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Spectral-acceleration-based attenuation relation in seismic hazard analysis (Case study: Qazvin city)

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Abstract

Considering the situation of Iran on the seismic belt and its permanent exposure to earthquakes with different magnitudes, in design of structures, special attention should be paid to seismic parameters. To this effect, and in order to reduce the structures exposures to the expectable earthquakes short-term, mid-term and long-term planning is required. Numerous methods have been so far applied to assessment of earthquake magnitude some of which were built up on a single parameter such as PGA and PGV and some others were multi-parameters such as *spectral displacement* and *spectral acceleration* (SA). At any rate, today scientists using new parameters such as earthquake energy, earthquake intensity have introduced different methods for design purposes. One of the most widely applied design methods is the single parameter measure Peak Ground Acceleration (PGA) which has its own limitations and shortcomings such as error input into the calculations and ignoring earthquake content. Therefore, researchers decided by applying spectrum-based attenuation relation to use direct relationships for determining input data of structure design. In line with these efforts, profiting from SA-based power attenuation relation, this research as a case study attempts to retry the seismic hazard analysis calculations on the Qazvin region.

Keywords: spectral acceleration, fault, attenuation relation, hazard analysis, earthquake.

Introduction

In the seismic analysis of buildings, according to the current regulations in the world particularly the Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800), seismic hazard analysis has been always appreciable based on single-parameter and multi-parameter measures. The most prevalent single-parameter measure is PGA and the most common multi-parameter method is Spectral Acceleration (SA). At length, the codes of practice introduce a number as PGA to structure designer for seismic resistant design. This parameter is obtained from seismic hazard analysis by PSHA or DSHA. For calculation of the mentioned parameter, the attenuation relation specific to Iran should be used and this is found from seismic behavior, type of soil, activity of adjacent faults, and the target area and alike. Depending on the type of (attenuation) relation, different inputs such as earthquake magnitude and length of fault may be required for the calculations. The output of the above calculations, according to type of attenuation relationship can be as a constant number like PGA or as a group of spectral curves. Today, it is demonstrated that use of spectra such as acceleration spectra (multi-parameter) explains the nature of seismic behavior much better than the single-parameter measures. As a result, in recent years, also attenuation relationship has been inclined towards spectra including Spectral Acceleration (SA). Therefore, for determining seismic parameters, given the earthquake hazard and its recurrence interval,

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in linear and non-linear dynamic analyses, direct design by means of engineering softwares is applied.

Review of technical literature

In regard to attenuation relation, researchers so far have introduced a large variety of models a brief history of which will be treated in this section. In 1981, Campbell *et al*. based on the data of Iran, California, and Caucasia have presented a model of attenuation relation in which they used a combination of remoteness and magnitude. In 1982, Joyner and Boore proposed another relation based on remoteness, earthquake depth, magnitude and maximum acceleration, which is used in many reports including Green and Hall (1994). Campbell and Borognia (1995) proposed attenuation relation for near-field earthquake. This relation is based on different parameters such as earthquake acceleration records, remoteness and depth of focus. In 1999, Ashtiyani *et al.* using data of Iran proposed a logarithm relation with standard deviation. In 2003, Fukushima *et al* presented a relation based on PGA in which earthquake occurrence area was divided into two near and far fields. In 2006, Ambraseys and Elnashai calculated a relation for south Iran using a number of constants which had been obtained based on the structure periodicity. In this relation, the understudy soil (ground) was divided into hard and soft soil (ground). Ghodrati *et al.* (2008) provided a relation using multi-parameter measures (SA) in which the constants obtained according to periodicity were used.

Materials and Methods

Choice of Seismic Hazard Analysis Method and its phases

In general, in SHA is performed by two methods: PSHA and DSHA. In DSHA (Deterministic Seismic Hazard Analysis), first, a fault with a specific remoteness is chosen and then a magnitude as probabilities is determined for the fault and using the assumed attenuation relation the spectral velocity or acceleration of earthquake is obtained. By applying an engineering judgment in the beginning of the hazard analysis, the phases can be simply followed.

In PSHA (Probabilistic Seismic Hazard Analysis), first, the faults affecting the understudy site (figure 1) is specified and then the earthquake catalogue is determined from reliable sources (in this research, these sources are the Seismology Research Center and the International Earthquake Research Center) (table 1). Next, the probability density function of the site remoteness from seismic sources is determined and using Gutenberg – Richter Relation the probability density function of the likely earthquake magnitude will be found. At this stage, using the chosen attenuation relation and by determining the annual seismic event probability, hazard curve is drawn. Different stages in this study are obtained and utilized based on Green & Hall report [2].

