

Evaluation of Conversion Coefficients of Design Base Acceleration to Accelerations of Other Seismic Risk Levels

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Abstract—The objectives of structural seismic design against various seismic risk levels (weak, moderate, severe and maximum credible earthquakes) are different. However in seismic design codes, only the design base earthquake ground motion (severe earthquake) is usually proposed. This research attempts to determine conversion coefficients of design base earthquake ground motion (10% probability of occurrence) to other earthquake acceleration levels (2%, 5%, 20%, 50% and 64%). For this purpose, two susceptible areas of Sari (Elburz zone in North of Iran) and Fereidoonshahr (Zagros zone in west part of Iran) were chosen and their design accelerations relevant to the various seismic levels were determined. Major fault systems of the sites were reviewed and modeled using *suiTable* attenuation parameters. The conversion coefficients are (0.2, 0.28, 0.64, 1.51 & 2.41) and (0.36, 0.43, 0.74, 1.33 & 1.88) for Sari and Fereidoonshahr, respectively.

Index Terms—Seismic risk analysis, seismic factors, maximum horizontal acceleration, Seismic risk levels, Sari, Fereidoonshahr.

I. INTRODUCTION

In seismology, the earthquakes of each region are divided into four levels. In seismic design codes, different levels of earthquake are named variously, but the general nomination is as weak, moderate, severe (or strong) and maximum credible (maximum) earthquakes. Here definitions of each of these levels for a particular region are given:

- a) Weak earthquake is an earthquake that happens several times during the serviceable life of a building in a particular region.
- b) Moderate earthquake is an earthquake that sometimes or at least one time happens during the serviceable life of a building in a particular region.
- c) Strong earthquake rarely happens in a given region during the serviceable life of a building.
- d) Maximum earthquake is the strongest one that may happen in a particular region.

In 3th edition of Iran's seismic design codes (2800 standards) [1], two seismic risk levels have been defined for each region; weak (operation) earthquake and strong (Design Base Earthquake). According to these codes, weak earthquake is a one that its occurring probability is 99.5% during the fifty years of the serviceable life of a building. Return period of this kind of earthquake is 10 years. Strong earthquake (Design Base Earthquake) is a one that its

occurring probability is 10% during the fifty years of the serviceable life of a building. Return period of this kind of earthquake is 475 years. In 2800 standards, the amounts of design acceleration are only presented for 475-year earthquake and it is suggested that in the case that the acceleration of 10-year earthquake is needed the acceleration of design base earthquake is divided by six and used as weak earthquake; that is conversion coefficient is defined as 1/6.

In Instruction for Seismic Rehabilitation of Existing Buildings (Iranian code for rehabilitation) [2], different levels of earthquakes have been defined, which two more important of them are strong earthquake (risk level-1) and maximum earthquake (risk level-2). Risk level-1 determined based on 10% probability of occurring in 50 years that is return period of 475 years, and Risk level-2 determined based on 2 percent probability of occurring in 50 years that is return period of 2475 years and is known as MPE (Maximum Probable Earthquake).

In 96-01 SSC report of Applied Technology Council (ATC), three levels of moderate, strong and maximum earthquake have been defined for each region. According to this guide, moderate earthquake is the one that its probability of occurring is 50% during the 50 years of serviceable life of a building. The return period of this earthquake is 70 years and is reputed as 70-year earthquake. Strong (Design Base) earthquake, is an earthquake that its probability is 10% during the 50 years of serviceable life of a building and its definition is the same as those of design base earthquake in 2800 standards and Risk level-1 of Instruction for Seismic Rehabilitation of Existing Buildings. Maximum earthquake is a one that its probability is 5% during 50 years and its return period is 1000 years. Based on this guide, if the design base acceleration is available, it is possible to determine the design acceleration of moderate earthquake as half of that of design base earthquake (conversion coefficient of 0.5); and design acceleration of maximum earthquake as 1.25 to 1.5 of that of design base earthquake (conversion coefficient of 1.25 to 1.5) [3].

