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Methodology for Probabilistic Seismic Risk Evaluation of Building Structure Based on Pushover Analysis

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Abstract - As more and more emphasis is being laid on inelastic analysis of RC framed structures subjected to earthquake excitation; the pushover (non-linear static) analysis is in forefront compared to time history (nonlinear dynamic) analysis. The paper presents the overview of seismic provisions of IS1893 (Part 1)-2002 keeping probabilistic format in to consideration published by Bureau of Indian Standards with regard to seismic analysis and design. Since the country lie in earthquake prone area and many of the destructive earthquakes occurred in the history so far resulting in high number of casualties due to collapse of buildings and dwellings. Hence, the paper proposes the methodology in a probabilistic manner to assess the seismic risk/ performance of RC (Reinforced Concrete) building by considering uncertainties based on pushover analysis due to non-existence of code of practices in Indian context. Thus, the methodology may be used as guidelines for seismic risk evaluation of building structure.

Keywords - Probabilistic Risk Analysis (PRA), Pushover Analysis, Performance Criteria, Reliability, Fragility Analysis

1. Introduction

India has experienced destructive earthquakes throughout its history. The most notable major earthquakes in India from 1819 to 2001 are: the 1819 earthquake with epicenter in Kutch, Gujurat and the later 2001 earthquake at Bhuj, Gujarat. In many respects, including seismological and geotechnical, the January 26, 2001 earthquake was a case of history repeating itself 182 years later and it made the engineering community in India aware of the need of seismic evaluation and retrofitting of existing structures. The Bhuj earthquake of 26 January 2001 caused 14,000 casualties. The main reason for such huge casualties was low earthquake awareness and poor construction practices, highlighting inherent earthquake safety characteristics. The seismic code is usually revised based on technology advances and knowledge gained after earthquake occurrences, The last revision of IS 1893 (Criteria for earthquake resistant design of structures) was done in 2002 after a long gap of about 18 years. Some new clauses were included and some old provisions updated.

Assessing the capacity of existing building per the present codes of practice is an important task in performance-based evaluation. In order to enhance the performance of existing buildings to the present level of ductile design prescribed by present codes and find the retrofit or design a rehabilitation system, there is an urgent need to assess accurately the actual lateral load resistance and the potential failure modes. The non-linear static analysis (Pushover Analysis) gives a better understanding and more accurate seismic evaluation of buildings as the progression of damage and failure can be traced. Hence, seismic performance evaluation is like a crying need in an Indian context, which is prerequisite/ precursor to retrofitting.

1.1. General Problems and Factors

General problems and factors involved in the earthquake-resistant design and assessment of structures have been discussed from a macroscopic point of view [1]. These are illustrated in Figure 1, where X1 represents the problem associated with the accurate estimation of base rock motion, X2 represents the problem associated with the correct evaluation of motion transmission from the rock base to the free ground surface, X3 represents the problem of accurately estimating the ground motion at the foundation of the building and X4 is the problem associated with the estimation of the deformation of the top storey of the structure. The parameters A, I, and D represent respectively attenuation or amplification factor, a factor that relates the interaction between the soil and the structure and a dynamic operator that predicts the top displacement from the foundation displacement. The estimation of these factors has proven to be very difficult in the sense that there exist large uncertainties in their estimation.

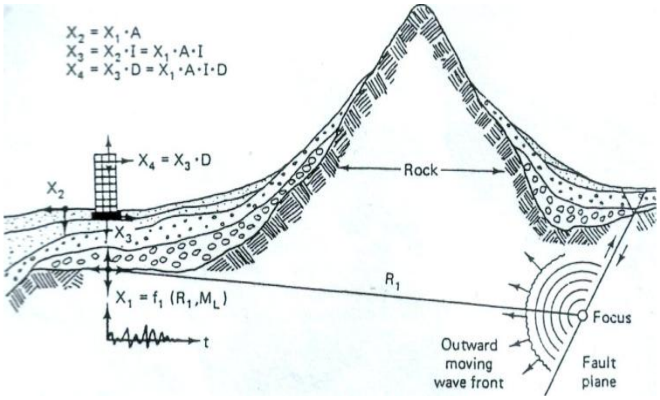

Figure 1. General problems and factors involved in the earthquake-resistant design of structures.