Table 1. Information on fault activities within the understudy area (Seismic Catalogue)

Date	Time(Local)	Lat.	Lon.	Mag.	Region
5/20/1901	15:59:00	36.39	50.48	Ms:5.4	Ghazvin, North of Abyek
6/24/1903	20:26:00	37.48	48.96	Ms:5.9	Gilan, West of Rezvanshahr
1/9/1905	9:47:00	37	48.68	Ms:6.2	Zanjan, West of Abbar
11/8/1924	12:35:00	35.5	48	Ms:5.5	Hamedan, North-East of Qorveh
11/8/1924	21:15:20	35.5	48	Ms:5	Hamedan, North-East of Qorveh
11/10/1924	0:38:56	35.5	48	Ms:5	Hamedan, North-East of Qorveh
11/10/1924	1:24:56	35.5	48	Ms:5.5	Hamedan, North-East of Qorveh
11/11/1924	19:23:40	35.5	48	Ms:5	Hamedan, North-East of Qorveh
11/12/1924	12:58:20	35.5	48	Ms:4	Hamedan, North-East of Qorveh
6/15/1927	10:16:10	35.5	48	Ms:4	Hamedan, North-East of Qorveh
10/31/1927	9:53:00	36.5	49	Ms:4	Zanjan, South of Abbar
10/2/1930	19:02:00	35.76	51.99	Ms:5.2	Tehran, Damavand

Analysis of number of active faults within the target area

For this purpose, a circle with a radius of 200km was drawn and the faults situated within this area were analyzed (figure 1).

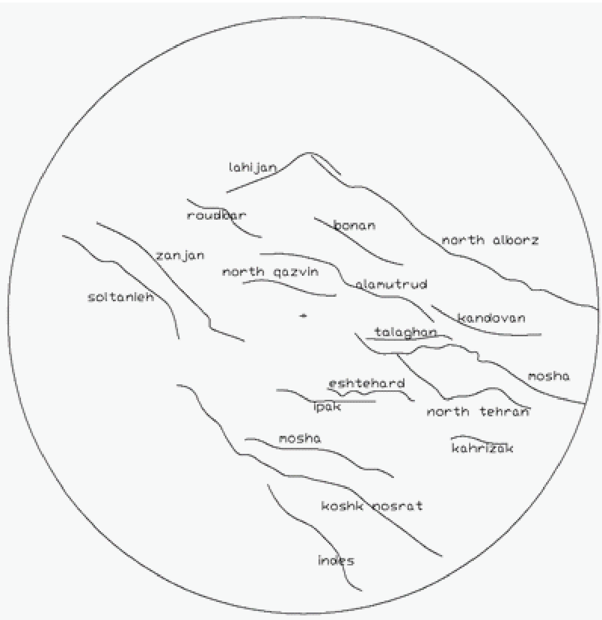

Figure 1. Faults in a 200km radius round city of Qazvin

In this study, in place of determining single-parameters (e.g. PGA), acceleration spectrum is obtained using the spectral acceleration relation developed by Dr. Ghodrati and colleagues (2007) and (2008) which in 2008 was published in the authoritative international journals in structural calculations. To do this, for each understudy fault, a specific remoteness and magnitude has to be determined. In table 2, the understudy length of faults, number of parts in each fault, remoteness of each part of the fault to the site, and its situation (position) relative to the project site are represented. It should be noted that since magnitude of each fault is not separately determined, we can use the relation based on the fault effective length to obtain an estimate for the likely magnitude of each fault. Relation 1 based on Reference No.1 is as follows:

$$\log L = -4.1 + 0.804 \Rightarrow M_w = \frac{4.1 + \log L}{0.804} \quad (1)$$

Using relation 1, each fault within the understudy area can be analyzed and the greatest possible earthquake can be predicted. In table 3, profiting from this relation the probable amount of surface magnitude of each fault is obtained.

