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DEVELOPMENT OF FRAGILITY AND VULNERABILITY CURVES FOR RC BUILDINGS

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ABSTRACT

The damage to the buildings during recent earthquakes has demonstrated the need of seismic evaluation which is used to predict the probability of damage to the building. This paper describes the vulnerability assessment of reinforced concrete buildings using fragility curves. Fragility curves are used to describe the probability of being exceeding a particular damage state. For the development of fragility curves, guidelines given by Cornell (2002) have been used. For the analysis, the RC buildings were modelled in ETABS 2015. Non-linear dynamic analysis procedure is used for the analysis of RC buildings. Models of buildings designed are developed in ETABS Software for nonlinear dynamics analysis on which a set of twenty natural time histories is applied. In the present study, Fragility Curves are generated for each building, by developing a Probabilistic Seismic Demand Model (PSDM). The time history analysis is carried out as per the FEMA P-58 guidelines. Results from time history analysis were used for plotting fragility curves. Vulnerability curve is generated as a result of time history analysis. The Fragility Curves are plotted considering Peak Ground Acceleration as a ground motion parameter.

The performance of each building is studied using the Fragility Analysis method introduced by Cornell (2002). Finally, using constructed fragility curves various performance level requirements were estimated. The fragility and vulnerability curves developed from the analysis were used to study the seismic performance of building models.

Keywords: ***Fragility Curves, Performance levels, PSDM Model, Time History Analysis, Nonlinear dynamic analysis***

I. INTRODUCTION

Seismic vulnerability assessment is a method used for quantification of risk involved due to expected earthquake in a region. The vulnerability is usually represented in terms of either Damage Probability Matrices (DPM) or Vulnerability (Fragility) curves. The seismic vulnerability of structures is commonly expressed through probabilistic fragility functions representing the conditional probability of reaching or exceeding a predefined damage state given the measure of earthquake shaking. Fragility curves are the conditional probability of exceedance of response of a structure for a given ground motion intensity. Fragility curves are used commonly for the estimation of probability of structural damage due to earthquakes as a function of ground motion indices or other design parameters. The most basic inelastic method of seismic analysis is complete non-linear time history analysis. Therefore, Non-linear dynamic procedures are used in this paper for the generation of fragility curves as per the Cornell (2002) method.

Three building frame models were considered in this paper for the development of fragility curves and vulnerability curves. Peak Ground Acceleration is used as a ground motion parameter. ETABS 2015 is used for the modelling of building and Time History analysis. Results from Time History analysis are used for development of fragility curves. The infill walls are not considered in modelling of RC buildings

II. LITERATURE REVIEW

The researchers have recognized that the need of vulnerability assessment for seismic evaluation of buildings. They have identified Fragility curves is one of the tool for vulnerability assessment. The literature has been referred from various research papers is illustrated.

Murat and Zekeriya (2006) presented a study on Fragility analysis of mid-rise RC buildings. They had performed incremental dynamic analysis on 3, 5, 7 storey RC buildings using 12 artificial earthquake records. Yielding and collapse capacity of the buildings was determined from the analysis. They used PGA and elastic spectral displacement as ground motion parameters. Also they used inter-storey drift and spectral displacement values as a damage measurement parameter.

Farsi, et.al. (2015) presented a work to estimate the seismic vulnerability of existing buildings in Algeria. For this purpose, capacity curves were developed for the reinforced concrete buildings using push-over method. In the modeling of nonlinearity three types of plastic hinges were considered which are Flexural plastic hinges (M2, M3), Compound compression and bending plastic hinges (PMM), and shear plastic hinges (V2, V3). The analysis was performed using ETABS software. Four performance levels, corresponding to the expected damage after an earthquake OL, IO, LS and CP were considered in the vulnerability assessment of buildings in Algeria. Elastic response spectra, plotted for each soil type in acceleration vs. period coordinates are based on estimates of seismic coefficients CA and CV presented in ATC-40(4) report.

