Research Note

Urban Planning of Kermanshah City Based on the Seismic Geotechnical Hazards

Mahnoosh Biglari[1*], Iman Ashayeri[1] and Rozhin Moftizadeh[2]

1. Assistant Professor, Department of Civil Engineering, Razi University, Kermanshah, Iran,
* Corresponding Author; email: m.biglari@razi.ac.ir
2. Graduate Student, Department of Civil Engineering, Razi University, Kermanshah, Iran

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ABSTRACT

The main target of seismic microzonation is to reduce the seismic risk vulnerability. The application of seismic microzonation in urban planning is an effective step towards decreasing hazards and damages of earthquakes. In this research, the risk of earthquake occurrence in Kermanshah has been taken into account in the form of maximum acceleration and spectral acceleration values for the three return periods of 475, 975 and 2475 years. It was found that ground accelerations at bedrock level increase from north to south of the city. Next, geophysical studies have been done to produce the fundamental frequency map of the ground. They show that the alluvium layer in most parts of Kermanshah is rather thin but at the central extend of the city. The fundamental frequency map is also used to assess the determination of land usage in Kermanshah for future, based on avoiding resonant hazard for the buildings as built according to national regulations.

Keywords:
Uniform hazard spectra; Seismic microzonation; Ambient microtremor; Seismic Geotechnical hazard; Urban planning

1. Introduction

Locating at the central region of Alpide seismic belt, Iran is the second most seismic zone of the earth, which has a high seismicity potential. Thus, different regions of the country have experienced destructive earthquakes hitherto. The analysis of seismological data reveals that averagely every five years, an earthquake of $M=7$ Richter happens in Iran and leaves serious effects on the society [1].

The historic city of Kermanshah geographically centered at 34.3142° N and 47.0655° E and extended about 20 Km in N-S and 10 Km in E-W. With a population of about one million (census 2011), the center of Kermanshah province is one of the mega-cities in Iran. The city is surrounded by active faults from north and south, the closest distance of which is about 25 kilometers south of the city (Major Active Faults of Iran, www.iiees.ac.ir). Furthermore, the surface topography of the city varies considerably from north-east to south-west of the city. The elevation of the city at central zone is about 200 meters lower than northern and southern region. The geophysical shape of the Kermanshah basin assures that the depth of the alluvial soil layers exceeds 40 meters at central zone and therefore, various seismic site effects are expected due to the topography and thickness of the soft soil on the seismic bedrock [2]. With respect to seismically active faults surrounding the city and various seismic Geotechnical aspects of the city, the seismic hazard and Geotechnical microzonation of the city was carried out as a Global Bank Project No. 4697-IRN at 2009 [2]. The current study is aimed to present an urban planning based on the available seismic and geotechnical investigations to reduce the seismic risk and vulnerability. The goal is achieved by updating seismic hazard assessment of the region with respect to newly occurred earthquakes (2008-2014) and performing new geophysical investigation to make the available data more accurate and reliable. The geophysical investigations contain studying ambient vibration using the horizontal to vertical spectral ratio (HVSR) [3]. Meanwhile, uniform hazard spectra for three return periods of 475, 975, 2475 years were calculated at grid points of 0.05 degrees in latitude and longitude. Finally, with processing all data in a Geographic Information System (GIS), recommendations for future construction of different buildings in terms of their importance and earthquake resistant system were made.

2. Seismicity Characteristics and Seismic Hazard

Zagros is the most active seismic area in Iran. Several earthquakes with the magnitude 5 to 6.5 have happened in this area. There is no evidence proving that an earthquake bigger than Silakhor 1909 with magnitude of 7.4 has happened.

In this research, probabilistic approach is used to assess the seismic hazard. This approach involves specifying the likelihood magnitude, location, and nature of earthquakes that might have damaging effect in the region of the site and estimating the seismic parameter of the ground shaking [4-5]. More important, in this approach, the probability of earthquakes with variable intensity and magnitude is included. Another priority of probabilistic assessment of seismic hazard is that it ends in correct parameter assessment of the big ground shaking as well as other signs of destruction in the site under assessment [5]. Steps taken to perform PSHA are explained as follows:

2.1. Defining Seismic Sources

In order to define the seismic sources all strong motion events occurred in an area with the center of Kermanshah and radius of 200 Km were reviewed from certified earthquake catalogues [1]. Consequently, six area sources were considered for the seismic hazard assessment, Figure (1). While, the sources 1, 3 and 5 involve main active faults, the sources 4 and 6 are around Kermanshah with less seismic activity and the source 2 belongs to north-west of Zagros with sparse earthquake causing.

