Fragility Estimates of Rc Building Using Etabs

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Abstract: Earthquakes are the most destructive natural disaster causing lot of casualties, injuries and economic losses leaving behind a trail of panic. Earthquake risk assessment is needed for disaster mitigation, disaster management, and emergency preparedness. Vulnerability of building is one of the major factors contributing to earthquake risk. The vulnerability functions framed for a particular building is input parameter for loss estimation. Procedure for developing fragility curves of specific building type is discussed. Seismic fragility curves were developed and damage probability threshold has been constructed for the chosen problems.

Keywords: Risk assessment, vulnerability, fragility curves, damage state threshold.

1. INTRODUCTION

The need for evaluating the seismic assessment of existing buildings has come into focus following the enormous loss of life and property during the recent earthquakes in India. After the Bhuj(Gujarath) Earthquake in 2001 considerable interest in this country has been directed towards the damaging effect of earthquakes and has increased the awareness of the threat of seismic risk events. Most of the mega cities in India are in seismically active zones and are designed just for gravity loads. A large number of existing buildings in India need seismic evaluation due to various reasons such as, nonconformity with the codal requirements, revision of codes and design practice and change in the use of building. Hence fragility estimation of the existing RC buildings in India is a growing concern.

A fragility curve, also known as vulnerability curve, is a continuous curve graphically representing the relationship between probabilities of exceeding a particular level of damage versus earthquake intensity. It describes the probability of damage to building. It is based on a concept that similar type of structures (structural typology) will have same probability of a given damage state for given earthquake intensity. The use of fragility curves for the assessment of seismic losses is in increasing demand, both for pre earthquake disaster planning as well as post-earthquake recovery and retrofitting programs.

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1.1. Scope of Present Study

Risk assessment represents an important research topic in recent years, emphasizing the necessity to evaluate the built environment in order to reduce the seismic effects. The seismic damage evaluation in urban area is highly influenced by uncertainties in each step of the evaluation process. The most recent trends in fragility estimation with simplified mechanical models are essentially based on the Capacity Spectrum Method.

The main objective of this paper is to study the influence of uncertainties in the damage states thresholds of a reinforced concrete structure. The used methodology is based on developing probabilistic fragility curves which consider the damage states threshold as random. This method defines building fragility curves from the capacity spectrum and evaluates the expected seismic performance of the structure by comparing the capacity spectrum with the demand spectrum of the seismic hazard. Four damage states are considered in this paper for a building, defined according to Risk-UE handbook specifications, obtaining the damage expressed as probability matrices. Even though the used approaches have been improved significantly, the uncertainties in the structural characteristics and in the damage state thresholds have a great influence on the results.

2. THEORETICAL BACKGROUND

2.1. Capacity Spectrum Method

To estimate the seismic behaviour of the building, pushover analysis is done to obtain the capacity

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curves. The pushover analysis is a nonlinear static incremental procedure which describes the structural behaviour in a simplified way when subjected to earthquake load. It allows the determination of weak structural members and the failure mechanisms. Even though there are different methods to evaluate the behaviour of the structure, it is considered that the pushover analysis is an accurate approximation in comparison with the nonlinear dynamic analysis. The capacity curve is the graphical representation of the relation between the base shear and the displacement at the roof of the structure. The capacity spectrum method requires the following steps: (1) perform the pushover analysis of the building;(2) plot the capacity curve of the building; (3) represent it in a ADRS format, that is, spectral displacement – spectral acceleration coordinates; (4) calculate and plot the bilinear representation of the capacity spectrum; (5) plot the demand spectrum of the considered earthquake; and finally (6) intersect capacity and demand spectra to obtain the performance point, and thus the expected spectral displacement.

2.2. Fragility Estimation

To evaluate the seismic risk of the building damage fragility curves are used. Fragility curves define the probability that the expected global damage, *d*, of a structure exceeds a given damage state, *dsi*, as a function of a parameter quantifying the severity of the seismic action. Thus, for each damage state, the corresponding fragility curve is completely defined by plotting $P[d \geq dsi]$ in the ordinate and the spectral displacement, S_d, in the abscissa. For a given damage state, *dsi*, a fragility curve is well described by the following lognormal probability density function [1]:

$$P\left[\frac{ds}{S_d}\right] = \phi\left[\frac{1}{\beta_{ds}} ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \tag{1}$$

where *Sd* is the spectral displacement which is a seismic hazard parameter, representing the median value of spectral displacement at which the building reaches a certain threshold of the damage state, *dsi*, *βdsi*– the standard deviation of the natural logarithm of the spectral displacement of the damage state *ds* and Φ – the standard normal cumulative distribution function.