Cornell et. al. (2002) investigated a formal probabilistic framework for seismic design and assessment of structures and its application to steel moment-resisting frame buildings based on the 2000 SAC, Federal Emergency Management Agency (FEMA) steel moment frame guidelines. The framework is based on realizing a performance objective expressed as the probability of exceedance for a specified performance level. Demand and capacity were represented by an explicitly nonlinear, dynamic, and displacement-based structural response, the maximum inter storey drift ratio. Probabilistic models distributions were used to describe the randomness and uncertainty in the structural demand given the ground motion level, and the structural capacity. A common probabilistic tool the total probability theorem was used to convolve the probability distributions for demand, capacity, and ground motion intensity hazard. This provided an analytical expression for the probability of exceeding the performance level as the primary product of development of framework. Consideration of uncertainty in the probabilistic modelling of demand and capacity allowed for the definition of confidence statements for the likelihood performance objective being achieved.

Raipure P. (2015) presented a study on development of fragility for open ground storey buildings. She had used probabilistic seismic demand model (PSDM) as per power law for the generation of fragility curves. a typical ten storied OGS framed building was considered and the building considered is located in Seismic Zone-V. The

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design forces for the ground storey columns were evaluated based on various codes such as Indian, Euro, Israel, and Bulgarian suggested approach. She designed various OGS frames considering MF as 1.0, 2.1 (Israel), 2.5 (Indian), 3.0 (Bulgarian), and 4.68 (Euro). The performance of each building was studied using the fragility analysis method introduced by Cornell et. al (2002). Twenty computational models were developed in the program ETABs for nonlinear dynamics analysis for each case. For the analysis, a set of twenty natural time histories was selected.

III. SYSTEM DEVELOPMENT

In this paper the methodology used for development of fragility curve is divided into two parts. Firstly Time History analysis is performed on building models is ETABS 2015. The results from Time History analysis are used for generation of fragility curves as per Cornell method.

3.1 Time History Analysis

In order to examine the exact nonlinear behaviour of structures, nonlinear time history analysis has to be carried out. In this method, the structure is subjected to real ground motion records. This makes this analysis method quite different from all of the other approximate analysis methods as the inertial forces are directly determined from these ground motions and the responses of the building either in deformations or in forces are calculated as a function of time, considering the dynamic properties of the structure.

3.2 Cornell's methodology

3.2.1 Probabilistic Seismic Demand Model (PSDM)

It has been suggested by Cornell et. al (2002) that the estimate of the median engineering demand parameter (EDP) can be represented by a power law model as given in Eq.

$$EDP = a\,(IM)^{b}$$

In this present study, inter-storey drift (δ) at the first floor level (ground storey drift) is taken as the engineering damage parameter (EDP) and peak ground acceleration (PGA) as the intensity measure (IM) , 'a' and 'b' are regression coefficients.

3.2.2 Construction of Fragility Curves

The fragility can be expressed in closed form using following equation as

$$P(DS/IM) = \emptyset\left(\frac{\ln IM - \ln IM_m}{\beta_{comp}}\right)$$

Where $IM_M = exp\left(\frac{\ln S_c - \ln a}{b}\right)$, a and b are the regression coefficients of the probabilistic Seismic Demand Model (PSDM) and the dispersion component, $\beta_{D/IM}$ is given as

$$\beta_{D/IM} = \sqrt{\frac{\sum(\ln(d_i) - \ln(a\,IM^b))^2}{N-2}}$$

Bcomp is given as,

$$\beta_{comp} = \sqrt{\frac{\beta_{d/IM}^2 + \beta c^2}{b^2}}$$

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The dispersion in capacity, βc is dependent on the building type and construction quality. For βc, ATC 58 50% draft suggests 0.10, 0.25 and 0.40 depending on the quality of construction. In this study, dispersion in capacity has been assumed as 0.25.

3.2.3 Generation of Vulnerability Curves

By Calculating mean damage probability values for given seismic intensity Vulnerability curve can be generated.

$$\mu_D = \sum P_k \cdot D_k$$

Where μ_D is the mean damage, P_k is the probability and D_k is quantity of damage to structure

IV. RESULTS AND DISCUSSION

In this paper three building models are considered for the development of fragility curves. Fragility curves are generated for three performance levels as per Cornell. No infill walls were considered in the modelling of all the buildings. Peak Ground Acceleration is used as ground motion parameter.