Table 2. Calculation of surface magnitude of faults in the target area using relation 1

Row	Name of Fault	Fault length (km)	Nearest remoteness to site	Surface magnitude
1	North-Qazvin Fault	60	20	7.3
2	Alamout-Roud Fault	132	37	7.7
3	Soltanieh Fault	112	100	7.6
4	Banan Fault	69	60	7.3
5	Zanjan Fault	120	50	7.6
6	Kandovan Fault	78	90	7.4
7	Talaghan Fault	58	70	7.2
8	Eshtehard Fault	60	55	7.3
9	Ipak Fault	60	52	7.3
10	Indes Fault	100	120	7.5
11	North-Tehran Fault	100	75	7.5
12	Roudbar Fault	57	65	7.2
13	North-Alborz Fault	220	110	7.5
14	Mosha Fault	170	40	7.5

It should be noted that for putting the effective length in the above formula, careful analysis of fault is required, but in general case and in worst case, approximate length of fault has been entered into the calculations and the results have been tentatively examined.

Table 3. Study of active faults and their classification

Row	Name of fault	Understudy length (km)	Number of parts	Remoteness from center	
1	North-Qazvin Fault	60	6	40.18	1
				31.57	2
				22.96	3
				17.22	4
				17.22	5
				22.96	6

Table 4. Parameters of Gutenberg – Richter Relation

M	4	4.5	5	5.5	6	6.5	7	7.5
	4<M	4.5<M	5<M	5.5<M	6<M	M>6.5	M>7	M>7.5
N	90	58	39	13	7	4	3	2

Gutenberg – Richter Recurrent Relation (G-R)

Given a magnitude growth of 0.5, cumulative frequencies from a magnitude of 4 to a magnitude of 7.5, respectively, are obtained using the made records in previous section the summary of which is presented in table 4. It is noteworthy that the type of magnitude in attenuation relation utilized in this analysis is based on Ms. Hence, by magnitude the surface magnitude is meant and for transformation of magnitude the respective relations have been applied.

To make use of table 4 and to transform it into structural calculations, a diagram is drawn horizontal axis of which there is magnitude and on the vertical axis of it logarithm to base e for the number of earthquakes with M > m condition. Now, using regression softwares (in this project, excel is used) a relation is extracted for the obtained points. In this study, G – R Relation is obtained as the following relation:

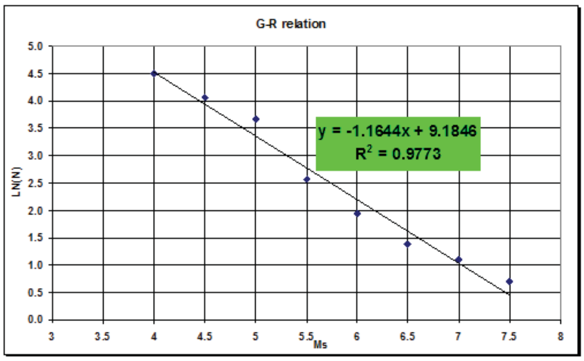

Figure 2. G – R Relation and its linear regression

Table 5. Calculation of Probability Density Function and Seismic Probability

Mmax	Mmin	α	β	C	f(m)	P(M<m)		Mmid	f(Mmid)* M
7.5	4	9.18	1.1644	1.017279	1.18452	0	4<M<4.5	4.25	0.44268
7.5	4	9.18	1.1644	1.017279	0.661753	0.4489578	4.5<M<5	4.75	0.24731
7.5	4	9.18	1.1644	1.017279	0.3697	0.6997761	5<M<5.5	5.25	0.13816
7.5	4	9.18	1.1644	1.017279	0.20654	0.8399003	5.5<M<6	5.75	0.07719
7.5	4	9.18	1.1644	1.017279	0.115387	0.9181832	6<M<6.5	6.25	0.04312
7.5	4	9.18	1.1644	1.017279	0.064463	0.9619173	6.5<M<7	6.75	0.02409
7.5	4	9.18	1.1644	1.017279	0.036013	0.9863501	7<M<7.5	7.25	0.01346
7.5	4	9.18	1.1644	1.017279	0.02012	1			

The obtained relation is determined with 98 percent accuracy.

$$Ln(y) = -1.1644 \times M + 9.1846$$

In this relation, we have:

y: number of earthquakes the magnitude of which is higher than a certain degree

M: magnitude

Event rate (v)

Using Poisson Relation, mean even rate can be obtained:

$$P(n,t) = \frac{(vt)^n e^{-vt}}{n} \quad (2)$$

$$n1 = (N(4) - N(7.5)) \times L \quad (3)$$

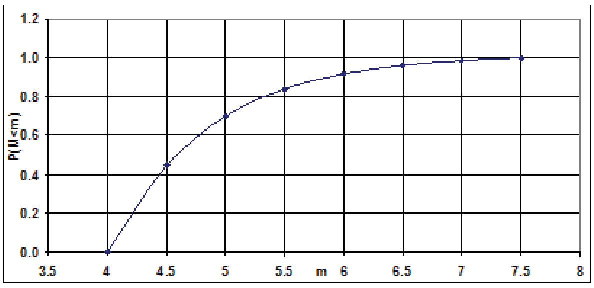

Figure 3. Seismic Probability Function

Using relations 2 and 3, earthquake occurrence rate can be obtained by Poisson Probability model. The obtained values for each fault are separately provided in table 6.

