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Short Period Spectral Acceleration Zonation of Tehran a Comparison between Slip and Activity Rates Data's

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Abstract: This study presents seismic hazard analysis and provides spectral iso acceleration maps based on slip rate (SR) and also activity rate (AR) of the faults. Nowadays modern seismic design of structures is complicated so special attention to the nature of the seismicity in active seismic zones like Tehran is required. Many studies, based on seismic hazard analysis have been done in Tehran. However, none of these studies provided comparison between SR, AR and spectral seismic zonation. In order to reduce the loss of life and property in metropolitan Tehran such studies are undeniable. The process of this study is identification of seismic sources, estimation of seismic parameters and interpretation the results of paleoseismology. Seismic hazard assessment for grid points has been done based on seismic sources and the determination of shear wave velocity. Based on these studies, the shear wave velocity for the upper 30 m has been prepared as a basic parameter for seismic hazard analysis. In addition, iso acceleration spectral maps were prepared based on the SR and AR, for 475 years return period. Referring to paleoseismology studies, it is apparent that some faults in South and South East of Tehran should be considered as an ancient coast line; therefore, they were excluded from the seismic studies. As a result, acceleration in South East Tehran has dramatically declined. In a general comparison, it can be stated that the acceleration based on data from the SR is higher than the AR for the period of 0.4 seconds. The results are equal, in period of 0.4 s and after that the acceleration based on AR is higher than SR.

Keywords: Spectral Iso Acceleration Map, Activity Rate, Slip Rate, Paleoseismology, Seismic Sources

Introduction

Tehran area with a population of over 15 million is one of the most active seismic zones in the Middle East. Iran plateau is situated between the interaction of Arabian plate and Eurasian plate (Copley and Jackson, 2006) which is waiting for a huge catastrophe this collision area stretches from west of Turkey to east of Iran and Alborz Mountain forms the most part of it. Iran is situated between two old continents Eurasia; in north and Africa-Arabia in south and behaves like a brittle platform and is known for its tectonics. Awareness of the dangers of such earthquakes in this area needs study seismic hazard analysis. Some seismic hazard studies have been done based on activity rate in this area, but none of them considered paleosesimology or slip rate (Gholipur *et al*., 2006; Mansouri *et al*., 2010; JICA, 2000; Mansouri and Ghafory-Ashtiany, 2009; Jafari, 2003a; 2003b; Jafari *et al*., 2005; Ghodrati *et al*., 2003; 2008; 2010; Majd Jabari and Zare, 2007). The list of events used in this study included from 30000 BC to 2014 (Ambraseys and Melville, 1982; Berberian, 1994; Engdahl *et al*., 2006; Moinfar *et al*., 1994; Berberian, 2014; ICS center) that according to the long recurrence periods earthquake in this region no longer properly reflects the seismicity and seismotectonics nature of seismic sources (Gholipur *et al*., 2006; Ghodrati *et al*., 2010). In other words, considering only paleoseismology for Tehran faults may hide the effect of the recent seismicity of the sources. Therefore, in this metropolis, studies based on both types of data, based on seismic slip rates and activity rate seem to be useful. This research is about a comparison between the results of activity rate and slip rate, by using the spectral seismic zonation of acceleration in Tehran (Pitilakis *et al*., 2006; Borcherdt, 1994; Zaslavsky *et al*., 2009). In this study, the seismic sources have been defined (Nazari, 2005; Hessami *et al*., 2003; Abbasi and Shabanian, 1999; Berberian, 2014; Berberian *et al*., 1985). Earthquake catalogue of Tehran and adjacent areas was updated and seismic parameters have been estimated (Gutenberg and Richter, 1956; Kijko, 2010; 2012) then slip rate was determined for each seismic source, based on paleoseismology. To determine the distribution of shear wave velocity, in the top 30 m of soil, (Vs_{30}) as the key variables in the calculation, Vs_{30} distribution map was prepared. After study the tectonics (Shoja-Taheri *et al*., 2010) and attenuation relations (Douglas, 2011, five New Generation Attenuation relations (NGA) have been selected and considered for this study (Chiou and Youngs, 2008; Campbell and Bozorgnia, 2008; Idriss, 2008; Abrahamson and Silva, 2008; Boore and Atkinson, 2008). Finally, regular grid points were selected and spectral acceleration seismic zonation, based on the slip rate and activity rate, were considered.

Geographical Location and General Tectonic

The considered region covers a quadrangle, limited by 35° 33' 58" N to 35 50'6"N and 51 03' 34" E to 51 35' 48"E including North of Iran in Tehran province. Active tectonics plays an important role in shaping this part of the Iranian plateau, between Eurasia and Arabian plate (Berberian, 1983; Berberian and King, 1981; Berberian *et al*., 1982) and shows Convergence of about 25 mm per year in direction of north, north east-south and south west (Sella *et al*., 2002). Current physiographic and active morphotectonic in this region, including high mountains, fertile plains, springs of water and active faults in the vicinity of the mountain passages, are caused by this compression. Measured current changes by GPS, in crust of Iran, in period of two years (Vernant *et al*., 2004) and six years (Masson *et al*., 2007) reported historical earthquakes. Till 1755 morphotectonic evidences show that the faults in this area are active, hence knowledge of seismic design variables for retrofitting this metropolis has a great importance (Fig. 1).

