razi University, Kermanshah, Iran
[2] Civil & Architechture Department, Malayer University, Malayer, Iran
[3] Mining Engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: Kangavar city is located at Kermanshah province west of Iran and northern part of Zagros Mountains. Zagros is known to be the most seismic region in Iran. Thus, seismicity and geotechnical micro-zonation of Kangavar are set the goals of this research. To do this, firstly, following a probabilistic seismic hazard analysis the peak ground acceleration and spectral acceleration on seismic bedrock is elaborated using the CRISIS2007 software. Secondly, to investigate the site conditions series of microtremor measurements at 15 points in the vicinity of the city is carried out and the natural frequency map and shear wave velocity profile for the ground are determined using Geopsy software. This should note that the thickness of the alluvial is small in northern part of the city. Furthermore, the results of electrical resistivity tests are used to investigate the alluvium depth and discontinuity in ground profile. This analysis confirmed the existence of thicker alluvial in southeast part of the city. Finally, according to all findings of this research a general recommendation for urban planning and future building and construction is proposed according to Iranian national code for earthquake resistant buildings, as a function of three variables; Geo-hazards type, Importance, and lateral resistant structural system.

Review History:

Received: 25 March 2018
Revised: 19 April 2018
Accepted: 25 April 2018
Available Online: 17 July 2018

Keywords:

Kangavar City
PSHA
Geotechnical Seismic Microzonation
Ambient Vibration
Electrical Resistivity

1- Introduction

Iran is laid on active Alpide seismic belt and various parts of Iranian plateau have been experienced devastating earthquakes several times in their history. Kangavar city is placed at west of Kermanshah province and northern part of Zagros fold and thrust belt (FTB). The city is located at 34.494 ^{0}N and 47.943 ^{0}E and its population is estimated over 51352 persons (according to 2015 statistics). Zagros FTB extended from eastern parts of Turkey to Oman Sea, consists of long folds affecting the Phanerozoic sediments of Arabian Plate on eastern edge [1]. The Main Zagros Reverse Fault, usually known as High Zagros Fault, clearly separates metamorphic-multi phase sediments of Southern edge of Iran Plain from Sanandaj [2]. Geological survey indicates that the Kermanshah province is located on two formations of Sanandaj-Sirjan and Zagros FTB, which the active seismic faults of Morvarid and Sahneh are their boundary [3].

Kangavar had experienced important earthquakes like Farsinaj with approximated Mw=7.4 at 22 of Azar 1336 (13 Dec. 1957) that resulted in 1119 persons' death, 900 injured, and 15000 homeless and other earthquakes in 1958 (Mw=6.6) and 1963 (Mw=5.8) [4], as well as historical records of Gowdin earthquake (around 1600-1650 BC), Kangavar earthquake (around 224-459 AD), and Dinevar earthquakes (1008 and 1107 AD) [5]. The city is located near active seismic fault of Main Zagros Reverse Fault, which is consisted of a series of narrow fault zones extended 800 km from Iran and Turkey border in Lat. 37 ^{0}N to South-East. These fault zones are named locally like Dorood, Nahavand, Garoon, Sahneh, Morvarid, and Piranshahr faults with different levels of seismicity [6].

Earthquakes are generated because of sudden rupture due to gradually rise of stress in plate tectonics of the Earth's crust. In the vicinity of a city the ground response and damage level of an earthquake not only are related to source parameter and distance to rupture, but also functions of mechanical and geometrical specifications of subsurface layers of the ground [7]. Application of Geotechnical seismic micro-zonation investigations is known to be an effective step toward management and risk reduction of earthquakes in an urban construction plans. There are several examples of such investigations worldwide and in Iran, published in the literature, which investigations of Tehran [8], Mashahad [9], Shiraz [10], Tabriz [11], Qom [12], Bam [13], and Kermanshah [14] can be named. Most of these studies resulted in micro-zonation of seismic hazard maps in terms of PGA, PGV, and spectral acceleration of the area through a probabilistic seismic hazard analysis as well as micro-zonation of ground types in terms of natural frequency of the site, average shear

Corresponding author, E-mail: i.ashayeri@razi.ac.ir

wave velocity, and geotechnical specifications and finally combination of hazard maps with site class maps to present design spectra and construction plans. For instance, the PGA at bedrock level for Kermanshah city was found to increase from north to south, while the thickness of the alluvium was found to be more at central parts of Kermanshah city with natural frequency of the ground around 1 Hz compared with rock site at northern and southern parts of the city [14]. Similarly in Qom, it was recommended that construction of buildings to comply the amplification and near fault maps of the site [12].

The current research investigates seismic hazard of Kangavar to find possible strategies for preparation and planning of seismic risk reduction in three parts. Firstly, seismic hazard of the city is evaluated using probabilistic approach to find out the maximum ground and spectral acceleration on bed rock according to attenuation laws like [15-20] and to do this, the software package of CRISIS2007 is used. In the second part, field investigations in the vicinity of the city is presented that are ambient vibration analysis with a broad band seismometer at 15 stations and also electrical resistivity tests in Kangavar plain. The aims of the field tests are Geotechnical micro-zonation of the city and presenting maps for natural frequency of the ground, shear wave velocity profiles, thickness of alluvium as well as discontinuity in the ground structure. This analysis are performed with aid of Geopsy software and ArcGIS package. The final part of the study tries to use the results of the two previous parts in planning for future constructions according to Iranian code for resistant building against earthquakes. This recommendations are suggested in terms of three variable of Geo-hazard type, importance of the building and its structural system. Geo-hazard type includes ground amplification and near fault effects, building importance and structural system include building height, usage as well as various lateral load bearing systems like moment resistant frames, eccentric and concentric bracings and shear walls. Accordingly, construction permission are suggested for each structural system in terms of hazard type and building importance and height.

2- PSHA of the city

Probabilistic Seismic Hazard Assessment (PSHA) is performed in four steps as followings.

