COMPARISON OF SEISMIC RISK OF LOW RISEIMPORTANT BUILDINGS DESIGNED BYDIFFERENT EDITIONS OF IRANIAN SEISMIC CODE

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ABSTRACT

Buildings with high degree of importance and facilities such as hospitals, police stations, fire stations and other vital facilities play crucial role in crisis and risk management of cities. Therefore special attention has been paid to design and construct these buildings in order to maintain their performance during and after the earthquake. Design of important building in Iran is conducted based on the Iranian code of practice for seismic resistant design of buildings (ISC). Since the first lunch of ISC, three editions of ISChave been introduced. In this study, improvement of seismic safety of important buildings in different editions of ISC are examined and the results are compare that with acceptable level of safety. In this study, a very important 3-story steel moment resisting frame is selected and designed base on different editions of ISC for high seismic zone. The seismic fragility functions of buildings are estimated in all four soil classifications. The probability of failure of frames are estimated for Tehran and Tabrizwhere are two major citieslocated in high seismic zones. Results shows a good improvement in safety of different frames in recent editions of ISC, especially from first to second edition. However, the functionality and safety of buildings were not satisfy the minimum requirement of the code. In addition the probability of failure of frames located in softer soil types is higher than others.This indicated that within any code edition, a constant limit of safety was not provided indifferent soil types.

INTRODUCTION

Iranian seismic code (ISC) or standard number 2800, which first introduced just before Manjil-Rudbar earthquake in 1988, has been used for designing of buildings and other facilities.So far, three editions of code are introduced and the fourth edition released recently. The introduction of the code improve the quality of construction and reduce the vulnerability of structures. But experience of recent earthquake such as Varzaghan earthquake, demonstrate that some structures, especially important buildings such as hospitals are vulnerable to earthquake.

Although many improvement in design requirement of important buildings have been introduced in the recent versionsof ISC, some studies have shown that the important buildings (or very important building which indicated in the code) designed based on the latest version of ISC are not satisfied the ISC's criteria. Mahmoodi (2009) studied the effect of regularity in very important building designed based on ISC. Also, Mahmoudi and Ghobadi (2011) are studied the performance of important building which donot remain operationally after serve earthquake. The uncertainties in the application of R factor in static design and vulnerability seismic evaluationof important building consequently are studied by Behnamfar and Nafarieh

(2003) andShakib (2000) and concluded that constant R factor make very important buildings vulnerable due to earthquake events. The results have shown that the performance of important buildings designed by the code are not suitable.

To study the seismic risk of importance buildings from the probabilistic point of view, the seismic performance and safety of important buildings in different editions of ISCs in high seismic hazard zone and all soil types are estimated and compared. For this purpose, a low rise steel moment resistant frame are selected and designed for all ISC editions in all soil type. The probability of losing functionality of the buildings and probability of collapse are estimated based on the probabilistic approach and development of seismic fragility functions. The probability of failure frames are estimated for two different high seismic zone in Iran.

DEVELOPMENT OF EDITIONS OF IRANIAN SEISMIC CODE

Iranian Seismic Code (ISC No. 2800, 2005) was first introduced just before Manjil-Rudbar earthquake in 1988. Since then, three different editions of code introduced consequently in 1999 and 2005. Through these promotion, many improvement have been applied to seismic definitions and parameters such as improvement in the level of applied load by refining the code spectrum and the ductility of structures. In all editions of the code, the seismic base shear are evaluated by $V = CW$ in which W is the total effective weight of structure and C is the seismic coafficent calculated by $C = {}^{ABI}/_{R}$. The parameters of seismic coefficients for all three editions of ISC have been compared in Table 1.

