Journal of Civil Engineering and Environmental Technology
Print ISSN : 2349-8404; Online ISSN : 2349-879X; Volume 2, Number 11; April – June, 2015 pp 72 – 76
Krishi Sanskriti Publications
http://www.krishisanskriti.org/jceet.html

Damage Assessment of Structural System Using Fragility Curves

Suraj V. Borele[1], Dr. Debarati Datta[2]

[1]*M. Tech (Structural Dynamics and Earthquake Engg.)*
Visvesvaraya National Institute of Technology
[1]*09860654111, surajborele@gmail.com*
[2]*Assistant Professor, Department of Applied Mechanics*
Visvesvaraya National Institute of Technology
[2]*07304912308, d_debarati@yahoo.co.in*

Abstract : *The damage to the buildings during recent earthquakes in India has demonstrated the need of seismic risk assessment of the building that is capable of predicting the probability of damage of the building. This paper focuses on the generation of fragility curve which is the graphical representation of the seismic risk of a structure. For the development of fragility curve guidelines given by HAZUS technical manual have been used. For the study, RC building models with bare frame and infilled frame are considered. The infill wall is modeled as an equivalent diagonal strut in which width of the struts for each infill panel is evaluated by using the guidelines given in FEMA 356.The RC buildings modeled in SAP-2000 considering IS 456:2000 and IS 1893(Part 1):2002 by using M 25 concrete and Fe 415 reinforcement steel. The structure was designed for only gravity load. Non-linear analysis of the building models have been done by using pushover analysis. The results of the capacity curve were used to plot the fragility curve. The fragility curves developed from this study were used to compare the seismic performance of the building models.*

1. INTRODUCTION

Earthquakes occur periodically in different parts of the country, which causes damages to the vulnerable structures and loss of the lives. Therefore, evaluation of seismic vulnerability of buildings before occurrence of an earthquake is essential step in preventing damages to the building and loss of lives. The seismic vulnerability of the building can be evaluated by using the fragility curve. Fragility curve is the graphical representation of the seismic risk of a structure. It describes the probability of reaching or exceeding structural damage states for the particular range of spectral displacements. This curve distributes damages in terms of slight, moderate, extensive and complete damage states. Fragility curve can be obtained from the empirical or analytical methods, based on the source of the data and the type of analysis. Empirical fragility curve is based on the interpretation of post-earthquake damage data and engineering judgment. Analytical fragility curve is based on the analysis of structural models under increasing lateral loads. In this paper analytical procedure as per the guidelines of HAZUS has been used.

2. MODELING

The plan considered in the present study is of residential building. The building plan is having approximately regular, identical plan geometry and is modeled in SAP 2000 as a two and four storey. The plan is symmetrical in longitudinal and transverse direction (Fig.1). The building models are considered with bare frame and infilled frame. The infill wall is modeled as an equivalent diagonal strut in which width of the struts for each infill panel is evaluated by using the guidelines given in FEMA 356.

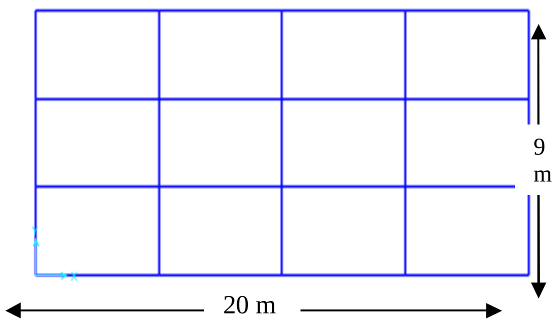

Figure 1. Plan of the building model

The following parameters are considered in the analysis and design of the building model:

Height of each storey	3.5 m
Grade of steel	Fe 415
Grade of concrete	M25
Thickness of outer wall	0.230 m
Thickness of inner wall	0.115 m

Density of Reinforced concrete members	25.0 kN/m^3
Density of Brick	20.0 kN/m^3
Live load for the floors	3.5 kN/m^2

Flexural hinges were assigned to all the beams and columns by using the auto hinge property of SAP 2000. SAP 2000 does not have auto hinge tool for modeling the infill. So manually hinge properties assigned to the infill. The slab thickness is assumed as 120mm.

