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A Comparison of Seismic Safety of Steel MRF Designed According to Different Editions of Iranian Seismic Code

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Abstract

In this paper, efforts are made to compare the safety of steel moment resistant frames designed according to different editions of the Iranian code of Practice for seismic resistant design of buildings. Also, failure risk of a low and medium height frame which designed for high and low seismicity regions according to three editions of the code are evaluated. First, the testing cases were designed and based on a simplified method the fragility functions of frames were evaluated. The probability of failure of frames was calculated by multiplying the fragility function and hazard curves in probabilistic manner. The results indicate that, apart from some exceptions, every edition of new code provides better safety for structures. However, within a single version of the code, the consistency of safety has not been maintained. The structures designed for low seismicity regions are more reliable than those which designed for high seismicity regions. Further research should address this issue and fix the possible.

Keywords: Seismic safety; Code safety; Seismic code Edition; 2800 Standard

1. Introduction

Iran has experienced several devastating earthquakes including the most iconic ones; Manjil 1990 and the Bam 2003 earthquakes which claimed hundreds of thousands of lives and cost billions of dollars direct and indirect losses. Since the Manjil earthquake, significant efforts have been made to reduce the seismic risk in Iran. In the modern days, the first edition of Iranian Code of practice For Seismic Resistant Design of Buildings (ICSDB-88) [1] was introduced right after the Manjil earthquake and became mandatory for construction of new buildings after the earthquake. So far, three editions of the code based on the recent developments in earthquake engineering science have been issued. Although the performance of the buildings which were designed according to the code was relatively acceptable in the past earthquakes including the Bam 2003, the reliability of the buildings designed according to this code has not been studied.

It is believed that each edition of the code makes a positive progress toward building safer structures and the latest version of ICSDB [2] provides the safest structures compared to the two previous ones. This hypothesis is tested in this research by comparing the probability of failure of two low and medium height frames located in high and low seismicity regions designed according to the three editions of the code. The results show the trend of improving safety in different editions of the code.

2. Evolution of the ICSDB

The first regulation of seismic design in the buildings is introduced in Minimum design loads in buildings and other structures [3] in which the minimum design load of 0.1 of total weight of the building was considered for the seismic design of buildings without any consideration of site, seismic region and structural type. The first edition of the ICSDB was introduced in 1988in which most of the modern elements of seismic design codes such as usage of the local seismicity, response spectrum and structural modification factors were utilized. The main components of the code were taken from the 1985 edition of the Uniform Building Code UBC code (UBC85)[4]. The second

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edition of the (ICSDB-97)[5] code was introduced in 1997 based on the main changes of the 1994 edition of the UBC (UBC-1994)[6]. In this edition, some modifications were made to update the amount of seismic force in the structure including some changes in the response spectrum and structural modification factors. It also introduced some measures to preserve the local and global ductility of some types of structures including high rise buildings and important buildings such as hospitals and schools. The third edition of the ICSDB code was introduced in 2005 [2]. The code includes some features of the 1997 edition of the UBC code and 2000 edition of the International building code (IBC-2000)[7]. In the third edition, the level of the seismic force has been increased and some modifications were made to the maintaining of minimum ductility in the structures.

In the code, the seismic force is estimated from Eq.(1):

$$V = C.W = \frac{ABI}{R}W \quad (1)$$

In this equation, "**V**" is the base shear use for design of structures, "**C**" is the seismic base shear coefficient, "***W***" is the effective weight of structure. The "***C***" factor consists of several factors:"**A**" is design acceleration which is estimated for each site and demonstrates the seismicity level of the site and calculated for a certain level of seismic hazard (i.e. 10% probability of earthquake in 50 years which is equal to 475 year return period), "***B***" is the response spectrum of earthquake and is a function of local site, "***I***" is the importance factor of building which is function of building usage and importunacy and "***R***" is the response modification factor which is a function of structural type and represent the reduction of elastic forces as a result of ductility and over strength of structures.

The main changes of seismic force in different editions of the code stem from the changes in the response spectrum "***B***" and structural modification factor "***R***". The comparison of seismic response spectrum of three editions of the code for soil type III (medium soil equal to soil type C in UBC) is shown in Figure 1. As Figure 1 illustrates, the earthquake spectrum which represents the force levels almost increased in every edition of the code. But due to changes in the response modification factures in different edition of the code, the level of design force for different structural types are not necessary increased in every edition. For instance, the B/R ratio for moment resistant frames is shown in Figure.2. As it can be seen, the seismic design force in the third edition of the code dropped relatively compared to the second edition of the code due to an increase of minimum level of ductility in this type of structure.