Table 1. Comparison of seismic coefficient's parameter of for all three editions of ISC

Iranian Seismic Code 2800		Third Edition	Second Edition	First Edition
Seismic Zone Factor (A)	Very high risk	0.35	0.35	-
	High risk	0.30	0.30	0.35
	Moderate risk	0.25	0.25	0.30
	Low risk	0.20	0.20	0.25
Predominant Period (T) (Moment resisting frame)		$\begin{cases} \text{Steel} : 0.08H^{\frac{3}{4}} \\ \text{Concrete} : 0.07H^{\frac{3}{4}} \end{cases}$	$\begin{cases} \text{Steel} : 0.08H^{\frac{3}{4}} \\ \text{Concrete} : 0.07H^{\frac{3}{4}} \end{cases}$	$\begin{cases} \text{Steel} : 0.08H^{\frac{3}{4}} \\ \text{Concrete} : 0.07H^{\frac{3}{4}} \end{cases}$
Responsecoefficient (B) – normalized code spectra		$\begin{cases} B = 1 + S\left(\frac{T}{T_0}\right) & T \leq T_0 \\ B = 1 + S & T_0 \leq T \leq T_S \\ B = (1 + S)\left(\frac{T_S}{T}\right)^{\frac{2}{3}} & T \geq T_S \end{cases}$	$B = 2.0\left(\frac{T_0}{T}\right)^{\frac{2}{3}} \leq 2.5$	$0.6 \leq B = 2.0\left(\frac{T_0}{T}\right)^{\frac{2}{3}}$ $0.6 \leq B \leq 2.0$
Seismic Importance Factor (I)	Very Important	1.4	-	-
	Important	1.2	1.2	1.2
	Moderate	1.0	1.0	1.0
	Slight	0.8	0.8	0.8
Response Modification Coefficient (R)	Range	$4 \leq R \leq 11$	$4 \leq R \leq 11$	$4 \leq R \leq 8$
	Steel Moment resisting frame	Ordinary Sway: $R = 5$ Intermediate Sway: $R = 7$ Special Sway: $R = 10$	Ordinary Sway: $R = 6$ Special Sway: $R = 10$	Ordinary Sway: $R = 6$ Intermediate Sway: $R = 8$

As it can be observed from the Table 1, the main differences in the design of important buildings are in the response spectrum (B coefficient), seismic importance factor (I), response modification factor (R). The seismic response spectrum for different editions of the code are shown in Figure 1. A quick look at this figure, indicated that the code spectrum has increased significantly in different editions of the code. The importance factor for important buildings especially hospitals, which is the main focus of this paper, was similar in first and second edition of ISC (I=1.2) and increased in the third edition (I=1.4) (ISC No.2800, 2005). Considering the high ductility for design of important buildings was mandatory for the third edition of the code which was not the case for the second and first edition of the code. In addition, the ductility requirement for the ductile frame has been improved in the latest editions of the code. Therefore, it is expected that important buildings that designed according to the newer editions of the code has more ductility capacity and experience less vulnerability.