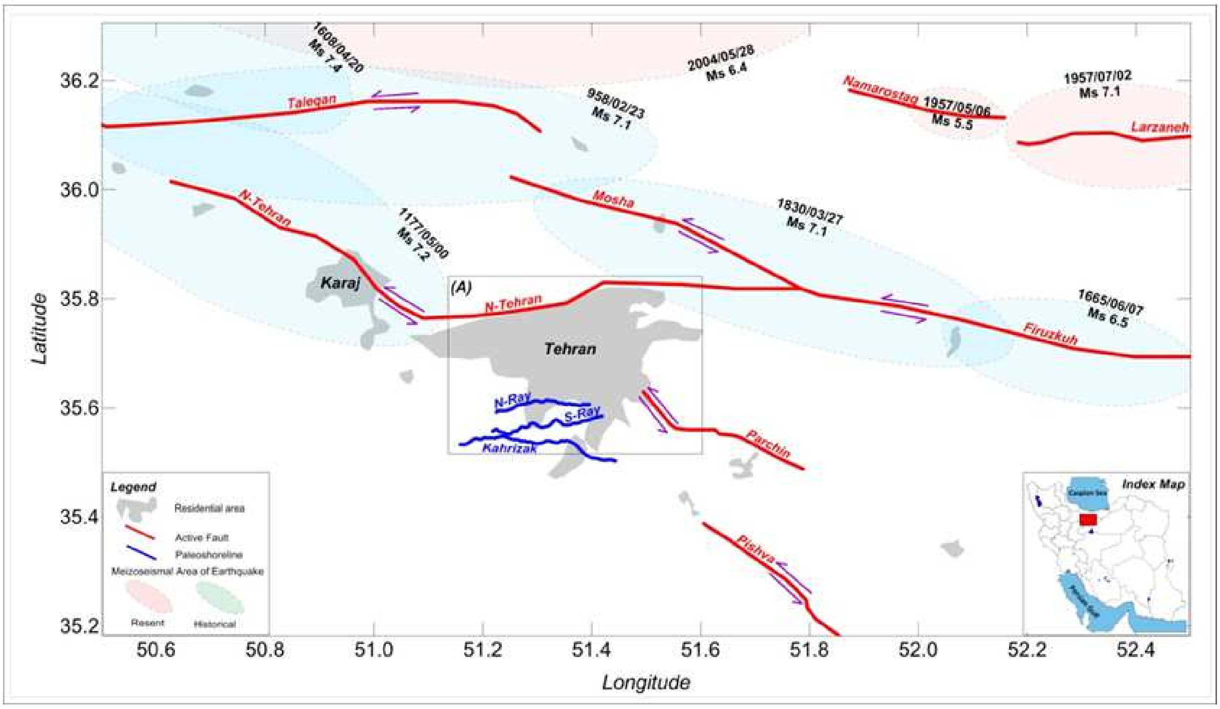

Fig. 1. Tehran and surrounding structural elements. Paleoshorelines are modified from (Nazari *et al*., 2010); Meizoseismal area of earthquakes and active faults are modified from (Berberian *et al*., 1985; Berberian, 2014)

Table 1. Data from the paleoseismology study of Tehran

		Events				
No.	Seismic source	No.	Magnitude (Mw)	Period of Activity (y)	Slip rate (mm/y)	References
1	N-Tehran	5	7.0	30000	0.05±0.3	Ritz *et al.* (2012)
2	Mosha	8	6.5 to 7.0	8000	2	Eslami (1999) Soleimani *et al*., 2003) Allen *et al.* (2003) Bachmanov *et al.* (2004) Ritz *et al.* (2006)
3	Firuzkuh	4	6.6. to 7.5	2000	2.3	Ritz *et al.* (2006) Nazari *et al.* (2007)
4	Taleqan	4	6.5 to 7.2	5300	0.6	Nazari (2006) Nazari *et al.* (2009)
5	Pishva	5	5.9 to 7.0	3265	1.8	Majidiniri *et al.* (2011)
6	N-Ray	Paleo-Shoreline				Nazari (2006)
7	S-Ray					Nazari *et al.* (2010)
8	Kahrizak					Berberian (2014)

Seismicity Variables

These variables are generally divided into two parts; slip rate and activity rate. The estimation of these variables will be discussed (Golabatunchi, 2013).