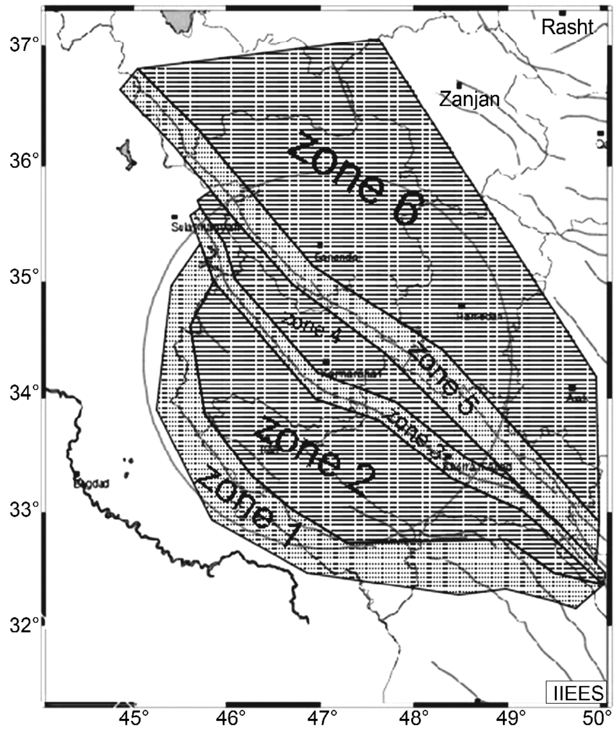

Figure 1. Definition of seismic sources.

The earthquake recurrence model was determined from the earthquake catalogues in the form of Eqs. (1) and (2).

$$\lambda(M) = \lambda_0 \frac{\exp(-\beta M) - \exp(-\beta M_u)}{\exp(-\beta M_0) - \exp(-\beta M_u)} \qquad M_0 \le M \le M_u \tag{1}$$

$$P(M_u) = \frac{1}{\sigma\sqrt{2\pi}} \frac{\exp\left[\frac{-1}{2}\left(\frac{M_u - EM}{\sigma}\right)^2\right]}{\phi\left[\frac{M_2 - M_1}{\sigma}\right] - \phi\left[\frac{M_1 - EM}{\sigma}\right]} \qquad M_1 \le M_u \le M_2 \tag{2}$$

where the seismic parameters are given in Table (1) and defined as: M_0, the least earthquake regarded for a specific seismic source, λ_0 or Lambda (M_0), the yearly number which has a magnitude less than M_0, β (Beta), the parameter of source seismicity, CV (Beta) the coefficient of variation of Beta, EM the amount considered between M_1 and M_2 in Gaussian distribution for the highest number of the earthquakes occurred in the source, σ (Sigma) the standard deviation regarded for the magnitudes, M_1 the most historical earthquake in the source that is

Table 1. The Earthquake recurrence parameters.

Source	M_0	Lambda (M_0)	Beta	CV(Beta)	EM	Sigma	M_1[4]	M_2[4]
4	4	0.8821	1.675	0.1033	7.4	0.4	7	8
5	4	0.4843	1.7913	0.1457	7.4	0.4	7	8
6	4	2.3189	2.0699	0.0556	7	0.2	6.8	7.4
9	4.5	0.2284	2.3009	0.1569	6.8	0.3	6.5	7.6
10	4.5	0.2492	1.8453	0.1658	7.4	0.4	7	8
11	4	1.8763	1.9535	0.0850	7	0.2	6.8	7.4

considered to be the minimum limit of M_u, M_2 the most experienced earthquake that is computed according to tectonic conditions of the source and considered as the maximum limit of $M_u, \phi[M]$ is the cumulative probability of standard normal distribution, and $P(M_u)$ the probability density of the earthquake magnitude.

