SEISMIC VELOCITY AND DISPLACEMENT HAZARD ASSESSMENT FOR TEHRAN, INCLUDING SITE EFFECTS

G. Ghodrati Amiri [*a], M.J. Mahtabi [b] and S.A. Razavian Amrei [b]
[a]Centre of Excellence for Fundamental Studies in Structural Engineering, Iran University of Science and Technology, Narmak, Tehran-16, Iran
[b]School of Civil Engineering, Iran University of Science & Technology, Tehran, Iran

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ABSTRACT

Estimation of earthquake parameters using probabilistic method has become very common in recent years. In Iran and especially for Tehran several studies have been performed to analyze the seismic hazard. Regarding the rapid development of lifeline facilities and the construction of few tall buildings in Tehran as well as the good correlation that exists between Peak Ground Velocity (PGV) and Peak Ground Displacement (PGD) with seismic behavior of such structures, seismic velocity and displacement hazard analyses for the region can be very useful. In this study probabilistic seismic hazard analyses of PGV and PGD, for a network of 31×31 points within Tehran are conducted. For each element incorporated in analysis (e.g. seismicity parameters, attenuation relationships, etc.) various alternatives are employed. Results of hazard analysis using any combination of these alternatives are obtained using SEISRISK III program, for 4 hazard levels including site effects and combined subsequently using logic-tree approach.

According to the results, for the probability of exceedence of 2, 10, 20 and 50 percent in 50 years, the maximum values of PGV are 105, 51.5, 35.4 and 18.7 cm/s, respectively. For the aforementioned hazard levels, the corresponding PGDs are 56, 20, 11.7 and 4.5 cm, respectively.

Keywords: Probabilistic seismic hazard analysis (PSHA); PGV; PGD; hazard level; Tehran; Iran

1. INTRODUCTION

Tehran, the capital of Iran, is the most important city of the country. This city is located at the foot slope area of the Alborz Mountains, which forms part of the Alps-Himalayan organic zone. The urban area of Tehran has been developed on alluvial layers. In recent years, urban

[*] E-mail address of the corresponding author: ghodrati@iust.ac.ir (G. Ghodrati Amiri)

development in Tehran was progressively growing in a high and unbelievable rate. Almost 10 million people live in Tehran and most of the economical, political, cultural and other important centers of the country placed there. Since the development of lifeline facilities in recent years was significant, it is necessary to estimate the earthquake hazard, related to these facilities, in the region. The damage of an earthquake to lifeline facilities has many consequences, because their safety is vital for humans after an earthquake and their failure will cause many direct and indirect losses of life.

In this study seismic hazard of velocity and displacement, which are suitable parameters for analyzing seismic behavior of lifelines, is addressed. Peak Ground Velocity (PGV) and Peak Ground Displacement (PGD) are very important parameters of an earthquake and have many applications in earthquake engineering and engineering seismology. Newmark et al. [1] used both PGV and PGD together with PGA to construct the elastic response spectra for design. Several studies have been showed that PGV correlates well with shear strain in the soil (Newmark, [2]). Based on this concept several studies showed that PGV is an appropriate parameter to estimate the capability of an earthquake to cause liquefaction in the soil (Kostadinov and Towhata [3], Trifunac and Todorovska [4]). Akkar and Özen [5] explored the influence of various ground-motion parameters on the inelastic demand on single-degree-of-freedom (SDOF) oscillators; found that a good correlation exists between PGV and the inelastic demand in the intermediate period range. Bommer et al., [6] used PGV/PGA and PGD/PGV ratios to estimate the respective corner periods at which the constant acceleration plateau ends and the constant displacement plateau begins. PGV has also been found to correlate well with earthquake damage to buried pipelines (O`Rourke and Ayala [7]; Eidinger et al. [8]).

Trifunac and Todorovska [9] showed that the increase in the shear forces for peripheral columns (on individual foundations), caused by differential ground-motion is significant and must be considered in design of novel structures and retrofitting of existing structural systems. Their work has recently been extended by Trifunac and Gicev [10], who explored that the linear out-of-plane earthquake response of long structures supported by individual columns, experiencing differential motions, at their foundation can be described by a new form of response spectra that is a function of the relative motions.

Despite the wide range of applications that PGV and PGD have in earthquake engineering, there are surprisingly few studies that use these parameters in seismic hazard assessment for Tehran (Ghodrati et al. [11]) and majority of seismic hazard studies deal with PGA as earthquake parameter (Ghodrati et al. [12]; Tavakoli and Ghafory-Ashtiany [13]).

2. SEISMIC HAZARD ANALYSIS (SHA)

In general, a SHA can be classified as either deterministic or probabilistic depending on the approach taken. A brief description of these methods is presented below.

2.1 Deterministic seismic hazard analysis (DSHA)

Deterministic method in seismic hazard analysis is always used for site-specific seismic hazard analysis of very important structures such as nuclear power plants, dams, etc. (Reiter

[14]). In this method an estimation of ground motion parameter (i.e. velocity, displacement, acceleration, etc.) results from only a single magnitude earthquake, on a single source, in a single distance from the site, without regard to the likelihood that an event with the selected magnitude and distance will occur (Green and Hall [15]).

2.2 Probabilistic seismic hazard analysis (PSHA)

In probabilistic seismic hazard analysis, all the probable earthquakes (from all sources, magnitudes and distances) are considered and combined in a statistical method. The consistency of PSHA with the nature of earthquakes makes this method popular. The predicted ground motion in this method is for a probability of exceedence per a determined period of time. This tool make user capable to encounter the economical considerations.

In general, the PSHA method comprises of four steps as follows (Green and Hall [15]):

a) Determination of seismic sources.
b) Determination of seismicity parameters.
c) Selection of appropriate ground motion prediction equations.
d) Calculation of seismic hazard in the region.

3. SEISMIC SOURCES OF THE REGION

In order to perform seismic hazard analysis for Tehran, all the seismic sources (faults) in a radius of 200 km from the center of the city are considered. There are many active faults in the region. Most of these faults caused many earthquakes in the past. For this reason many studies have been performed to determine the active faults in the region (Takin [16], Stocklin [17], Tchalenko [18], and Berberian et al. [19]).

As noted before, there are many faults in the study area. One of the important sources is the Mosha fault. This fault is about 200 km long and is situated in the north of the city. North Tehran Fault is another source in the northern part of the city which is situated in the south of Mosha fault. It has a length of about 90 km. Among faults in the southern part of the region, North Rey and South Rey faults are the most important ones. These faults are located at a distance of 10 kilometers south of the city. Approximate length of North Rey fault is about 16.5 km. South Rey fault that is located in south of North Rey fault and a distance of 14 km from the city, has a length of about 18.5 kilometers.

Many other important seismic sources exist in the region, namely Kahrizak Fault, Shiyan-Kowsar Fault, Garmsar Fault, Parchin Fault, Eyvanakey Fault.

4. SEISMICITY OF THE REGION

Tehran has been experienced many destructive earthquakes in the past. Fortunately most of this event occurred before development of the city. Many scientists have studied the historical earthquakes of Iran (Ambraseyse and Melville [20], and Moinfar et al. [21]). According to these studies, Rey city, which was the largest city near the current Tehran, has been suffered from many damaging earthquakes between years of 300 BC to 1400 AD. The earliest earthquake reported in the region, refers to year 300 BC. This earthquake has a magnitude of Ms=7.6 and intensity of I=X (Ambraseyse and Melville [20]). One of the other destructive earthquakes of the city refers to year 856 AD (Ms=7.1) which felt in Qom and Kashan (Ambraseyse and Melville, [20]). Ambraseyse and Melville [20] has reported another damaging earthquake in 958 AD with magnitude of Ms=7.7 and an intensity of Io=X that caused many damages in the Rey city. Many other great earthquakes such as those of years 1177 AD (Ms=7.2), and 1665 AD (Ms=6.5) have been reported by various studies (Ambraseyse and Melville [20], Moinafar et al. [21]).

A catalogue of earthquakes which is used in this study is showed in Appendix A. This catalogue is an updated version of that used by Ghodrati et al. [12] in which the aftershocks and foreshocks are filtered out by a time-distance window approach proposed by Gardner and Knopoff [22]. The former catalogue is supplemented by the main shocks of earthquakes after 2003. A map of recent seismicity in the country is shown in Figure 1.