Other seismic design codes like Japan seismic design codes (BSL), Tri-Services Manual of USA army, New Zealand seismic design codes (NZS), China seismic design codes (GBJ), and UBC have offers the same definitions for weak, moderate, and strong earthquake [4].

As it was mentioned, in various seismic design codes, there are different seismic risk levels for designing but mostly the design acceleration of strong earthquake (475 years) is introduced and to have the accelerations of other

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levels, the acceleration of strong earthquake should be multiply by a conversion coefficient.

The purpose of the present study was the investigation and evaluation of the offered coefficient of different seismic design codes for determining of designing accelerations of weaker and stronger than design base earthquake. For this purpose, two regions of Sari and Fereidoonshahr were chose as the sample and the amounts of design accelerations of different seismic risk levels for these regions were determined. Then, the proportion of these amounts to design basis earthquake acceleration was computed and they were compared with proposed amounts of the standard codes.

Risk evaluation maps are very important in preventing geological disasters or at least reducing them to minimum and also as the guide for reconstruction after earthquake [5]. Ghodrati Amiri *et al.* [6] analyzed seismic risk for East Azarbayejan, (East Province in Iran) through probability method using four attenuation equations of Ghodrati, Ambersis, Sedigh and Kampbel for a 20×21 mesh with distances of 15 km. They represent the results as the co-acceleration maps at two risk levels of 2% and 10% during 50 years of serviceable life of a building.

Ebadi *et al.* [7] studied the seismic risk of Khark island limits; and, according to the geological properties, divided the area to 11 seismic states. They computed seismic parameters based on seismological characteristics. They analyzed seismic risk using two methods of determining and probability and computed maximum acceleration of every state.

Ghodrati Amiri *et al.* [8], by means of probability method of seismic risk analysis, computed the maximum acceleration on bed stone in four seismic risk levels of 2%, 10%, 20%, and 50% for Sanandaj city. Besides, Ghodrati Amiri *et al.* [9] prepared the maps of co-acceleration lines of different seismic risk levels of the area of mashhad using three attenuation equations of Ghodrati, Ambersis, and Sarma.

Chey and *et al.* evaluate the behavior of smart building isolation system under multi-level earthquake excitations [10].

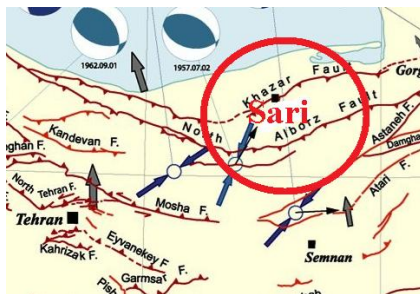


Fig. 1. Active faults in Sari region.

II. SEISMOTECTONICS OF SARI AND FEREIDOONSHAHR

In order to compute and evaluate the seismic risk of a region all sources of probable data should be recognized and be checked to see whether they have the capability of affecting plate movement (Plate Tectonics). First step to do this is accurate and perfect recognition of the faults of Sari and Fereidoonshahr's area. Therefore, a list of name, length, and maximum seismic power of the faults of Mazandaran

province's region (in a radius of 200km around Sari city) is presented in Fig. 1 and Table I [10]. Moreover, Figure 2 shows the map of active faults of Fereidoonshahr in a radius of 200km. It should be mentioned that the amounts of maximum seismic power computed based on the equation 1 proposed by Norouzi [11] in which L is the length of the fault.

$$M_s = 1.259 + 1.244 \log(L) \quad (1)$$

TABLE I: CHARACTERISTICS OF ACTIVE FAULTS IN SARI REGION

Fault Name	Fault Length (km)	Magnitude (R)
Behshahr	105	7.1
Gorgan	50	6.7
Babol	50	6.7
Khazar	130	7.2
North khazar	135	7.2

III. SEISMICITY OF REGIONS

The history of past earthquakes of each area shows the seismicity of that area. In order to access the geological characteristics of each area, a complete list of seismic events of the area should be provided. In the present study, large seismic events of Sari and Fereidoonshahr in a radius of 200km are presented.