2.2. Estimating the Ground Shaking Models

In this research, four attenuation models are used: Ambraseys et al. [6], Zare [7], Ghasemi-Zare [8] and Sinaeian-Zare [9]. Moreover, every model is explained.

2.2.1. The Attenuation Relation of Ambraseys et al. [6]

The general form of attenuation relation of Ambraseys et al [6] is as:

$$\log y = a_1 + a_2 M_W + (a_3 + a_4 M_W)\log(d^2 + a_5^2)^{0.5} + a_6 S_S + a_7 S_A + a_8 F_N + a_9 F_T + a_{10} F_O \tag{3}$$

where a_1 to a_{10} changes in harmony with various periods, M_W is moment magnitude, *d* is the distance to rupture surface, S_S regarded as 1 for the site with soft soil, otherwise it is zero, S_A regarded as 1 for the site with hard soil, otherwise it is zero, F_N regarded as 1 for normal faults, otherwise it is zero, F_T regarded as 1 for reverse faults, otherwise it is zero, F_O regarded as 1 for odd faults, otherwise it is zero, *y* is the parameter of intense ground shaking whether peak acceleration or spectral according to correspondent coefficients.

2.2.2. The Attenuation Relation of Zare [7]

The general form of attenuation relation of Zare [7] is as:

$$\log A = aM + bX - \log X + c_i S_i + \sigma P \tag{4}$$

where *A* is the parameter of intense ground shaking whether peak acceleration or spectral according to correspondent coefficients in m/s^2, *M* the moment magnitude, *X* the focal distance in kilometers and *c* the site's coefficient (*S*), *a*, *b*, c_i and σ are also coefficients that vary in harmony with various periods [7].

2.2.3. The Spectral Attenuation Relation of Ghasemi-Zare [8]

The general form of attenuation relationship of Ghasemi-Zare [8] is as follows:

$$\log_{10} S_a(T) = a_1 + a_2 M + a_3 \log_{10}(R + a_4 10^{a_5 M}) + a_6 S_1 + a_7 S_2 \tag{5}$$

where $S_a(T)$ is the amount of spectral acceleration in gal, the coefficients of a_1 to a_7 vary proportional to various periods, *M* moment magnitude, *R* the focal distance in kilometers and the coefficients S_1 and S_2 change with soil classification, so that of rock; $S_1 = 1$ and $S_2 = 0$ and soil; $S_1 = 0$ and $S_2 = 1$.

2.2.4. The Maximum Acceleration Attenuation Relation of Sinaeian-Zare [9]

The general form of attenuation relationship of Sinaeian-Zare [9] is as follows:

$$\log(PGM) = aMw - \log(R + d.10^{eM_W}) + bR + \sum C_j S_j + \sigma.P \tag{6}$$

where *PGM* is the design maximum parameter whose unit for acceleration is gal, the coefficients of *a*, *b*, C_j, *d*, *e* and σ are determined in considering the tables, *MW* is the moment magnitude, and *R* is the focal distance in kilometer [9].

2.3. PSHA in the Field of Study

Different PSHA analyses were performed using CRISIS2007 [10], the details of which are given in

Table (2). The results of the analysis are presented in the form of hazard graphs, uniform hazard spectra, maximum acceleration and spectral acceleration zonation maps at grid points in the field of Kermanshah. The hazard graphs show annual exceedance probability of acceleration. For instance, hazard graphs of peak acceleration in the center of the city is shown in Figure (2) for different attenuation relationships.

Table 2. The index of analysis worked out.

No. of Analysis	Attenuation Relation
1	PGA Amerces (2005)
2	S_a Amerces (2005)
3	PGA Zagros Horizontal Component Zara (2005)
4	S_a Iran Horizontal Component Zara (2005)
5	PGA Sinaeian-Zare (2007)
6	S_a Ghasemi-Zare (2009)

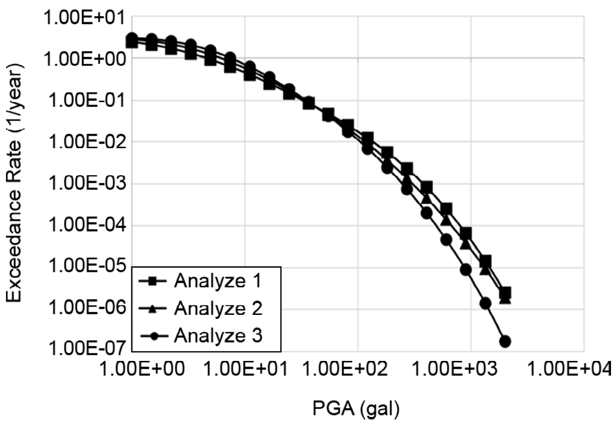

Figure 2. Hazard graphs of peak acceleration in center of the city.