2- 1- Definition of seismic sources

According to distribution of earthquakes within the radius of 200 km from the city and the geo-seismic formations six seismic sources are suggested, which are demonstrated in Figures 1 and 2 and with more details in Table 1. Zone Nos. 3 to 5 include active faults and zone Nos. 9 and 10 have relatively less seismic activity and zone No. 11 corresponds to north-west Zagros with distributed seismicity.

Table 1. Area of the seismic zones [24]

Zone No.	3	4	5	9	10	11
Area (km^2)	50380	21389	10497	84665	10853	35244

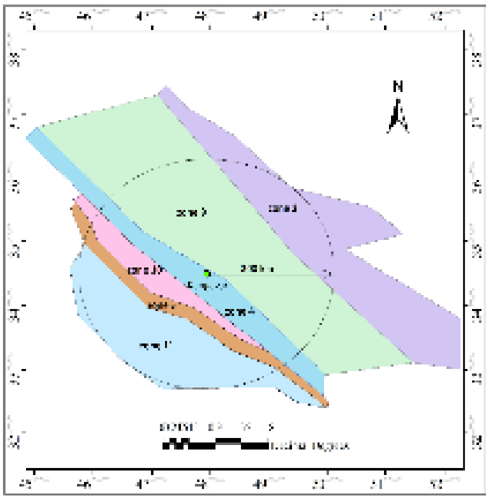

Figure 1. Seismic sources [21]

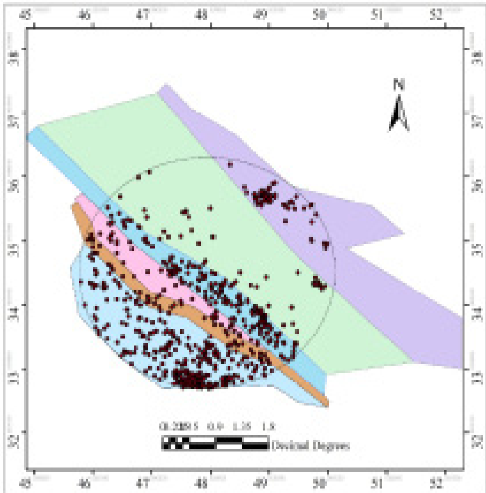

Figure 2. Distribution of earthquakes [21]

2- 2- Earthquake reoccurrence characteristics

Determination of earthquake reoccurrence characteristics of each seismic source is the next step. This is introduced by giving the number of earthquakes in relation with their magnitude for each source. The Gutenberg-Richter rule gives the exponential relation of average number of earthquakes larger than a magnitude at a source [22]. This relation is introduced for seismic sources in the current research according to earthquakes from 1900 to 2015. The parameters of the maximum tectonic earthquake is selected according to tectonic province model of Iran [23]. Table 2 presents parameters of Gutenberg-Richter rule for this study. More details on the calculations are found in [24].

In Table 2, M_0 is the minimum magnitude of considered earthquake, Lambda (M_0) is the average number of events per year with magnitude larger than M_0, Beta is the seismicity, CV (Beta) is the coefficient of variation of Beta, EM assumed largest earthquake with magnitude between M_1 , M_2 happened according to Gaussian distribution, Sigma is the standard deviation for magnitudes, M_1 is the largest historic event, and M_2 is the largest event according to tectonic conditions of the source.

Table 2. Parameters of earthquake reoccurrence rule for each zone

Zone	M_0	Lambda (M_0)	Beta	STDV(Beta)	CV(Beta)	EM	Sigma	M_1	M_2
3	4.0	0.4499	1.6719	0.214	0.1280	7.4	0.3	7.1	7.9
4	4.0	1.6803	1.7057	0.173	0.1014	7.4	0.4	7.0	8.0
5	4.0	0.5085	1.7798	0.261	0.1466	7.4	0.4	7.0	8.0
9	4.0	0.5860	2.3079	0.361	0.1564	6.8	0.3	6.5	7.6
10	4.0	0.3526	1.9156	0.306	0.1597	7.4	0.4	7.0	8.0
11	4.0	3.9126	2.2512	0.166	0.07374	7.0	0.2	6.8	7.4

Table 3. Details of the several hazard assessment analyses

Analysis No.	Ground Motion Model	Motion Parameter	Integration Radius
1	Ambraseys et al. (2005)	PGA	
2	Ambraseys et al. (2005)	Sa	
3	Zare (1999) for Zagros	PGA (Horizontal)	
4	Zare (1999) for Iran	Sa (Horizontal)	
5	Sinaiean and Zare (2007)	PGA	
6	Ghasemi and Zare (2009)	Sa	
7	Campbell and Bozorgnia (2003)	PGA (uncorrected)	150 km
8	Campbell and Bozorgnia (2003)	PGA (corrected)	
9	Campbell and Bozorgnia (2003)	Sa	
10	Campbell (1997)	PGA	
11	Campbell (1997)	Sa	

2- 3- Estimation of strong ground motion

In this study six models for estimation of strong ground motion including in Ambraseys et al. (2005), Campbell and Bozorgnia (2003), Campbell (1997), Zare (1999), Sinaiean and Zare (2007), Ghasemi and Zare (2009) are used [13-20]. Details of the parameters of these models are presented in [24].

2- 4- Site hazard assessment

To perform the final step the software CRISIS2007 [25], is used and several probabilistic seismic hazard analyses are performed that are listed in details in Table 3.

The results of hazard assessment analyses are presented using hazard curves and uniform hazard spectra as well as micro-zonation maps of PGA and Sa. Micro-zonation maps are generated from values of PGA and Sa at 32 points distributed in the city, which is approximately one point per 0.2 km2. Hazard curve presents the annual probability of exceedance to a corresponding intervals of strong ground motion. Figure 3 presents the hazard curves for the center of the city (Lat. 34.494, Long. 47.943) at bedrock from each analysis in Table 3. Such hazard curves are elaborated for other 31 points in the city. Uniform hazard spectra present the ground motion parameter for a specific value of probability of exceedance at various periods of vibrations. Uniform hazard spectra for the center of the city at bedrock corresponding to earthquake scenarios of return period of 475, 975, and 2475 years are shown in Figures 4 to 6, respectively.