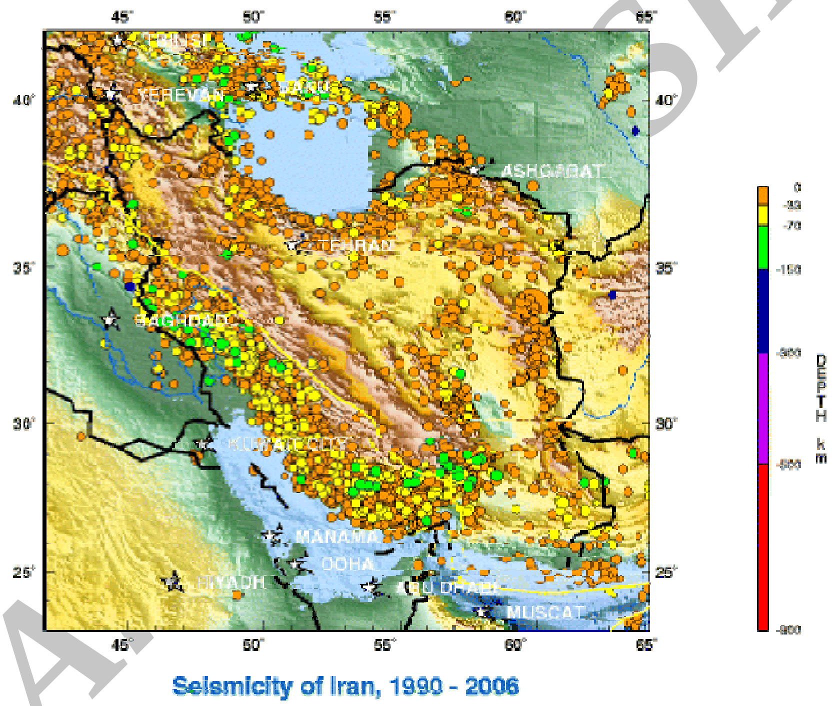


Figure 1. Recent seismicity map of Iran*

5. INPUT DATA FOR SHA

As mentioned before, in order to perform a more reliable seismic hazard analysis, one must gather a well known input data and perform a realistic modeling of the collected data. The data used in this study is described below.

* Derived from http://earthquake.usgs.gov

5.1 Seismic sources and estimation of earthquake magnitude

Seismic sources of the region considered in a radius of 200 km based on previous studies (Tchalenko [18], Berberian et al. [19]) and the last map of faults published by Geological Survey of Iran. These faults are modeled as linear sources in hazard calculations.

In this paper the estimation of the magnitude an earthquake caused by a fault rupture length of L, is performed by using two various relations between fault rupture length and the magnitude of caused earthquake. These relations are those for Nowroozi [23] and Wells and Coppersmith [24].

5.1.1 Nowroozi relation.

Nowroozi [23] using data from 10 great earthquakes of Iran and after analyzing the rupture of their causative faults such as Zagros, North Alborz Fault, Tabriz Fault, North Tabriz Fault and some others, obtained the empirical relation between fault rupture length and earthquake magnitude. The equation is:

$$M_s = 1.259 + 1.244 \log L \tag{1}$$

In this equation, L is the rupture length in meter and M_s is surface-wave magnitude of the earthquake.

5.1.2 Wells and coppersmith relation

Wells and Coppersmith [24] after analyzing several earthquakes of the world, consisting of some Iranian earthquakes (e.g. Tabas, Rudbar), obtained the following relation between fault rupture length and earthquake magnitude:

$$\text{Log } L = -3.22 + 0.69M \tag{2}$$

In which L is rupture length in kilometer and M is earthquake magnitude (M_w). Since most of earthquake magnitudes in Iran are expressed in M_S or m_b, a conversion is necessary. In this country, for magnitudes $M \geq 6$, M_w is equal to M_S and for values $M < 6$, M_w is equal to m_b (Zare` et al. [25]). For the conversion between M_S and m_b the Equation (3) is used (IRCOLD [26]):

$$M_s = 1.29 m_b - 1.259 \tag{3}$$

5.2 Seismicity of the region and seismicity parameters

Seismicity parameters of Tehran are calculated based on the last earthquake catalogue of the region (Appendix A). Since in PSHA, one of the inherent assumptions is the independence of events, the main shocks of the early catalogue is cropped by filtering-out the foreshocks and aftershocks using time-distance window method proposed by Gardner and Knopoff [22].

In this study, seismicity parameters of the region obtained by two methods; the first one is using values calculated by Tavakoli [27] and the other is the maximum likelihood method proposed by Kijko [28]. The results of using each method in seismic hazard analyses are combined in a Logic-tree method.

- **Using parameters obtained by Tavakoli**

Tavakoli [27] divided Iran into 20 seismotectonic provinces and computed seismicity parameters for each zone. Tehran is located in the zone 15. Table 1 shows the calculated parameters for each zone.

Table 1: Seismicity parameters for seismotectonic provinces of Iran (Tavakoli [27])

Province No.	Span of Time	Beta	M_{max}	Lambda (M_s=4.5)
01	1926-95	1.55±0.12	8.1±0.4	2.09
02	1963-95	1.19±0.32	7.2±0.4	0.35
03	1960-90	1.30±0.27	7.2±0.3	0.26
04	1941-90	1.17±0.17	7.6±0.3	0.21
05	1927-95	1.27±0.28	7.4±04	0.44
06	1929-95	1.39±0.16	7.6±0.3	0.64
07	1923-95	1.95±0.15	7.5±0.3	0.47
08	1924-95	1.99±0.17	7.4±0.4	0.16
09	1922-95	1.94±0.16	7.3±0.3	0.27
10	1932-95	1.47±0.27	6.6±0.2	0.88
11	1944-95	2.24±0.11	7.6±0.4	0.48
12	1920-95	2.12±0.05	7.2±0.2	1.70
13	1925-95	2.49±0.13	7.0±0.4	0.27
14	1928-95	1.98±0.13	7.6±0.4	0.33
15	1927-95	1.41±0.11	7.9±0.3	0.37
16	1900-92	1.68±0.17	7.6±0.4	0.14
17	1907-92	1.72±0.15	7.5±0.3	0.53
18	1924-92	1.61±0.12	7.9±0.4	1.05
19	1900-95	1.68±0.07	7.9±0.2	0.84
20	1929-95	2.32±0.16	7.5±0.9	0.33

- **Kijko Method**

Another method, used in this study, to calculate the seismicity parameters is Kijko method [28].

The assumptions considered in Kijko method are as follows:

- The occurrence of earthquakes is assumed independent from time and space domains to conform the Poisson distributions.
- Uniform seismicity properties were assumed in the radius of 200 km around Tehran.

In order to use this method, the earthquakes in the main catalogue, departed into 3 parts;

historical earthquakes (earthquakes before 1900 AD), instrumental analogue data (events between 1900 and 1964 AD) and instrumental digital data (after 1964 AD) and seismicity parameters calculated by Kijko method [28], for three types of data:

a) Using only historical earthquakes, with magnitude uncertainty from 0.3 to 0.5.

b) Using instrumental earthquake records.

c) Using both historical and instrumental data.

Computed parameters for each case is shown in Table 2.

5.3 Ground – motion prediction equations (attenuation relationships)

Attenuation relationships are mathematical-based expressions that relate a specific strong-motion parameter of ground shaking (e.g. velocity, displacement, acceleration, etc) to one or more seismological parameters of an earthquake (magnitude, soil conditions, etc.) (Campbell [29]). These relationships are momentous tools in seismic hazard assessment. Selection of an appropriate attenuation equation that well predicts the ground motion parameter in the desired site depends on several factors, such as earthquakes mechanism in the region, soil conditions, focal depth of earthquakes, and etc. Regarding these factors four attenuation relationships are selected for both velocity and displacement. Those equations selected for prediction of velocity are: Ghodrati et al. [30], Tromans and Bommer [31], Margaris et al. [32] and Gregor et al. [33]. For performing seismic displacement hazard analysis, the relations of Zare` et al. [25], Tromans and Bommer [31], Margaris et al. [32] and Gregor et al. [33] are selected. One important point in selection of each of these relationships is their range of applicability.

The results of seismic hazard using each relationship are combined in a logic-tree method.