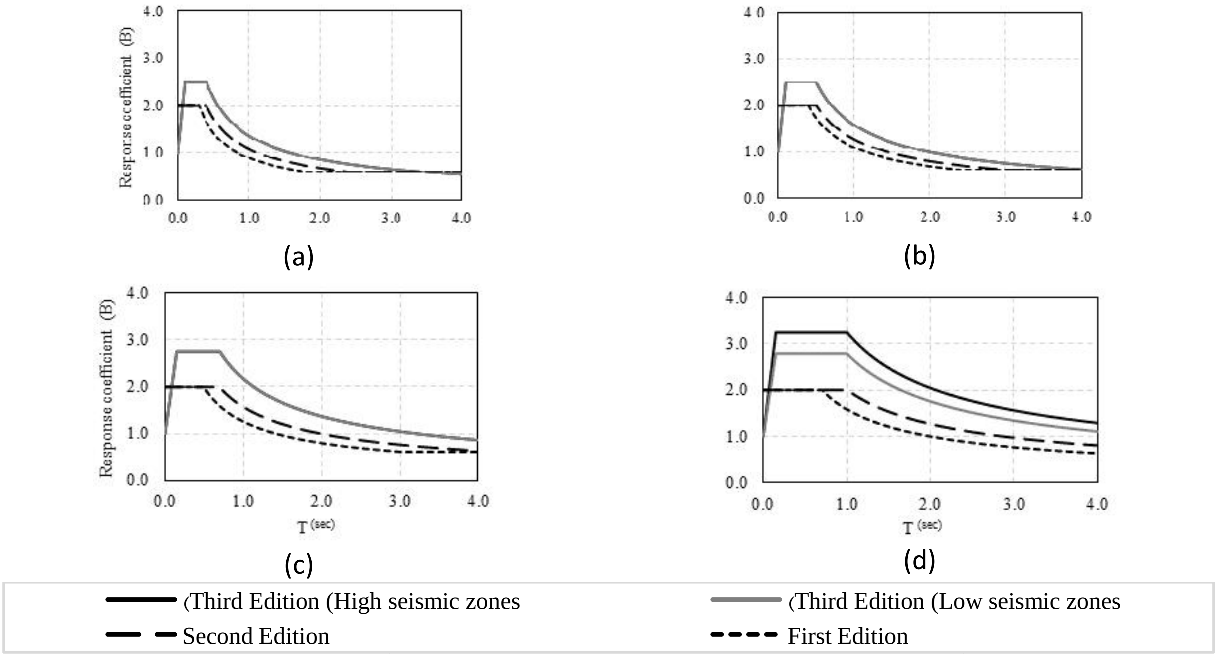

Figure 1. Comparison of seismic response spectrum in different editions of Iranian seismic code (a) Soil I; (b) Soil II; (c) Soil III (d) Soil IV.

THE STUDY METHODOLOGY

For evaluation of the seismic risk of the important buildings in this study, following steps have been conducted:

1) A moment resisting frame (MRF) has been selected and designed base on different editions of ISC.For this purpose, seismic coefficient is evaluated for all three editions of ISC.
2) The frame are deigned according to the estimated seismic force.
3) The fragility curves of designed frames were evaluated by analytical method through numerous nonlinear dynamic analysis.
4) The seismic risk of frames are evaluated and compared for two different high risk zone in Iran: Tabriz and Tehran.

The detail of each step is given in the following sections.

SELECTION AND DESIGN OF BUILDING FRAMES

A 3-bay, 3-sroty steel frame located in high seismic zone has been selectedfor study which is illustrated in Figure 2. Seismic coefficients of this frame is calculate based onall three editions of ISC for all four different soil classifications which leaddifferent coefficient given in Table 2.In the Table 2, the values of seismic coefficient and the number of repeat time is shown. The frame is designed based on each seismic coefficientand standard European sections (I shape for beams and H shape for columns) were used. Due to similarity in the result of designed section for different cases, all designed frames were fallen into three types that illustrate inTable 3.As it can be seen, the designed frames based on 2nd and 3rd edition of ISC are similar.