Fig. 2. Active faults of Fereidoonshahr region.

TABLE II: HISTORICAL SEISMIC DATA OF SARI

Earthquake	Year	Magnitude (R)
Chardangeh	1127	6.8
Farim	1301	6.8
Gorgan	1436	5.3
Gorgan	1470	5.5
Gorgan	1498	6.5

Historical sources and reports of destructions and damages of previous centuries, demonstrates the number and repetition of fault movements Sari and Fereidoonshahr. seismic data of twenty century contain different errors in surface center, focal depth, and magnitude of the earthquakes, they have more importance because of machinery recording; and with the advent of seismograph network in 1963 and the use of telemetric method in recent decades, these errors have been reduced.

The list of the characteristics of machinery recording earthquakes in the area under the study during 21 century was compiled according to different sources and more accurate records were chosen. The most important earthquakes of the area of Sari are presented in Tables II and III. Table II shows the data before 20 century and Table III is related to machinery recording earthquakes of Sari.

Besides, Table IV and V demonstrate the earthquakes of Fereidoonshahr since 1052 till now. These Tables (II, III, IV, and V) report the name, coordinates of focus, magnitude, and the source of the reports of the earthquakes [12].

IV. SEISMICITY PARAMETERS OF SARI AND FEREIDOONSHAHR

In order to compute the basic parameters of Seismicity of each region, which are λ and β , the historical and recorded data of regions should be gathered. As the independency of earthquake is the fundamental assumption in estimating the basic parameters of Seismicity, temporal and spatial window [13] method was used to eliminate pre- and post-earthquakes.

TABLE III: RECORDED SEISMIC DATA OF SARI

Earthquake	Year	Magnitude (R)
Talar roud	1935	5.8
Kosout	1935	6.3
Bandpey	1957	6.8
Babolkenar	1971	5.2
Bayjan	1983	5

In analyzing seismic risks usually a magnitude like M_s related to surface waves or m_b of volume waves is used. However, as the earthquakes that both of their magnitudes were available were not numerous in the previously mentioned list of the study, the following equation that offered by Iran's national committee of large dams was utilized [14]:

$$M_s = 1.21m_b - 1.29 \quad (1)$$

TABLE IV: IMPORTANT HISTORICAL EARTHQUAKES IN FEREIDOONSHAHR

Occurrence of earthquake	North latitude	East longitude	Magnitude
Khouzestan 1502	31.50	50.00	6.8
Golpaygan 1316	33.50	49.40	6.2
Zagros 1666	32.10	50.50	6.5
Kashan 1844	33.60	51.40	6.4
1853	32.60	50.30	5.5

TABLE V: IMPORTANT RECORDED EARTHQUAKES IN FEREIDOONSHAHR

Occurrence of earthquake	North latitude	East longitude	Magnitude
1929	32.06	49.60	6.3
1951	32.26	49.80	6.2
1973	31.99	50.70	6.1
1978	32.14	49.65	6.1
2002	32.00	49.33	5.6

The seismicity parameters are computed based on occurring the earthquakes and their frequency-magnitude ratio. In the present study the new method of Kijko and Selol [15] was utilized in computing the seismic parameters. In this method by considering the errors of seismic data during various eras and by means of Kijko's model, the occurring of earthquakes can be used in estimation of seismic parameters λ and β . The results of this method consist of parameters λ and β , return period, occurring probability, and non-occurring of earthquake in different times. In this method three types of earthquake have

generally been considered:

- 1) First type was the historical earthquakes that their magnitudes were considered as 0.3, 0.4, and 0.5 unit of magnitude for good, average, and bad respectively.
- 2) Second type was the earthquakes of present century before the installation of international geometer (from 1900 to 1963) that their magnitude was considered as 0.2 unit and threshold magnitude as $M_s=4.5$.
- 3) Third type was the earthquakes after 1964 that were recorded and had high accuracy. Their magnitude was considered as 0.1 unit and threshold magnitude as $M_s=4$.