Table 2: Calculated seismicity parameters using Kijko method [28]

Catalogue	Parameter	Value	Data contribution to the parameters (%)		
			# 1	# 2	# 3
Instrumental Earthquakes data	Beta	1.73	---	40.5	59.5
	Lambda (M_S = 4)	0.83	---	28.8	71.2
Historical Earthquakes data	Beta	2.35	100	---	---
	Lambda (M_S = 4)	0.65	100	---	---
Historical and Instrumental data	Beta	1.55	34.6	32.5	32.9
	Lambda (M_S = 4)	0.82	19.4	15.9	64.7

Another usefull output from Kijko method [28] is the annual rate of earthquake magnitudes which is shown in Figure 2.

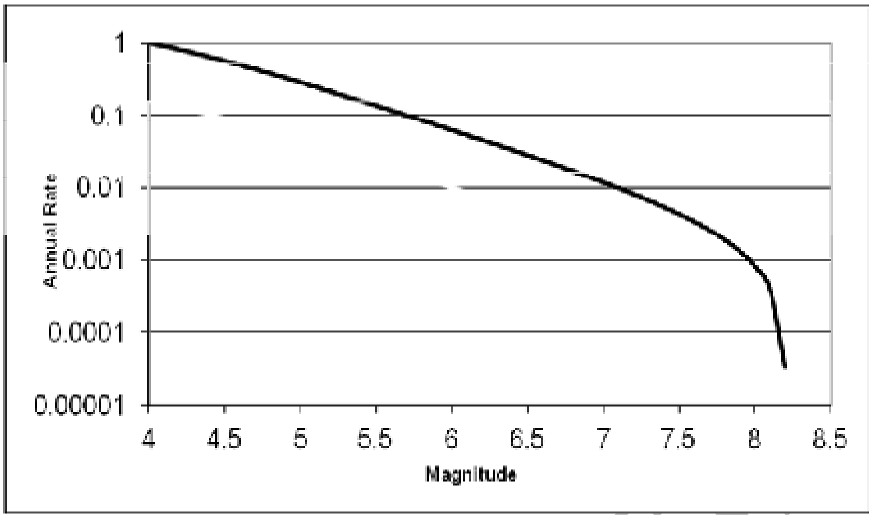


Figure 2. Computed annual rate of earthquakes using Kijko method [28]

6. SEISMIC HAZARD ANALYSIS RESULT

With the assumption that earthquake occurrences follow the Poisson distribution (Eq. (4)):

$$P(n,t)=\frac{(ut)^n.e^{-ut}}{n!} \tag{4}$$

In which *P(n, t)* is the probability of having exactly *n* events in a future time period of *t*, and u is the average occurrence rate, the probability of exceedence of ground motion parameter (*g.m.*) from a threshold (*Thr*) is:

$$P(g.m.>Thr)=1-\prod_k\left\{1-P_k(g.m.>Thr)\right\} \tag{5}$$

In which:

P: Probability of exceedence due to all sources

P_k: Probability of exceedence due to k^th^ source

$\prod_k$: Series product.

In order to compute seismic hazard in the region the SEISRISK III software (Bender and Perkins [34]) is utilized. As mentioned earlier the seismic sources are modeled as linear sources. Seismic hazard for the region is conducted for 4 hazard levels. These hazard levels are:

- 2% probability of exceedence in 50 years.
- 10% probability of exceedence in 50 years.
- 20% probability of exceedence in 50 years.
- 50% probability of exceedence in 50 years.

7. COMBINATION OF RESULTS USING LOGIC-TREE METHOD

Logic-tree method is a powerful tool for dealing with uncertainties in seismic hazard analysis. The logic-tree used in this study for each parameter is shown in Figure 3.

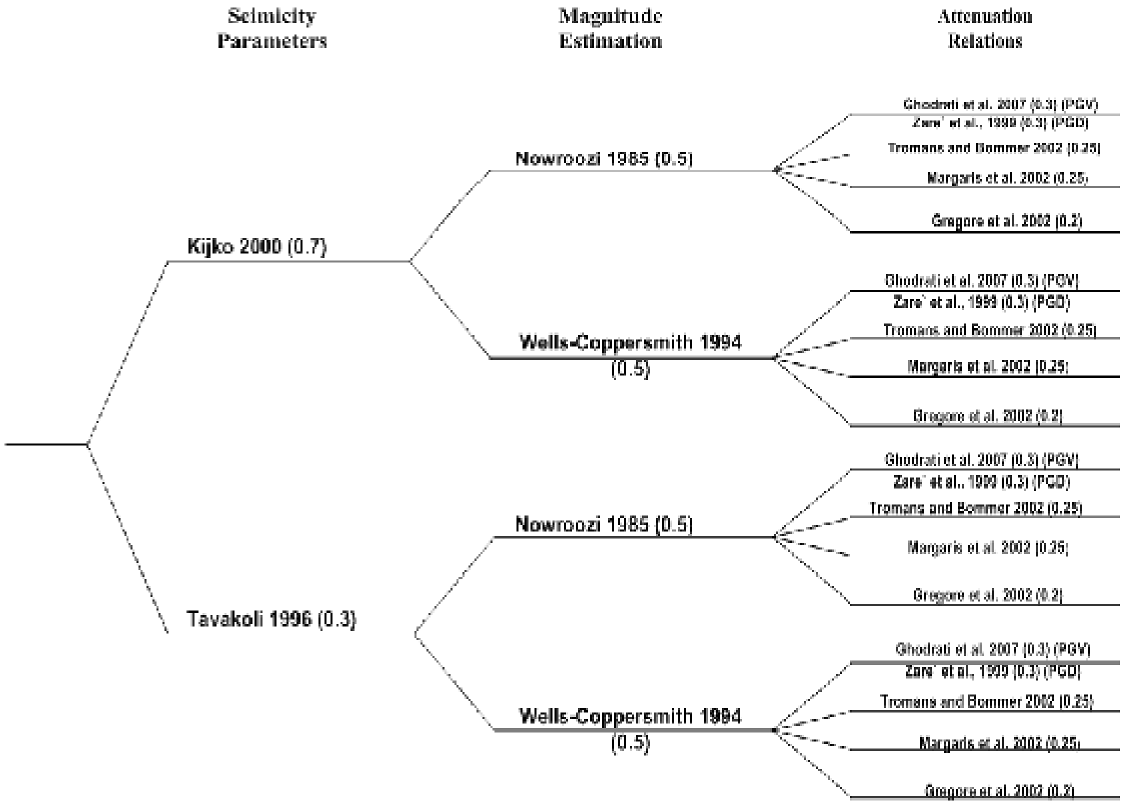
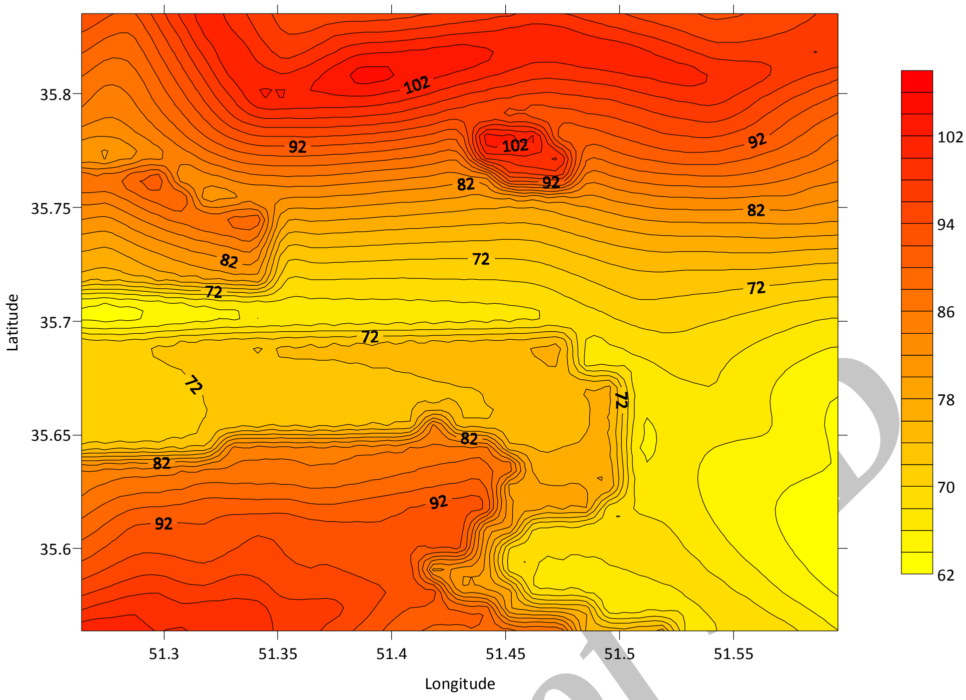