Slip Rate

Many researchers in recent decades such as Nazari (2006; Nazari *et al*., 2009; 2010; Ritz *et al*., 2006; 2012) and others have been studied about the paleoseismology and historical events in Tehran region (Table 1). The review of existing research results together, with aleoseismology studies, have been considered in this study. The results of such studies can be divided into two main parts in the following. The first part is about the date and magnitude of the pre historical events and the second part shows slip rate of fault, based on millimeter per year (during the active time). Normally, geochronology data are associated with errors and in some cases; geochronology is not useful for some events. Also magnitude of the each seismic event could not be exactly determined. Therefore, these earthquakes cannot be used in statistical analysis. However, since the amount of displacement along the fault is known, the total slip rate can be calculated with good accuracy. Hence the study of slip rate could be useful and important.

In South-East Tehran, over the past 4 decades, many researchers have categorized the linear structures, which are sometimes associated with scrap (south alluvial plain is considered as fault scarp) (Emami *et al*., 1993; Berberian *et al*., 1985; Martini *et al*., 1997; Ghodrati-Amiri *et al*., 2003; Hessami *et al*., 2003; Nazari, 2005). Based on historical events related to Rey and adjacent area and geomorphology evidences north Rey, south Rey and Khrizak faults are known as the most prominent faults in south of Tehran. Last studies (Nazari, 2006; Nazari *et al*., 2009; 2010) show that these faults are the remains of an ancient lake shoreline that covers large parts of Iran's central Dasht-e Kavir so they could not be considered as seismic sources (Table 1). Several studies on other faults in Tehran area have been done and the results are shown in Table 1 including Mosha fault (Allen *et al*., 2003; Bachmanov *et al*., 2004; Ritz *et al*., 2006), Firoozkooh fault (Nazari *et al*., 2007; Ritz *et al*., 2006), North Tehran fault (Ritz *et al*., 2012; Eslami, 1999; Soleimani *et al*., 2003), Taleghan fault (Nazari, 2006; Nazari *et al*., 2009), Pishva fault (Majidiniri *et al*., 2011), Kahrizak fault (Nazari *et al*., 2010; Martini *et al*., 1997), North Rey and south Rey (Berberian, 2014; Nazari *et al*., 2009; 2010; Nazari, 2006).

Activity Rate

A uniform catalog of earthquakes containing prehistoric, historical and instrumental events covering the period from 30000 BC to 2014 is used. The earthquake database is mainly compiled from ISC and USGS/NEIC for the modern instrumental time period (1964-2012), (also Engdahl *et al*., 2006; Moinfar *et al*., 1994; Zare *et al*., 2014) and the catalog of earthquakes provided by Ambraseys and Melville (1982) and Berberian (1994) is the basic source of parameters for the historical (before 1900) and early instrumental (1900-1963) time periods. Prehistoric earthquakes are given from Ritz *et al.* (2012) paleoseismological studies (Table 2).

The catalog of earthquakes has been made uniform using the relationships between M_s and m_b defined by Mirzaei *et al.* (1998) for Alborz-Azerbaijan seismotectonic province. Activity rate shows the number of earthquakes of a certain magnitude over a year and will be calculated based on statistical analysis of the seismic data, in a specific region. All aftershocks and foreshocks were detected and eliminated from the catalogue (Powell and Duda, 1975; Keilis-Borok *et al*., 1972; Gardener and Knopoff, 1974). Since we encountered an incomplete earthquake catalog in the study region, the procedures introduced by Kijko and Sellevoll (1992), which permit incorporation of magnitude uncertainty to estimate seismicity parameters from incomplete data files, are applied to the uniform catalog of earthquakes for estimating the seismicity parameters. The seismicity parameters *a* and *b* and activity rate were calculated for each seismic source (Kijko and Sellevoll, 1992; Kijko, 2010; 2012). Results of the estimation of seismicity parameters in the study area are presented in Table 3. Seismic sources have been delimited mainly based on the fault extent, seismogenic crust (a part of the earth crust in which large earthquakes usually originate) and mechanism of earthquake faulting or a type of active faults. The estimation of maximum magnitude in potential seismic sources is usually according to the features of seismic activity and tectonic analogy.

Seismic Source

To identify the seismic sources, satellite images, seismotectonic maps and geomorphology studies were considered (Nazari, 2005; Hessami *et al*., 2003; Abbasi and Shabanian, 1999). Rupture length of each fault has been estimated (Ambraseys and Melville, 1982; Zare, 1995) based on empirical relations that have a good connection with seismicity and also seismicity of each source has been calculated (Ambraseys and Jackson, 1998; Wells and Coppersmith, 1994; Nowroozi, 1985; Zare, 1995). Other variables such as magnitude of completeness (Willemann, 1999), maximum magnitude (Kijko, 2004) and rupture variables (Wells and Coppersmith, 1994) are estimated and have been shown in Table 3.

Attenuation Relations

Different attenuation relations were studied (Douglas, 2011), based of geology, seismotectonic and tectonics characters of the region (Shoji-Taheri, 2010) and finally five New Generation Attenuation relations (NGA) have been selected and considered for seismic hazard assessment in this area (Chiou and Youngs, 2008; Campbell and Bozorgnia, 2008; Idriss, 2008; Abrahamson and Silva, 2008; Boore and Atkinson, 2008).