Table 6. Seismic event rate for each fault

Event rate	Fault Name
0.0412	North-Qazvin Fault
0.0908	Alamutrud Fault
0.077	Soltanieh Fault
0.0467	Banan Fault
0.0825	Zanjan Fault
0.053	Kandovan Fault
0.0399	Taleghan Fault
0.0412	Eshtehard Fault
0.0412	Ipak Fault
0.0688	Indes Fault
0.0688	North-Tehran Fault
0.0392	Roudbar Fault
0.1513	North-Alborz Fault
0.1401	Mosha Fault

Table 7. Constant parameters of attenuation relation

period	c1	c2	c3	@
0.05	2.164	0.317	-1.255	0.37
0.1	2.454	0.294	-1.253	0.366
0.15	2.333	0.293	-1.14	0.359
0.2	2.092	0.302	-1.028	0.336
0.25	2.004	0.33	-1.078	0.345
0.3	1.973	0.336	-1.113	0.344
0.35	1.857	0.349	-1.127	0.339
0.4	1.648	0.363	-1.083	0.335
0.45	1.491	0.376	-1.066	0.338
0.5	1.337	0.392	-1.054	0.341
0.55	1.199	0.417	-1.076	0.343
0.6	1.138	0.424	-1.084	0.347
0.65	1.09	0.427	-1.09	0.36
0.7	1.015	0.43	-1.081	0.366
0.75	0.911	0.432	-1.055	0.368
0.8	0.84	0.439	-1.057	0.366
0.85	0.767	0.447	-1.057	0.366
0.9	0.696	0.457	-1.068	0.365
0.95	0.613	0.462	-1.053	0.368
1	0.548	0.463	-1.038	0.368
1.05	0.483	0.469	-1.037	0.368
1.1	0.426	0.48	-1.055	0.369
1.15	0.353	0.494	-1.074	0.376
1.2	0.313	0.51	-1.113	0.38
1.25	0.249	0.521	-1.127	0.381
1.3	0.18	0.53	-1.127	0.385
1.35	0.146	0.535	-1.138	0.387
1.4	0.114	0.544	-1.157	0.388
1.45	0.074	0.55	-1.165	0.389
1.5	0.031	0.554	-1.164	0.387
1.55	-0.005	0.555	-1.157	0.385
1.6	-0.042	0.555	-1.15	0.387
1.65	-0.06	0.553	-1.148	0.389
1.7	-0.073	0.553	-1.152	0.391
1.75	-0.088	0.554	-1.16	0.392
1.8	-0.102	0.557	-1.169	0.392
1.85	-0.118	0.56	-1.181	0.394
1.9	-0.132	0.564	-1.195	0.394
1.95	-0.153	0.57	-1.209	0.394
2	-0.18	0.574	-1.218	0.396

Choice of Attenuation Relation

According to the relation proposed by Dr. Ghodrati (2008), SA-based attenuation relation is as follows:

$$\log(S_a) = C_1 + C_2 \times M_s + C_3 \times \log(R) \quad (4)$$

In which, R represents remoteness from site, M_s is surface magnitude, C_1, C_2 and C_3 are the constants which are obtained from table 7 based on the structure period.

For application of the mentioned attenuation relation, all the present magnitudes in the project should use relation 5.

$$M_s = 1.21\, m_b - 1.29 \quad (5)$$

Where,

m_b: magnitude in bulk waves
M_s: magnitude in surface waves

Calculation of Hazard Analysis Curve

In this section, using the relations below value of p (SA > s_α) is calculated. For a particular record (k), event probability can be obtained as follows. (6)

$$P_K(S_a > s_a : EQ_K) = \Sigma_j \Sigma_i\, p\,(Sa > sa : EQ_K : M_{iQ} R_j)\, F(M_i)\, \Delta M f(RJ)\, \Delta R$$

In which, ΔR almost for all faults invariably is considered 10km. f(R)ΔR is equal to a division by number of parts in each fault. ΔM is set equal to 0.5. Value of F (Mmid) is obtained based on the procedure in table 4.