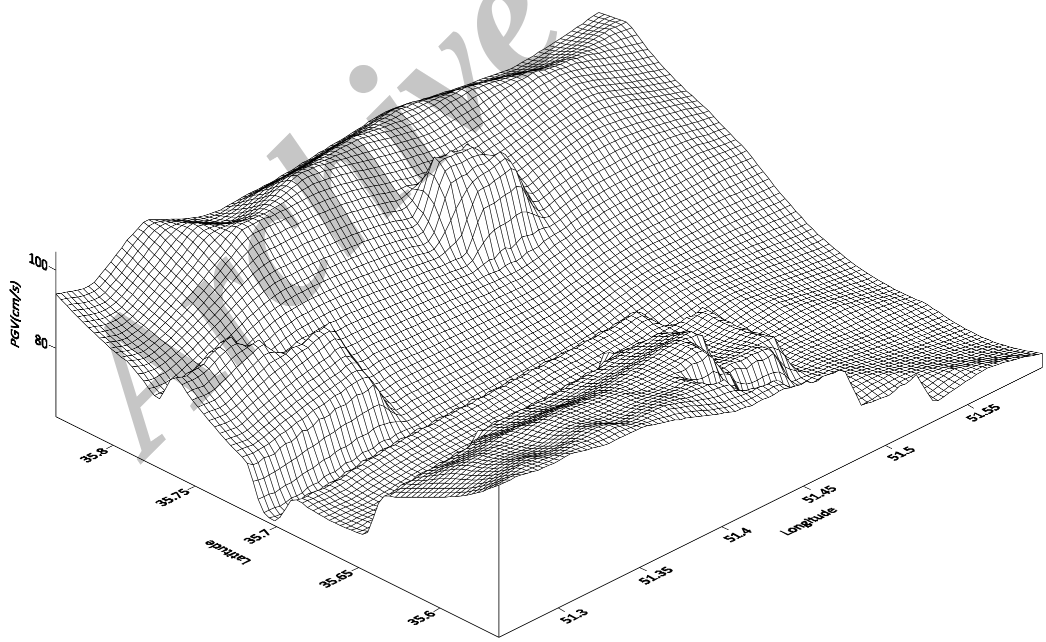
Figure 3. logic-tree used in seismic hazard analysis

8. RESULTS

Final results of seismic velocity and displacement hazard analysis using logic-tree approach are presented as iso-velocity and iso-displacement contour maps. These maps are shown in Figures (4) to (7) for PGV and Figures (8) to (11) for PGD.

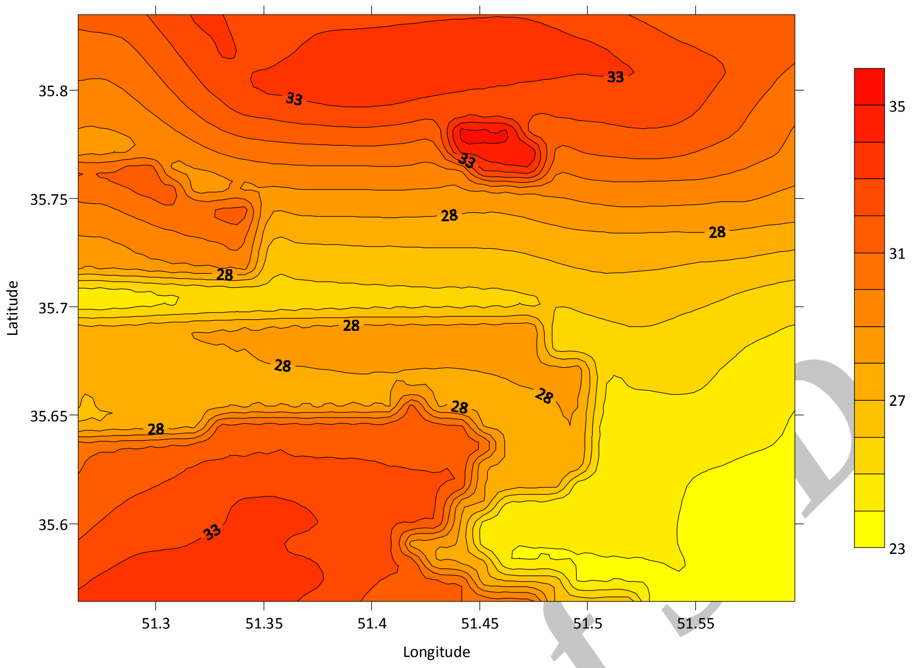


(a)

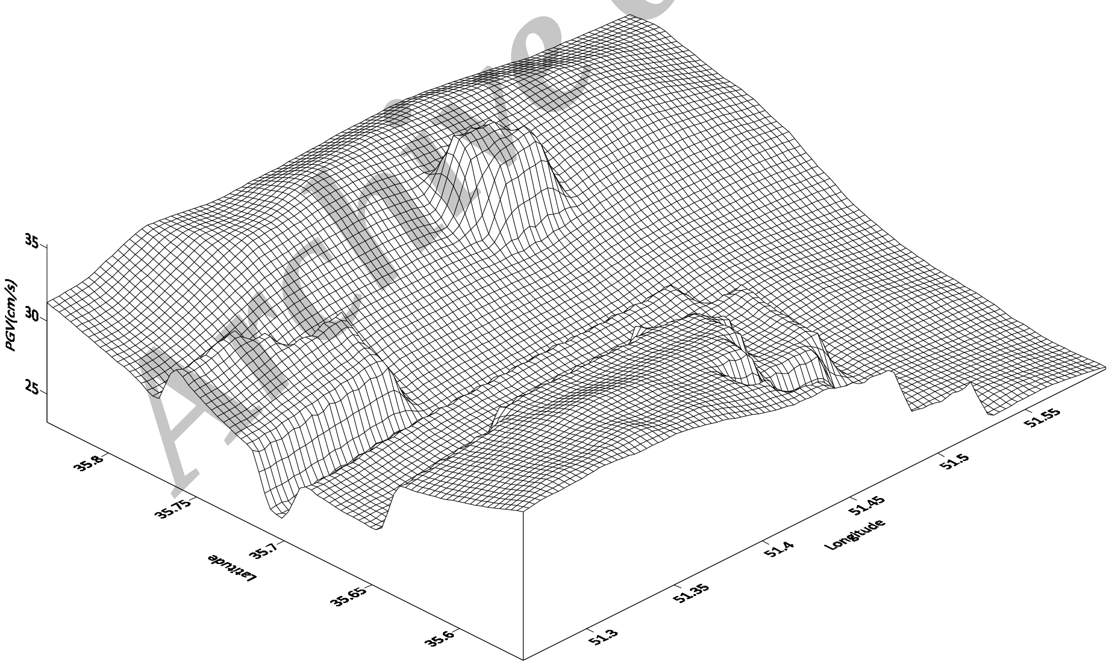


(b)

Figure 4. Final seismic zoning map of Tehran for PGV (cm/s) using logic-tree method for 2% probability of exceedence in 50 years (a) two-dimensional zoning map and (b) three-dimensional zoning map