The enforcement of minimum ductility in structures in the form of design considerations was made in the three editions of the code. The summary of these changes are shown in Table 1.

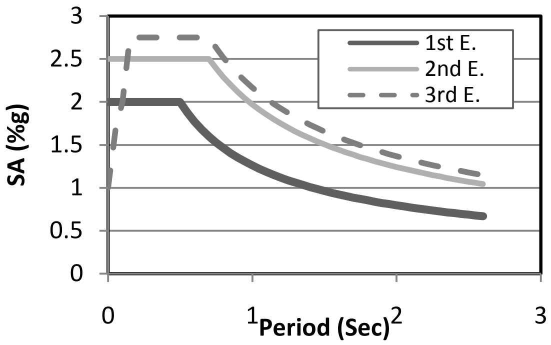

Fig. 1.Comparison of soil type III response spectrum for three editions of the code.

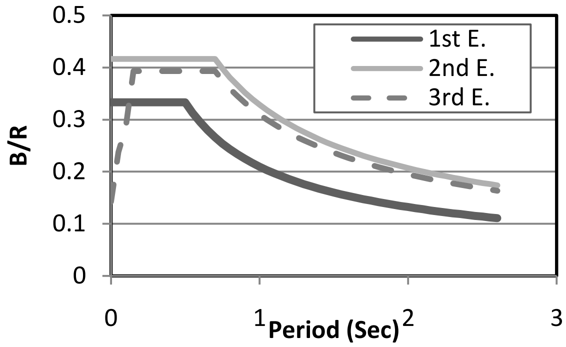

Fig. 2. Comparison of B/R ratio of steel frame buildings for three editions of the code.

Table1. Ductility measures in three editions of the code for studied steel moment resistant frames.

Types of measures	First edition	Second edition	Third edition
Strong column weak beam consideration	N/A	N/M	N/M
Ductility of panel zone and usage of continuity plate	N/A	N/M	M
Prevention of column failure during earthquake	N/A	M	M
Usage of compact sections	N/A	N/M	M
Minimum strength of moment resisting connections	N/A	N/M	M

N/A: not available

N/M: not mandatory for studied frames.

M: mandatory for studied frames.

It is believed that each edition of the code make a positive progress towards safer structures and the latest version of ICSDB [2] provides safer design compared to the two previous versions. This hypothesis is being tested in this research by comparing the probability of failure of two low and medium structures located in the high seismicity and low seismicity regions designed according to the three editions of the code.

3. Methodology

Providing a minimum level of safety for any structure is the main goal of applying code provisions. The level of acceptable risk varies from country to country and is considered based on the economic and social conditions of each country or community. In the seismic design of residential buildings, the concept of life saving is the minimum consideration. Since the earthquake is a random phenomenon, it is difficult to translate this concept into quantitative terms. Two general approaches for dealing with this problem are used. In the first approach, which is being followed in the contemporary design practice, structures are designed to withstand a certain level of earthquake forces which correspond to a level of earthquake occurrence probability. It means that the intensity of a defined level of earthquake (e.g. an earthquake with 10% probability of occurrence in the 50 years which is the lifetime of structures) are estimated and associated as a design level of earthquake and structures are designed to satisfy the forces created by this intensity. In this approach, the probability of structural failure and the total risk will not calculate and it is assumed that the level of earthquake probability will implicitly maintain the reliability of structures.

On the contrary, the second approach which is less popular in engineering practices, evaluates the probability of failure in the structure by considering the uncertainty of loads and structural behaviors. The results could be used to calculate the reliability of structures or the associated failure risk. Although this procedure provides tangible results for evaluation of human risk, the analysis method is complex and cannot provide the force for design of structures. So, this method, in the present form, cannot be used in the design of structures.

In this study, the second method is used to evaluate the failure risk of two moment resistant frames designed according to the three editions of the code.

3.1 *Risk Assessment Method*

The probability of certain structural response is estimated from total probability theorem. For continuous hazard parameter, it can be written as follows [8]:

$$P[R < r] = F_R(r) = \int F_{R|S}(r;s)\, f_s(s) ds \qquad (2)$$

In which, $f_s(s)$ is Probability Density Function (PDF) of seismic hazard, R denotes structural response and $F_{R|S}(r;s)$ is conditional Cumulative Distribution Function (CDF) of response in given ground motion , "s". The probability of exceeding damage from a damage state (d_i) is derived by replacing damage state in structures instead of structural responses:

$$P[D > d_i] = \int F(D > d_i \mid im).\left|d\left[P(IM \geq im)\right]\right|.d(im) \qquad (3)$$

Where $F(IM \geq im)$ is hazard curve which estimates the exceeding probability of ground motion Intensity Measure, *IM*, from certain level, "*im*" and $F(D > d_i \mid im)$ is fragility function which estimates the conditional exceeding probability of damage, *D*, from a damage level , d_i, in given "*im*". Since the failure probability is being studied in this paper, the fragility curve of total damage is considered from now on.