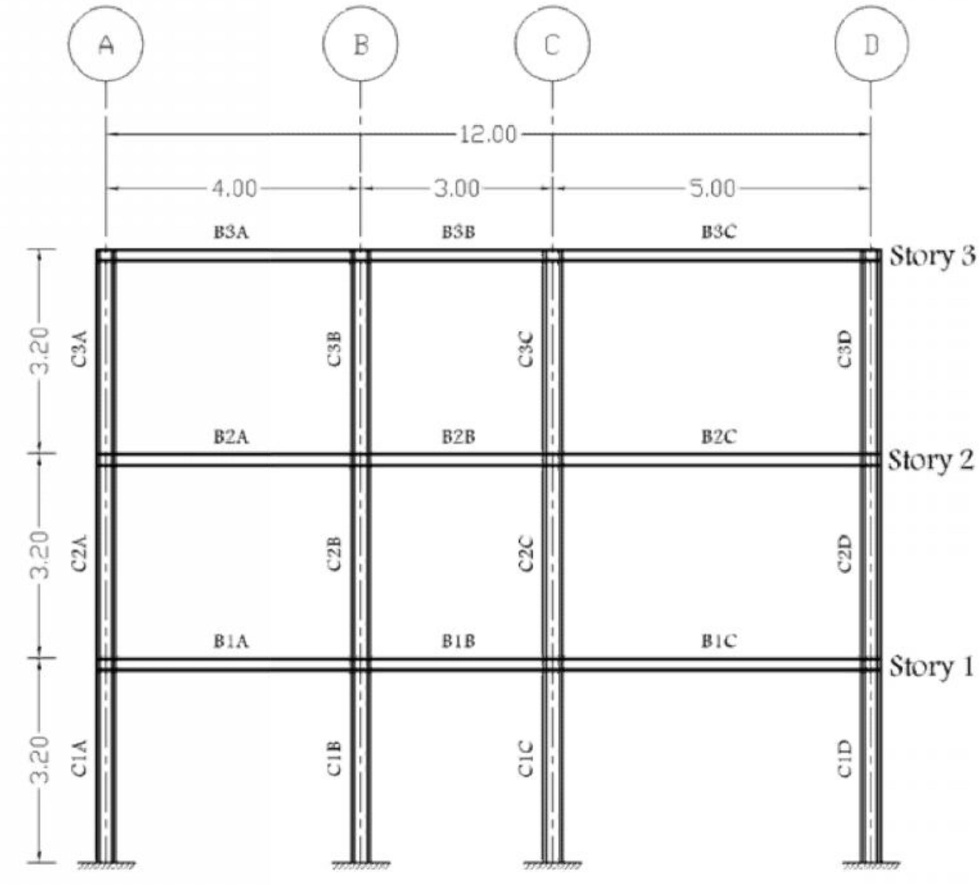

Figure 2.General feature of selected 3-story frames from a very important buildings.

Table 2. Seismic coeficient evaluated for selected important frame in all four soil classification based on ISC

	Soil I		Soil II		Soil III		Soil IV	
	C_{Value}	No.	C_{Value}	No.	C_{Value}	No.	C_{Value}	No.
First Edition	0.0940	4	0.1139	4	0.1321	4	0.1400	4
	0.0783	2	0.0949	2	0.1101	2	0.1167	2
	0.0671	2	0.0813	2	0.0944	2	0.1000	2
	0.0559	1	0.0678	1	0.0786	1	0.0833	1
Second Edition	0.0854	2	0.0991	2	0.1050	2	0.1050	2
	0.0732	4	0.0849	4	0.0900	4	0.0900	4
	0.0712	1	0.0826	1	0.0875	1	0.0875	1
	0.0610	4	0.0708	4	0.0750	4	0.0750	4
	0.0508	1	0.0590	1	0.0625	1	0.0625	1
Third Edition	0.0971	1	0.1148	1	0.1348	1	0.1365	1
	0.0832	4	0.0984	4	0.1155	4	0.1348	1
	0.0713	4	0.0843	4	0.0990	4	0.1170	2
	0.0693	2	0.0820	2	0.0963	2	0.1155	3
	0.0594	4	0.0703	4	0.0825	4	0.1138	1
	0.0495	1	0.0586	1	0.0688	1	0.0990	2
							0.0975	3
							0.0963	1
							0.0825	1
							0.0813	1

Table 3. The typical designed frames for this study

Edition of ISC 2800			First	Second	Third
Column sections	3rdFloor	C3A	HE140B	HE220B	HE220B
		C3B	HE120B	HE280B	HE280B
		C3C	HE160B	HE300B	HE300B
		C3D	HE180B	HE300B	HE300B
	2nd Floor	C2A	HE160B	HE220B	HE220B
		C2B	HE180B	HE280B	HE280B
		C2C	HE180B	HE300B	HE300B
		C2D	HE160B	HE300B	HE300B
	1st Floor	C1A	HE160B	HE220B	HE220B
		C1B	HE200B	HE280B	HE280B
		C1C	HE200B	HE300B	HE300B
		C1D	HE180B	HE300B	HE300B