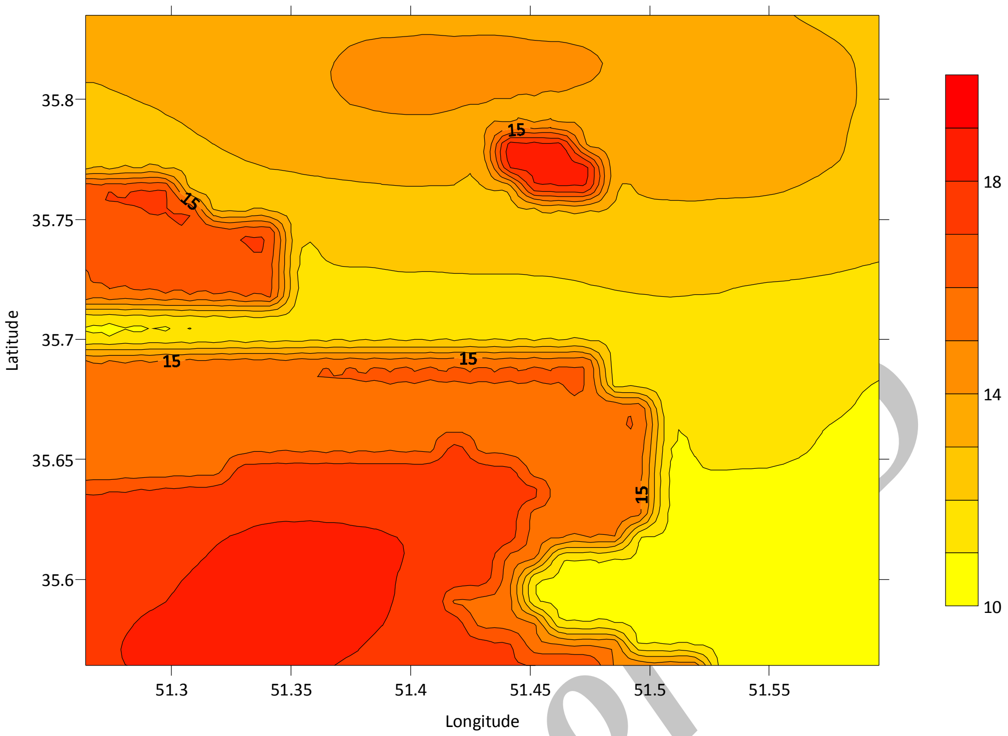


(a)

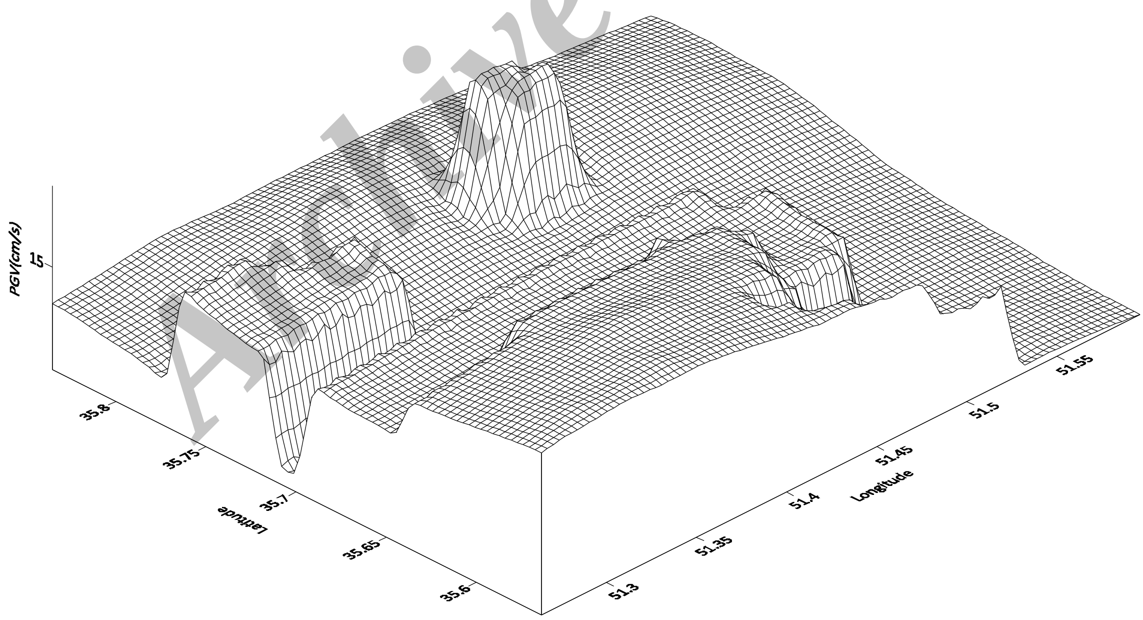


(b)

Figure 6. Final seismic zoning map of Tehran for PGV (cm/s) using logic-tree method for 20% probability of exceedence in 50 years (a) two-dimensional zoning map and (b) three-dimensional zoning map

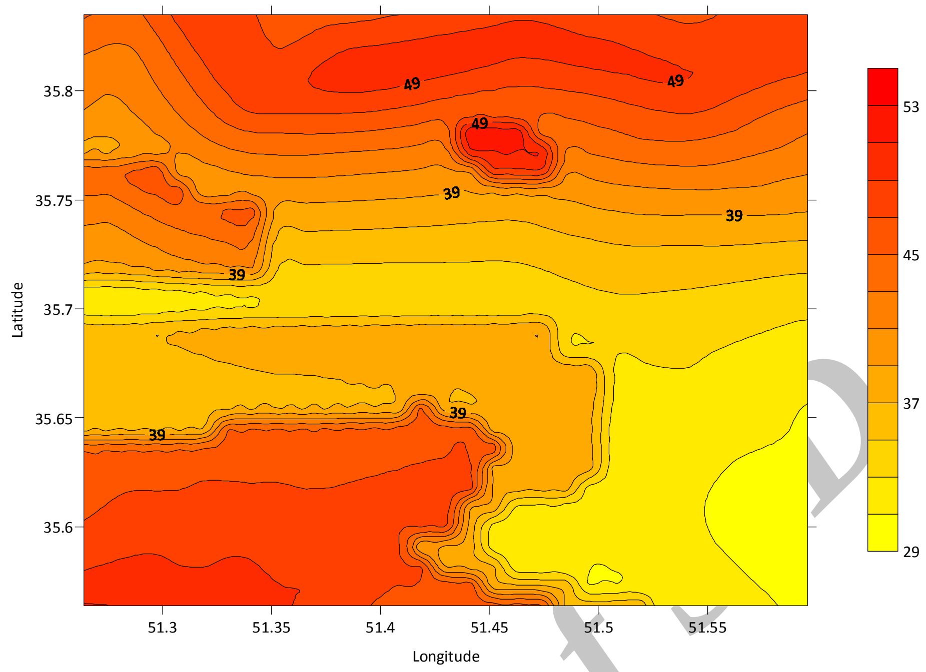


(a)

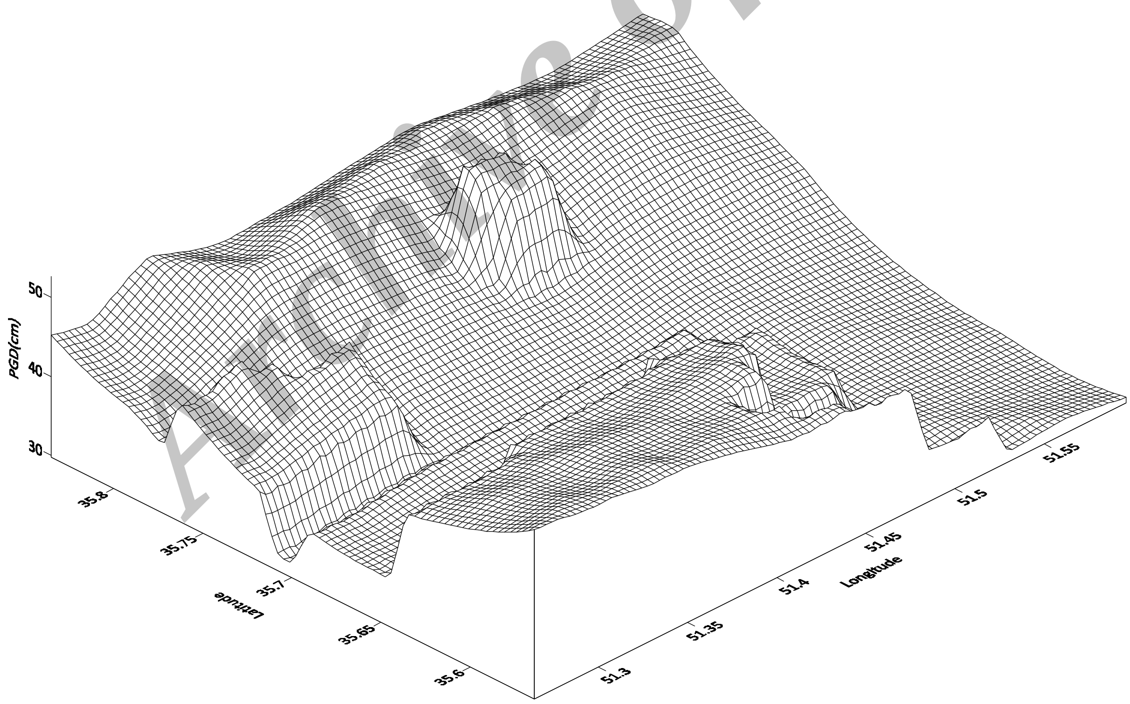


(b)