The hazard curves are estimated from seismic hazard analysis from the current well known method which can be found in [9]. The results of seismic hazard of studied sites in the low and high seismic region of Iran are shown in Figure 3.

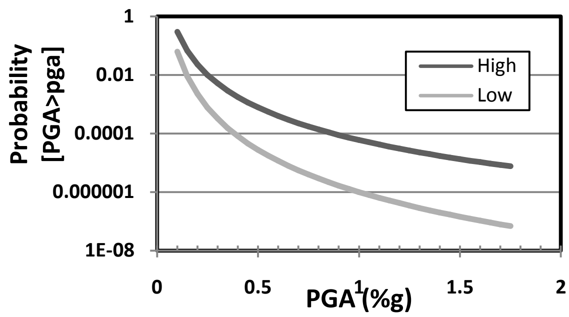

Fig. 3. The hazard curves for two selected study region.

3.2 *Fragility Function Estimation Method*

Fragility function estimates the conditional exceeding probability of damage from a damage state at given ground motion intensity: $F(D > d_i \mid im)$. In a stochastic methodology described by Nasserasadi et.al., the fragility curves of a selected structure are estimated [10]. By evaluating the distribution of damage index in the structures at every ground motion intensity and calculation of the exceeding probability of damage index from every damage index thresholds at every ground motion intensity, the fragility value are estimated.

The distribution of damage index can be evaluated by a massive set of non-linear analyses of structures which consume significant amounts of analysis and processing time. To reduce the analysis time, a simplified and fast method is introduced by Nasserasadi et.al. 2008 [10]. In this method, the distribution of the damage index are evaluated through the pushover curve of structure which is evaluated by a simple non-linear static analysis. In this paper, the simplified method is used for evaluating the fragility function of the structures under study.

4. Studied Cases

In order to study the performance of different buildings designed based on the different editions of the ICSDB, two moment resistant frames are selected: a three story three bay frame and a seven story three bay frame. The frames are designed for the high and low seismicity regions for the minimum requirement of three editions of code. The seismic base shear coefficient are estimated for these frames and shown in Table 2.

Table2. the seismic base shear coefficient for studied cases.

Frame type	Seismicity level of region	ICSDB Edition 1	ICSDB Edition 2	ICSDB Edition 3
3 Story	High	0.116 L	0.145 L	0.192 L
	Low	0.066 L	0.083L	0.11 L
7 Story	High	0.087L	0.134 L	0.13 M
	Low	0.05 L	0.076 L	0.104 L

L: represent the frame with low level of ductility

M: represent the frame with medium level of ductility

Based on each edition of code, a minimal level ductility stage should be considered for the design shown by "***L***" and "***M***" in the table representing low and medium level of ductility respectively. The comparison of the base shear coefficient is shown in Figure 4.

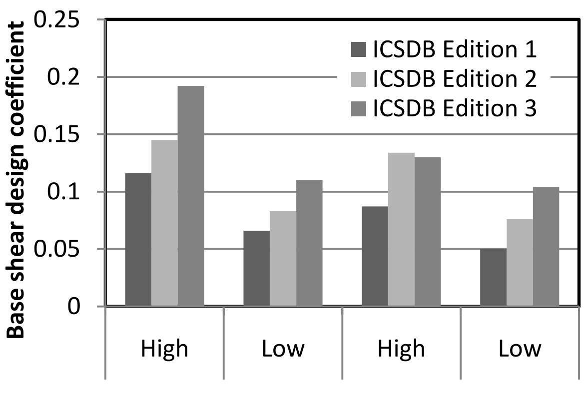

Fig. 4. The base shear coefficient comparison

As Figure 4 depicts, the base shear level has increased in different editions of the code except for the seven story frame in the high seismicity region. The elevations view of seven story structure designed for high seismicity regions is shown in Figure 5.