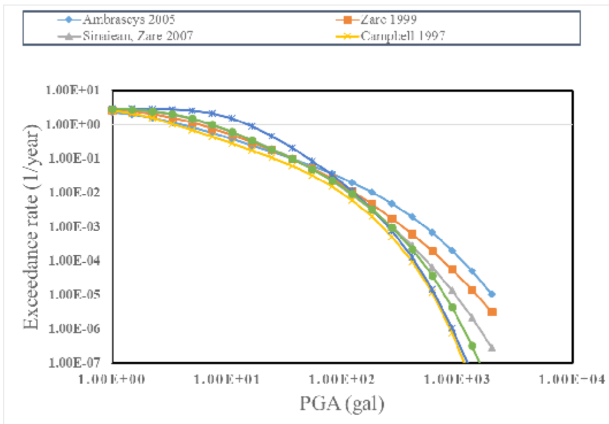

Figure 3. Hazard curves for the center of Kangavar at bedrock

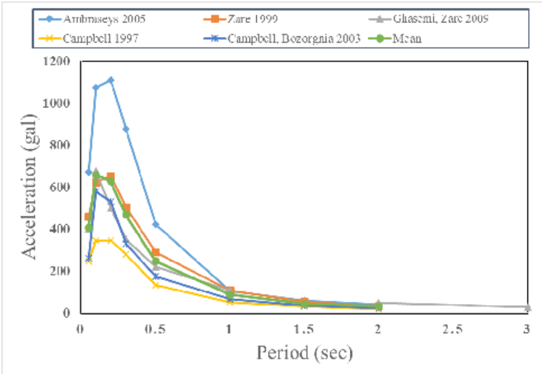

Figure 4. Uniform hazard spectra for center of Kangavar at bedrock with earthquake return period of 475 years

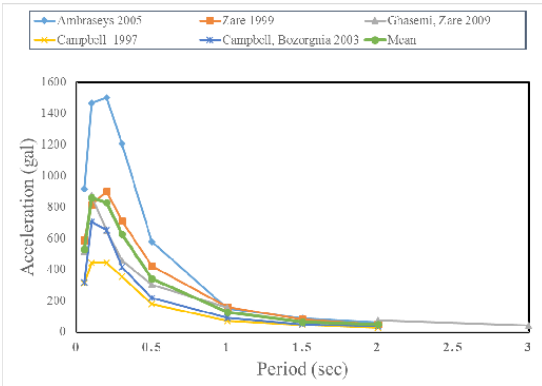

Figure 5. Uniform hazard spectra for center of Kangavar at bedrock with earthquake return period of 975 years

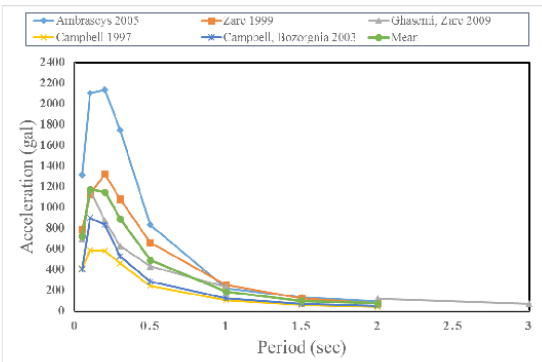

Figure 6. Uniform hazard spectra for center of Kangavar at bedrock with earthquake return period of 2475 years

As it is shown in Figures 4 to 6, the uniform hazard spectra are different for different ground motion models. For example, the ground motion model [15] gives higher spectral accelerations for short period range in comparison to other models, which can be interpreted as inherent effect of ground motion estimation models. Since no ground motion model is considered with privilege of usage, consequently the average of all uniform hazard spectra are presented. This is shown for Sa at period of 0.1 second and PGA at bedrock across the city using interpolation of 32 point by ArcGIS in Figure 7 to 12, respectively. Observation of spatial distribution of PGA in Figures 10 to 12 reveals that it increases from north to south of the city. This is explained by the distance to the main Zagros reverse fault. However, the value of PGA varies about 10 percent from north to south.

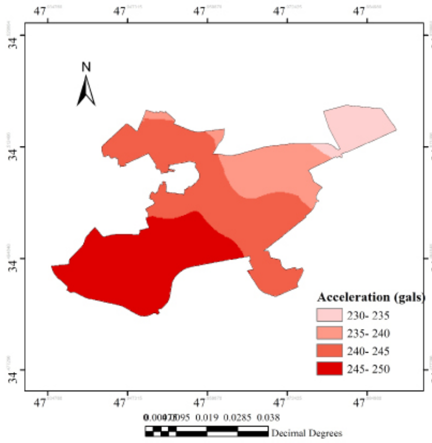

Figure 7. Micro-zonation of average horizontal Sa at 0.1 sec. and bedrock with earthquake return period of 475 years

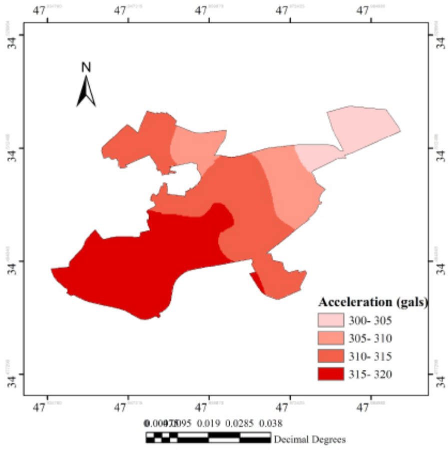

Figure 8. Micro-zonation of average horizontal Sa at 0.1 sec. and bedrock with earthquake return period of 975 years