Edition of ISC 2800			First	Second	Third
Beam sections	3rdFloor	B3A	IPE270	IPE270	IPE270
		B3B	IPE220	IPE200	IPE200
		B3C	IPE330	IPE330	IPE330
	2nd Floor	B2A	IPE270	IPE270	IPE270
		B2B	IPE240	IPE200	IPE200
		B2C	IPE330	IPE330	IPE330
	1st Floor	B1A	IPE270	IPE270	IPE270
		B1B	IPE270	IPE200	IPE200
		B1C	IPE330	IPE330	IPE330

FRAGILITY FUNCTION DEVELOPMENT

In this study, the probability of two different damage state of structures, the disruption of functionality (or slight damage state) and collapse (or complete damage state), are evaluated by developing the fragility function of structure by the stochastic approach (see Nasseraadi et.al.(2009) for full description of methodology). To achieve this goal, the response distributions of frame were evaluated through multi-stripe analysis (MSA) presented by Jalayer (2003), in which ground motions in different soil classification have been selected.. In this study,the fragility functions is estimated as a function of peak ground acceleration (PGA) as intensity measure and inter story drift (ISD) is used as damage measure. The threshold of two damage states (slight and completer) was chosen from HAZUS's methodology (HAZUS-MH MR3, 2003). Hazus has been categorized damage thresholds based on structural seismic resisting system, designed codes and the limit state of predefined damage which are presented in
Table 4.

Table 4. Typical inter story drift ratio threshold represent in Hazus-MH MR3 (2003)

ISC No.2800	Disruption of functionality (slight damage)	Collapse (complete damage)
First edition	0.005	0.080
Second edition	0.005	0.060
Third edition	0.005	0.040

EVALUATION OF DISTRIBUTION OF ISD AND RECORDS SELECTION

The distribution of ISDs of designed frames in each IM were estimated through MSA analysis by finite element software OpenSEES(OpenSEES; McKenna, F.; Fenves, G.L., 2001). To evalusate the response distribution in each four soil classification, numorus ground motions in different soil classification have been selected from PEER strong ground motions(1) shown in Table 5 by their record sequence number (RSN) and their associates soil type. The records consistant of 37 in soil I, 44 in soil II, 45 in soil III and 37 in Soil IV.

Medians of ISD distribution of frames in all version of ISCs and different soil types have been plotted as a function of PGA in Figure 3. Median of response distribution (with 50% probability of occurrence) have been shown by bold line, median minus a deviation (16%) and median plus a deviation (84%) are shown by narrow line.It can be observed from the figure that the response distribution of second and thirdeditions are very close in all soil classification whileresponse distribution of first edition have higher value in the all IM. In addition, soil types have significant effect on distributions of response. The median of response in softer

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1. http://peer.berkeley.edu/products/strong_ground_motion_db.html

soil are higher. In general, the higher displacement can be interpreted as higher vulnerability that will be projected in the fragility functions.

The fragility of frames are estimated and shown by Eq. 1.

$$P(D > d_i \mid pga) = \Phi\left(\frac{\ln(pga / pga_{mi})}{_i}\right) \tag{1}$$