Shear Wave Velocity Distribution (Vs_{30}) in Tehran

Geology and shear wave velocity in Rock and Alluvium, especially in upper 30 meters, play an important role in seismic hazard studies. To determine the distribution of shear wave velocity in the Greater Tehran, a down hole shear wave measurements data from last studies: Jafari *et al*. (2002) and Tehran Municipality (Appendix 1), were collected. All points were located by GIS and the Vs_{30} contours were drawn.

Table 2. Frequency of earthquakes in different time interval. To convert mb to Ms, Mirzaei *et al*. (2003) empirical relationship were used

Date Range	Magnitude Range (Ms) 3-3.9	4-4.9	5-5.9	6-6.9	7-7.4	Grand total
Prehistoric (-30,000)			2	7	2	11
Historical (0-1900)			6	6	4	16
1900-1909			1			1
1910-1919						0
1920-1929			1			1
1930-1939			9			9
1940-1949		2	1			3
1950-1959		5	5	2	3	15
1960-1969	1	12	10	3	3	29
1970-1979	1	40	8			49
1980-1989	1	42	28			71
1990-1999		69	22			91
2000-2009	15	39	9			63
2010-2014	111	44	4	5		164
Grand Total	129	253	106	23	12	523

Table 3. Seismicity Parameters of seismic sources in study area. M_{max} is calculated as the percentage weight of every relationship as shown in front of it. In this process four empirical relations have been used and earthquakes associated with each fault as a determination factor for M_{max} is intended

Seismic source	M_{max} (Mw) 1 (20%)	2 (20%)	3 (10%)	4 (10%)	5 (40%)	Weighted	M_{min}	Rate type Slip (mm/y)	Activity (event/y)
N-Tehran	7.2	7.1	7.1	7.0	7.3	7.2	4.3	3.20E-01	4.30E-02
Mosha	7.0	7.0	7.0	6.9	7.1	7.0	4.3	2.00E-00	2.87E-02
Firuzkuh	6.5	6.8	6.7	6.6	6.5	6.6	4.3	2.30E-00	2.89E-02
Taleqan	6.9	6.9	6.9	6.8	7.4	7.0	4.3	6. 0E-00	2.60E-02
Pishva	6.8	6.8	6.8	6.8	?	6.8	4.3	1.80E-00	1.40E-02
Parchin	6.2	6.3	6.5	6.3	?	6.5	4.3	No data	2.80E-02

1. Zare (1995); 2. Wells and Coppersmith (1994); 3. Nowroozi (1985); 4. Ambraseys and Jackson (1998); 5. Occurrence Events

Finally, using similar geology of sedimentary materials in this region contours were corrected and shear wave distribution Vs_{30} map, based on NEHRP (BSSC, 2001) was achieved in Tehran. In some areas where no data is available (or not consistent with the geology) Vs_{30} were estimated, based on relationship between the slope of the Earth and shear wave velocity (Allen and Wald, 2007; 2009; Wald and Allen, 2007; Wald *et al*., 2004; Farr and Kobrick, 2000).

Spectral Acceleration Zoning

Normal zoning and spectrum zoning is largely similar to each other, except that in the spectral method, acceleration is calculated for periods higher than zero (Pitilakis *et al*., 2006; Borcherdt, 1994; Zaslavsky *et al*., 2009). Based on this method and other studies (Jarahi *et al*., 2013; Jarahi, 2011), spectral acceleration zoning in short periods of 0, 0.2, 0.5 and 1 s, based on probability of exceedance in 100 years (McGuire, 1995), were calculated for Tehran Region. For this purpose, 400 of points with the distance of 1km have been considered (Fig. 2). Horizontal acceleration has been calculated according to attenuation relations and $Vs_{30}$for each point. Calculation has been done in two parts, based on activity rate and slip rate (Fig. 3). At a glance, it can be clearly seen that the greatest danger is on the north east of Tehran, where there is a sharp bend in the region of North Tehran fault (Madadi, 2012). Most of metropolitan Tehran residential areas are located in the southern and center part. The acceleration is low to moderate in this regions and this is against of previous studies (Gholipur *et al*., 2006; Mansouri *et al*., 2010; JICA, 2000; Mansouri and Ghafory-Ashtiany, 2009; Jafari, 2003a; 2003b; Jafari *et al*., 2005; Ghodrati *et al*., 2003; 2008; 2010). As mentioned, active faults in the south and southeast of the region (North Rey, South Rey and Kahrizak Fault) were the beach line and never considered as the seismic source, consequently the southern and south-east and the vast majority of residential metropolitan Tehran has been placed in low-risk areas. Therefore seismic design standards such as the 2800 Code should be reformed. Seismicity rate, after removal of mentioned faults in this area, remains constant in sequence most probably the attributed events to these faults are related to the other seismic sources, like North Tehran, Firoozkooh and Mosha faults. Actually, the seismic share of other faults has been increased dramatically and the acceleration related to other sources has been increased. This results in the more residential areas of northwest of Tehran, in the area, with high relative risk, is justified.