2. Literature Review

The following review is concerned with studies of the development and application of pushover analysis (POA) and probability risk assessment of RC buildings. It is provided in order to offer an insight into the attempts that have been made to verify the potential, shortcomings and limitations of these methods.

Shinozuka et al. presented a method for the seismic risk analysis of structures using a concept of damage probability matrix in which probability of occurrence of damage stress is defined by combining the seismic risk with the probability of exceedance of certain response level [2]. Bolotin presented a systematic study of random factors involved in risk assessment of structures subjected to strong seismic action using Monte Carlo Simulation procedure [3]. A comprehensive study of vulnerability of buildings and structures to various earthquake intensities has not been conducted in a systemic way in the country (India) so far [4]. Chowdhary et al. carried out the reliability assessment of reinforced concrete frames under seismic loading using response spectrum method [5].

So far as Probabilistic Risk Analysis (PRA) is concerned, it has not been so widely used for building frames. The reason for this is the large number of failure mechanisms that are to be investigated for performing the non-linear analysis. No attempt has been made to simplify this complexity of the problem and provide a methodology for finding a preliminary estimate of the probability of failure of frame structures.

The review on POA has shown that for structures that vibrate primarily in the fundamental mode the method will provide good information on many of the response characteristics, which includes [6]:

• Identification of critical regions in which the deformation demands are expected to be high and hence which lead to careful detailing.

• Identification of strength discontinuities in plan or elevation that will lead to changes in dynamic characteristics in the inelastic range.

• Estimation of inter-storey drifts accounting for strength or stiffness discontinuities that may be used to control or gauge damage.

Finally, it has been suggested that pushover procedures imply a separation of structural capacity and earthquake demand, whereas in practice these two quantities appear to be interconnected.

Relatively large work done by researchers to improve the predictions of demand on the structure [7, 8, 9, 10, 11, 12& 13] took a back seat to the evaluation of capacity and was next to demand. It is mainly due to the fact that due to the lack of experimental data, the results of analysis are relied up on and considered adequate. It is true that the calculation procedures to predict the capacity curve for the structures are well understood and documented [14, 15, 16 & 17], the evaluation of capacity curve is highly sensitive to the models and procedures followed to evaluate the characteristics of the members and therefore validation with experimental results is the only way to establish the most suitable modeling techniques.

3. A Critical Review of IS 1893(Part 1)-2002

Seismic provisions are used to arrive at the design forces for earthquake resistant structures. They are formulated to reduce the seismic risk and to protect life from earthquake hazard. Seismic codes are under frequent revisions adopting the lessons learnt from failures and damage caused during earthquakes. Other than the common design philosophy based on which most of the seismic codes are formulated, database regarding local seismicity, geology and geotechnical stratification forms the basis for seismic provisions. Seismic zone map is usually the outcome of probabilistic or deterministic hazard analyses for a specified region. The risk level associated with the hazard specified in seismic zone is not clear in Indian seismic code.

Building cannot be designed for elastic behavior under earthquake load; hence reduction factors are used account for ductility characteristics of building. There are difficulties in estimation of inelastic parameters viz., ductility factors, response reduction factors and strength reduction factors for different building types, since it requires precise knowledge about the load deformation behavior under earthquake excitation. Experimental results, to certain extent, help in arriving at these numbers.