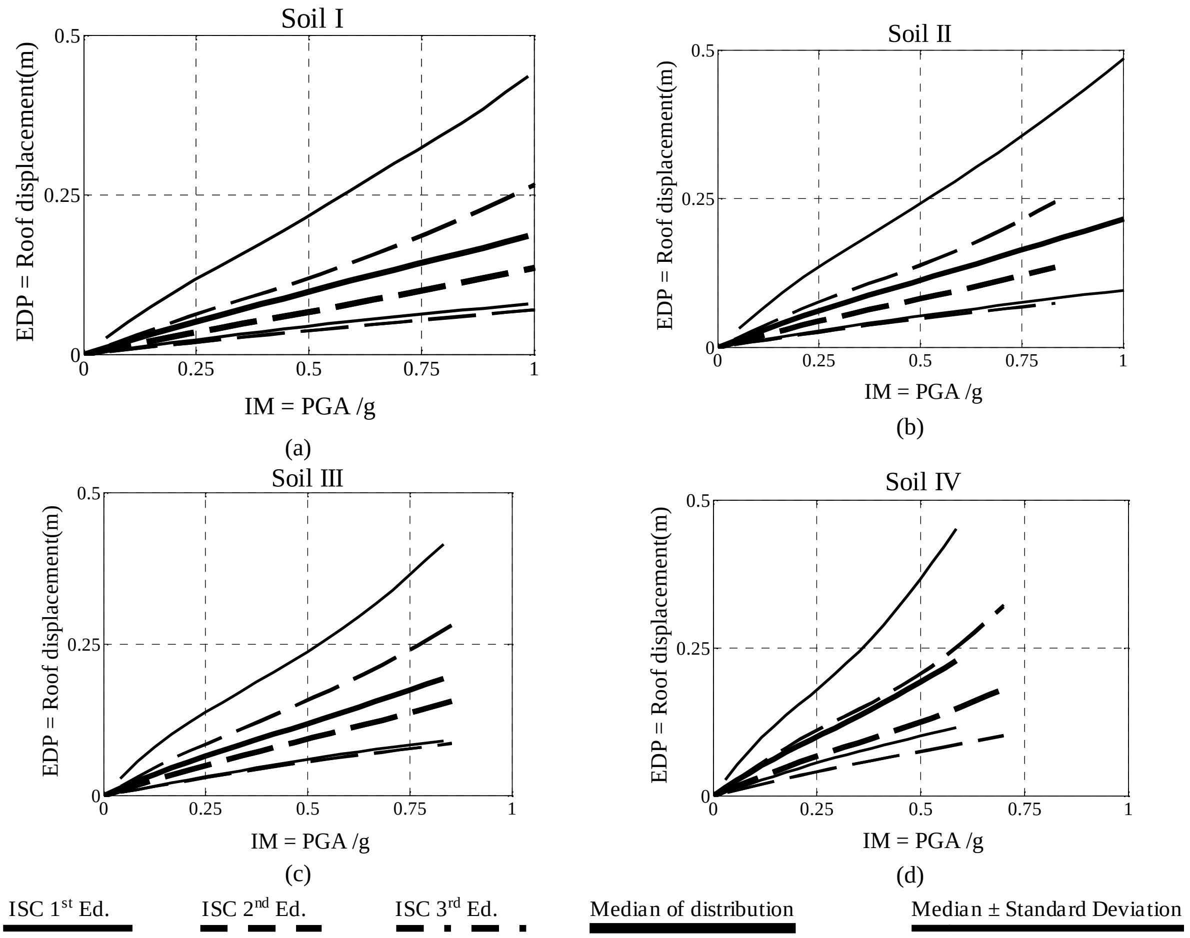
In which, $P(D > d_i \mid pga)$ is fragility function or exceeding probability of damage (D) in structure from any damage state d_i (i.e. loss of functionality or collapse) in any given pga , pga_{mi} and $_i$ are the fragility parameters called median and lognormal deviation of ith damage state respectivley. These parameters are estimated by Nasserasadi et.al. (2009) methodology for studied frames and are given in Table 6.

Table 5. Selected ground motion shown by their RSN from PEER database and associated sol type.