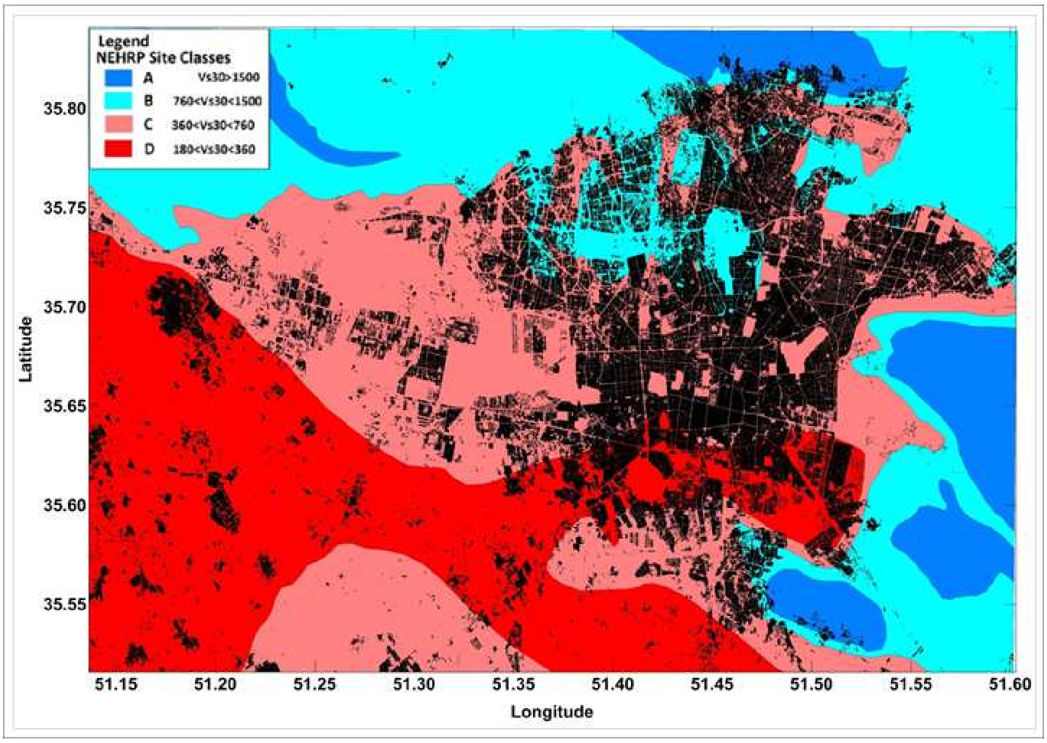

Fig. 2. Shear wave velocity Vs_{30} map in Tehran, based on NEHRP. Most part of Tehran city (black parts) is situated in areas with velocity less than 360 m/s. Higher values of Vs_{30} are situated in northern, eastern and southern mountain areas and categorized in A, B. On the other hand, Vs_{30} changes in Tehran plain from B to the north of Tehran, C to the north and center of area and D in south of Tehran. Based on Vs_{30} values, it can be clearly resulted that older parts show higher values. In Tehran there is no area categorized in E zone