3.1. Evolution of Seismic Codes

The provisions in the standards do not ensure that structures suffer no damage during earthquake of all magnitudes. But, to the extent possible, they ensure that structures are able to respond to moderate earthquakes without structural damage and to severe earthquakes without total collapse. IS 1893(Part1)-2002 [18] meant for provisions for earthquake resistant design of structures. The seismic code aims at guidelines regarding the provisions to arrive at design base shear and lateral forces for safe design of buildings. Design depend on the mass and seismic coefficient of the structures; the later in turn depends on properties like seismic zone in which structures lies, importance of the structure, its stiffness, the soil on which it rests, and its ductility.

3.2. Risk Level

Risk level considered for the seismic zone map of the Indian seismic code is not explicitly defined in the Indian seismic code IS 1893 (Part 1)-2002[18]. Design peak ground accelerations (also known as zero period acceleration) for different seismic zones are specified; the Maximum Considered Earthquake (MCE) defined as most severe earthquake effects considered by the standard. The structures are designed for a Design Basis Earthquake (DBE) defined as the earthquake that is reasonably be expected to occur at least once during the design life of the structure. DBE is taken as half of MCE in IS 1893(Part 1)-2002.

3.3. Seismic Zone Map

The latest version of seismic zoning map of IS 1893: -2002(Part 1) of India (Figure 2) divides India into four seismic zones (Zone II, III, IV and V) and assigns four levels of seismicity in terms of zone factors as given in Table1 [18]. According to the present zoning map, Zone V experiences the highest level of seismicity where as Zone II is associated with the lowest level of seismicity. To facilitate the Consulting Structural Engineers, zone factors for some important towns are also listed in the code of practice [18]. IS 1893(Part 1)-2002 do not have hazard map in terms of spectral acceleration and spectral displacements are obtained from the response spectra.

Table 1. Seismic Zone Factors, Z as per IS 1893 (Part 1)-2002

Seismic Zone	II	III	IV	V
Seismic Zone Factor, Z	0.10	0.16	0.24	0.36

3.4. Response Spectra

IS: 1893 (Part 1)-2002 [18] has normalized spectrum common for all earthquake zones for three different types of soil as shown in Figure 3. It characterizes its spectra based on variation of spectral acceleration coefficient and time period. The flat portion of spectra represents the site periods, 0.4 s, 0.55 s and 0.67 s for hard soil (Type I), medium soil (Type II) and soft soil (Type III), respectively. The amplification factors for higher periods for the three soil types are 1, 1.36 and 1.67. The criteria to classify the site are mentioned clearly in IS 1893(Part 1)-2002 given the variation of soil profile in a particular locality. However soil types I to III are defined based on standard penetration test results (SPT N value) and the nature of soil mainly constituting the foundation.

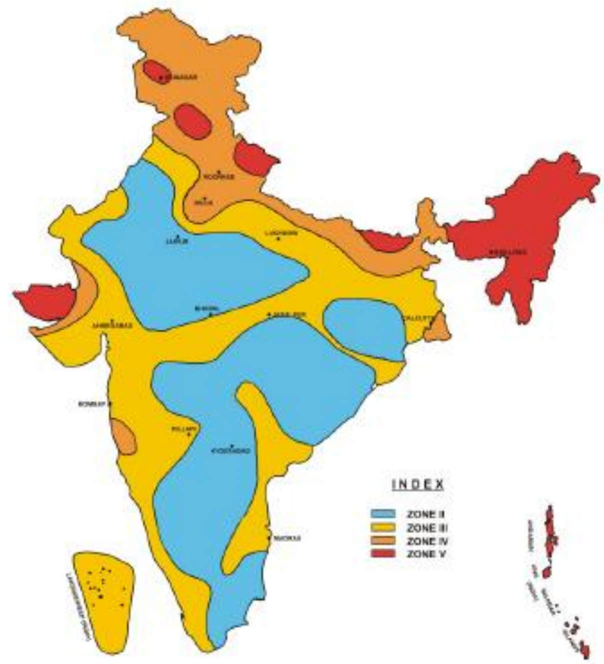

Figure 2. Seismic Zone Map of India

3.5. Soil Types

Indian provision defines three types of soil i.e. hard soil; medium soil and soft soil based only on standard penetration test (SPT) N value (Table 2) [18]. However the standard penetration test has many limitations. It is difficult to determine the appropriate value of N for layered soil and soil profiles can and will have large variations for given region. Because of the limitations of this method, it is best to use the shear wave velocity as a supplement for the standard penetration test N values.