The considered approach proposes four damage states: (a) Slight – the damage is considered negligible; (b) Moderate – slight structural damage and moderate non-structural damage; (c) Severe – moderate structural damage and heavy non-structural damage; (d) Collapse - when structure is on the verge of danger of collapse. Table **1** shows a summary of the used parameters for the damage state thresholds as functions of the yielding displacement, *dy*, and the ultimate displacement, *du*, of the structure.

Table 1: Damage State Threshold [6]

Damage State	Median Spectral Displacement, $\bar{S}_{d,ds}$
Slight	$\bar{S}_{d,S} = 0.7 S_{d,y}$
Moderate	$\bar{S}_{d,M} = S_{d,y}$
Extensive	$\bar{S}_{d,E} = S_{d,y} + 0.25\left(S_{d,u} - S_{d,y}\right)$
Complete	$\bar{S}_{d,C} = S_{d,u}$

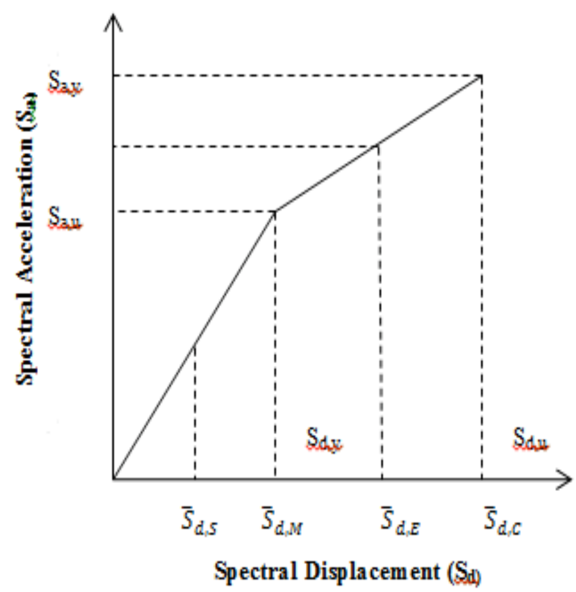

Figure 1: Damage state threshold on bilinear capacity spectrum.

3. CASE STUDY

3.1. Building Description

In order to bridge the gap between experimental and analytical data, Reactor Safety Division (RSD), Bhabha Atomic Research Centre (BARC) conducted a national round robin exercise in which a full-scale four-storied RCC structure was tested under lateral monotonically increasing Pushover loads at the tower testing facility at Central Power Research Institute (CPRI), Bangalore. The test was conducted under gradually increasing monotonic lateral load in an inverted triangular pattern till failure. Complete details of the structure including modelling concepts and their effect on the analysis results have been supplied by RSD. A brief summary of the building is presented in Table **2** below.

Table 2: Experimental Building Description

Type of the structure	Ordinary Moment Resisting RC Frame
Grade of the concrete	M20
Grade of reinforcing steel	Fe 415
Plan size	5 m x 5m
Number of stories	G + 3 storey
Building height	12 m above ground storey
Type of foundation	Raft foundation which is supported on rock bed using rock grouting.

One of the most important requirements in good concrete construction is that the quality of concrete placed in the structure should conform to that specified in the design. For most of the construction works, concrete used in developed countries is produced in central ready mix plants rather than mixed at site. But in India, most of it is mixed at site and, as different from the steel made in the factory, its quality can vary from site to site and at the same site, from day to day. The partial safety factor for material strength has been introduced to account for constructional faults, workmanship and supervision. Table **1** depicts the value of partial safety factor for material strength. It will be seen that the partial safety for material strength of concrete is much greater than that of steel because of variation in strength of concrete depends on number of uncontrollable factors while steel is rolled in factories due to which the strength variation is much less.