Parameters of seismic activity that were used in this study are shown in Tables VI, VII, and VIII

TABLE VI: COMPUTED PARAMETERS OF SEISMIC ACTIVITY FOR SARI

β	b	$\lambda_{ms}=3.9$	Mmax
0.01 ± 2.09	0.01 ± 0.82	0.10 ± 1.39	0.64 ± 8.4

TABLE VII: PERCENT OF THE CONTRIBUTION OF DATA OF DIFFERENT ERAS

Seismic parameters	Before 1900	1900-1964	1964-2011
β	34.2	32.8	33
λ	9.2	34	56.8

TABLE VIII: PARAMETERS OF SEISMICITY OF FEREIDOONSHAHR

β	b	$\lambda_{ms}=3.99$	Mmax
0.08 ± 2.09	0.03 ± 0.91	0.1 ± 1.39	0.71 ± 7.90

V. PROBABILISTIC METHOD (PSHA)

In Probabilistic method, economic and safety issues are considered. By modeling the seismic sources of the region and probabilistic theory for every percent of seismic risk, the maximum acceleration (PGA) would be computed. The software of SEISRISK III [16] was used for modeling and computing maximum acceleration. In order to have more logical results, a number of attenuation equations in addition to logical tree were utilized to calculate average weight of the accelerations.

A. Choosing Attenuation Equations

Selecting of attenuation equation is important for determining of seismic parameters. This selection depends on the kind of earthquake (the kind of fault split), the soil of the region, the texture of the stones, focal depth, and the type of acceleration component. In order to have more logical results, a number of attenuation equations in addition to logical tree, were utilized to calculate average weight of the accelerations. The important factors in choosing the weight of these equations are their conformity with the conditions of the region and their calculation method. In the present study three attenuation equations of Ghodrati [17], Ramzi [18], and Sarama [19] were selected in a way that confirm the conditions of the under study regions. The first and second equations are suggested for Iran and the third one for all over the world. Figure 3 shows the coefficients of each of these equations in logical tree for horizontal acceleration.

B. Design Base Acceleration

According to aforementioned issues, forming a 6×7 mesh for Sari and a 5×7 mesh for Fereidoonshahr with dimensions of about 1000m, and calculating the acceleration in different parts, co-acceleration map of risk levels of 10% in 50 years, 10% in 50 years, 2% in 50 years, 5% in 50 years, 20% in 50 years, 50% in 50 years, and 64% in 50 years was provided. The final results of probable risk analysis of Sari region for different risk levels are shown in Figs 4 to 9. In these Figures vertical and horizontal axes show the location of Sari that the amounts of acceleration of each part are given on co-acceleration curves. In Fig. 4 which shows the acceleration of risk level of 2%, the maximum acceleration is 0.96g and minimum is 0.56g. As the distance from the fault becomes larger the acceleration reduces. The amount of 0.96g is related to very close area to the fault.

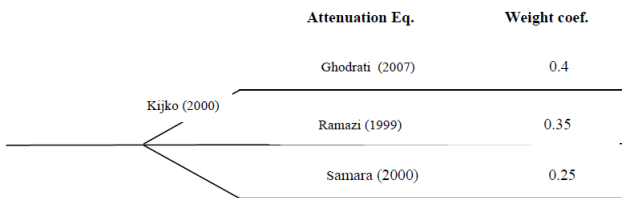


Fig. 3. Logical tree of maximum horizontal axe.

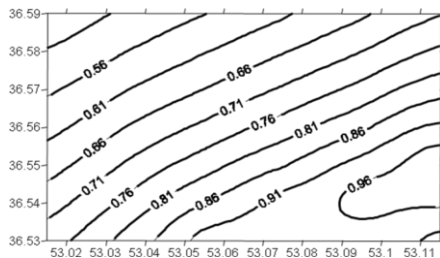


Fig. 4. Acceleration (PGA) for risk level of 2%.