At this stage, using the obtained values and the following formula, the required calculations are done for SA of 0.1 to 1.4.

$$p(Sa > sa \mathrm{I} EQ : R, M) = 1 - \Phi\left(\frac{\log(sa) - \log Sa}{\sigma_{\log Sa}}\right)$$

In figures 4 to 17, seismic event probability spectra are drawn based on the above mentioned formula.

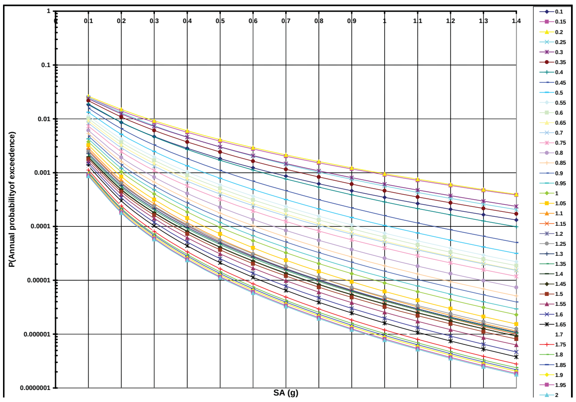

Figure 4. Annual seismic event probability spectrum for North Qazvin Fault

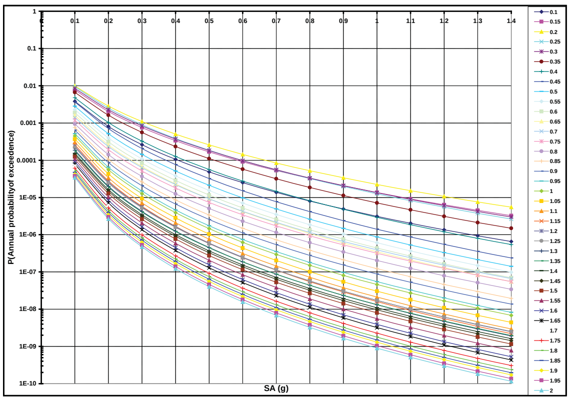

Figure 6. Annual seismic event probability spectrum for Banan Fault

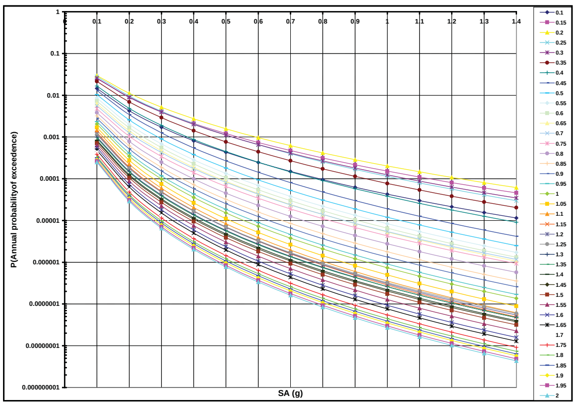

Figure 5. Annual seismic event probability spectrum for Alamout-Rood Fault

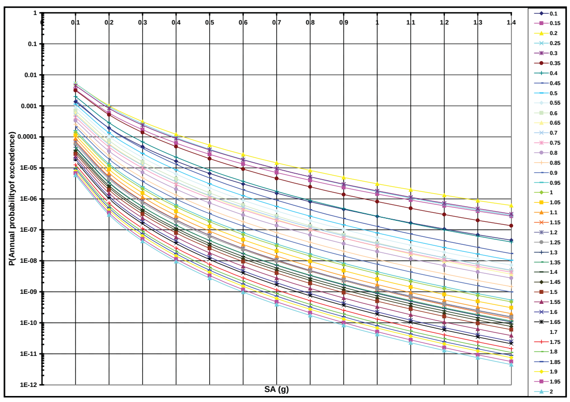

Figure 7. Annual seismic event probability spectrum for Soltanieh Fault

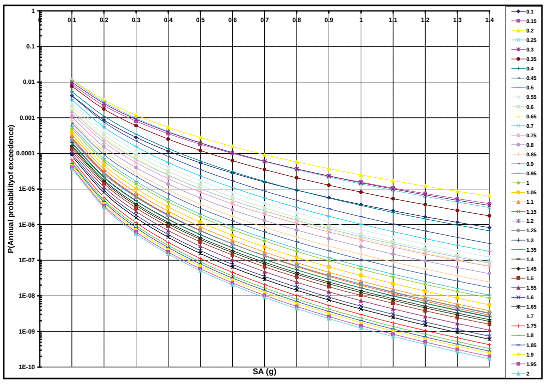

Figure 8. Annual seismic event probability spectrum for Zanjan Fault

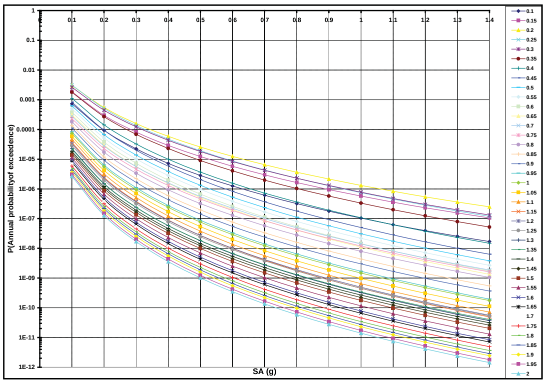