3.2. Structural System

The building is an RC framed structure. The floor plan is same for all floors. The beam arrangement is different for the roof. It is symmetric in both the direction. The concrete slab is 120 mm thick at each floor level. Overall geometry of the structure is shown in the Figure **2**. The beam layout of all the floors is as shown in Figure **3** below. Further the details of the various structural systems are shown below. Figure **4** shows the reinforcement details of floor beams and Figure **5** shows the reinforcement details of roof beams. The column details are shown in the Figure **6**.

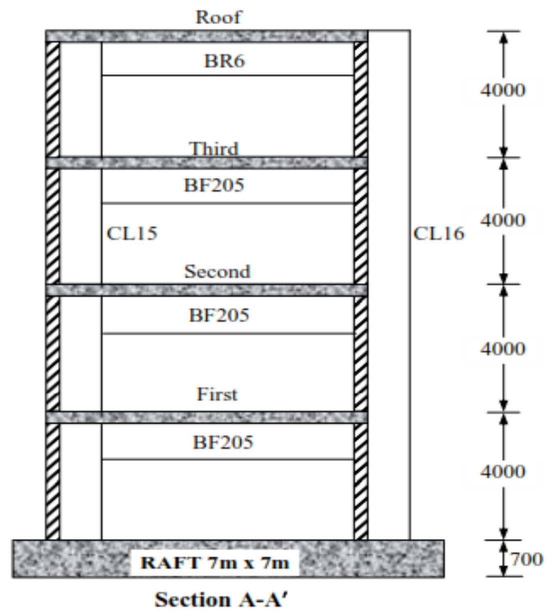

Figure 2: Overall geometry of the structure.

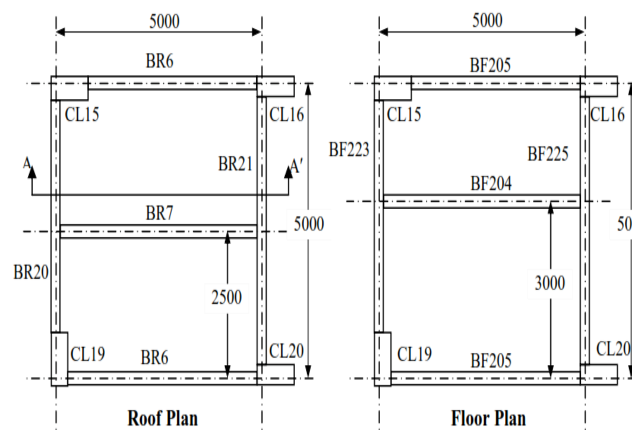

Figure 3: Beam layout of all the floors.

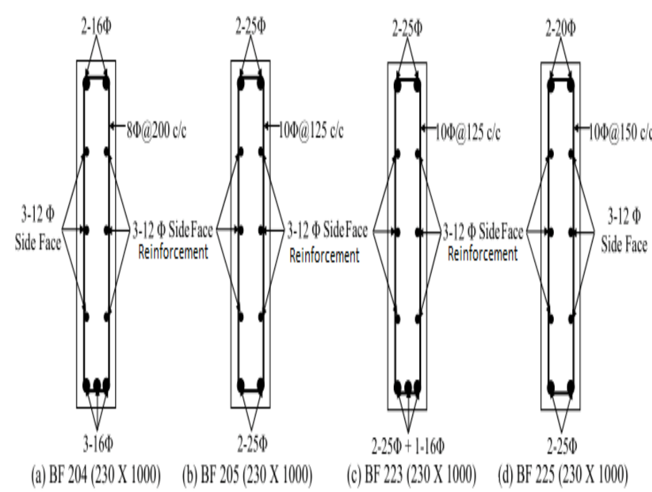

Figure 4: Reinforcement details of floor beams.