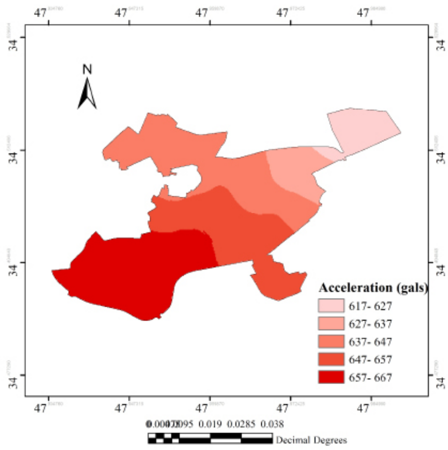

Figure 9. Micro-zonation of average horizontal Sa at 0.1 sec. and bedrock with earthquake return period of 2475 years

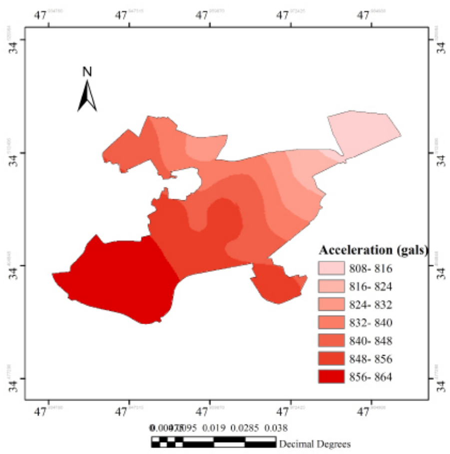

Figure 10. Micro-zonation of horizontal PGA at bedrock with earthquake return period of 475 years

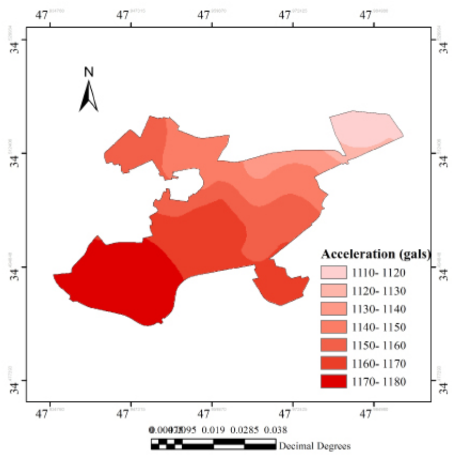

Figure 11. Micro-zonation of horizontal PGA at bedrock with earthquake return period of 975 years

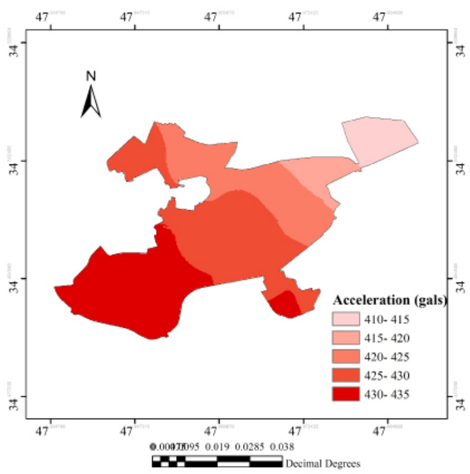

Figure 12. Micro-zonation of horizontal PGA at bedrock with earthquake return period of 2475 years

3- Geophysical investigation of Kangavar

The main goal of geophysical investigation is estimation of subsurface structure to evaluate the seismic risk at ground level. The horizontal to vertical spectral ratio (HVSR) was first time introduced by [26] and then extended by [27]. They have mentioned that the peak frequency of the HVSR matches with the natural resonant frequency of the site and suggested that this technique can be used for determination of natural frequency of alluvial structure of subsurface ground. Several investigations have confirmed the effectiveness of this technique [27]. HVSR or H/V spectral analysis is based on the measurement of ambient vibrations of a single station with a three component seismometer. Meanwhile, measurement of ambient vibrations with single station seems practical at various site conditions and rather economic.

The ambient vibration measurements are performed at 15 stations with covering approximately 0.4 km^2 by each station for Kangavar in this study. The recorded noise and vibrations are analyzed by Geopsy software and according to SESAME [28] guidelines. Geopsy is a user friendly freeware specifically designed to analyze noise and ambient vibrations. The process of calculating HVSR includes in filtering the recorded noise, calculating Fourier transform of all three components of the vibrations, and elaboration of the ratio of average horizontal components' spectra to the vertical component spectrum [28]. The peak frequency (f_0), of the 15 stations as well as their standard deviation (σ), and coordinates of the stations are presented in table 4. Furthermore, the results of 15 ambient vibrations are analyzed using geographic information system of ArcGIS, to interpolate and generate the micro-zonation map of natural frequency of Kangavar as in Figure 13. The natural frequency of the ground gives the general overview of the depth of sedimentary layers of ground. The interpretation of Figure 13 clears that the alluvial layer at Kangavar is not thick and the lowest thickness is observed at northern parts of the city. In fact, high frequency values at northern parts resembles no alluvium or rock sites. However, low frequency values indicates existence of the sedimentary layers with more thickness at southern parts.