Figure 9. Annual seismic event probability spectrum for Kandavan Fault

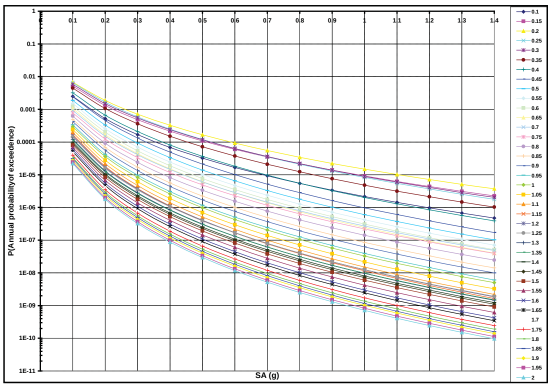

Figure 10. Annual seismic event probability spectrum for Taleghan Fault

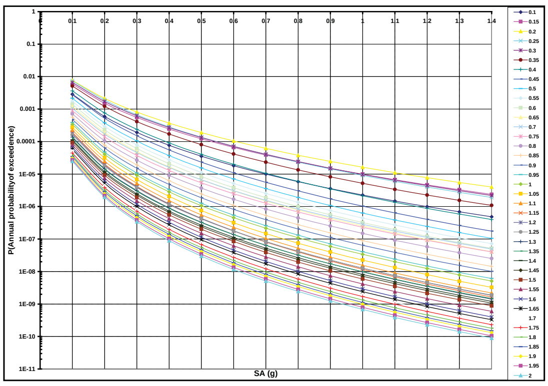

Figure 11. Annual seismic event probability spectrum for Eshtehard Fault

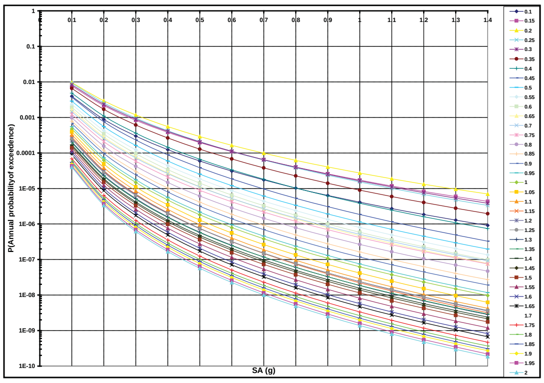

Figure 12. Annual seismic event probability spectrum for Ipek Fault

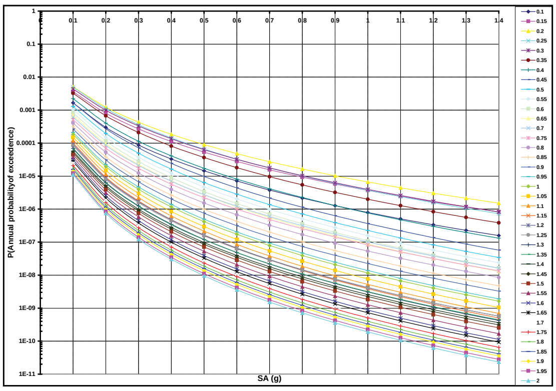

Figure 13. Annual seismic event probability spectrum for Roodbar Fault

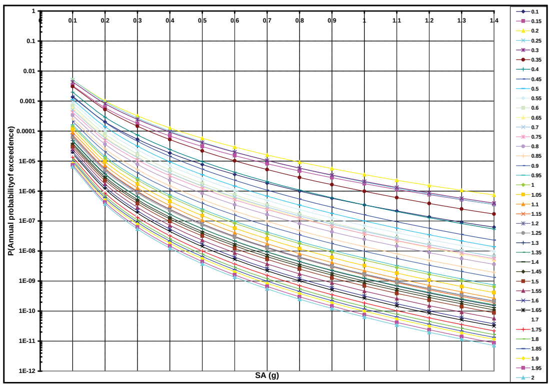

Figure 14. Annual seismic event probability spectrum for North-Tehran Fault

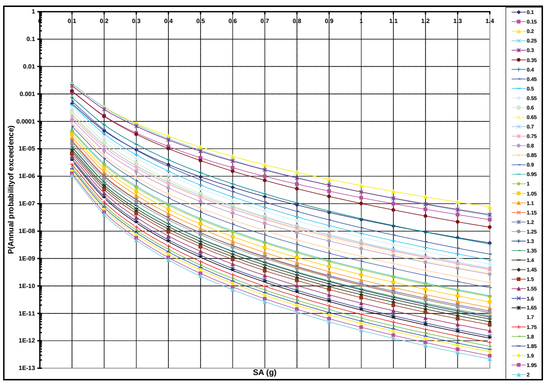

Figure 15. Annual seismic event probability spectrum for Indez Fault

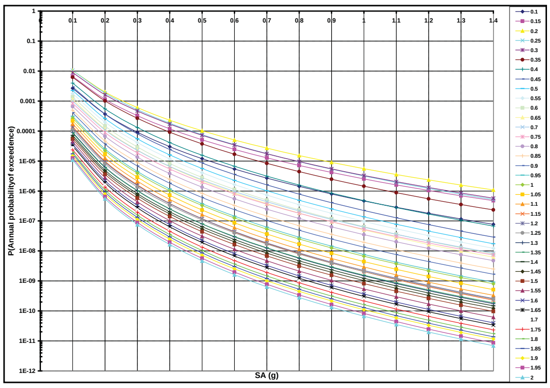

Figure 16. Annual seismic event probability spectrum for Alborz Fault

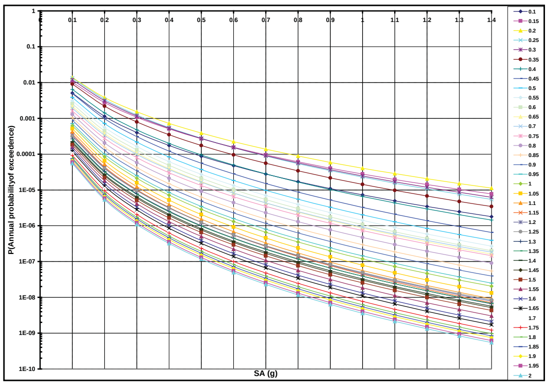

Figure 17. Annual seismic event probability spectrum for Masha Fault