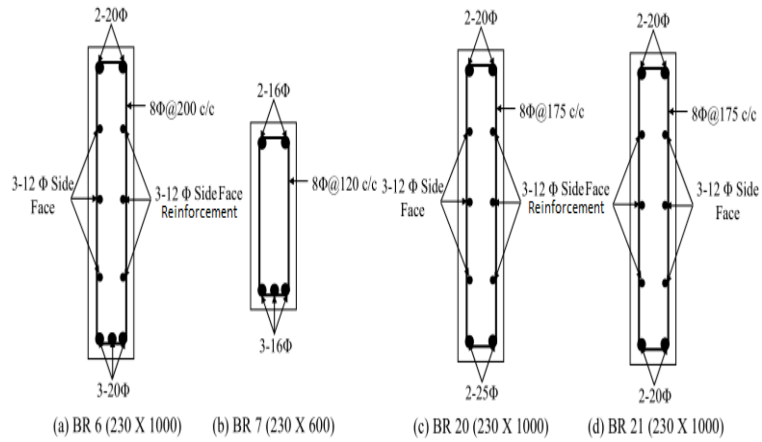

Figure 5: Reinforcement details of roof beams.

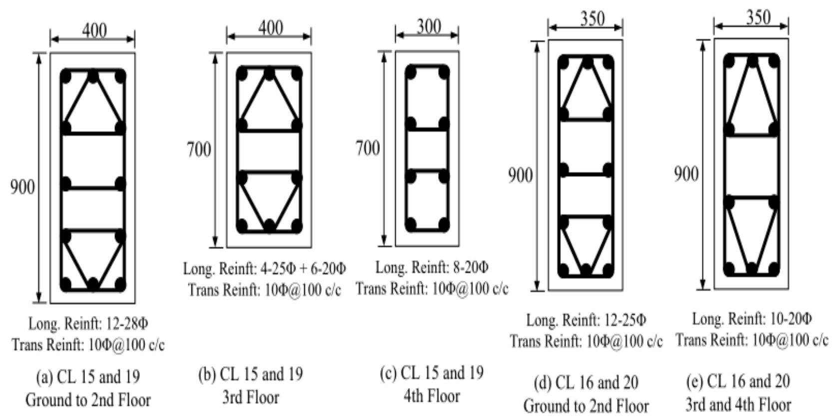

Figure 6: Reinforcement details of columns.

3.3. Foundation

The structure is resting on a 700 mm thick raft resting on rock below, with rock anchors provided. For analysis purpose it is modeled as fixed end in ETABS.

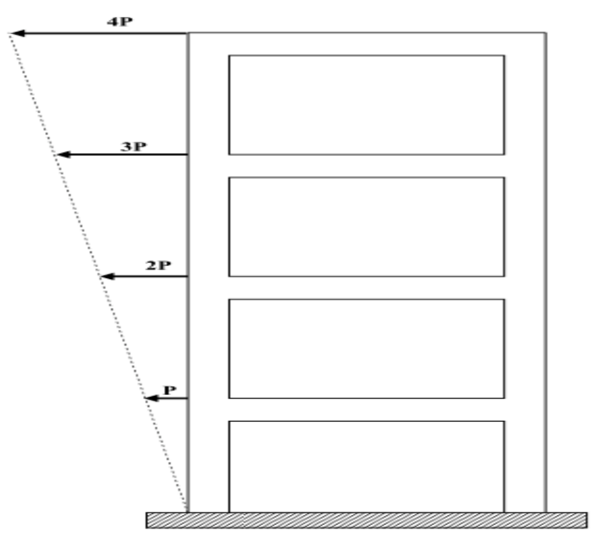

Figure 7: Loading pattern.

3.4. Loading

The test was conducted under gradually increasing static lateral load in an inverted triangular pattern till failure. The ratio of force at “first level : second level : third level : fourth level” was kept as “1: 2 : 3 : 4”. The loading pattern is as shown in Figure **7**.

3.5. Experimental Results

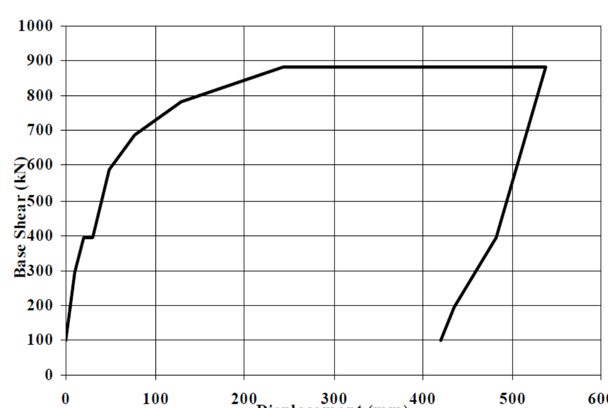

Figure 8: Pushover curve obtained from experiment done at CPRI, Bangalore.