Figure 7. Final seismic zoning map of Tehran for PGV (cm/s) using logic-tree method for 50% probability of exceedence in 50 years (a) two-dimensional zoning map and (b) three-dimensional zoning map

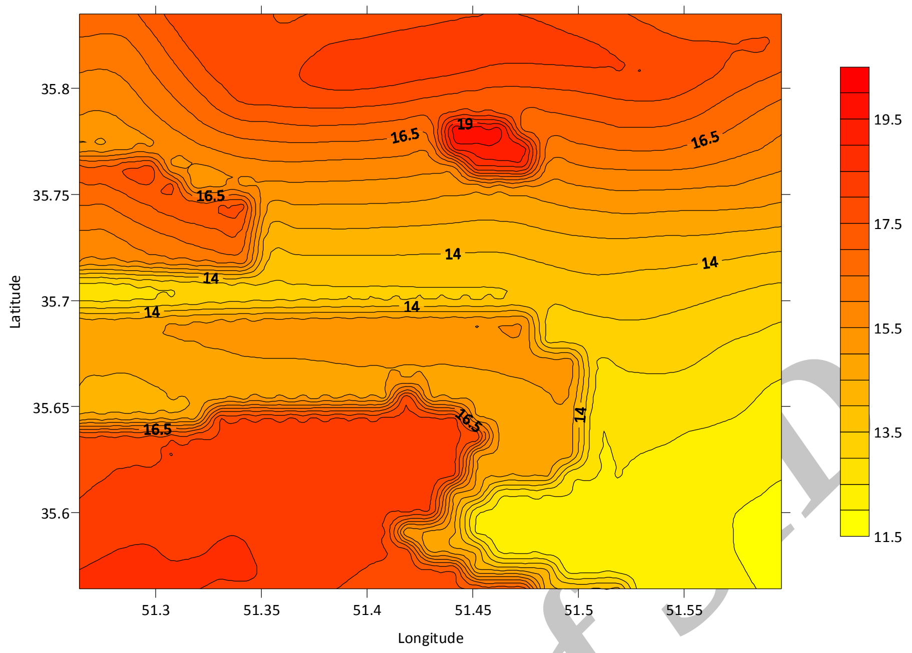


(a)

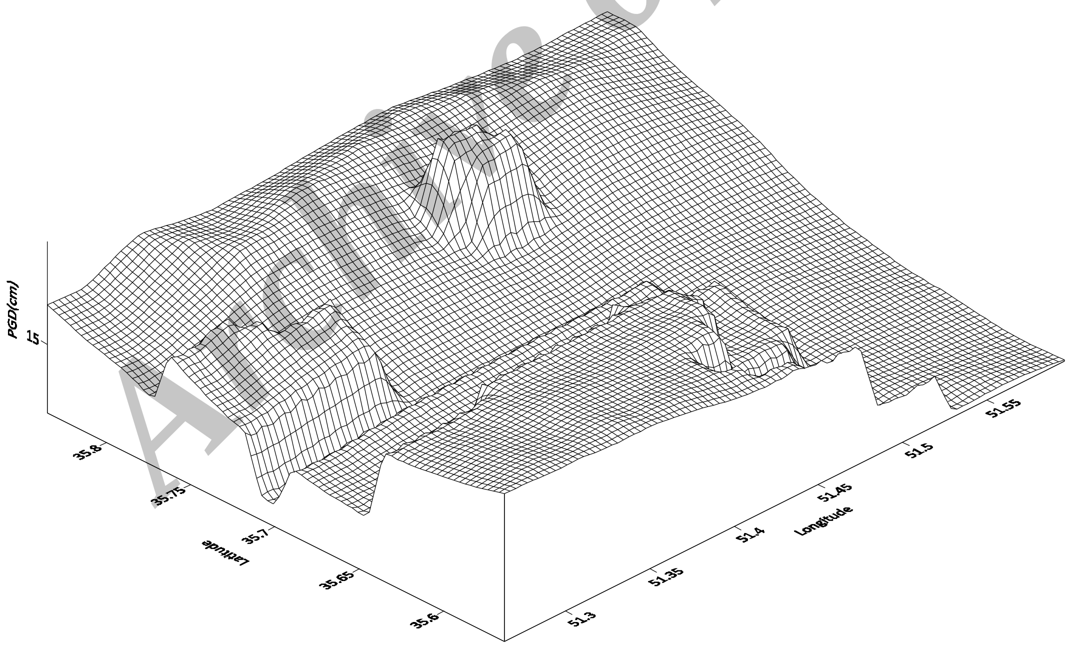


(b)

Figure 8. Final seismic zoning map of Tehran for PGD (cm) using logic-tree method for 2% probability of exceedence in 50 years (a) two-dimensional zoning map and (b) three-dimensional zoning map

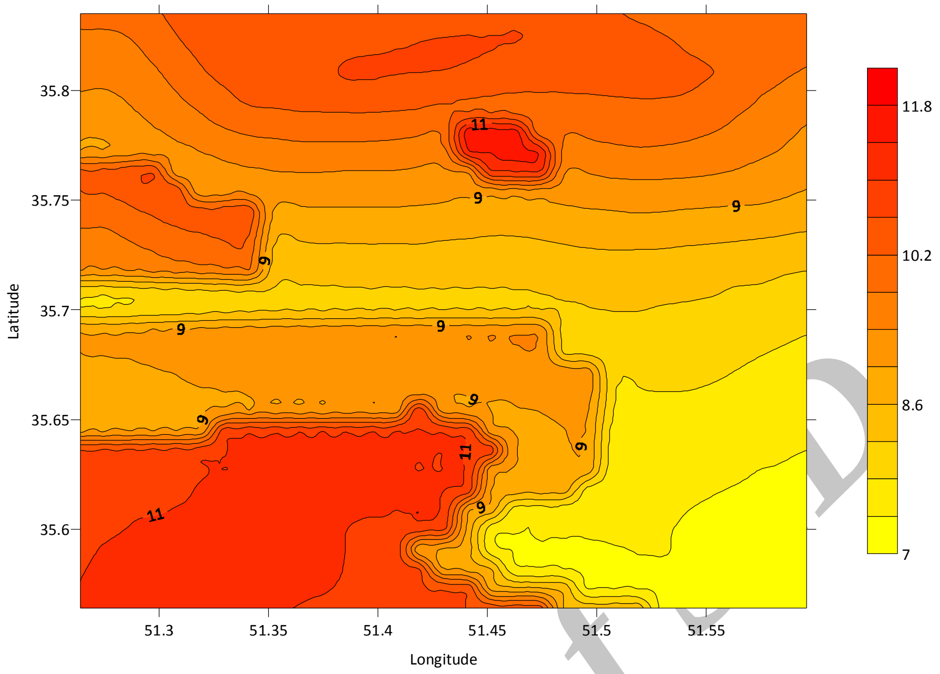


(a)

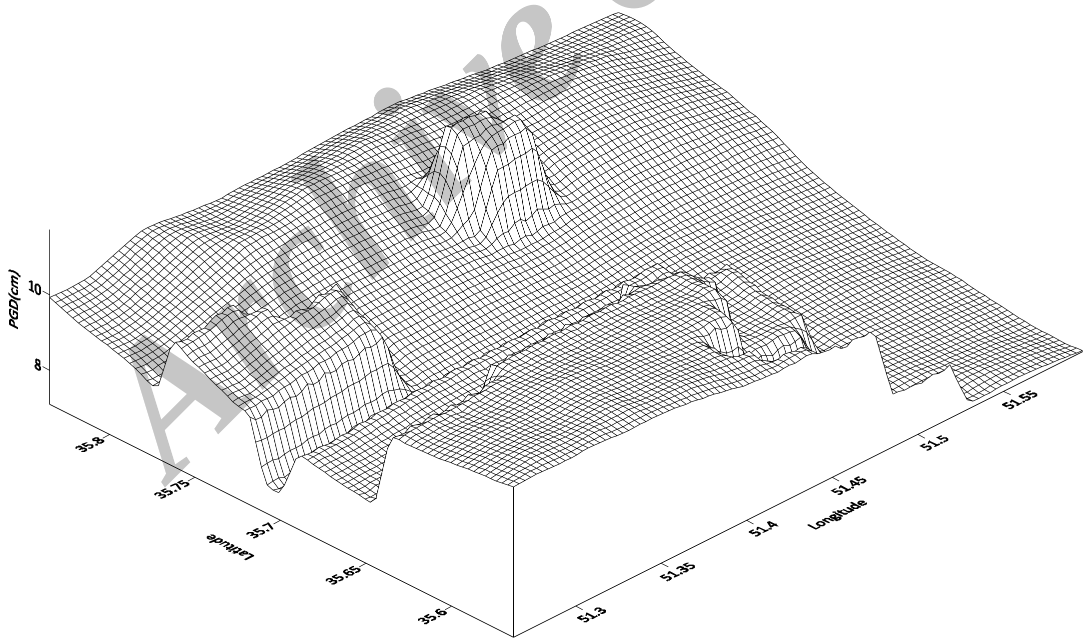


(b)