4.1 Low Rise Building (2D and 3D)

A Three dimensional and Two dimensional model of G+2 RCC frame is considered. The model specification and the loading data is given in Table 1. This frame is designed for gravity loads in ETABS 2015. Time History analysis is performed for the gravity load designed frame.The probability of damage for a particular performance level is worked out.

Table 1: Description Low Rise Building (2D and 3D):

Parameter	**value**	**parameter**	**value**
No. of stories	3	**No. of bays in X-direction**	4
Height of each storey	3.06 m	**No. of bays in Y-direction**	3
Bay width (X direction)	5 m	**Grade of concrete**	M25
Bay width (Y direction)	3 m	**Grade of Steel**	HYSD 415
Beam size	0.25 x 0.4 m	**Column Size**	0.4 x 0.4 m
Live Load	3.5 kN/m^2	**Zone (IS-1893 2002)**	V

The Probabilistic Seismic Demand Model (PSDM), fragility curve and Vulnerability curve obtained considering three performance level is shown below.

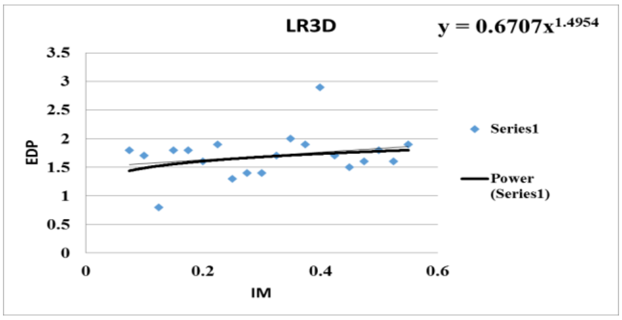

Fig 1: Parameters of Probabilistic Seismic Demand Model for Low Rise 3D Building.

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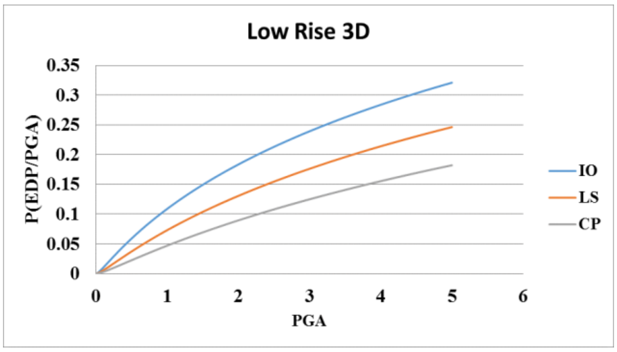

Fig 2: Fragility Curve for Low Rise 3D Building.

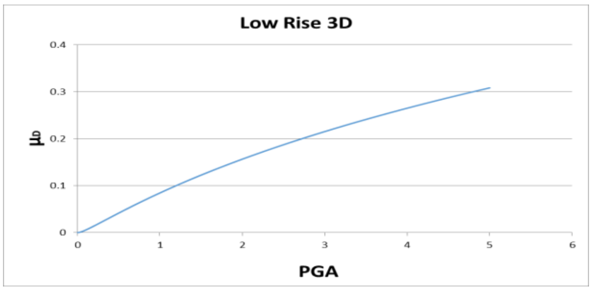

Fig3: Vulnerability Curve for Low Rise 3D Building Respectively.

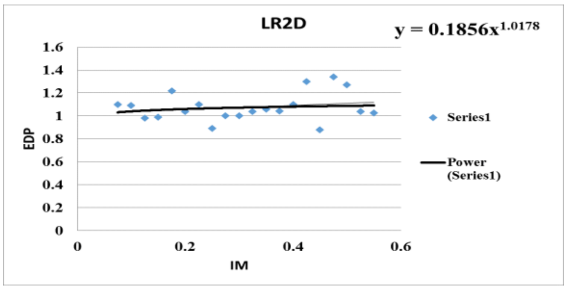

Fig 4: Parameters of Probabilistic Seismic Demand Model For Low Rise 2D Building.