4. ANALYTICAL STUDY

4.1. Computational Building Model

4.1.1. Material Properties

The material properties of both concrete and steel used for the analysis are as shown in Table **3**.

Table 3: Material Properties of the Considered Model

Material	Characteristic strength (MPa)	Modulus of Elasticity (MPa)
Concrete	f_{ck}= 20	E_c = 22360
Reinforcing steel	Tensile strength (MPa)	Modulus of Elasticity (MPa)
	f_y= 520	E_s= 200000

4.1.2. Structural Modelling

The analytical model was created in such a way that the different structural components represent as accurately as possible the characteristics like mass, strength, stiffness and deformability of the structure. Non-structural components were not modelled. The various primary structural components that were modeled are as follows:

1. Beams and columns: Beams and columns were modeled as 3D frame elements. The characteristics like strength, stiffness and deformability of the members were represented through the assignment of properties like cross sectional area, reinforcement details and the type of material used.

2. Beam-column joints: The beam-column joints were assumed to be rigid modelled. A rigid zone factor of 1 was considered to ensure rigid connections of the beams and columns.

3. Slab: The slabs were not modelled physically, since modelling as plate elements would have induced complexity in the model. However the structural effects of the slabs i.e., the high in-plane stiffness giving a diaphragm action and the weight due to dead load were modelled separately.

4. Foundation modelling: The foundation was modelled based on the degree of fixity which is provided. The effect of soil structure interaction was ignored in the analysis. In the model, fixed support was assumed at the column ends at the end of the footing.

5. Load combination: In the limit state design method, the following 13 load combinations were applied as per BIS 1893 (Part 1): 2002.

Table 4: Load Combination and Load Factors

Load Combination	Load Factors
Gravity Analysis	1.5 (D.L + LL)
Equivalent Static Analysis	1.2 (D.L + L.L ± EQX) 1.2 (D.L + L.L ± EQY)
	1.5 (D.L ± EQX) 1.5 (D.L ± EQY)
	0.9 (D.L ± EQX) 0.9 (D.L ± EQY)

Where, D.L, L.L, EQX and EQY denote dead load, live load, earthquake load in x and y direction respectively.

5. ANALYSIS RESULT

5.1. Pushover Analysis Result

The objective of this study is to see the variation of load-displacement graph and check the maximum base shear and displacement of the frame. From nonlinear static pushover analysis conducted, base shear v/s roof displacement was obtained from ETABS 9.7 as shown in Figure **9**. It can be seen that the maximum base shear obtained from the analysis result in ETABS 9.7 is almost comparable to that of the experimental result.

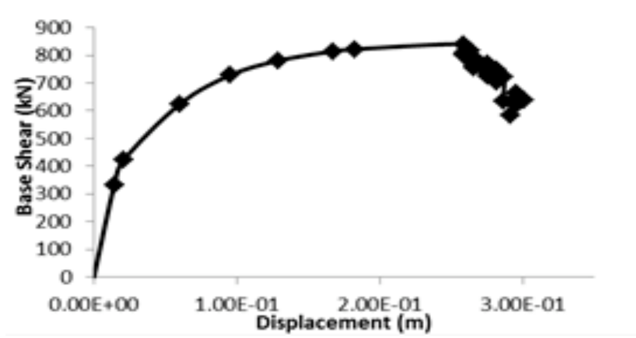

Figure 9: Pushover curve.

5.2. Capacity Spectrum Curve

Capacity spectrum method is a method used to determine the performance point. It is also known as the Acceleration-Displacement Response Spectra method (ADRS). In this method both the capacity curve and the demand curve should be represented in response spectral ordinates.

As displacement of the structure increase, the period of the structure lengthens. This is reflected directly in the capacity spectrum curve. Inelastic displacements increase damping and also reduce demand. The Capacity Spectrum Method reduces the demand to find an intersection with the capacity spectrum, where the displacement is consistent with the implieddamping. The Figure **10** shows the conversion of Pushover curve to capacity spectrum curve.