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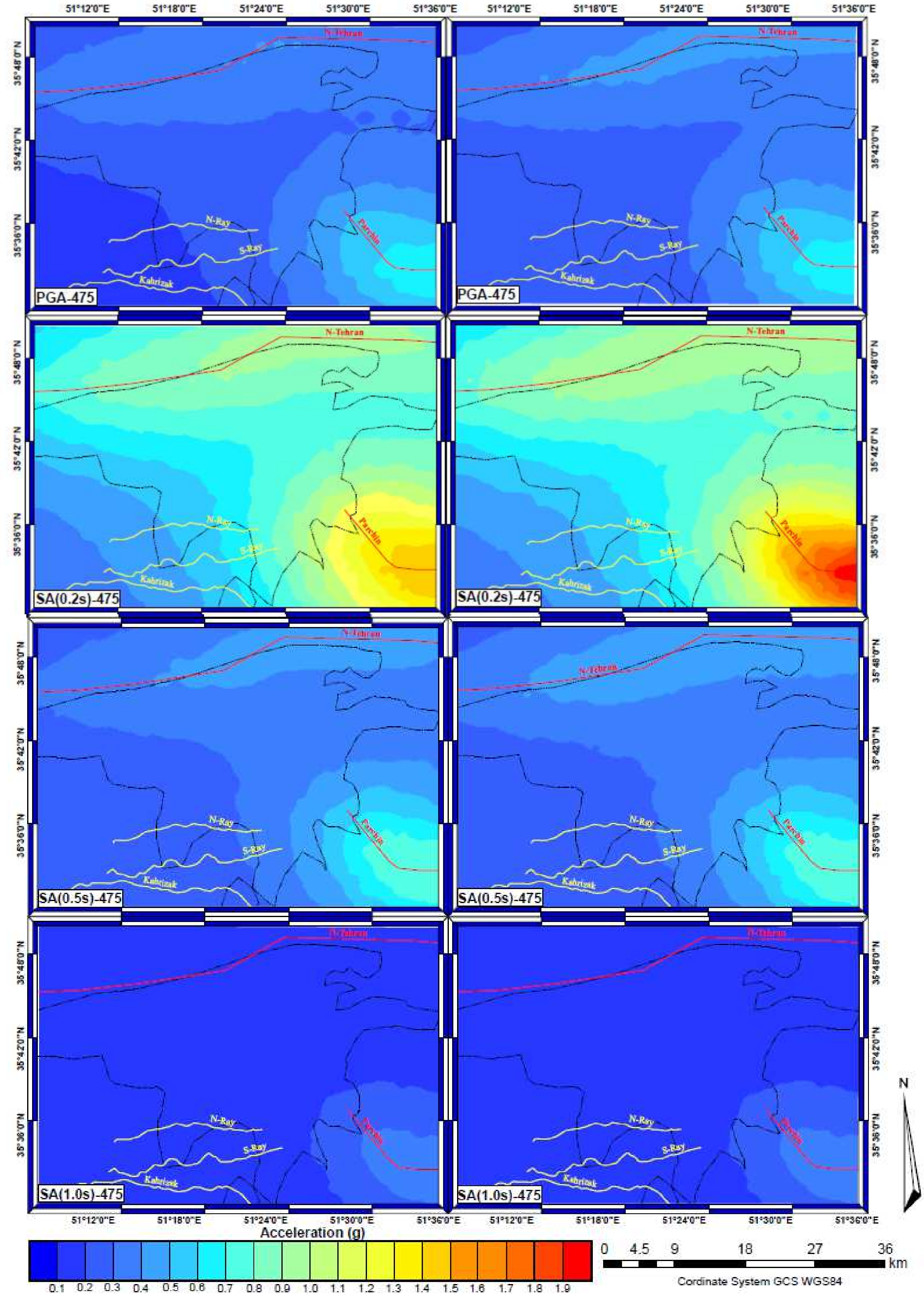

Fig. 3. Tehran seismic hazard zonation based on AR (left) and SR (right) for a return period of 475 years at 5% damping for periods PGA, 0.2, 0.5 and 1 second, Tehran metropolitan area is shown in dash line. Red lines are faults and yellow lines are paleoshorelines

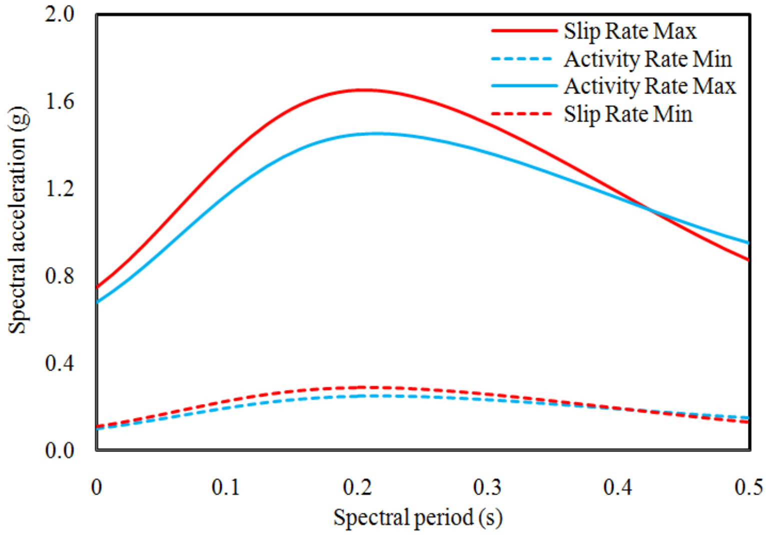

Fig. 4. The spectral acceleration changes in short periods

Table 4. Numerical values of spectral acceleration data obtained from the analysis of SR and AR

	Slip Rate		Activity Rate	
Spectral Period (s)	Max	Min	Max	Min
PGA	0.75	0.11	0.68	0.10
0.2	1.65	0.29	1.45	0.25
0.5	0.87	0.13	0.95	0.15
1	0.41	0.06	0.48	0.08

Comparing results based on activity rate and slip rate shows that for the period of 0 to 0.4 s maximum and minimum spectrum acceleration is higher for the data based on slip rate comparing with the data of activity rate. For the period of 0.4 s spectrum acceleration is equal for both data and after this period Spectral acceleration values of the slip rate is less than the rate of activity rate (Fig. 4 and Table 4).