As shown in uniform hazard spectra at seismic bedrock in Figures (3) to (5), for return periods of 475, 975 and 2475 years respectively, the spectra derived from Ambraseys' attenuation relation place higher than others and the spectra related to Ghasemi-Zare attenuation relation place lower. Since no privilege can be given to one attenuation relation, the average spectra given in Figures (3) to (5) must be taken into account.

With respect to the analysis performed for grid points in the extent of the city, the peak and spectral acceleration zonation maps at seismic bedrock are generated using GIS analysis. Figures (6) and (7) show the spectral acceleration at period 0.2 sec. for

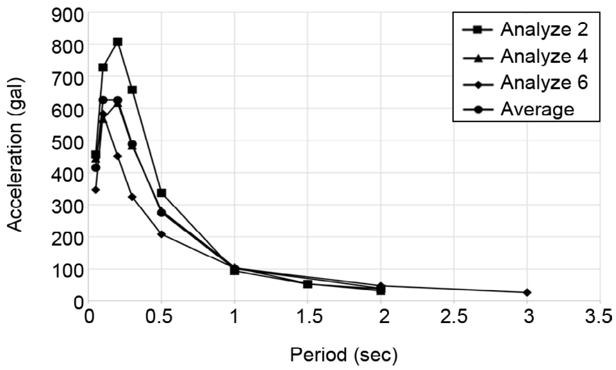

Figure 3. Spectral graphs for return period of 475 years in center of the city.

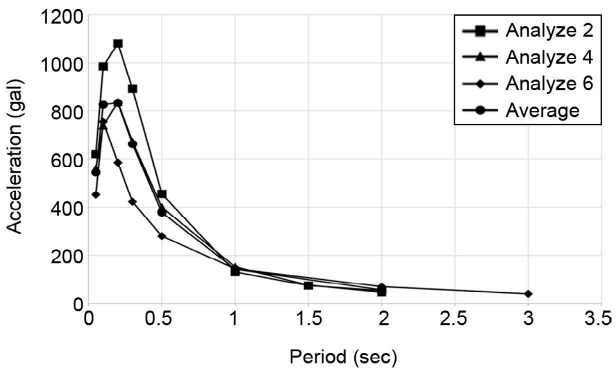

Figure 4. Spectral graphs for return period of 975 years in center of the city

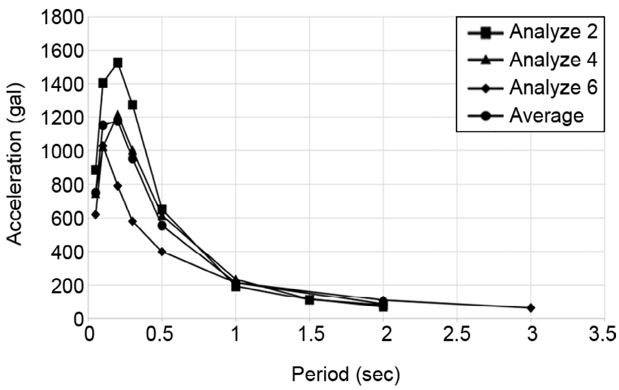

Figure 5. Spectral graphs for return period of 2475 years in center of the city.

instance, which owns the maximum amounts and for return periods of 475 and 975 years, respectively. Similarly, Figures (8) and (9) represent the peak acceleration for return periods of 475 and 2475 years.