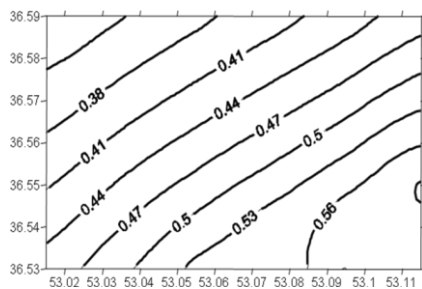


Fig. 5. Acceleration (PGA) for risk level of 5%.

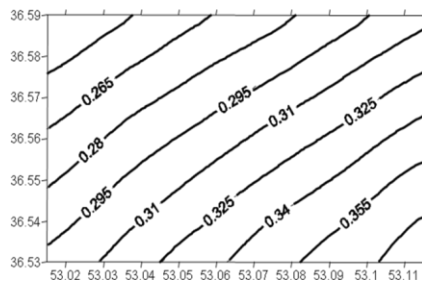


Fig. 6. Acceleration (PGA) for risk level of 10%.

Fig. 6 is related to risk level of 10%. Its maximum acceleration is 0.35g and minimum is 0.26g. In 2800 standards, the amount of the acceleration of risk level of 10% for Sari was suggested as 0.3g.

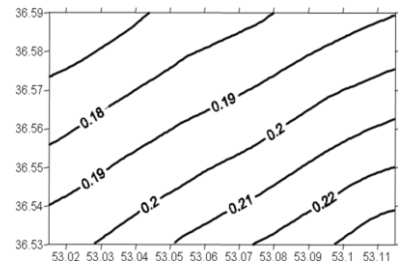


Fig. 7. Acceleration (PGA) for risk level of 20%

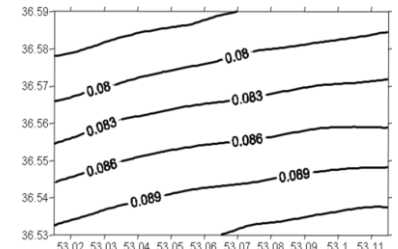


Fig. 8. Acceleration (PGA) for risk level of 50%

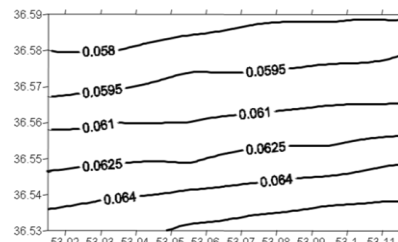


Fig. 9. Acceleration (PGA) for risk level of 64%.

The results related to Fereidoonshahr are presented in Fig. 10 to 15.

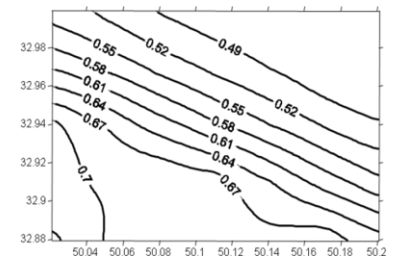


Fig. 10. Acceleration (PGA) for risk level of 2%.

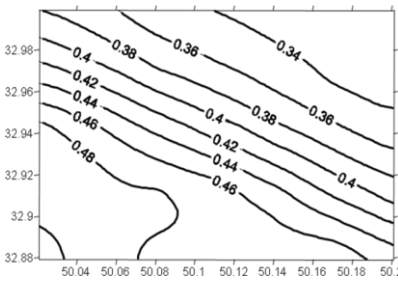


Fig. 11. Acceleration (PGA) for risk level of 5%.

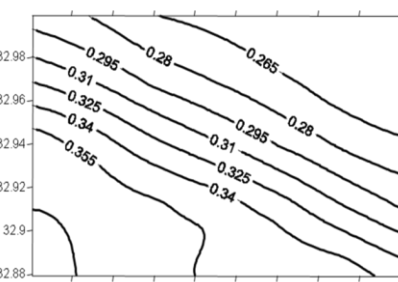


Fig. 12. Acceleration (PGA) for risk level of 10%.