Conclusion

As mentioned before, spectral acceleration zoning has not been done in Tehran before, so this research has a considerable importance in seismic design of structures. The main results of this study could be summarized as followed:

- Based on Paleoseismology North Rey, South Rey and Kahrizak are considered as ancient lake shore not an active fault
- Based on Vs_{30} most dense, urban areas are situated on alluvial materials with shear wave velocity less than 360 m/s
- Acceleration is increased in period of 0 to 0.2 s and in this period, it reaches to its maximum value and then shows downward trend
- Comparing results, based on activity rate and slip rate, shows that for the period of 0 to 0.4 s, maximum and minimum spectrum acceleration, is higher for the data, based on slip rate comparing with the data of activity rate. For the period of 0.4 s spectrum acceleration is equal, for both data and after this period Spectral acceleration values of the slip rate is less than the rate of activity rate so combination of both method based on logic tree, is recommended to estimate spectrum acceleration for seismic designs

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Author's Contributions

Hadi Jarahi: Developed the conceptual idea, designed the study, collected data and made the interpretation.

Noushin Naraghiarghi: Made the interpretation and edited the manuscript.

Malihe Nadalian: Carried out the study and helped to data collection.

Ethics

This article is original and contains unpublished materials. The corresponding author confirms that all of the other authors have read and approved the manuscript and there are no ethical issues involved.

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Appendix 1. Downhole share wave measurement test results in Tehran region