3. DEVELOPMENT OF FRAGILITY CURVES

There has been numerous works in the literature for the evaluation of the fragility curves of the structures, however there is no unified approach available. For the development of fragility curves, guidelines given by HAZUS technical manual have been used. HAZUS methodology was developed for FEMA by National Institute of Building Science (NIBS) to reduce seismic hazard in United States. HAZUS technical manual provides the procedure for deriving the fragility curves for different types of structures.

Building fragility curves are lognormal functions that describe the probability of reaching, or exceeding, structural and non-structural damage states, given median estimates of spectral response, for example spectral displacement. These curves take into account the variability and uncertainty associated with capacity curve properties, damage states and ground shaking. (HAZUS, FEMA 2003)

The conditional probability of being in or exceeding a particular damage state, ds, given the Spectral displacement S_d and is defined by Eq. (1)

$$P[ds \mid S_d] = \Phi\left[\frac{1}{\beta ds}\ln\left(\frac{S_d}{S_{d,ds}}\right)\right] \quad (1)$$

Where,

S_d is the spectral displacement defining the threshold of a particular damage state,

$S_{d,ds}$ is median value of spectral displacement at which the building reaches the threshold of damage states, can be calculated by various damage state models,

βds is standard deviation of natural logarithm of spectral displacement for damage state, ds and

ϕ is standard normal cumulative distribution function.

3.1. Development of Damage state Variability (βds)

The lognormal beta or standard deviation describes the total variability of the damage states. The variability associated with the capacity curve, β_C, demand spectrum, β_D, and the variability associated with the discrete threshold of each damage state, β_{Tds} are to be accounted while calculating the total variability. The demand spectrum and capacity curves are inter dependent, the variability accounted by both are combined by convolution process. The third component β_{Tds} is mutually independent from the first two variability components and its effect is considered by combining it with the results of CONV process using SRSS method.

$$\beta ds = \sqrt{\left(CONV[\beta_C, \beta_D]\right)^2 + \left(\beta_{Tds}\right)^2} \quad (2)$$

Where,

β_{Tds} is the lognormal standard deviation parameter that describes the total variability of damage state, ds,

β_C is the lognormal standard deviation parameter that describes the variability of the capacity curve,

β_D is the lognormal standard deviation parameter that describes the variability of the demand spectrum (values of β_D = 0.45 at short periods and β_D = 0.50 at long periods)

The βds values can also be taken directly from the tables given in HAZUS technical manual by choosing appropriate values of degradation or Kappa factors and β_C and β_D values for different types of buildings. The variability values shown in table 1 and table 2 are used for the two storey and four storey respectively considering the moderate cases of degradation.

Table 1. Variability Values used for two storey model

Damage State	Kappa Factor (κ)	Degradation values for		
		Damage (β_{Tds})	Capacity Curve (β_C)	Total (βds)
Slight	Minor Degradation (0.9)	Moderate (0.4)	Moderate (0.3)	0.80
Moderate	Major Degradation (0.5)	Moderate (0.4)	Moderate (0.3)	0.95
Extensive	Extreme Degradation (0.1)	Moderate (0.4)	Moderate (0.3)	1.05
Complete	Extreme Degradation (0.1)	Moderate (0.4)	Moderate (0.3)	1.05

Table 2. Variability Values used for four storey model

Damage State	Kappa Factor (κ)	Degradation values for		
		Damage (β_{Tds})	Capacity Curve (β_C)	Total (βds)
Slight	Minor Degradation (0.9)	Moderate (0.4)	Moderate (0.3)	0.7
Moderate	Major Degradation (0.5)	Moderate (0.4)	Moderate (0.3)	0.8
Extensive	Extreme Degradation (0.1)	Moderate (0.4)	Moderate (0.3)	1
Complete	Extreme Degradation (0.1)	Moderate (0.4)	Moderate (0.3)	1

3.2. Building Capacity Spectrum:

In the present study, fragility curves have been obtained on the basis of capacity spectra which are obtained from pushover analysis. These capacity spectra are used to obtain the yield spectral displacement (S_{dy}) and ultimate spectral displacement (S_{du}). The values of the yield spectral displacement and ultimate spectral displacement are used to obtain the values of medians at different damage states.