3. Geophysical Investigation of Kermanshah

The spectral *H/V* ratio technique originally proposed by Nogoshi and Igarashi [11], and

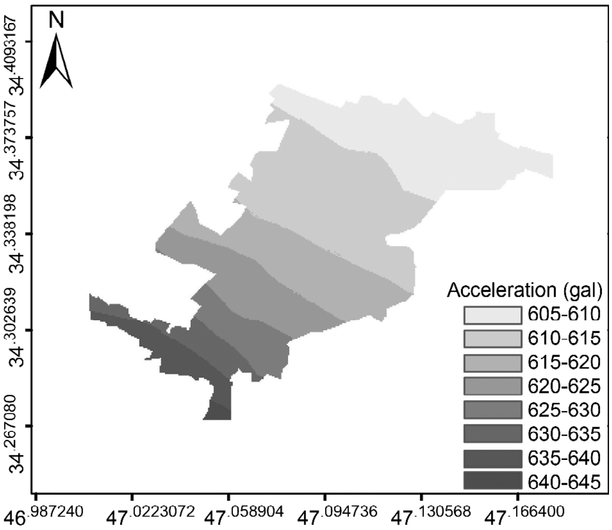

Figure 6. Average spectral horizontal acceleration map for period of 0.2 sec. and return period of 475 years at seismic bedrock.

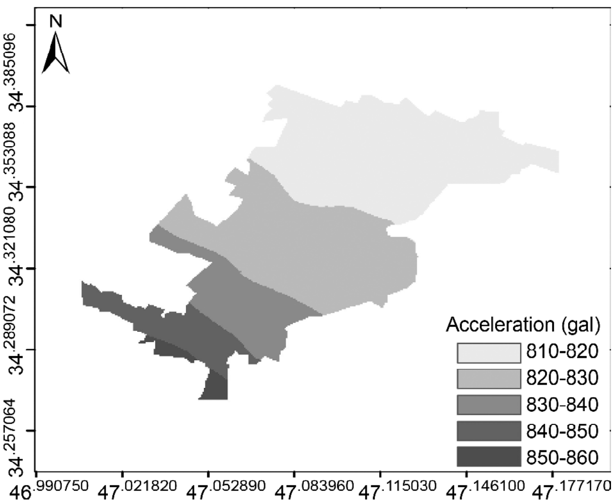

Figure 7. Average spectral horizontal acceleration map for period of 0.2 sec. and return period of 975 years at seismic bedrock.

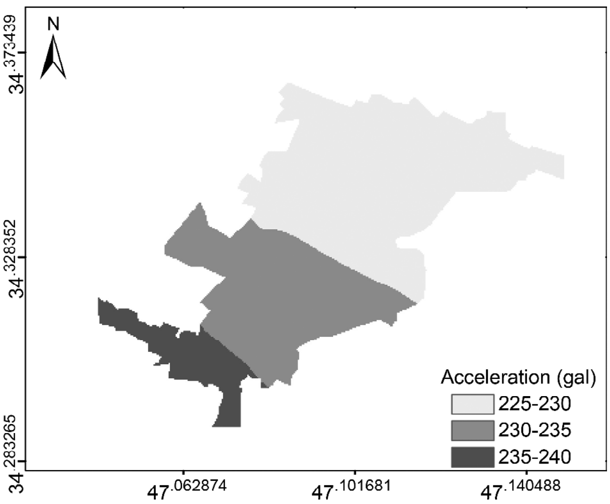

Figure 8. Average maximum horizontal acceleration map for 475 years return period at seismic nedrock.

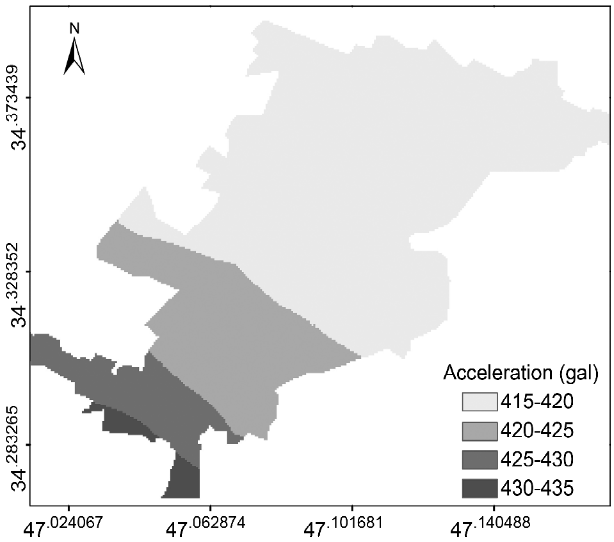

Figure 9. Average maximum horizontal acceleration map for 2475 years return period at seismic bedrock.

wide-spread by Nakamura and Samizo [12], consists in estimating the ratio between the Fourier amplitude spectra of the horizontal (*H*) to vertical (*V*) components of the ambient noise vibrations recorded at one single station. Recording the seismic microtremor together with using the *H/V* spectral ratio is one of the methods introduced to help knowing the local characteristics of a site. It was shown that there is a good correlation between the value of the peak frequencies of microtremor and strong motion HVSRs [13].