No.	Longitude	Latitude	Vs_{30}	No.	Longitude	Latitude	Vs30	No.	Longitude	Latitude	Vs30
1	51° 21' 40	35° 35' 12	200	56	51° 19' 30	35° 49' 22	1170	111	51° 32' 1	35° 38' 49	1170
2	51° 22' 27	35° 35' 22	203	57	51° 17' 54	35° 49' 57	1420	112	51° 34' 16	35° 47' 44	1160
3	51° 22' 9	35° 35' 40	206	58	51° 17' 38	35° 49' 48	1460	113	51° 25' 26	35° 44' 4	1183
4	51° 23' 31	35° 35' 38	200	59	51° 17' 4	35° 50' 1	1170	114	51° 25' 32	35° 45' 12	1198
5	51° 20' 5	35° 35' 48	203	60	51° 17' 9	35° 49' 15	1420	115	51° 25' 44	35° 45' 34	1420
6	51° 18' 33	35° 35' 40	206	61	51° 17' 2	35° 48' 57	1460	116	51° 25' 25	35° 45' 35	1320
7	51° 18' 12	35° 35' 47	270	62	51° 16' 26	35° 48' 34	1198	117	51° 25' 41	35° 45' 22	1220
8	51° 18' 16	35° 36' 19	280	63	51° 16' 29	35° 48' 55	1183	118	51° 29' 30	35° 46' 3	1290
9	51° 18' 54	35° 36' 50	300	64	51° 16' 10	35° 48' 58	1160	119	51° 28' 37	35° 46' 39	1450
10	51° 18' 12	35° 37' 32	320	65	51° 15' 53	35° 48' 57	1183	120	51° 30' 11	35° 47' 2	1460
11	51° 18' 10	35° 37' 45	270	66	51° 15' 49	35° 49' 12	1198	121	51° 31' 12	35° 46' 4	1170
12	51° 16' 57	35° 35' 56	280	67	51° 16' 10	35° 49' 12	1450	122	51° 32' 7	35° 46' 15	1160
13	51° 18' 50	35° 38' 37	300	68	51° 16' 21	35° 49' 41	1183	123	51° 32' 50	35° 46' 5	1183
14	51° 16' 56	35° 38' 33	320	69	51° 15' 59	35° 49' 32	1290	124	51° 21' 12	35° 44' 24	1198
15	51° 17' 33	35° 38' 43	270	70	51° 15' 55	35° 50' 1	1160	125	51° 19' 12	35° 43' 50	1450
16	51° 21' 26	35° 38' 33	280	71	51° 16' 22	35° 49' 54	1183	126	51° 18' 54	35° 45' 11	1183
17	51° 21' 36	35° 38' 0	206	72	51° 31' 17	35° 48' 41	1703	127	51° 19' 19	35° 45' 43	1290
18	51° 20' 57	35° 37' 50	300	73	51° 28' 44	35° 48' 46	1706	128	51° 19' 19	35° 46' 17	1160
19	51° 22' 40	35° 39' 30	320	74	51° 28' 55	35° 48' 57	1700	129	51° 23' 1	35° 46' 25	1183
20	51° 23' 12	35° 39' 32	280	75	51° 29' 33	35° 49' 15	1703	130	51° 19' 57	35° 45' 2	1290
21	51° 23' 32	35° 40' 18	300	76	51° 22' 30	35° 49' 55	1706	131	51° 16' 11	35° 46' 33	1160
22	51° 23' 56	35° 39' 16	203	77	51° 23' 1	35° 49' 41	1770	132	51° 15' 46	35° 46' 37	1450
23	51° 25' 9	35° 34' 59	200	78	51° 23' 0	35° 49' 54	1780	133	51° 15' 58	35° 46' 49	1183
24	51° 24' 48	35° 34' 44	203	79	51° 23' 32	35° 49' 51	1800	134	51° 16' 13	35° 47' 17	1290
25	51° 24' 43	35° 33' 57	206	80	51° 24' 28	35° 49' 44	1820	135	51° 16' 13	35° 47' 17	1160
26	51° 27' 41	35° 37' 48	200	81	51° 24' 51	35° 49' 41	1770	136	51° 16' 23	35° 47' 28	1170
27	51° 27' 12	35° 38' 28	203	82	51° 24' 19	35° 49' 12	1780	137	51° 17' 4	35° 47' 18	1420
28	51° 28' 27	35° 37' 57	206	83	51° 25' 16	35° 49' 12	1800	138	51° 18' 40	35° 47' 22	1460
29	51° 28' 44	35° 38' 7	200	84	51° 25' 58	35° 49' 12	1820	139	51° 19' 5	35° 47' 24	1198
30	51° 28' 54	35° 37' 19	203	85	51° 26' 10	35° 49' 35	1770	140	51° 20' 9	35° 47' 23	1183
31	51° 29' 52	35° 38' 24	280	86	51° 25' 49	35° 49' 39	1780	141	51° 21' 15	35° 48' 37	1160
32	51° 28' 14	35° 39' 34	270	87	51° 26' 54	35° 49' 51	1706	142	51° 21' 12	35° 49' 15	1450
33	51° 23' 25	35° 36' 24	660	88	51° 28' 5	35° 49' 30	1800	143	51° 20' 58	35° 49' 46	1183
34	51° 23' 53	35° 36' 16	560	89	51° 28' 56	35° 49' 24	1820	144	51° 19' 40	35° 49' 59	1290
35	51° 24' 9	35° 36' 31	460	90	51° 29' 19	35° 49' 41	1780	145	51° 19' 40	35° 49' 42	1160
36	51° 23' 47	35° 36' 50	530	91	51° 16' 21	35° 41' 15	423	146	51° 24' 36	35° 35' 43	690
37	51° 23' 31	35° 37' 23	690	92	51° 16' 12	35° 41' 32	530	147	51° 25' 2	35° 35' 34	423
38	51° 21' 48	35° 36' 30	700	93	51° 16' 5	35° 41' 51	400	148	51° 26' 26	35° 34' 59	530
39	51° 20' 34	35° 36' 22	410	94	51° 15' 56	35° 41' 59	690	149	51° 16' 50	35° 40' 43	400
40	51° 19' 49	35° 36' 30	400	95	51° 16' 55	35° 38' 56	530	150	51° 17' 52	35° 39' 49	560
41	51° 16' 12	35° 34' 51	423	96	51° 21' 9	35° 39' 45	690	151	51° 17' 0	35° 39' 45	460
42	51° 16' 13	35° 42' 11	423	97	51° 29' 14	35° 44' 8	410	152	51° 20' 38	35° 46' 29	530
43	51° 16' 35	35° 42' 9	530	98	51° 30' 53	35° 44' 59	660	153	51° 20' 11	35° 45' 31	400
44	51° 29' 7	35° 40' 17	400	99	51° 30' 54	35° 46' 38	700	154	51° 21' 53	35° 37' 3	423
45	51° 30' 47	35° 40' 14	410	100	51° 20' 10	35° 44' 10	410	155	51° 24' 54	35° 36' 0	530
46	51° 30' 46	35° 39' 30	660	101	51° 19' 54	35° 43' 13	660	156	51° 29' 0	35° 34' 41	1320
47	51° 32' 18	35° 39' 57	700	102	51° 18' 30	35° 43' 54	700	157	51° 26' 13	35° 37' 21	1220
48	51° 34' 34	35° 44' 30	438	103	51° 18' 14	35° 43' 32	438	158	51° 31' 39	35° 35' 33	1290
49	51° 32' 40	35° 43' 31	423	104	51° 17' 27	35° 43' 54	423	159	51° 30' 23	35° 37' 28	1450
50	51° 30' 9	35° 42' 11	400	105	51° 15' 55	35° 44' 20	400	160	51° 30' 56	35° 38' 11	1460
51	51° 27' 10	35° 42' 23	690	106	51° 16' 15	35° 45' 26	423	161	51° 24' 32	35° 36' 30	700
52	51° 26' 15	35° 41' 37	423	107	51° 17' 29	35° 45' 33	438	162	51° 24' 31	35° 36' 14	410
53	51° 28' 10	35° 45' 27	530	108	51° 18' 10	35° 44' 58	690	163	51° 24' 51	35° 36' 15	400
54	51° 29' 33	35° 45' 11	400	109	51° 20' 28	35° 46' 39	423	164	51° 25' 14	35° 36' 11	423
55	51° 15' 56	35° 41' 59	690	110	51° 19' 3	35° 39' 18	438	165	51° 25' 3	35° 35' 48	438