Figure 9. Final seismic zoning map of Tehran for PGD (cm) using logic-tree method for 10% probability of exceedence in 50 years (a) two-dimensional zoning map and (b) three-dimensional zoning map

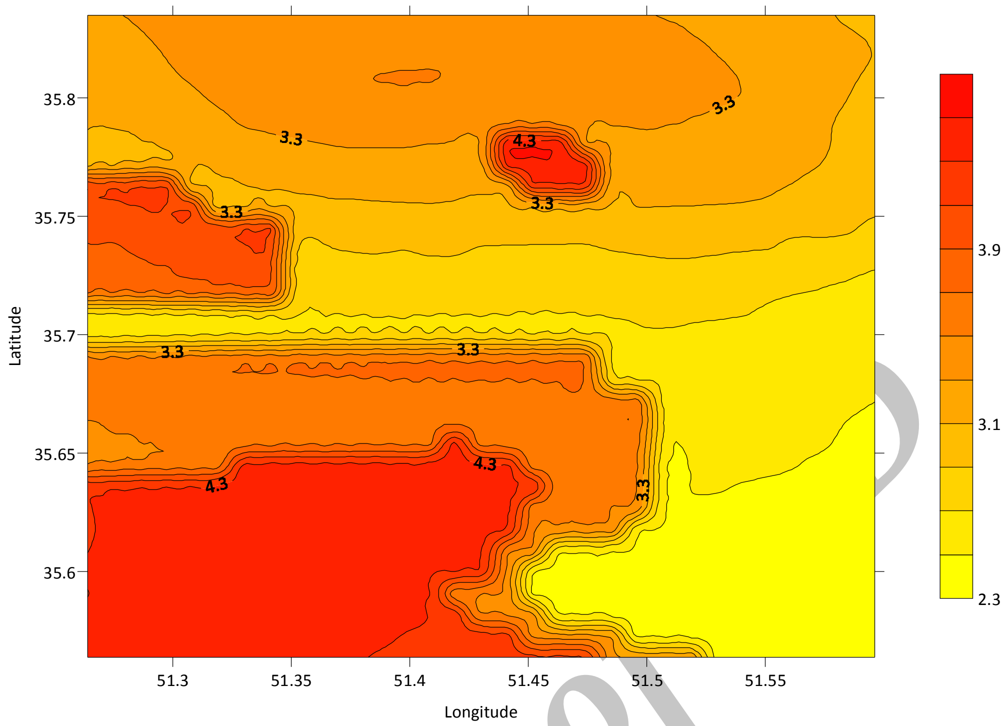


(a)

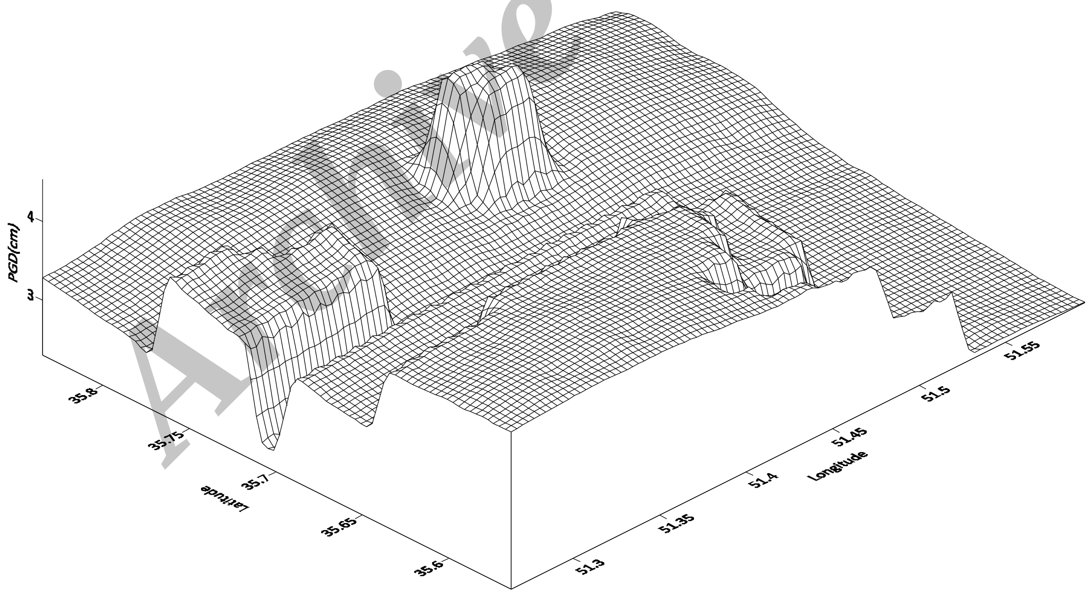


(b)

Figure 10. Final seismic zoning map of Tehran for PGD (cm) using logic-tree method for 20% probability of exceedence in 50 years (a) two-dimensional zoning map and (b) three-dimensional zoning map



(a)



(b)

Figure 11. Final seismic zoning map of Tehran for PGD (cm) using logic-tree method for 50% probability of exceedence in 50 years (a) two-dimensional zoning map and (b) three-dimensional zoning map

9. CONCLUSIONS

Results of seismic velocity and displacement hazard analysis for Tehran, using various alternatives for seismicity parameters, attenuation relationships, etc, are combined with the logic-tree method. These results show high values of PGV and PGD in northern and southern parts of Tehran. For an earthquake with return period of 2475 years (2% probability of exceedence in 50 years), the maximum values for PGV and PGD are 105 cm/s and 56 cm, which occurs in the north and south western parts of the city where the soil type is softer. On the other hand, the minimum values of PGV and PGD, corresponding to above earthquake, are 62 cm/s and 29 cm which take place in the central and south-eastern parts of the city. Regarding these results, it is important to consider the secondary effects of an earthquake such as liquefaction and landslides.

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APPENDIX A - CATALOGUE OF MAIN SHOCKS IN A RADIUS OF 200 KM AROUND TEHRAN

(This catalogue is an updated version of the catalogue used by Ghodrati et. al. [12])

No	Date			Earthquake Time (h:m:s)	Epicenter		FD (km)	Magnitude			References
	Year	Month	Day		Lat	Long		M_S	m_b	M_L	
1	4th BC				35.5	51.8		7.6			AMB
2	743				35.3	52.2		7.2			AMB
3	855				35.6	51.5		7.1			AMB
4	864	1			35.7	51		5.3			AMB
5	958	2	23		36	51.1		7.7			AMB
6	1119	12	10	1800	35.7	49.9		6.5			AMB
7	1127				36.3	53.6		6.8			AMB
8	1177	5			35.7	50.7		7.2			AMB
9	1301				36.2	53.4		6.5			NEIC
10	1485	8	15	1800	36.7	50.5		7.2			AMB
11	1495				34.5	50		5.9			AMB
12	1608	4	20	1200	36.4	50.5		7.6			AMB
13	1665				35.7	52.1		6.5			AMB
14	1678	2	3	600	37.2	50		6.5			AMB
15	1687				36.3	52.6		6.5			AMB
16	1755	6	7	1200	34	51.4		5.9			AMB
17	1778	12	15	2400	34	51.3		6.2			AMB
18	1808	12	16	1800	36.4	50.3		5.9			AMB
19	1809			1200	36.3	52.5		6.5			AMB
20	1825				36.1	52.6		6.7			AMB
21	1830	4	6	1200	35.7	52.3		7.1			AMB
22	1868	8	1	2000	34.9	52.5		6.4			AMB
23	1901	5	20	122900	36.39	50.48		5.4			AMB
24	1927	7	22	35510	34.9	52.9		6.3	6.3		AMB
25	1930	10	2	153312	35.76	51.99	33	5.2			AMB
26	1932	5	20	191611	36.5	53.5		5.5	5.6		USGS