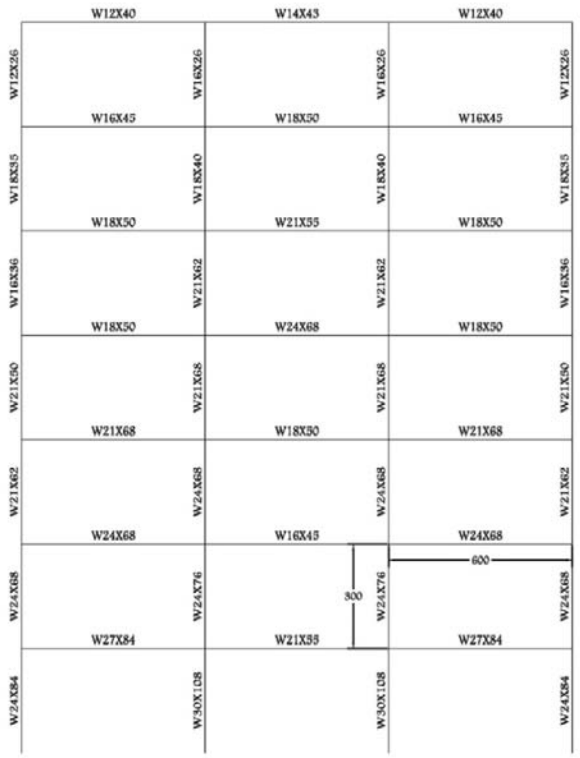

Fig. 5. Elevation view of 7 story building designed for high seismic region.

For the development of the seismic fragility function of the designed frames, based on the simplified method, the pushover curve of frames should be derived from a static nonlinear analysis. To perform the analysis, the nonlinear behavior of elements should be defined based on their expected behavior. These behavior sand other required information of analysis are defined based on the recommendation of the instruction for seismic rehabilitation of existing buildings, MPO 360-2007 [11], which are adopted from the FEMA 356-2000 [12]. The results which are the pushover curves of structures are calculated and shown in Figure 6and 7.

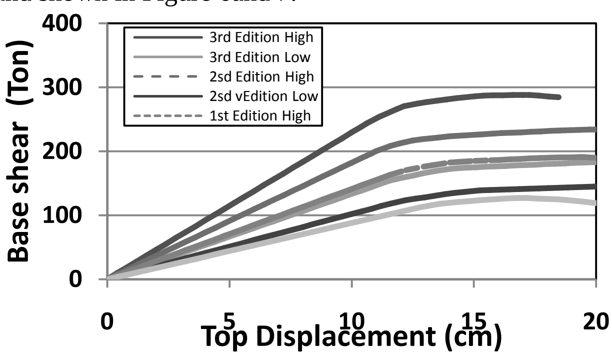

Fig. 6. The pushover curve of three story structures design according to the differnet edition of code.

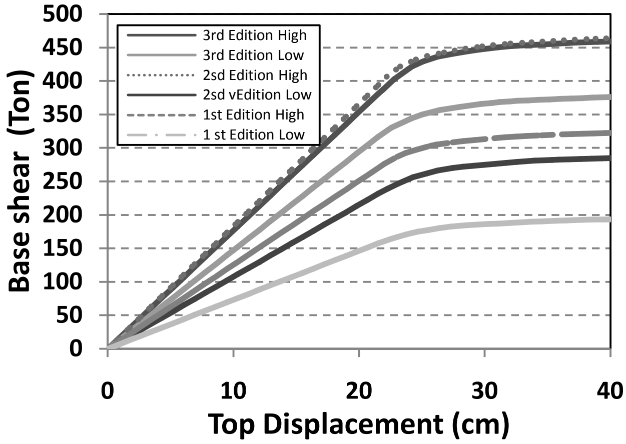

Fig. 7. The pushover curve of seven story structures design according to the differnet edition of code.

Based on the simplified method, the fragility curve of frames are developed by considering Inter-Story Drift (ISD) of structures as damage index and PGA as damage measure parameters. According to the available references, including HAZUS 1997 [13], the ISD of total damage of structures are taken as 0.05 and based on that the fragility functions are developed. An example of fragility development data and fitting function are shown in Figure 8. The fragility results of designed structures are shown in Figure 9 and 10

