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Study of the Seismic Vulnerability of Steel Moment-Resisting Frames Designed Based on the Tenth Code of the Iranian National Building Regulations Using Fragility Curves

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1-Introduction

Severe earthquakes occurred in recent years have caused intensive financial loss for government and people. Therefore, lots of researches are needed in the field of earthquake engineering to reduce the risk of seismic hazards. So far, on the acceptable level of seismic risk, no comprehensive study has been done in Iran and this is a challenge and a prerequisite for the study of vulnerability.

Seismic fragility curves are the essential tools for vulnerability assessment of the structural damages and can correlate probability of damage with different intensity measures of probable earthquakes. These curves can be used as indices for comparison of different structural systems performance and also can show the increase or decrease of the probability of damage to structures excited by earthquakes. Also, priority of structures for retrofitting actions can be managed by these curves.

Until now, a comprehensive study on seismic risk assessment of steel frames designed based on Iranian codes has not been done. In this study, the seismic performance of steel moment-resisting frames designed based on the tenth code of the Iranian national building regulations is investigated.

2- Modeling of the structures

Design and modeling of the frames should cover all possible cases of the structures. Therefore, in this study frames with 3, 5, 8 and 12 stories are designed based on the third edition of 2800 standard, the sixth and the tenth code of the Iranian national building regulations. Story height is 3.2 meters and the number of spans are 3 for each frame.

In order to consider the different levels of seismicity in the design of frames, moderate seismicity (A=0.25) and high seismicity (A=0.35) are used. Also, in order to determine the effects of span dimension, frames are designed based on 4 and 6 meters spans. Gravity loads of the frames can also be different. Therefore, two cases for gravity loads are considered: moderate and severe. For moderate gravity load, dead load and live load are 500 and 200 kg per square meter, respectively and for severe gravity load, these two are respectively 700 and 500 kg per square meter. Therefore, 16 models are used for incremental dynamic analysis of the frames and generating fragility curves. In this study, the frame with 4 meters span which designed for moderate gravity and seismic loads is considered as the basis model.

Incremental dynamic analyses are done for each frame modeled nonlinearly by Perform 3D software. For nonlinear time history analyses, 14 accelerograms are used (Table 1).

Table 1. Ground motions used in this study

Date	Earthquake Name	Magnitude (Ms)	PGA (cm/s^2)
06/28/92	Landers	7.5	167.8
10/17/89	Loma Prieta	7.1	494.5
10/17/89	Loma Prieta	7.1	349.1
10/17/89	Loma Prieta	7.1	433.1
10/17/89	Loma Prieta	7.1	239.4
04/24/84	Morgan Hill	6.1	280.4
01/17/94	Northridge	6.8	504.2
10/15/79	Imperial Valley	6.8	200.2
02/09/71	San Fernando	6.5	107.9
10/17/89	Loma Prieta	7.1	153.0
10/17/89	Loma Prieta	7.1	166.9
04/24/84	Morgan Hill	6.1	95.0
07/08/86	Palmsprings	6	129.0
01/17/94	Northridge	6.8	84.9

3- Generating fragility curves

Fragility curves are generated based on damage probability of engineering demand parameters. Usually a proper probability distribution function such as normal distribution is used for this purpose. Equation 1 is used for generating fragility curves in this study.

$$\text{Fragility} = \text{P}\left[\text{EDP} > \text{AC}\middle|\text{IM}\right] \qquad (1)$$

In the above equation, EDP is engineering demand parameter which is interstory drift ratio in this study, IM is intensity measure which is peak ground acceleration (PGA) in this study and AC is the acceptable limit for EDP. ACs are considered to be 0.007, 0.025 and 0.05 for Immediate occupancy (IO), Life safety (LS) and Collapse Prevention (CP) performance levels, respectively.

Assuming a normal distribution for fragility curves, Equation 2 can be derived:

$$\begin{aligned}\text{Fragility} &= 1 - \text{P}\left[\text{EDP} < \text{AC}\middle|\text{IM}\right] \\ &= 1 - \phi\left(\frac{\text{AC} - \mu}{\sigma}\right)\end{aligned} \qquad (2)$$

In this equation, μ and σ are average and standard deviation of EDP and ϕ stands for normal distribution.

4- Comparison of fragility curves

Fig 1 shows fragility curves of the 3 - story frames.

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The possibility of exceeding CP level is almost zero for these frames. This is due to the low height and low story drifts of these frames. Also, by increasing span width and gravity loads of these frames, probability of damage increases. But the performance of these frames against increasing seismic design loads is vice versa.

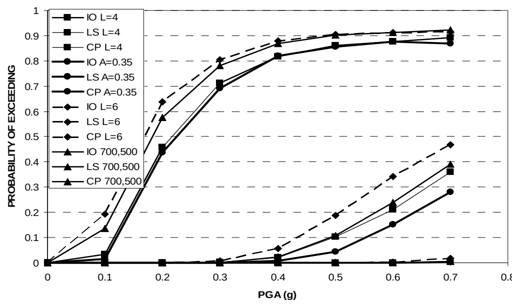

Fig 1. Fragility curves of 3 story frames

Fig 2 shows the effect of increasing the number of stories on the damage probability of the frames. It can be seen that the performance of taller frames are worse than shorter ones. It can be concluded that more attention should be paid to vulnerability of taller frames.

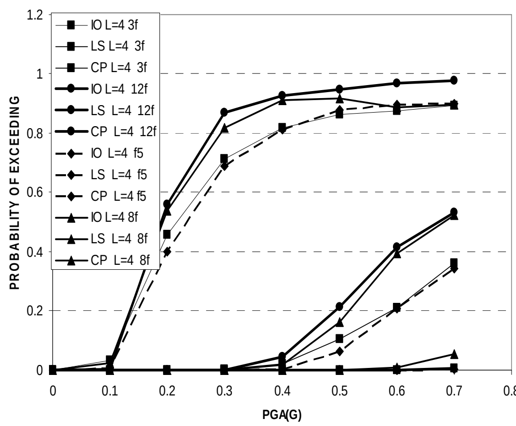

Fig 2. Fragility curves of frames with different stories

Fig 3 shows interstory drift ratios of 5 story frame at different IMs. In this frame, lateral displacements of the third and fourth floors at lower intensity are larger than other floors. By increasing the intensity of the earthquakes, interstory drift ratios of the mentioned floors increase, drastically.

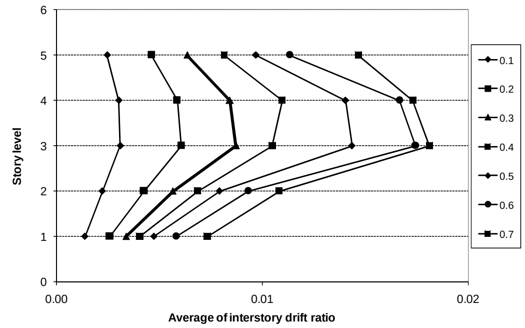

Fig 3. Interstory drift ratios of 5 story frame at different IMs

5- Conclusions

Based on the incremental dynamic analyses of the frames, the following conclusions are drawn:

1. By increasing the number of stories of the frames, probability of the frames damage increases. The worst case is for the 12 - story frame.
2. Moment resisting frames designed based on the tenth code of the Iranian national building regulations are more reliable for buildings having 8 stories and less.
3. Frame designed based on LS performance level advised for design base earthquake of 2800 standard would also be appropriate for other performance levels recommended by seismic codes.
4. PGA is not always a good IM because it is not related to the structural response.