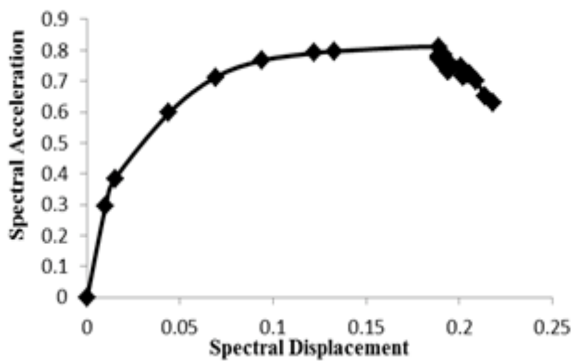

Figure 10: Capacity curve.

5.3. Seismic Risk Evaluation

In order to evaluate the seismic risk of a building, damage fragility curves are used. Fragility curves define the probability that the expected global damage, d, of a structure exceeds a given damage state, dsi, as a function of a parameter quantifying the severity of the seismic action. Thus, for each damage state, the corresponding fragility curve is completely defined by plotting P[d ≥ dsi] in the ordinate and the spectral displacement, Sd, in the abscissa. The damage state index is calculated from the Capacity curve obtained from static nonlinear analysis. Table **5** below shows a summary of the used parameters for the damage state thresholds as functions of the yielding displacement, dy, and the ultimate displacement, du, of the structure.

Table 5: Damage State Threshold

Damage State	$\overline{SD}_{dsi}$ *Values* (mm)	
Slight	0.7dy	8.75
Moderate	dy	12.5
Severe	dy+0.25(du-dy)	63.875
Collapse	du	218

Graphical representation of the damage thresholds in the bilinear capacity spectrum is as shown in the Figure **11**.

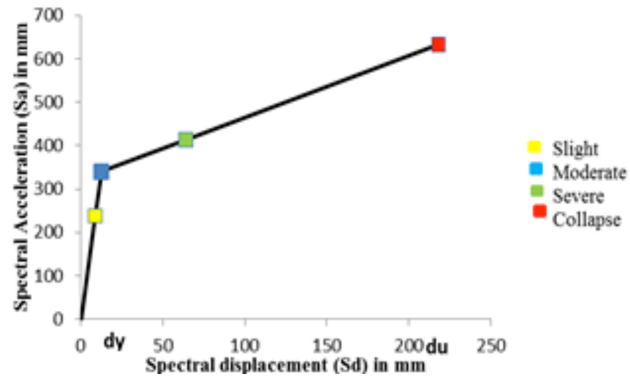

Figure 11: Bilinear representation of capacity curve.

Based on the mean damage index obtained from the Table **5** and proceeding with the probabilistic approach, 100 random samples were generated for the ultimate spectral displacement (du) of the capacity curve because of the lack of enough ground motion records. The standard deviation, σ is computed for these 100 random samples. In order to establish the influence of the variation of ground motion record, three levels of the ultimate spectral displacement is considered, μ, μ + σ and μ + 2σ. Where μ is the ultimate spectral displacement of the capacity curve. The fragility curves are computed for all the combinations of μ, μ + σ and μ + 2σ in both X and Y directions and plotted in Figures **11, 12 and 13**.

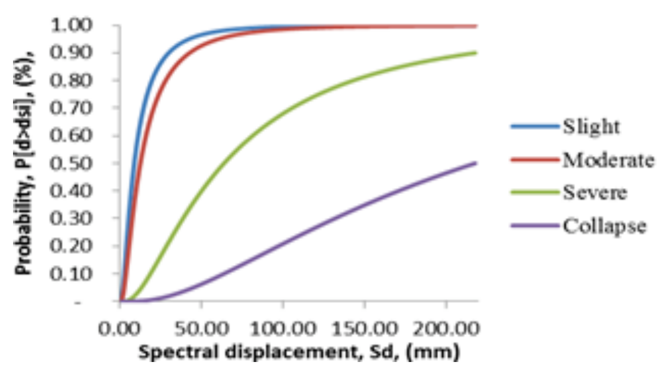

Figure 12: Fragility curve representation for μ.