The maximum and minimum of design base acceleration for risk level of 10% according to Fig. 12 are 0.35g and 0.26g respectively. 2800 standards suggested the amount of 0.3g for this region.

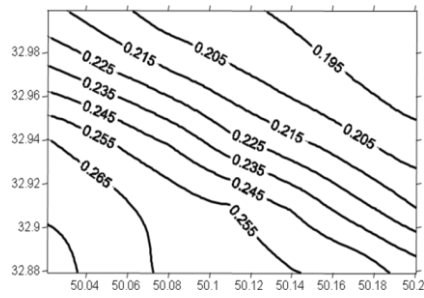


Fig. 13. Acceleration (PGA) for risk level of 20%.

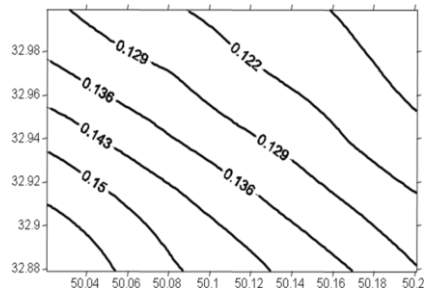


Fig. 14. Acceleration (PGA) for risk level of 50%.

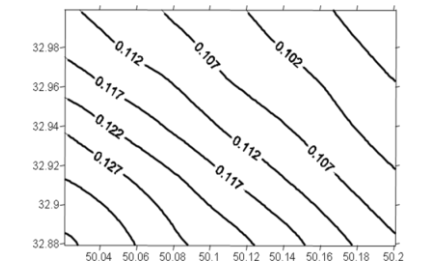


Fig. 15. map of acceleration (PGA) for risk level of 64%.

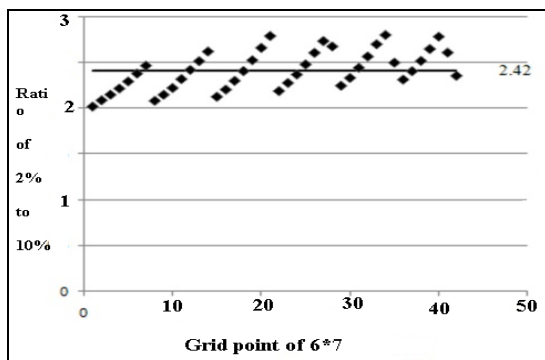


Fig. 16. Proportion of acceleration of 2% to acceleration of 10% for under study parts of Sari.

VI. DETERMINING CONVERSION COEFFICIENTS OF ACCELERATION

According to the data represented in pervious parts, conversion coefficients of acceleration can be calculated for every part and for every risk level. This was done for nodes of the mesh for risk levels of 2 to 64 percent. For example for calculating conversion coefficients of a part with risk level of 2% the acceleration of this risk level would be divided by the risk level of 10% in that part. Figure 16 shows this proportion for all under study parts of Sari. In

order to make these proportions applicable, the average of them was computed and came out as 2.42. Therefore, based on the results of this study, it can be said that by having the acceleration of risk level of 10% and multiplying it by 2.42, the acceleration of risk level of 2% would be obtained. Fig. 17 shows these computations for Fereidoonshahr and the proportion came out as 1.88.

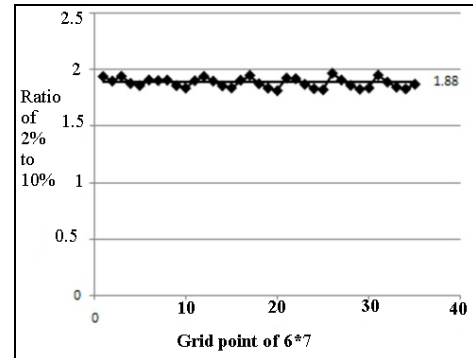


Fig. 17. Proportion of acceleration of 2% to acceleration of 10% for under study parts of Fereidoonshahr.