Combination of the obtained hazard analysis graphs from different faults

The obtained hazard analysis graphs from each fault can be combined with each other by the following formula:

$$P\,(PGA > acc) = 1 - \Pi_k\,\{PGA < acc\}_k = 1 - \Pi_k(1 - P_k)$$

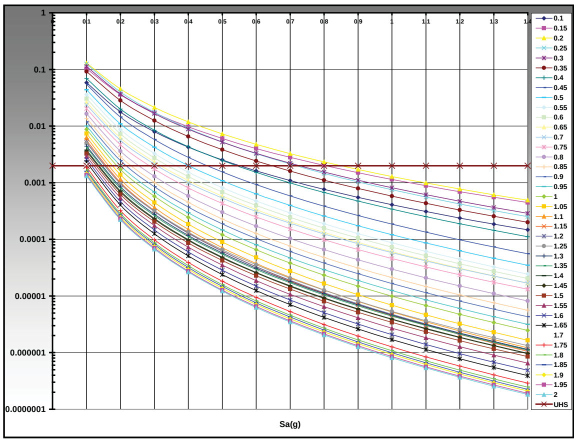

Figure 18. Combination of annual seismic event probability of various faults

Hazard probability level and Uniform Hazard Analysis

Hazard level for 10 percent earthquakes in 50 years can be obtained from the formula below:

$$R = 1 - (1 - p)^t \quad (9)$$

Considering the earthquakes with a recurrence period (interval) of 475, the annual excess probability (p) will be 0.002. To obtain Spectral Acceleration with uniform hazard, on the vertical axis a line equal to 0.002 is drawn and the points which intersect hazard analysis curves are found and by connecting these points eventually the following diagram is obtained.