RSN#	**Soil type in ISC**	**RSN#**	**Soil type in ISC**	**RSN#**	**Soil type in ISC**	**RSN#**	**Soil type in ISC**	**RSN#**	**Soil type in ISC**	**RSN#**	**Soil type in ISC**
23	I	201	IV	352	II	731	II	1170	II	1707	III
41	II	246	III	424	II	732	IV	1172	II	1708	III
43	I	247	III	439	II	733	III	1175	III	1709	I
44	III	283	I	452	IV	740	II	1177	III	1710	III
45	II	284	I	455	I	743	III	1183	III	1843	IV
46	III	285	I	468	III	745	II	1184	II	1846	IV
47	II	286	I	469	III	750	II	1185	III	1852	IV
51	III	287	III	472	II	758	III	1209	III	1861	IV
55	II	288	II	476	II	759	IV	1211	II	1866	IV
58	II	290	III	511	II	760	IV	1214	II	2178	IV
59	I	291	II	512	II	765	I	1228	IV	2192	IV
72	I	292	I	513	III	780	IV	1229	IV	2193	IV
77	I	293	II	515	III	785	III	1310	IV	2266	IV
88	II	294	II	543	III	786	III	1334	IV	2284	IV
89	II	295	I	546	III	788	I	1357	IV	2718	IV
93	III	296	I	562	III	789	I	1599	III	2736	IV
124	II	297	I	586	II	790	III	1600	II	2737	IV
131	III	298	III	587	II	808	IV	1601	III	2818	IV
135	II	299	II	596	II	962	IV	1613	I	2958	IV
143	I	301	III	604	III	1159	II	1619	II	3091	IV
155	I	302	II	608	IV	1160	III	1620	II	3285	IV
169	III	303	I	715	I	1162	II	1691	I	3302	IV
178	IV	304	II	717	III	1165	I	1695	II	3303	IV
194	III	322	III	724	III	1168	II	1696	I	3403	IV
200	III	323	II	730	III	1169	II	1705	III		

Table 6. Parameters of developed fragility functions in three code editions and various soil types for two damage states: loss of functionality and collapse.

Editions of ISC	**Soil Classification**	**Damage state**			
		Loss of functionality (slight)		**Collapse**	
		PGA$_{m1}$	$_1$	**PGA$_{m2}$**	$_2$
First edition	**I**	0.1812	1.0647	1.4296	1.0108
	II	0.1462	0.9864	1.4308	1.0017
	III	0.1353	0.9411	1.2384	0.8633
	IV	0.0820	0.8144	0.7266	0.8310
Second edition	**I**	0.2727	0.8037	2.3189	0.6907
	II	0.2077	0.7946	2.2428	0.7147
	III	0.1762	0.7724	2.2131	0.7178
	IV	0.1331	0.6809	1.2956	0.6183
Third edition	**I**	0.2727	0.8037	2.7509	0.6732
	II	0.2077	0.7946	2.7450	0.6967
	III	0.1762	0.7724	2.6395	0.6824
	IV	0.1331	0.6809	1.5442	0.6036



(a) (b) (c) (d)

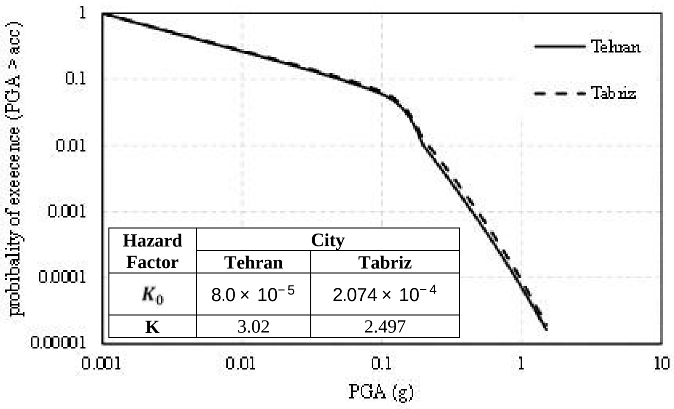
Figure 3. Median of ISD distribution for different editions of ISC. (a) Soil I,(b) Soil II, (c) Soil III, (d) Soil IV.

In order to evaluate the seismic risk of different frames, the probability of exceeding of damage from two mentioned damge states are evaluaed. The exceeding probability is estimated by multiplying the seismic hazard by the fragility function in probabilistic manner. A simplified formulation can be used for estimation of this probability given in Eq. (2) see Nasserasadi (2006).

$$P(D>d_i) = K_0 PGA_{mi}^{-K}\, e^{\frac{{}_i^{2} K^{2}}{2}} \qquad (2)$$

In which, $P(D>d_i)$ is the exceeding probability from any damage state, K_0 and K are the parameters of hazard curve, pga_{mi} and $_i$ are the parameter of fragility function for given damage state ith.