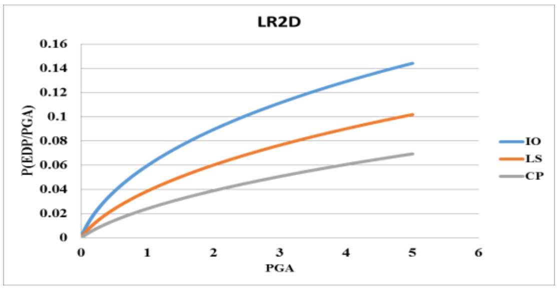

Fig 5: Fragility Curve for Low Rise 2D Building.

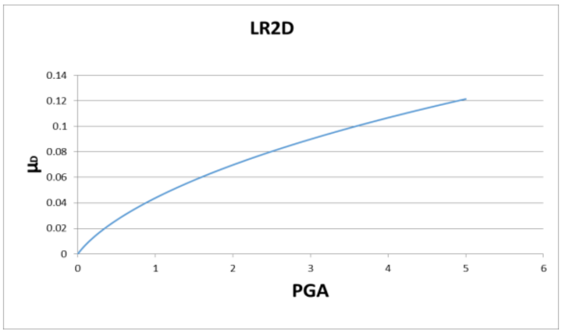

Fig 6: Vulnerability Curve For Low Rise 2D Building Respectively.

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The probability of damage or the probability of exceedance for the three performace levels i.e. Immediate Occupancy, Life Safety and Collapse Prevention can be read from the fragility curve. The table 2 shows the probability of exceedance of particular performace levels for same Peak Ground Acceleration value.

Table 2: Comparison of Probability of Performance Level

Building Model Type		Low-Rise 3D		Low-Rise 2D	
Performance Level		PGA(g)	Prob	PGA(g)	Prob.
Fragility	IO	5	0.32	5	0.15
Fragility	LS	5	0.25	5	0.11
Fragility	CP	5	0.17	5	0.07
Vulnerability	Mean	5	0.31	5	0.13

4.2 Mid Rise Building (2D and 3D)

A Three dimensional and Two dimensional model of G+5 RCC frame is considered. The model specification and the loading data is given in Table 3. This frame is designed for gravity loads in ETABS 2015. Time History analysis is performed for the gravity load designed frame.The probability of damage for a particular performance level is worked out.

Table 3: Description Mid Rise Building (2D and 3D):

Parameter	**value**	**parameter**	**value**
No. of stories	5	No. of bays in X-direction	4
Height of each storey	3.06 m	No. of bays in Y-direction	3
Bay width (X direction)	6 m	Grade of concrete	M25
Bay width (Y direction)	4 m	Grade of Steel	HYSD 415
Beam size	0.3 x 0.5 m	Column Size(1-3) storey	0.5 x 0.5 m
Live Load	3.5 kN/m^2	Column Size(4-5) storey	0.4 x 0.4 m

The Probabilistic Seismic Demand Model (PSDM),fragility curve and Vulnerability curve obtained considering three performance level is shown below.

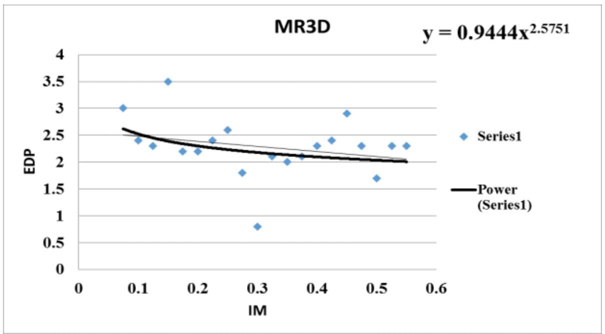

Fig 7: Parameters of Probabilistic Seismic Demand Model For Mid Rise 3D Building.