3.3. Damage state model for median value of spectral displacement ($S_{d,ds}$)

Many researchers have proposed damage state models, out of which a model proposed by Giovinazzi and Lagomarsino has been used in the current study. The values of median at damage states as per given model are shown in the Table 2.

Table 3. Proposed Damage state model

Damage States	Spectral Displacement (m) ($S_{d,ds}$)
Slight	0.7 S_{dy}
Moderate	1.5 S_{dy}
Extensive	0.5 (S_{dy}+S_{du})
Complete	S_{du}

3.4. Generation of fragility curves

The fragility curves are plotted by using the HAZUS method for different damage states such as slight, moderate, extensive and complete or collapse for the two and four storey building models are as follows:

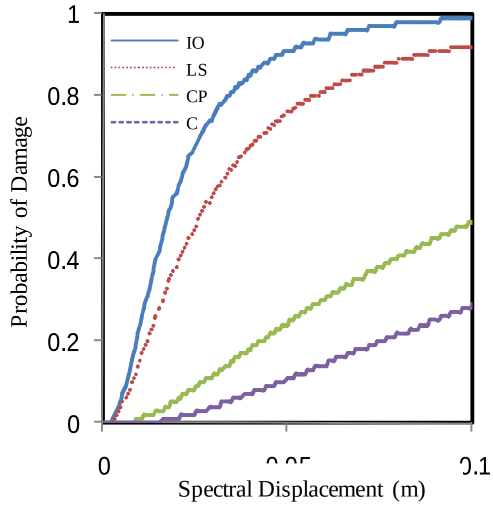

Figure 2. Fragility curves for two storey without infill

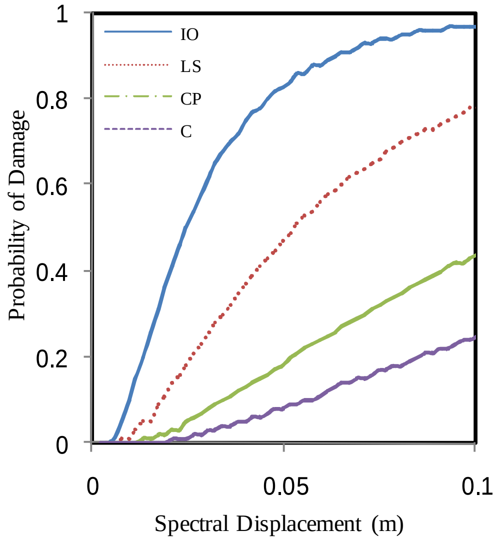

Figure 3. Fragility curves for two storey with infill

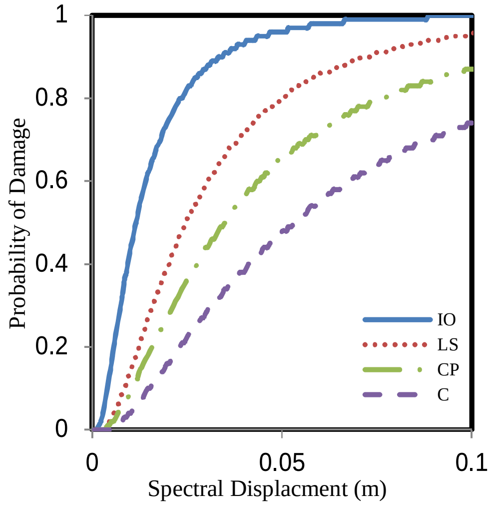

Figure 4. Fragility curves for four storey without infill

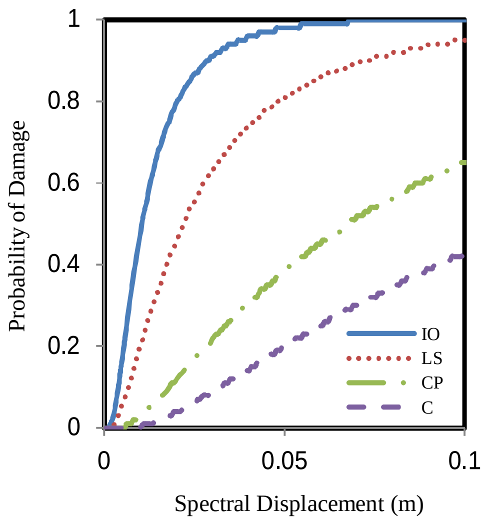

Figure 5. Fragility curves for four storey with infill

The probability of damage or the probability of exceedance for the four limit states i.e. immediate occupancy (IO), life safety (LS), collapse prevention (CP) and Collapse (C) can be read from the fragility curves. Table 4 shows the probability of exceedance of limit states for the spectral displacement value equal to 0.05m.

Table 4. Probability of Exceedance Damage Limit States

Storey		IO	LS	CP	C
Two	Without infill	0.9	0.78	0.3	0.12
	With infill	0.84	0.5	0.21	0.1
Four	Without infill	0.98	0.82	0.65	0.48
	With infill	0.97	0.81	0.39	0.2

4. SUMMARY AND CONCLUSIONS

In this study, HAZUS methodology for the generation of the fragility curves is discussed and the fragility curves are generated for low-rise and mid-rise reinforced concrete structures considering with infill and without infill. Results meet the expectations in the sense that it is only possible to obtain a rough estimate of the actual damage distribution due to the employment of such simplified fragility analysis.

Considering the fact that the results are based on the analytical data and guidelines given in the HAZUS technical manual, the following conclusions can be stated:

i) The increase in stiffness and strength is significant in both two and four storey buildings due to the addition of the infill walls when compared with the corresponding values of the bare frame building.

ii) For a specified level of spectral displacement, bare frame (compared to infilled frame) and four storey building (compared to two storey) has more probability of damage.

5. REFERENCES

[1] Altug Erberik, M., "Fragility-based assessment of typical mid-rise and low-rise RC buildings in Turkey" *Eng. Structures*, 30, 12, July 2007, pp. 1360–1374.

[2] Chande, S., Seismic vulnerability assessment of RC frame buildings, Visvesvaraya National Institute of Technology, Nagpur, M. Tech thesis, 2014.

[3] FEMA-356, Pre-standard and Commentary for Seismic Rehabilitation of Buildings, Federal Emergency Management Council, Washington DC, USA, 2000.

[4] FEMA, HAZUS-MH-MR 1 Technical Manual, Federal Emergency Management Agency, Building Seismic Safety Council, Washington, DC, USA, 2003.

[5] Giovinazzi, S., Lagomarsino, S., "Macro-seismic and mechanical models for the vulnerability and damage assessment of current building." *Bull Earthquake Engineering*, 30, 7, September 2006, pp. 415-443.

[6] Habibullah, A., Pyle, S., "Practical three dimensional nonlinear static pushover analysis." *Structure Magazine*, winter, 1998.

[7] Kose, M. M., “Parameters affecting the fundamental period of RC buildings with infill walls.” *Engineering Structures,* 31, July 2008, pp. 93_102.

[8] Lee C. L., Su, R. K. L., “Fragility analysis of low-rise masonry in-filled reinforced concrete buildings by a coefficient-based spectral acceleration method” *Earthquake Eng and Eng Vib*. 41, 2, March 2013, pp. 697-713.

[9] Patil, P., Singh, P., Prasad, J., Kumar, R., “Seismic performance and vulnerability assessment of URM buildings in Utterakhand.” *J. IUP, Structural Engineering, Vol. III, No. 2, 2010*.

[10] Rossetto, T., Elnashai, A., “A new analytical procedure for the derivation of displacement-based vulnerability curves for populations of RC structures.” *Engineering Structures*, 27, 7, January 2004, pp. 397-409.

[11] Ranganathan, R., *Reliability analysis and design of structures*, by Tata MaGraw-Hill publication, 1990.