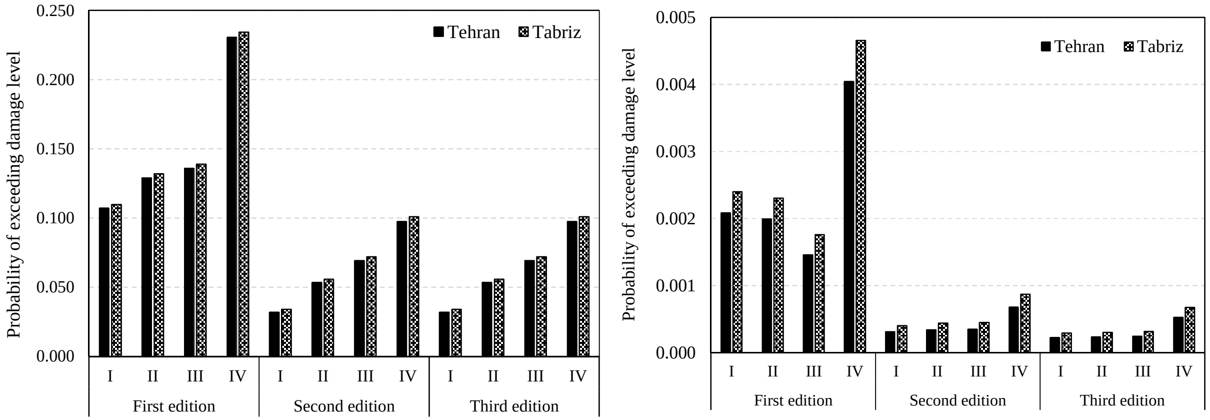
In this study, the exceeding probability of damage are estimated for Tehran and Tabriz that are located in high seismic zones. Seismic hazard curve of Tehran and Tabriz are shown in Figure 4. The parameter of fitted function to hazard curve (K and K_0) are illustrated, too (Ghafory-ashtiany and Nasserasadi, (2010)).



Hazard Factor	City	
	Tehran	Tabriz
K_0	8.0×10^{-5}	2.074×10^{-4}
K	3.02	2.497

Figure 4. Hazard Curves for Tehran and Tabriz (Ghafory-ashtiany and Nasserasadi, (2010)).

The seismic risk of studied frames have been calculated using Eq. 2 and shown in Figure 5. As illustrate in the figure a suitable improvement on reduction of seismic risk is obvious in newer editions of ISC. A significant improvement from first to second editions of code are observed but the improvement of second and third edition is not much significant. Soil type has effect of seismic safety of buildings. The building located in softer soil have higher seismic risk which means more vulnerability. In general the probability of loss of function in important buildings is in order to 10^{-2} and 10^{-1} which is not suitable. This fact also demonstrated in the literatures (such as Mahmoudi and Ghobadi (2011) and Shakib (2000)) in which, indicated that the performance of very important buildings are not satisfied ISC's criteria.



a) Loss of functionality

b) Collapse

Figure 5. Comparison of exceeding probability of damage from loss of functionality and collapse in important buildings located in Tehran and Tabriz designed based on different editions of ISC in all soil classification (I, II, III and IV).

CONCLUSIONS

In this paper the seismic risk of low raised important buildings designed based on different editions of ISC are compared. A steel resisting moment frame is selected and design according to different editions of ISCs. The probability of exceeding of damage from two damage stages of slight (loss of functionality) and collapse are estimated in Tehran and Tabriz. Fragility functions of studied frames are developed by analytical procedure through nonlinear dynamic analysis subjected to numerous ground motions in all soil types. Results have shown that seismic safety of important buildings in the second and third editions of ISC have been improved significantly but still the probability of loss of functionality and collapses are significantly higher than expected for these buildings. Within any code edition, a constant limit of safety was not provided for different soil types and structures designed for softer soil types, experiences more risk. More study in this filed for different building types with different heights needed to be conducted.

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