The first requirement, before any extraction of information and any interpretation, concerns the "reliability" of the *H/V* curve. Reliability implies stability, i.e., the fact that actual *H/V* curve obtained with the selected recordings, be representative of *H/V* curves that could be obtained with other ambient vibration recordings and/or with other physically reasonable windows selection. After proving the reliability of a curve, "clarity" should be checked. The clear peak case is met when the *H/V* curve exhibits a "clear, single" *H/V* peak. The "clarity" concept may be related to several characteristics: the amplitude of the *H/V* peak and its relative value with respect to the *H/V* value in other frequency bands, the relative value of the standard deviation $\sigma_A(f)$, and the standard deviation σ_f of f_0 estimates from individual windows. The property "single" is related to the fact that in no other frequency band, does the *H/V* amplitude

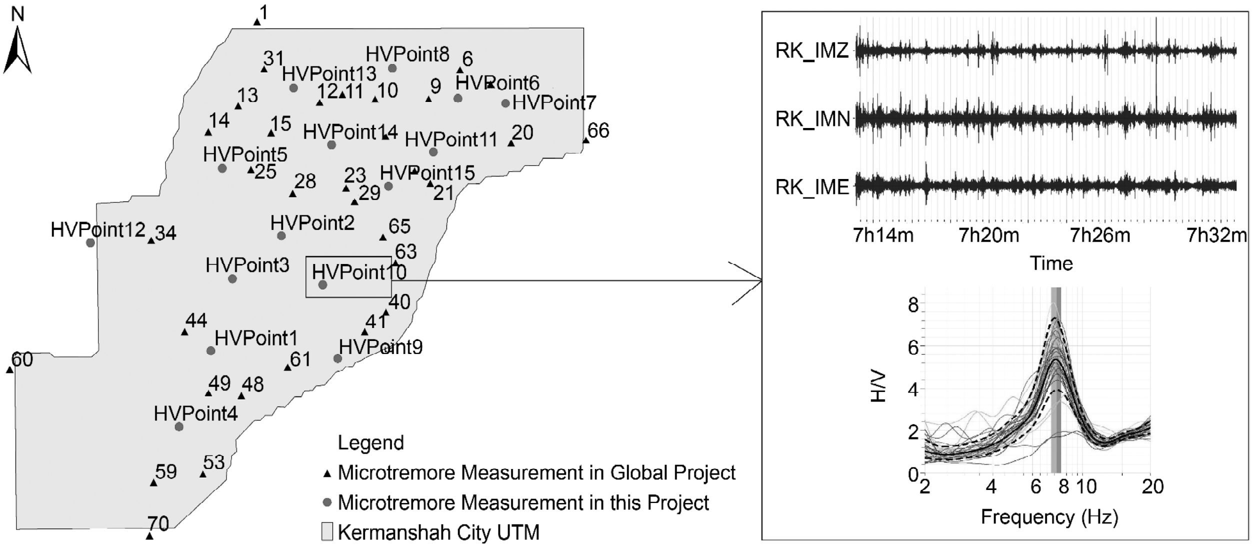

Figure 10. Geographic distribution of recorded microtremor in the city.

exhibit another "clear" peak satisfying the same criteria. To check the reliability and clarity of an *H/V* curve explained above, the criteria of SESAME-D23.12 [13] have been checked for each station.

The number of 85 microtremor were analyzed. Amongst them, 70 were performed during the Global Bank Project No. 4697-IRN and 15 were performed recently as part of the current study.