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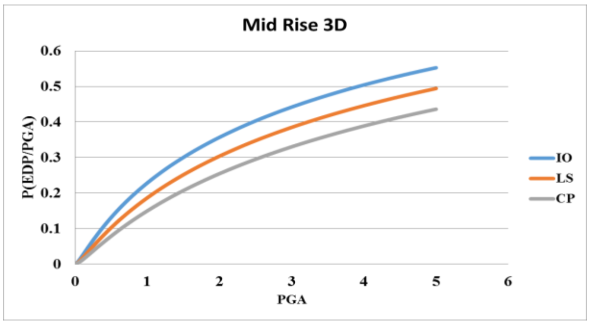

Fig 8: Fragility Curve for Mid Rise 3D Building.

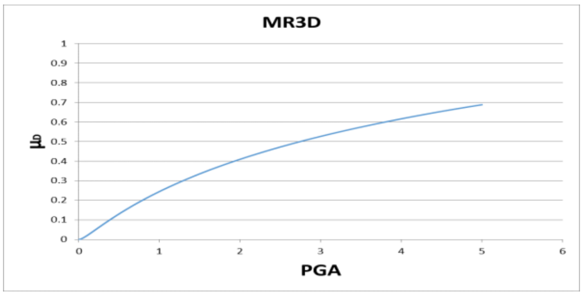

Fig 9: Vulnerability Curve for Mid Rise 3D Building Respectively.

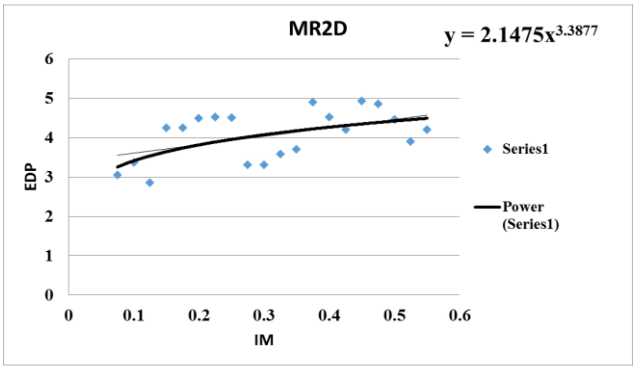

Fig 10: Parameters of Probabilistic Seismic Demand Model For Mid Rise 2D Building.

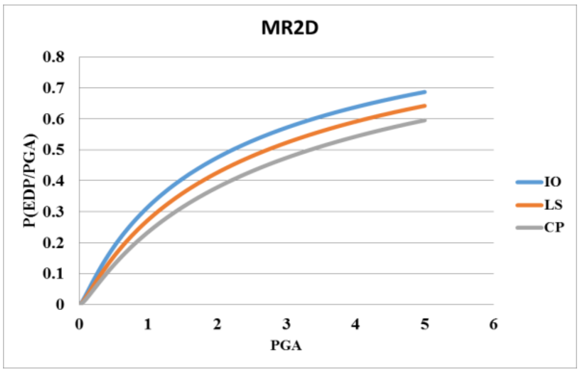

Fig 11: Fragility Curve for Mid Rise 2D Building.

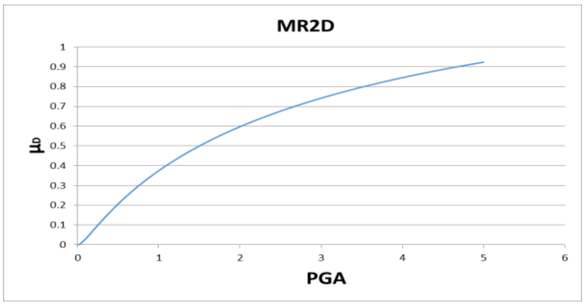

Fig 12: Vulnerability Curve for Mid Rise 2D Building Respectively.

The probability of damage or the probability of exceedance for the three performance levels i.e. Immediate Occupancy, Life Safety and Collapse Prevention can be read from the fragility curve. The table 4 shows the probability of exceedance of particular performance levels for same Peak Ground Acceleration value.