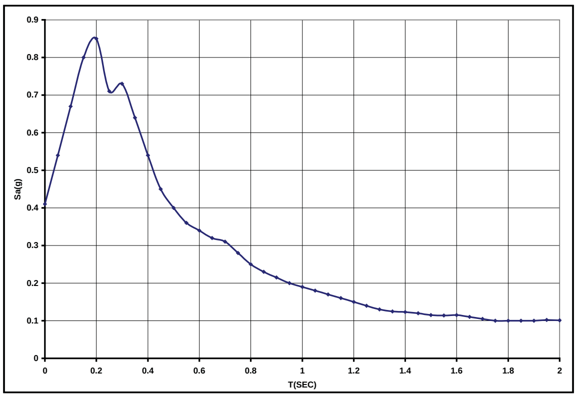

Figure 19. Determining hazard level of 10% in 50 years

Drawing the spectrum following exercise of engineering judgment

Now, by exercise of engineering assessment we can extract the project spectrum.

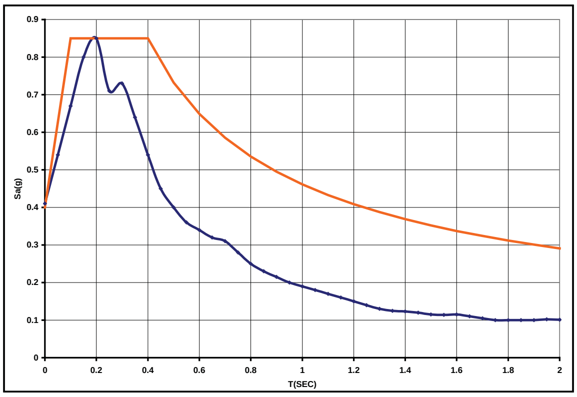

Figure 20. Hazard level of 10% in 50 years With Apply engineering judgment

Conclusions

From the performed analyses and application of Spectral Acceleration based relation in this study, the following outcomes are achieved:

1. To find earthquake spectral acceleration, 19 active faults in the understudy region were considered and after probability study and application of PSHA, event probability at different spectra was drawn.

2. According to the codes of practice, for 10% event in 50 years in case of earthquakes with recurrence interval of 475 years, it is enough to draw a line along the vertical axis at 0.002. This method enhances the calculation accuracy and reduces the errors at this stage.

3. To perform of engineering assessment, the drawing starts from the origin of acceleration spectrum and given the curve peak and SAfety margin, an area is introduced as the uniform acceleration the amount of which fully depends on accuracy of the calculations, exposure or vulnerability of the area, and value of confidence coefficient. Obviously, confidence coefficient varies for different parts.

References

Campbell, K. W. (1993). Comparison of contemporary Strong-Motion Attenuation Relationship, *Proceedings of the International Workshop on Strong Motion Data, California, 2,* 49-82

Campbell & Bozorgnia (1995). Available at http://www.sciencedirect.com/, PDF file.

Ghodrati Amiri.G. (2008). Attenuation relationship of spectral ordinates and arias intensity for Iran. *Journal of earthquake engineering*, May, 1-55.

Ghodrati Amiri.G., Mahdavian, A. and Manouchehri Dana (2007). Attenuation relationship for Iran. *Journal of earthquake engineering*, *11*(4), 409-492.

Green & Hall (1994). Available at http://www.earthquake.usgs.gov, June. PDF file.

Iran National Institute of standard, (2005). *Regulations designed buildings against earthquakes*, (Regulation 2008), Third Edition.

Joyner & Boore (1982). Available at http://www.sciencedirect.com/, PDF file

Zare, M., Badr, P.Y. and Ghafory-Ashtiany. M. (1999a). Site characterization for the Iranian Strong Motion Network, *Soil Dynamic and Engineering, 18*(18), 101-123.

Zare, M., Ghafory-Ashtiany, M. and Badr, P.Y. (1999b). Attenuation law for the Strong Motion in Iran, *Proceeding of the 3rd international Conference on Seismology and Earthquake Engineering*, Tehran, Iran, 345-354