The final results of microtremor in Kermanshah are presented in GIS map of fundamental frequency

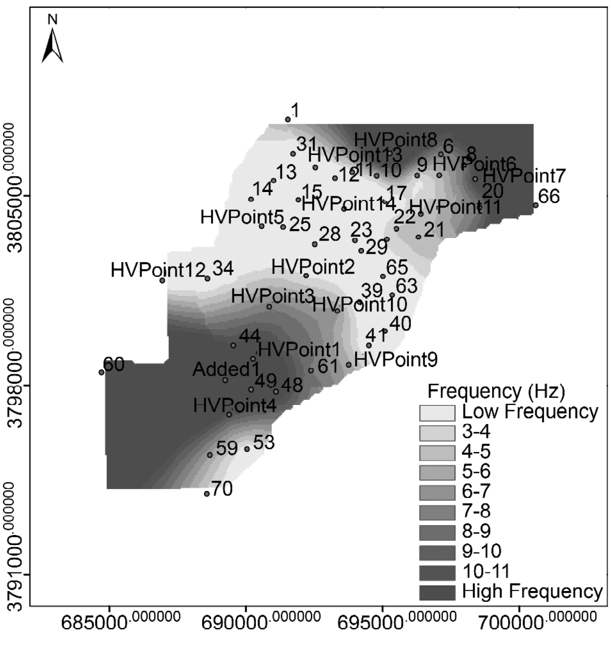

Figure 11. The map of fundamental frequency of the ground in Kermanshah achieved from microtremor data.

of the ground, Figure (11). From the fundamental frequency map, it can be seen that in northeast and southwest parts of Kermanshah plain, the frequency is high that shows the low thickness of alluvium layer and even rock outcrop. In central regions that the bedrock's depth is high even more than 40 meters, the fundamental frequency is lower.

4. Urban Construction Plan

Urban construction plan according to seismic Geotechnical considerations are based on three principles: First, the correct recognition of the site's seismic response and probable hazards due to the site effects. Second, the maximum avoidance of construction in risky, undeveloped zoned and barrens. Third, applying a method based on risk management especially in undeveloped areas. The city construction based on risk management is seeking the way that by regarding the kind of hazard and evaluating the importance and types of buildings, make such decisions to decrease the risk to the least [14-15]. Afterward, general decision criteria are presented to use the seismic geotechnical microzonation studies in urban planning, Table (3). These criteria are categorized based on the type of the geotechnical hazard as:

The zone of resonant hazard: the natural period of buildings to be close to the natural period of the site. Based on this, in places where resonance hazard exists, construction of tall and moderately

Table 3. A Summary of general standards for the use of results of the seismic geotechnical studies in planning city constructions [14].

The Site Situation \ Type of the Building		Short Period ($T \le 0.4sec.$)			Moderate Period ($0.4sec. < T \le 0.8sec.$)			Long Period ($T > 0.8sec.$)		
		Moderate Imp.	High Imp.	Very High Imp.	Moderate Imp.	High Imp.	Very High Imp.	Moderate Imp.	High Imp.	Very High Imp.
The Zone of Resonant Hazard	Short Period	Allowed	Con. Allowed	Con. Allowed*	Allowed	Allowed	Allowed	Allowed	allowed	Allowed
	Moderate Period	Allowed	Allowed	Allowed	con. Allowed	con. Allowed*	Pref. Forbidden	Allowed	allowed	Allowed
	Long Period	Allowed	Allowed	Allowed	Allowed	Allowed	Allowed	Con. Allowed*	Pref. Forbidden	Pref. Forbidden

Allowed: Building the certain construction in the mentioned field is allowed. However, enforcing the spectrum of the recommended plan from the permanent revision committee together with the seismic geotechnical microzonation studies is strongly recommended.

Conditionally allowed: Building is allowed on condition that the special design spectrum of the field is used or at least the conservative assimilation of the results taken from seismic geotechnical microzonation studies together with the recommended design spectrum offered by permanent revision committee is taken into account. The (*) shows that if possible, avoid constructing on the field.

Preferably forbidden: The first priority is avoiding construction on the certain field. If this priority cannot be observed, using special design spectrum of the field in structure designing is inevitable.

Forbidden: Any construction is strictly forbidden.