Table 4: Comparison of Probability of Performance Level

Building Model Type		**Mid-Rise 2D**		**Mid-Rise 3D**	
Performance Level		PGA(g)	Prob	PGA(g)	Prob.
Fragility	IO	5	0.55	5	0.67
Fragility	LS	5	0.49	5	0.63
Fragility	CP	5	0.41	5	0.59
Vulnerability	Mean	5	0.7	5	0.9

4.3 High Rise Building (2D and 3D)

A Three dimensional and Two dimensional model of G+11 RCC frame is considered. The model specification and the loading data is given in Table 5. This frame is designed for gravity loads in ETABS 2015. Time History analysis is performed for the gravity load designed frame. The probability of damage for a particular performance level is worked out.

Table 5: Description High Rise Building (2D and 3D):

Parameter	**value**	**parameter**	**value**
No. of stories	12	No. of bays in X-direction	4
Height of each storey	3.06 m	No. of bays in Y-direction	3
Bay width (X direction)	6 m	Grade of concrete	M25
Bay width (Y direction)	4 m	Grade of Steel	HYSD 415
Beam size	0.3 x 0.5 m	Column Size(1-9) storey	0.7 x 0.7 m
Live Load	3.5 kN/m^2	Column Size(9-12) storey	0.5 x 0.5 m

The Probabilistic Seismic Demand Model (PSDM),fragility curve and Vulnerability curve obtained considering three performance level is shown below.

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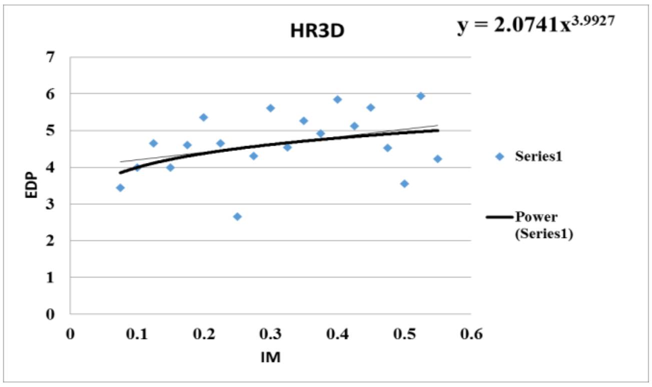

Fig 13: parameters of probabilistic seismic demand model for high rise 3D building.

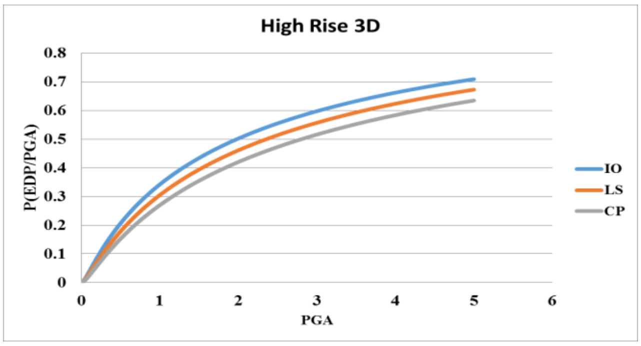

Fig 14: Fragility Curve For High Rise 3D Building.

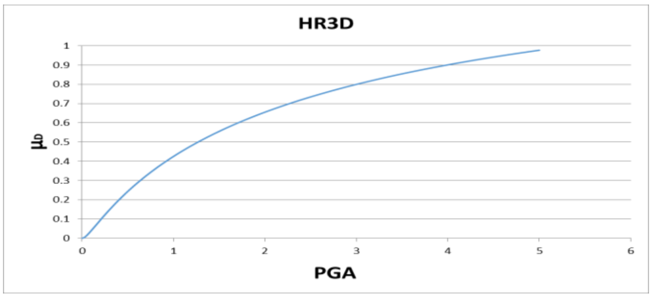

Fig 15: Vulnerability Curve For High Rise 3D Building Respectively.