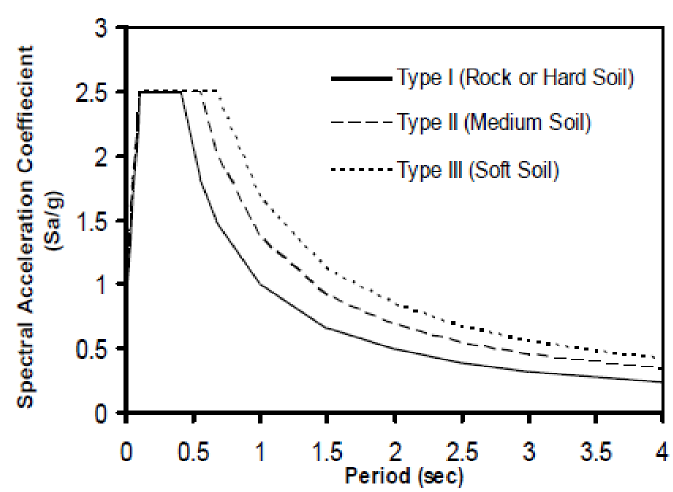

Figure 3. Response Spectra for Rock and Soil Sites for 5 % Damping

Table 2. Soil Types of IS 1893:1893(Part 1) -2002

Soil Types	**Description**
Hard Soil	Well graded gravel and sand gravel mixtures with or without clay binder, and clayey sands poorly graded or sand clay mixtures (IS 1498-1970) having SPT value, N, above 30.
Medium Soil	All soils with N between 10-30, and poorly graded sands or gravelly sands with little or no fines (designated as SP in IS 1498-1970) with N > 15.
Soft Soil	All soils other than SP with N<10.

3.6. Fundamental Natural Period

In IS: 1893-2002, the fundamental natural period is expressed by empirical expression for steel moment resisting frames, concrete moment resisting frames and fames with infill.

The time period estimated from dynamic analysis is generally higher than the time period from empirical formulae (since the contribution of infill is normally neglected). In order to account for under estimation of base shear, the response quantities are scaled up by the ratio of base shear estimated using time period from empirical formulae to base shear estimated from time period from dynamic analysis.

3.7. Ductility Provisions

The seismic reduction factor(R) in the Indian provision, is the factor by which the actual base shear force, that would be generated if the structure were to remain elastic during its response to the Design Basis Earthquake (DBE) shaking, shall be reduced to obtain the design lateral force. Ductility of a structure, or its members, is defined as the capacity to undergo large inelastic deformations without significant loss of strength or stiffness. The basis for deriving the response reduction factor value has not been stated in 1893 (Part 1)-2002.

3.8. Seismic Design Category

Indian seismic codes do not specify Seismic Design Category.

3.9. Importance Factor

On the other hand, IS 1893 (Part 1)-2002[18] specifies only one importance factor as given in Table 3. Even though the codes have different ways in determining their importance factor, they are specifying Importance Factor I greater than 1.0 for important structures. Importance Factor greater than 1.0 corresponds to structures whose failure or collapse might cause huge loss of lives, an extraordinary economic loss or a loss of irreplaceable structures, and for buildings that are essential during emergencies.