No	Date			Earthquake Time (h:m:s)	Epicenter		FD (km)	Magnitude			References
	Year	Month	Day		Lat	Long		M_S	m_b	M_L	
27	1935	4	11	2315	36.5	53.3	14	6.3			NEIC
28	1940	9	25	193120	36.2	52.2		4.8	5		CCP
29	1945	5	11	201728	35.18	52.4	33	4.4	4.7		BER,M
30	1948	6	30	193150	36.66	49.48	114	4		5	NOW
31	1951	11	13	140146	35.7	53.2		4.1	4.5		CCP
32	1954	9	2	224700	35.3	52		4.1	4.5		CCP
33	1956	4	12	223449	37.33	50.26	30	5		5.5	NOW
34	1957	5	6	141950	37.2	51.8	12	4.5	4.8		NOW
35	1957	7	2	4222	36.07	52.47		7.2	7		AMB
36	1958	1	16	22500	36.5	53		4.3	4.6		PT
37	1958	11	2	91428	36.7	51.5		4.1	4.5		BCIS
38	1960	6	23	132308	34.5	50.5		4	4.4		BAN
39	1961	2	11	193600	37	50		4.1	4.5		PT
40	1962	9	1	192050	35.71	49.81	21	7.1	6.9		AMB
41	1964	2	8	62823	37.07	50.99	11	4.3	4.6		NOW
42	1966	10	3	170508	35.8	53.44	14	4.6	4.9		ISC
43	1966	11	8	31414	36.1	50.8	38	4.8	5		USGS
44	1967	2	16	115532	35.74	51.88	16	4	4.4		CGS
45	1967	8	25	122650	35.58	49.33	55	4.4	4.7		ISC
46	1968	4	26	25822	35.1	50.2	21	5.1	5.3		USCGS
47	1968	5	19	164950	36.61	53.35	22	4.3	4.6		ISC
48	1968	12	12	185447	35.8	53.49	27	4.6	4.9		ISC
49	1970	6	27	75758	35.2	50.7	14	4.6	4.9		USGS
50	1971	4	30	90616	34.6	50.3	42	4.4	4.7		USCGS
51	1971	8	9	25435	36.27	52.81	12	5	5.2		ISC
52	1972	1	30	90617	34.68	50.33	38	4.4	4.7		ISC
53	1972	2	23	231337	36.2	53.5	73	4	4.4		ISC
54	1972	8	8	4455	36.3	52.6	47	4.4	4.7		USCGS
55	1973	9	17	40602	36.5	51.19	40	4.4	4.7		ISC
56	1974	11	5	200221	36.29	53.01	40	4.3	4.6		ISC
57	1975	4	11	142646	35.65	50.35	59	4.4	4.7		ISC
58	1975	11	6	40931	35.9	53	3	4.4	4.7		NEIS
59	1977	4	6	133700	34	50		6.4		6.2	HFS1
60	1977	5	25	110147	34.91	52.06	39	5.1	5.3		ISC
61	1978	5	26	134291	37	50		6.3	6.3		HFS1
62	1978	11	3	185259	37	51		4.8	5		HFS
63	1978	11	4	152141	34	51		6.7	6.6		HFS
64	1979	3	18	51951	36.48	52.64	33	4.1	4.5		USCGS
65	1979	3	25	23226	34.9	52.46	48	4.3	4.6		ISC
66	1980	7	22	51710	37.19	50.2	62	5.2	5.4		USCGS
67	1980	12	19	11656	34.58	50.65	33	5.8			USCGS
68	1981	8	4	185360	36.45	51.27		4.4	4.7		ISC
69	1982	2	5	233712	36.1	53.7	33	4.1	4.5		ISC
70	1982	7	5	155424	34.63	51.02	33	4	4.4		USCGS
71	1982	10	25	165452	35.13	52.38	44	4.1	4.5		ISC
72	1983	3	26	40719	35.96	52.22	33	5.2	5.4		NEIC
73	1983	5	29	171540	35.24	52.17	39	4	4.4		ISC
74	1983	12	20	222101	36.92	50.91	26	4.5	4.8		ISC
75	1984	9	9	175459	35.58	49.34	33	4.3	4.6		NEIC

No	Date			Earthquake Time (h:m:s)	Epicenter		FD (km)	Magnitude			References
	Year	Month	Day		Lat	Long		M_S	m_b	M_L	
76	1985	2	11	92645	34.56	50.67	50	4.4	4.7		NEIC
77	1985	7	8	170236	36.27	53.71	33	4.4	4.7		ISC
78	1985	10	14	152831	35.52	52.7	10	4.4	4.7		ISC
79	1986	3	20	151809	36.01	53.68	34	4.3	4.6		ISC
80	1987	11	25	20938	35.7	53.07	33	4	4.4		ISC
81	1988	1	14	112920	36.01	50.6	33	4.3	4.6		NEIC
82	1988	3	1	10203	34.48	50.79	16	4.2	4.5		ISC
83	1988	8	22	212335	35.28	52.35	10	4.7	5		NEIC
84	1990	1	20	12710	35.89	53	25	5.3	5.5		ISC
85	1990	6	20	21001	36.99	49.35	10	7.4			ISC
86	1991	1	22	120422	35.57	52.4	13	4.3	4.6		USGS
87	1991	8	23	221421	35.9	53.25	33	4.4	4.7		NEIC
88	1991	9	8	42035	35.32	53.31	66	4.1	4.5		USGS
89	1992	9	22	140555	36.3	52.65	33	4.7	5		NEIS
90	1993	3	8	191321	36.63	51.08	33	4	4.4		NEIC
91	1993	6	9	173336	34.76	53.27	30	4.7	5		NEIC
92	1993	8	19	100428	35.09	52.09	18	4.3	4.6		NEIC
93	1994	11	21	185516	35.9	51.88	33	4.2	4.5		NEIC
94	1995	6	26	211255	36.56	51.2	33	4.2			NEIC
95	1996	8	25	141708	35.96	52.95	33	4	4.4		NEIC
96	1997	6	7	202948	36.41	50.28	33	4	4.4		NEIC
97	1997	8	26	4449	36.54	53.07	33	4.2	4.5		NEIC
98	1997	11	5	224256	34.98	51.36	33	4.2	4.5		NEIC
99	1998	1	9	190613	36.47	52.17	33	4.5	4.8		NEIC
100	1998	12	3	131333	36.05	50.88	33	4.2	4.5		NEIC
101	1999	3	13	43015	35.38	53.46	33	4.2	4.5		NEIC
102	2002	4	8	183058	36.42	52.03	46	4.5	4.8		BHRC
103	2002	4	19	134649	36.57	49.81	33	5	5.2		BHRC
104	2002	5	21	104837	36.35	51.56	33	4	4.4		BHRC
105	2002	10	10	121343	35.89	52.33	33	4.4	4.7		BHRC
106	2003	6	21	150006	35.62	52.91	33	4.2	4.5		USGS
107	2003	12	24	34957	35.12	50.51	10	4.4	4.7		USGS
108	2004	5	28	123844	36.29	51.61	17	6.3			USGS
109	2004	8	21	135318	35.43	49.46	10	4.2	4.5		USGS
110	2005	2	20	4613	36.56	52.89	30	4.3	4.6		USGS
111	2005	3	25	124854	35.01	50.05	14	4.4	4.7		USGS
112	2005	9	5	93018	34.18	52.04	10	4.5	4.8		USGS
113	2007	6	18	142949	34.49	50.82	10	5.3	5.5		USGS

Table notification:

AMB: Ambraseys, N.N., Melville, C.P., **BCIS:** Bureau Central International de Seismologie, Strasbourg, France, **BER, M:** Berberian, Geological and Mining Survey of Iran, **BHRC:** Building and Housing Research Center, **CCP (BAN)**: Atlas USSR Earthquake, **FS (BAN):** Fisher, **HFS1:** Hagfors, Sweden, **ISC:** International Seismological Center, UK, **MOS**: Moscow, USSR **NOW:** Nowroozi, **NEIC:** National Earthquake Information Center, USA, **NEIS:** National Earthquake Information Service, USA**, PT:** Publication of Institute of Geophysics-Tehran University, **USCGS:** US Coast and Geodetic Survey, USA, **USGS:** United States Geological Survey.