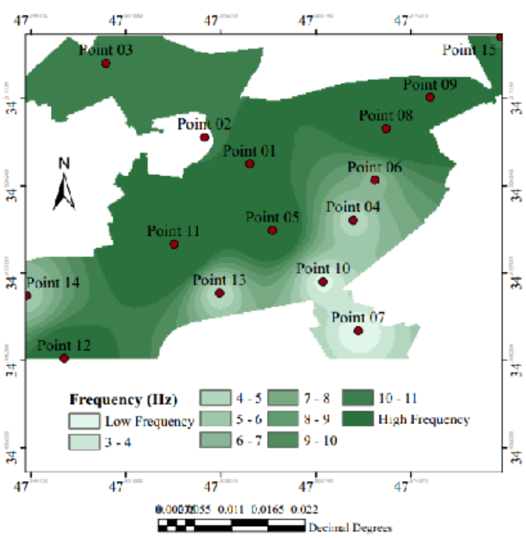

Figure 13. Micro-zonation map for natural frequency of the ground with location of ambient vibration measurements

Table 4. Coordinates and results of 15 ambient vibration measurements in Kangavar

σ (Hz)	f_0 (Hz)	Latitude	Longitude	Station No.
1.163	12.27	34.5060	47.9615	Point 01
1.422	10.4	34.5081	47.9572	Point 02
0.697	10.00	34.5140	47.9501	Point 03
0.418	4.11	34.5015	47.9697	Point 04
1.517	15.99	34.5007	47.9633	Point 05
0.776	6.47	34.5047	47.9714	Point 06
0.272	1.91	34.4927	47.9701	Point 07
0.976	16.56	34.5088	47.9723	Point 08
2.265	14.89	34.5113	47.9758	Point 09
0.357	2.56	34.4966	47.9673	Point 10
0.908	19.02	34.4996	47.9555	Point 11
0.936	13.22	34.4905	47.9468	Point 12
0.525	3.961	34.4957	47.9591	Point 13
0.902	5.26	34.4955	47.9438	Point 14
1.270	10.96	34.5161	47.9814	Point 15

4- Estimation of shear wave velocity

The shear wave velocity is usually measured in-situ borehole tests like up/down-hole and cross-hole as well as refraction of surface waves. However, it is possible to estimate the shear wave velocity profile from single station or array measurements of ambient vibrations. The in-situ borehole tests are time consuming and relatively expensive because they need borehole to be drilled first and maintained for future tests. Refraction test also cannot be done at any conditions of urban area [29]. On the other hand, to overcome these difficulties, ambient vibrations measurements at a single station can be performed in almost anywhere and practically fast with the possibility to repeat the tests for several times at not significantly high costs because they do not need to boreholes to be drilled or maintained [30]. In this method, shear wave velocity profile is estimated from solving an optimization problem of inversion of ellipticity curve of Rayleigh waves. This is done by searching for the optimum shear wave velocity profile with changing parameters like shear wave velocity of layers, thickness and their densities by matching with the natural frequency of the site with the measured value [31]. In the previous investigations, this method and the array measurement of ambient vibrations are introduced as effective, economic, and fast methods to determine the shear wave velocity profile and Geotechnical site effects, so that match accurately with other methods [32].

In this part of the current study, the results of 15 measurements of ambient vibrations at Kangavar are used to estimate the shear wave velocity and average shear wave velocity (Vs30) using inversion of ellipticity of Rayleigh waves. To do this reverse problem, four initial models for shear wave velocity consisting of 3, 5, 7, and 10 layers are suggested as in Table 5. The inversion analysis is performed using Dinver software of Geopsy package [33]. The required parameters for the initial models are number of layers, range of shear wave and compressional velocities of each layer, thickness, Poisson ratio, and their densities.

Figures 14 and 15 present the shear wave velocity profiles that are estimated for points 1 and 7 according to initial models of Table 5. Furthermore, the average of shear wave velocity for top 30 meters (V_{s30}), which is used to determine the site type, are calculated from estimated shear wave velocity profiles and is presented in Table 6. According to Table 6 the average of shear wave velocity shows that the ground is of type II ($375<V_{s30}<750$) or type III ($175<V_{s30}<350$) for the stations.

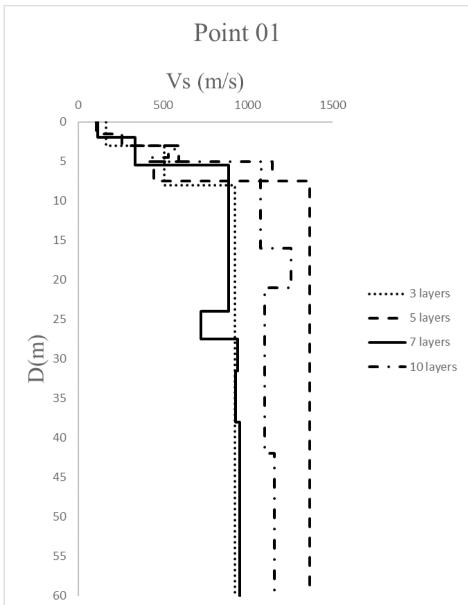

Figure 14. Shear wave velocity profile for the point 1 from four initial model with 3, 5, 7, and 10 layers by inversion of H/V spectrum

Table 5. Parameters of initial models for estimation of shear wave velocity profile

Model No.	Layers No.	V_s range (m/s)	Thickness (m)	
			f_0<1	f_0>1
1	1	100-1300	1-50	1-50
	2	200-1400	50-100	1-100
	3	300-1500	>100	>100
2	1	100-1100	1-25	1-25
	2	200-1200	25-50	1-50
	3	300-1300	50-75	1-75
	4	400-1400	75-100	1-100
	5	500-1500	>100	>100
3	1	100-1100	1-15	1-15
	2	200-1200	15-30	1-30
	3	300-1300	30-45	1-45
	4	350-1350	45-60	1-60
	5	400-1450	60-75	1-75
	6	450-1450	75-90	1-90
	7	500-1500	>90	>90
4	1	100-900	1-10	1-10
	2	200-1000	10-20	1-20
	3	300-1100	20-30	1-30
	4	350-1150	30-40	1-40
	5	400-1200	40-50	1-50
	6	450-1250	50-60	1-60
	7	500-1300	60-70	1-70
	8	550-1350	70-80	1-80
	9	600-1400	80-90	1-90
	10	650-1450	>90	>90

5- Geological description of Kangavar

Kangavar can be described geologically with outcrops of sedimentary-igneous rocks (JK), in northern part like Andesite, Rhyodacite, Rhyolite, Lithic Tuff, Tuff, and semi metamorphic limestone. In central part of the city, the (JKsl) unit is mostly observed that includes dark and dark gray Tuff with intrusions of limestone and sandstone. In southern part of the city, Arginine limestone (J2l), which are repeatedly overlaid by igneous rocks. These limestones have weathered crime, and fresh crime to gray colors and are recrystallized into very thin (3-5 cm) and thin (16-24 cm) slates. The lower layers of this formation has been metamorphosed due to thrust operation into Calc-schist with weathered color of gray to green and black with shine.