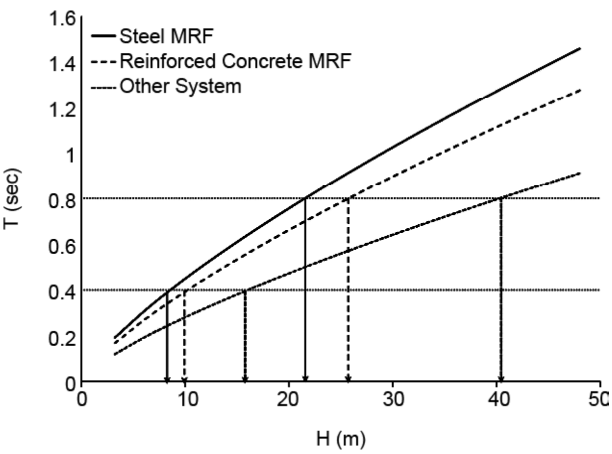

Figure 12. Definition of tall, moderately tall, and short buildings.

tall buildings with very high importance, and also construction of tall buildings with high impor-tance are preferably forbidden and other con-structions are conditional [14]. Accordingly, Figure (12) presents the criteria that are used to define the fundamental periods of buildings with different earthquake resistant systems and height.

According to the recommended criteria, Table (3), Figure (13) presents the resonance hazard map for the city. The map indicates that the probability of resonance hazard for short buildings in northeast and southwest is high, for tall buildings in central parts of Kermanshah it is the same and also for moderately tall buildings the probability exists for a relatively narrow region between central and northern and southern regions.

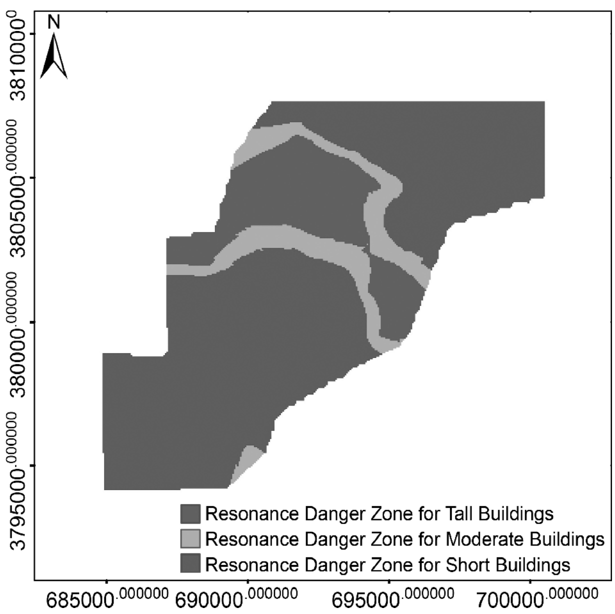

Figure 13. The map of seismic geotechnical hazard zones in Kermanshah

5. Summary and Conclusion

The current investigation is summarized into three parts including: seismic hazard assessment, seismic Geotechnical microzonation, and urban planning.

In the seismic assessment, the hazard curves and uniform hazard spectra of three return periods of earthquakes are calculated for different ground motion attenuation relations at grid points of 0.05

degrees distributed latitudinal and longitudinal. Respecting these maps, it is observed that the farther you go from the north to the south of the city, the more acceleration is faced at seismic bedrock.

In the seismic microzonation part, single station ambient vibrations are studied and the outcomes show that the alluvium layer in most parts of Kermanshah but the central region, where it is more than 40 meters is relatively thin.

Finally, it was tried to offer the general criteria for applying the outcomes of seismic Geotechnical microzonation surveys to decide the practical land use, making the designing of structures more accurate and consequently reducing the risk of earthquake damages. Therefore, the construction of moderately tall buildings with high and very high importance are facing more strict limitations than the short buildings in resonance hazard zone. It must be remarked that the outcomes of seismic geotechnical microzonation surveys is of great effect in city construction planning and seismic risk management just when they enjoy accuracy, validity, and legal positions. It is also mentioned that these criteria are just suggestions and according to the designer's idea, the limitations can be more or less. As a general survey of the land practical use for the city of Kermanshah, it can be said that for short buildings, the more important the building is, the more area of the central part can be used. For moderately tall buildings, only small parts of the city center face the limitation for construction, and construction is allowed for the other parts of the city. For tall buildings, the central parts face limitations but the other parts are allowed.

Acknowledgments

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