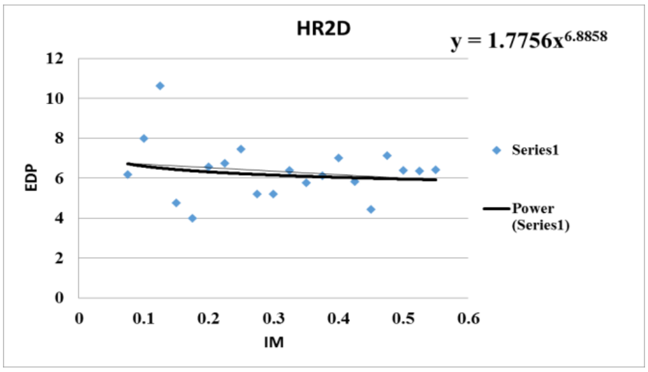

Fig 16: Parameters of Probabilistic Seismic Demand Model For High Rise 2D Building

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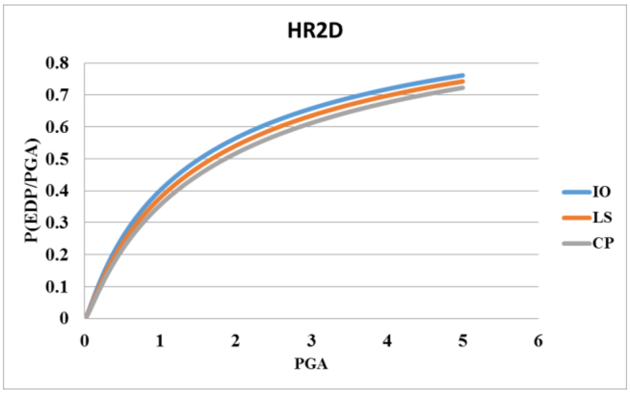

Fig 17: Fragility Curve For High Rise 2D Building.

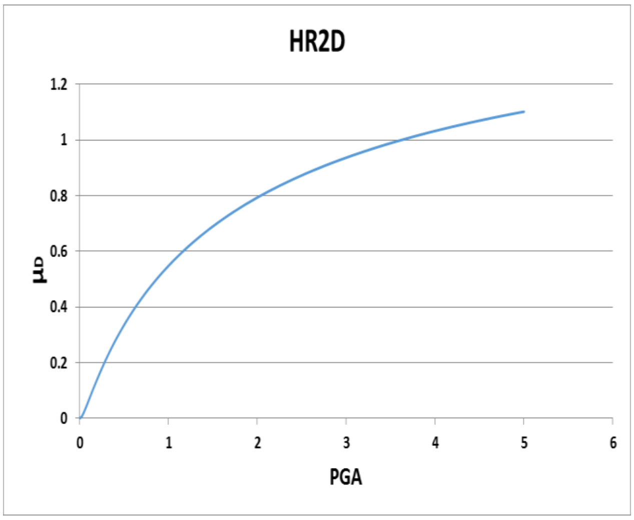

Fig 18: Vulnerability Curve For High Rise 2D Building Respectively.

The probability of damage or the probability of exceedance for the three performace levels i.e. Immediate Occupancy, Life Safety and Collapse Prevention can be read from the fragility curve. The table 6 shows the probability of exceedance of particular performace levels for same Peak Ground Acceleration value.

Table 6: Comparison of Probability of Performance Level

Building Model Type		**High-Rise 2D**		**High-Rise 3D**	
Performance Level		PGA(g)	Prob	PGA(g)	Prob.
Fragility	IO	5	0.72	5	0.79
Fragility	LS	5	0.65	5	0.75
Fragility	CP	5	0.61	5	0.72
Vulnerability	Mean	5	0.97	5	1.1

V. SUMMARY AND CONCLUSIONS

In this study, Cornell's methodology for the generation of fragility curves is discussed and the fragility curves are generated for low-rise, mid-rise and high-rise RC building structures without considering infill walls. From the results generated, it is concluded that this methodology gives an idea to predict the performance level of the building corresponding to particular value of peak ground acceleration. The damage state of the building is also identified from the above analysis.

As Cornell's method works on non-linear dynamic procedures, it is also concluded that the results from this paper need to be compared with another method, such as pushover method, IDA etc.

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