In south-western part of Kangavar outcrops of metamorphic igneous rocks with class of (JKmv) are observed, which contain Lava flows (Split, Spilitic Andesite) with holes filled with chlorite and calcite that means under sea volcanic operations. In between these metamorphic igneous rocks layers of limestone (J2l), and Andesitic Tuff exist with green color (Figure 16) [3].

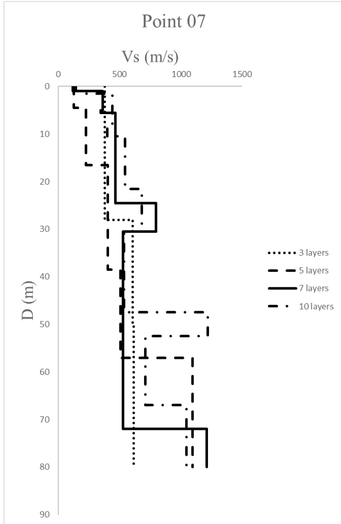

Figure 15. Shear wave velocity profile for the point 7 from four initial model with 3, 5, 7, and 10 layers by inversion of H/V spectrum

Table 6. Average shear wave velocity for 15 stations estimated by four initial models

Point No.	Vs30			
	3 layers	5 layers	7 layers	10 layers
1	-	663	539	626
2	-	495	582	366
3	477	438	332	378
4	-	695	352	549
5	-	-	563	550
6	317	425	338	604
7	390	247	439	477
8	-	474	596	508
9	-	487	596	630
10	248	292	511	557
11	593	415	501	500
12	-	-	518	561
13	-	384	336	404
14	423	387	410	365
15	-	362	600	434

6- Electrical resistivity map for Kangavar

In this part results of electrical resistivity tests are presented. The field measurements of electrical resistivity of Kangavar region are performed by a Geo-electric Terrameter SAS300 apparatus from ABEM equipped with current booster of SAS2000. The device is capable of measuring differential potential of at least 10 μv with 1 μv accuracy and the measurement of potential to current ratio with 0.05 mΩ accuracy. The electrical resistivity sounding was performed with 138 electrodes in a Schlumberger array configuration at 9 profiles with maximum length of current transmitter of 2000 meters.

Semi-electrical resistance map for current length of 200 meters are drawn. Figure 17 presents variations of apparent electrical resistivity to depth of 50 meters with range of variation 140 to 240 Ωm. The high, medium, and low electrical resistivity are shown by red, green, and blue colors, respectively. According to geological description of the region, the blue color corresponds to area with thicker sedimentary layers (mostly south and south-east of the city), and the red color corresponds to rock outcrops (mostly at south west of the city). It is clear that rapid increase of thickness of sedimentary layers that is found in Figure 17, which is observed more specifically at south-eastern part of Kangavar matches well with the findings of ambient vibration tests in Figure 13. Therefore, both tests confirm the variation of sedimentation depth in Kangavar.

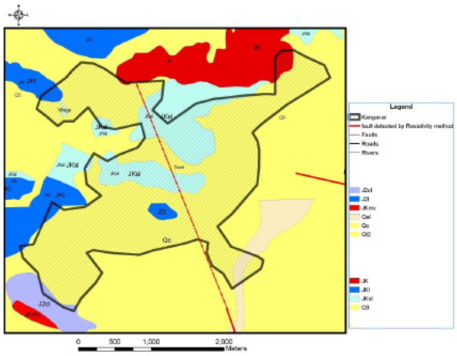

Figure 16. Geological map of Kangavar

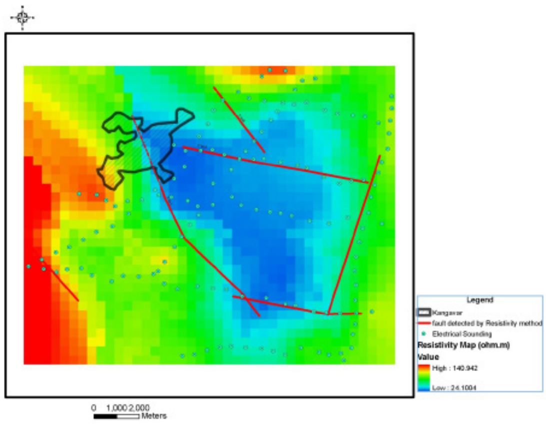

Figure 17. Semi-electrical resistivity map of Kangavar with locations of the sounding profiles

7- Kangavar urban construction planning

Urban construction planning according to geotechnical seismic considerations stands on three principles: first, identification of site seismic response and site effects hazards, which form geotechnical seismic micro-zonation investigation. Second, avoiding new constructions at high risk regions, which are identified in micro-zonation. Three, following a risk management plan for existing buildings at high risk regions. Such an urban construction planning is seeking for seismic risk reduction by considering hazard type, importance of building and its type, and engineering characteristics of construction sites [7].

In terms of site effects, buildings are classified upon their importance and natural period. The Iranian Code of Practice for Seismic Resistant Design of Buildings [34], classifies the buildings into four groups of importance; very important, important, moderately important, and low important. In term of, natural period of buildings, one can simplifies them into three categories of short with natural period of less than 0.4 sec., medium height with natural period of between 0.4 sec. to 0.8 sec., and tall buildings with natural period of more than 0.8 sec. [7].