This process was done for all risk levels. However, to save the space, just the results related to risk level of 64% are presented in Figs 18 and 19 for Sari and Fereidoonshahr respectively. Table IX represents the maximum accelerations for Sari and Fereidoonshahr.

For calculation of conversion coefficients of accelerations, the average of division outcomes of all accelerations with every risk level of every part by design base acceleration of that part with risk level of 10% was obtained. This was done for every risk level of every region of Sari and Fereidoonshahr separately and presented in Tables X and XI.

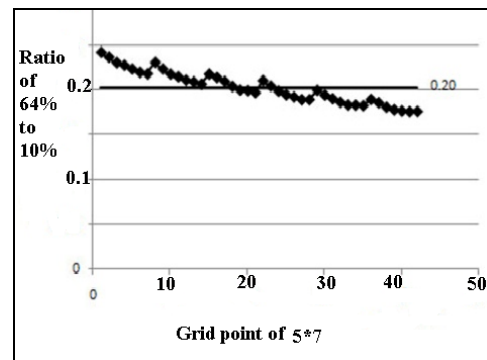


Fig. 18. Proportion of acceleration of 64% to acceleration of 10% for under study parts of Sari.

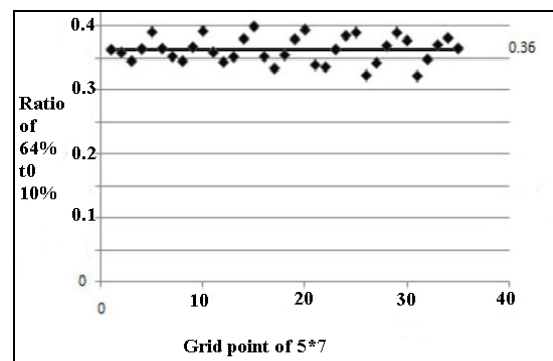


Fig. 19. Proportion of acceleration of 64% to acceleration of 10% for under study parts of Fereidoonshahr.

TABLE IX: FINAL RESULTS OF RISK ANALYSIS (PGA) FOR SARI AND FEREIDOONSHAHR

Risk (%)	Return Period (Year)	Sari	Fereidoonshahr
10	475	0.31	0.31
2	2475	0.75	0.59
5	975	0.47	0.41
20	225	0.2	0.23
50	72	0.08	0.13
64	50	0.06	0.11

TABLE X: CONVERSION COEFFICIENTS OF ACCELERATIONS FOR SARI

Risk (%)	Result
2	2.41
5	1.51
20	0.64
50	0.28
64	0.2

TABLE XI: CONVERSION COEFFICIENTS OF ACCELERATIONS FOR FEREIDOONSHAHR

Risk (%)	Result
2	1.88
5	1.33
20	0.74
50	0.43
64	0.36

VII. CONCLUSION

The purpose of this study was investigation and evaluation of the offered coefficient for different seismic design codes for determining of design accelerations of weaker and stronger earthquakes than design base earthquake with risk level of 10%. For this purpose design accelerations for risk levels of 2, 5, 10, 20, 50, and 64 percent for regions of Sari and Fereidoonshahr were calculated and their ratio of these amounts to accelerations with risk level of 10% was computed. Accordingly the following results were obtained:

- 1) The design base acceleration for Sari and Fereidoonshahr obtained as 0.31g which confirms with suggested amount in 2800 design code.
- 2) The conversion coefficients of accelerations of different risk levels of 2%, 5%, 20%, 50%, and 64% to design base earthquake (10%) for Sari were 2.41, 1.51, 0.64, 0.28, and 0.2 respectively.
- 3) The conversion coefficients of accelerations of different risk levels of 2%, 5%, 20%, 50%, and 64% to design base earthquake (10%) for Fereidoonshahr were 1.88, 1.33, 0.74, 0.43, and 0.36 respectively.
- 4) In ATC code, the conversion coefficient of 10% earthquake to 5% is suggested as 1.25 to 1.5 that confirms with obtained amounts for Sari and Fereidoonshahr.

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