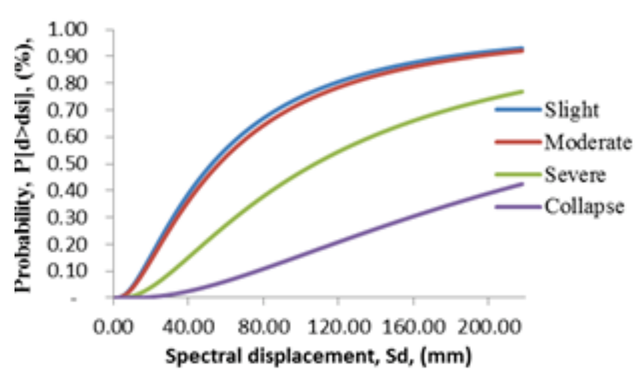

Figure 13: Fragility curve representation for μ + σ.

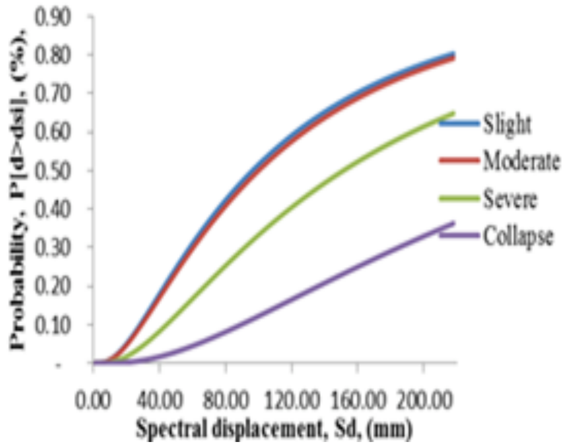

Figure 14: Fragility curve representation for μ + 2σ.

The combined damage state threshold values at the performance point Table **6** and the graph is displayed in the Figure **15**. It is observed from the Figure **15** that at the performance point, the probability of slight and moderate damage decrease and also it is found that the probability of severe and collapse damage is increased.

Table 6: Combined Damage State Threshold Probabilities

Damage State	Probability (%)		
	μ	μ + σ	μ + 2σ
Slight	0.45	0.43	0.41
Moderate	0.41	0.40	0.38
Severe	0.13	0.15	0.18
Collapse	0.01	0.02	0.03

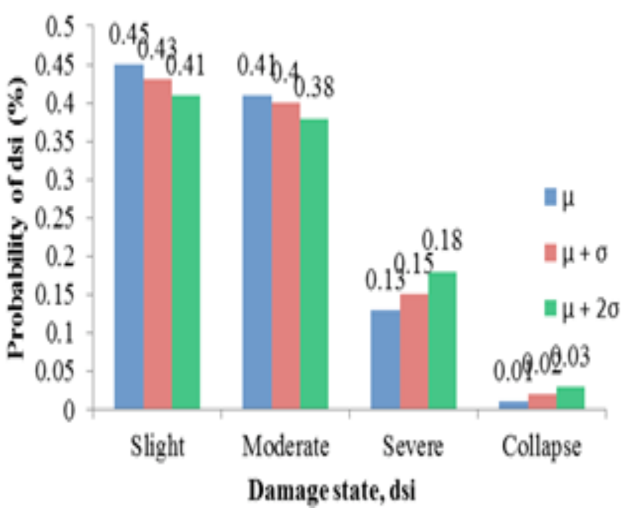

Figure 15: Combined damage state threshold probabilities.

6. CONCLUSIONS

The seismic risk evaluation of a RC building located in zone IV of IS 1893, keeping probabilistic format in view in an Indian context has been detailed and illustrated in this paper.

The paper aims to propose a methodology based on pushover analysis for fragility estimates of RC building using probabilistic approach.

It is observed that the analytical base shear values for the derived values of strength based on factor of safety into consideration were almost equal to that of experimental pushover values. Also, an attempt has been made to obtain fragility estimates for the reference building assumed to be located in zone IV and damage states were also established and reported.

The obtained values of fragility estimates and damage states are well within the limit for the statistic of (μ), (μ+ σ) and (μ+2 σ).

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