The final part of this study aims to presents guiding regulations for urban construction planning according to geotechnical seismic micro-zonation investigations. The seismic hazards are known as a) resonant hazard and b) near fault effects for Kangavar. It is recommended that the construction of buildings in urban area are planned so that the natural period of the buildings are far from resonant and site amplification. Therefore, where the site amplification and resonant is a potential hazard, construction of very important and important tall buildings as well as important tall buildings are restricted. Table 7 summarizes regulations for construction according to resonant and site amplification hazard for Kangavar. Figures 18 and 19 present examples of GIS implementation of Table 7 guidelines for infilled frame and filled frame earthquake resistant systems, respectively.

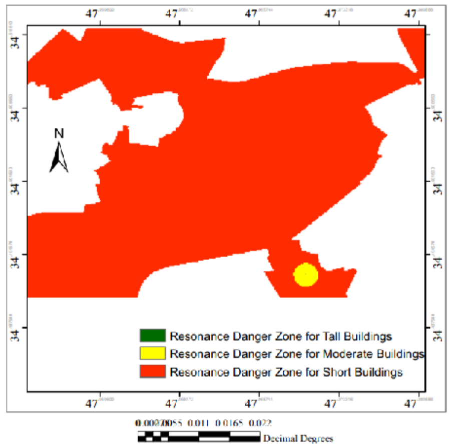

Figure 18. Construction guideline based on amplification hazard map for construction of infilled frame buildings

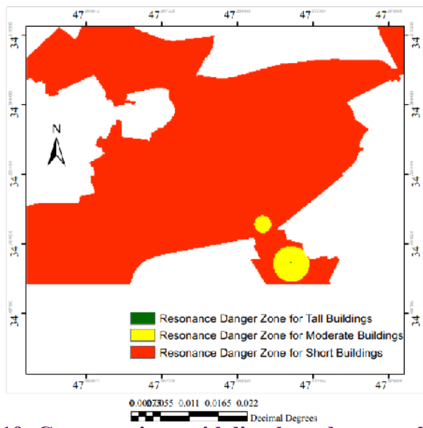

Figure 19. Construction guideline based on amplification hazard map for construction of filled frame buildings

8- Summary and conclusions

This study consists of three parts: probabilistic seismic hazard assessment, micro-zonation of geotechnical seismic hazards, and seismic urban construction planning of Kangavar. The summary and conclusions of each part are as followings.

First part of the study deals with seismic hazard assessment with probabilistic approach by presenting hazard curves for a grid of 32 points in the city with various ground motion laws. Uniform hazard spectra are calculated, which are found to be sensitive to the selected ground motion estimation relation. However, no privilege are given to ground motion laws and not weighted average are used to present peak ground acceleration and spectral acceleration for the vicinity of the city. The results of PGA and S_a at period of 0.1 sec. at grid points are used to generate the GIS map for these parameters. According to these maps, it is observed that the PGA at bedrock level increases from north to south of the city by approximately 10 percent. This is interpreted by the distance to the main reverse Zagros fault. In the center of the city the horizontal peak ground acceleration at bedrock level increases from 0.25 g for an earthquake of 475 years return period to 0.43 g for an earthquake of 2475 years return period. Similarly, the spectral acceleration at 0.1 sec. of the city center increases from 0.65 g for an earthquake of 475 year return period to 1.2 g for an earthquake of 2475 years return period.

The second part of the study are performed with measurements of ambient vibrations at 15 single stations using a broad band seismometer. The horizontal to vertical spectral ratio of the measured vibrations are calculated to estimate the natural frequency of the ground and thickness of the sedimentary layers on bedrock. The results of ambient vibration analysis reveal that the alluvial cover of the city is not thick in most of the regions. It is found by the high values of natural frequencies of the ground. Meanwhile, the value for the natural frequency varies relatively fast to lower frequencies at southern and south-eastern part of the city, where thick sedimentary layers exist. Results of a separate study of measurement of electrical resistivity at 9 profiles confirmed the rather sudden increase of alluvial thickness at south and south-east part of the city. Furthermore, the ambient measurements are used to estimate the shear wave velocity profile and average shear wave velocity for determination of ground type according to Iranian seismic code criteria. Results of this part are presented with GIS maps of natural frequency of the ground and average shear wave velocity of the ground.

The last part of the study deals with the using results of previous parts to present a guideline for urban construction plan. These guidelines are based on geotechnical seismic micro-zonation and aim to reduce the seismic risk of the city. These guidelines are based so that, if the level of importance of the building is higher and the natural period of the building falls in the range of potential resonant with the natural period of the site, the more restrictions are advised. For instance, construction of moderately high and very important buildings as well as very important and important tall buildings are restricted at regions with high natural period or near fault. Similarly, construction of very important and important short buildings are restricted to conditions at regions with low natural period or near fault.

It is worth noting that such a guideline is effective in reduction of seismic risk as they are applied in a risk reduction management plan by the governors. It is also recommended that individual designers take these guidelines as a base for their jobs and more restriction might be needed in different occasions.

References

[1] J. Stöcklin, “Possible ancient continental margins in Iran”, The geology of continental margins, Springer, (1974) 873-887.

[2] J. Stocklin, “Structural history and tectonics of Iran: a review”, AAPG Bulletin, 52(7) (1968) 1229-1258.

[3] Geological Survey & Mineral Exploration of Iran (www.gsi.ir).

[4] International Institute of Earthquake Engineering and Seismology (www.iiees.ac.ir).

[5] R.C. Henrickson, “A regional perspective on Godin III cultural development in central western Iran”, 24(1) (1986) 1-55.

[6] E. Shabani, N. Mirzaei, “Probabilistic seismic hazard assessment of the Kermanshah-Sanandaj region of Western Iran”, Earthquake Spectra, 23(1) (2007) 175-197.

[7] M. Kamalian, M.K. Jafari, “The General Standards of Urban Designing and Constructing Base On Seismic Geotechnical Considerations” Soffeh Scientific Publication of Architecture and Urban Planning, (2007) 140-164 (in Persian).

[8] M.K. Jafari, M. Kamalian, A. Razmkhah, A. Sohrabi, “North of Tehran site effect microzonation”, in: 13th World conference on earthquake engineering, Vancouver, BC, Canada. 2004.