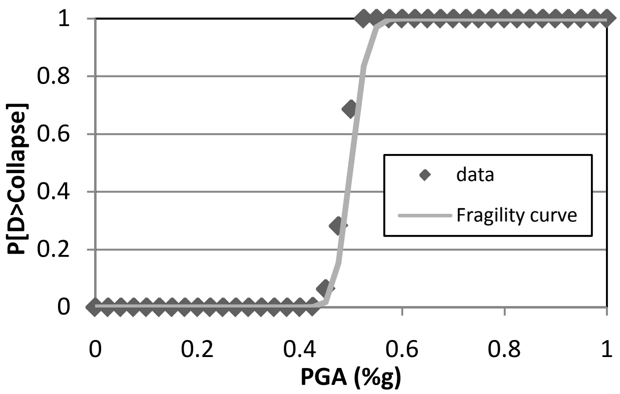

Fig. 8.An example of derived fragility data and fragility function**.**

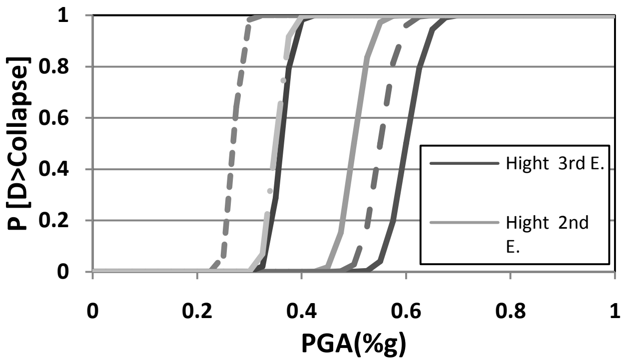

Fig. 9. Fragility functions of three story frames.

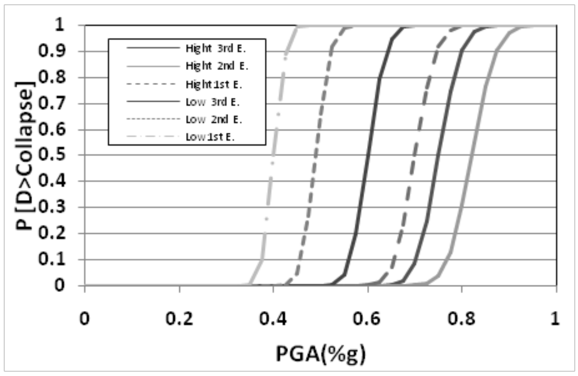

Fig. 10. Fragility functions of seven story frames.

The probability of structural failure is estimated from Eq. (3) by numerical method from the hazard curves and fragility functions for high and low seismicity regions and three editions of the code. The results are shown in. Figure 11

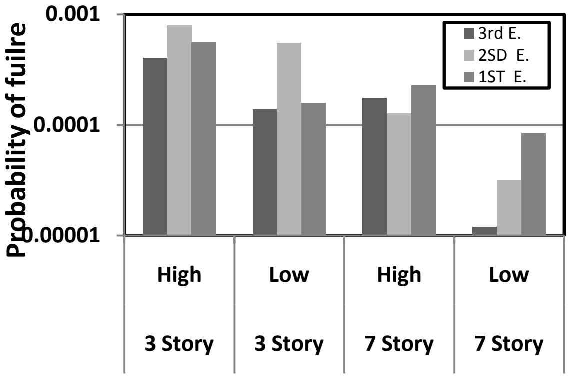

Fig. 11. Comparison of probability of failure of three and seven story frames designed for three editions of the code.

As it can be seen from the results, except for one case, the probability frames which designed for the third edition of the code are lower than the frames designed for previous edition of the code. The probability of seven story frame designed for the second edition of the code in the high seismicity region is lower than the other editions. This result was expecting, because the base shear design coefficient was higher than others, as shown in Figure 4. The unexpected result was the higher probability of failure for second edition of the three story frame which obtained despite the fact the base shear of frame in the second edition was higher than the first edition of the code, see Figure 4.

To compare probability of failure in the third and current editions of the code in high and low seismicity regions and in three and seven story buildings, it can been seen that first; the probability of failure of frames designed for lower seismicity region is generally lower than the high seismicity region. Second; the probability of failure of the seven-story buildings is lower than three-story buildings in every seismicity region.

Generally speaking, the annual probability of failure of structures is lower than one failure per thousand cases which might be acceptable for most of the structures including the residential buildings where life saving is the main priority.

5. Conclusions

In this paper, the failure risk of two types of moment resistant frames designed according to three editions of the ICSDB are studied to identify the relative safety of different editions of the code. The results showed that every edition of the code provides different safety levels for structures. In most cases, the newer editions of the code provided higher safety levels and from the relative safety of structures, the third edition (i.e. the current edition) of the code is safer than the previous editions.

Also, the results revealed some weakness in the safety of the codes. It is observed that every code will not provide the same level of safety for every structure and different structures with different geometrical and design bases may have different levels of safety. Based on the results of this study, it can be observed that structures designed for lower seismicity regions are safer than structures designed for high seismicity regions. By the same token higher structures are safer then shorter ones. Although these results are obtained based on some limited examples and simplified methods, it is shown that the code should be modified to fulfill the shortages observed in this study. Since the Iranian code has been adopted form the previous and existing UBC and IBC codes, it might be concluded that this inconsistency in the safety of the code might exist in these codes as well.

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