[9] M. Akbari, M. Ghafoori, N.H. Moghaddas, G.R. Lashkaripour, “Seismic microzonation of Mashhad city, northeast Iran”, Annals of geophysics, 54(4) (2011) 424-434.

[10] A. Ghalandarzadeh, S. Sahraeian, A. Kavand, B.K. Moghaddam, “Seismic Microzonation of Shiraz City, Southwest of Iran”, in: Geotechnical Earthquake Engineering and Soil Dynamics IV, (2008).

[11] S. Haeri, M.H. Bonab, “Seismic microzonation of the city of Tabriz in Iran”, Asian Journal of Civil Engineering (Building and Housing), 1(3) (2000) 63-70.

[12] M. Kamalian, M.K. Jafari, M.R. Ghayamghamian, A. Shafiee, H, Hamzehloo, E, Haghshenas, A. Sohrabi-bidar, “Site effect microzonation of Qom, Iran”, Engineering Geology, 97(1-2) (2008) 63-79.

[13] T.S. Hashemi, A. Mohamadi, A. Salamat, Multi Disciplinary Approach for Seismic Microzonation of Bam City, “Oloom-e-Zamin”, 20(78) (2011) 17-26 (in Persian).

[14] M. Biglari, I. Ashayeri, R. Moftizadeh, “Urban Planning of Kermanshah City Based on the Seismic Geotechnical Hazards”, Journal of Seismology and Earthquake Engineering, 17(3) (2015) 203-211.

[15] N. Ambraseys, N. Douglas, S.K. Sarma, P.M. Smit, “Equations for the estimation of strong ground motions from shallow crustal earthquakes using data from Europe

and the Middle East: horizontal peak ground acceleration and spectral acceleration", Bulletin of earthquake engineering, 3(1) (2005) 1-53.

[16] K.W. Campbell, Y. Bozorgnia, "Updated near-source ground-motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration response spectra", Bulletin of the Seismological Society of America, 93(1) (2003) 314-331.

[17] K.W. Campbell, "Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra", Seismological research letters, 68(1) (1997) 154-179.

[18] M. Zare, "An Introduction to Applied Seismology", International Institute of Earthquake Engineering and Seismology, Tehran, Iran, (2005).

[19] H. Ghasemi, M. zare, Y. Fukushima, K. Koketsu, "An empirical spectral ground-motion model for Iran", Journal of Seismology, 13(4) (2009) 499-515.

[20] F. Sinaiean, M. Zare, Y. Fukushima. "A study on the empirical PGA attenuation relationships in Iran", in: Proceedings of the fifth international conference on seismology and earthquake engineering, Tehran (2007).

[21] The Evaluation of Risks and Seismic Risksin Provinces Ghazvin, Zanjan, Hamedan, and Kermanshah. The Final Report of the First Part: Seismic Microzonation of Kermanshah, in: Global Bank Project Number 4697-IRN (2009).

[22] S.B. Shamoradi, "Seismic Microzonation and Recommendations on Land Use and Construction (Case Study)", Master's theses, Malayer University. Iran, (2016) (in Persian).

[23] B. Gutenberg, C.F. Richter, "Earthquake magnitude, intensity, energy, and acceleration: (Second paper)", Bulletin of the Seismological Society of America, 46(2) (1956) 105-145.

[24] B. Tavakoli, M. Ghafory-Ashtiany, "Seismic hazard assessment of Iran:, Annals of geophysics, 42(6) (1999).

[25] M. Ordaz, A. Aguilar, J. Arboleda, "CRISIS2007 Ver 7.6, PROGRAM FOR COMPUTING SEISMIC HAZARD, User Manual", http:/www.ecapra.org/sites/default/files/static/CRISIS2007/English/player.html.

[26] M. Nogoshi, T. Igarashi, "On the amplitude characteristics of microtremor, Part II", Journal of the seismological society of Japan, 24 (1971) 26-40.

[27] Y. Nakamura, "A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface", QR Railway Tech. Res. Inst., 30(1) (1989) 25-33.

[28] SESAME European research project D23. 12, "Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations Measurements, Processing and Interpretation", European Commission-Research General Directorate, Project No. EVGl-CT-2000-00026 SESAME (2004).

[29] D. Fäh, F. Kind, D. Giardini, "Inversion of local S-wave velocity structures from average H/V ratios, and their use for the estimation of site-effects", Journal of Seismology, 7(4) (2003) 449-467.

[30] K. Tokimatsu, "Geotechnical site characterization using surface waves", in: Proc., First International Conference on Earthquake Geotechnical Engineering, Tokyo, Japan (1995).

[31] A.K. Mundepi, J.J. Galiana-Merino, A.K.L. Asthana, S. Rosa-Cintas, "Soil characteristics in Doon Valley (north west Himalaya, India) by inversion of H/V spectral ratios from ambient noise measurements", Soil Dynamics and Earthquake Engineering, 77 (2015) 309-320.

[32] A. Ghalandarzadeh, A. Kavand, "Determining shear wave velocity of an alluvial sedimentary layers using microtremor measurements", Journal of civil engineering and surveying – Technical College, 44(4) (2010) 525-536.

[33] M. Wathelet, "An improved neighborhood algorithm: parameter conditions and dynamic scaling", Geophysical Research Letters, 35(9) (2008).

[34] Permanent Committee for Revising the Iranian Code of Practice for Seismic Resistant Design of Buildings, "Iranian Code of Practice for Seismic Resistant Design of Buildings Standard No. 2800 (Fourth Edition)", (2014).

Please cite this article using:

I. Ashayeri, M. Biglari, S. B. Shamoradi, H. Rashidi Gouya, Probabilistic Seismic Hazard Assessment and Geotechnical Seismic Micro-zonation of Kangavar with Ambient Vibration and Electrical Resistivity Analysis, *AUT J. Civil Eng*, 2(1) (2018) 29-38.

DOI: 10.22060/ajce.2018.14494.5479