Table 3. Importance Factor for Various Types of Building-IS 1893(Part 1)-2002

Category	Importance Factor
Important service and community buildings, such as hospitals; schools; monumental buildings; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subways stations, power stations	1.5
All other buildings	1.0

3.10. Building Configuration

The simplicity, symmetry and regularity are important factors governing seismic response of structures. Modern engineered frame structures that have performed remarkably well during earthquakes have had regularity and symmetry about two orthogonal axes in plan and regularity in elevation (i.e. vertical regularity). If a building is symmetric about orthogonal axes in plan then it does not twist during the action of earthquake. If the building also has rigid floor diaphragms then all columns are subjected to the same inter-storey drifts. Whereas, those that have not performed well during earthquakes have belonged to multistoried buildings with non-symmetric and non-regular plans and/or with vertical irregularities in the form of weak and/or soft stories in elevation, buildings undergone major structural alterations-addition of floors, removal of load resisting members, and structures constructed on weak, unstable, or diverse foundation soil systems.

The Indian provision mentions that buildings having simple regular geometry and uniformly distributed mass and stiffness in plan should be categorized as regular buildings. A criterion for plan irregularities and vertical irregularities are simplified in IS 1893 (Part 1)-2002 through tables and figures. Reinforced concrete multi-storied buildings are very complex to model as structural systems for analysis. The current version of the IS: 1893-2002 requires that practically all multistoried buildings be analyzed as three-dimensional systems. This is due to the fact that buildings have general irregularities in plan or elevation or in both and this may have a detrimental influence on the effectiveness of seismic performance itself.

3.11. Equivalent Static Analysis

The procedure to determine seismic base shear (V_B) using a fundamental natural time period given in the Indian provision also depends on the weight of the building, spectral coefficient, importance factor (I) and earthquake reduction factor (R). The spectral coefficient is replaced with normalized spectral coordinate (Sa/g) and zone factor corresponding to DBE (Z/2) as given in equation.

$$V_B = \frac{Z\, S_a I}{2gR} W \quad (1)$$

3.12. Dynamic Analysis

As per IS 1893 (Part 1)-2002[18], response spectrum methods of analysis shall be performed for regular buildings of height greater than 40 m height in zones IV and V and those greater than 90 m in zones II and III. For irregular buildings with heights greater than 12m in zones II and III dynamic analysis needs to be carried out using the design spectrum or a site-specific design spectrum to account for contribution of higher modes.

According to the Indian provision, as stated earlier, base shear from response spectrum analysis needs to be compared to base shear estimated using empirical formula. If it is found less than the empirical formula, all the response quantities (member forces, displacements, storey shears, storey forces and base reactions) shall be multiplied by the ratio of base shear from empirical formula to base shear obtained from response spectrum method. This feature is introduced in the code to avoid any non-conservative design due to error in estimation of time periods due to improper mathematical modeling or negligence of stiffening elements like masonry infill.

3.13. Performance Criteria

The performance criterion in the Indian provision is based on drift limitation. The storey drift in any storey due to minimum specified design lateral force, with partial load factor of 1.0 shall not exceed 0.004 times the storey height. For the purposes of displacement requirements only, it is permissible to use seismic force obtained from the computed fundamental period of building without the lower bound limit on specified design seismic force.

3.14. The Salient Observations of IS: 1893(Part 1)-2002

Keeping in view the constant revision of the seismic zones in India, lack of proper design and detailing of structures against earthquake, earthquake performance of RC bare frame has been well documented in the past. Also, damage patterns in reinforced concrete frames during the past earthquakes have been extensively studied. The salient observations of IS1893(Part 1)-2002[18] are indicated in Table 4[19].

Table 4. The Salient Observations

Risk level	Not specified
Number of seismic zones	Four
Design Spectra	Single normalized response spectra
Soil types	Classification is based on SPT N value and soil description
Fundamental time period	Empirical
Design Basis Earthquake	Half of maximum considered earthquake
Ductility factors	Response reduction factor
Scale factor for lateral forces	Ratio of base shear from equivalent static analysis to base shear from dynamic analysis
Vertical component of earthquake	2/3 of design horizontal earthquake
Design eccentricity (e_d)	e_{di}=1.5 e_{si} +0.05 b_i or e_{di}=1.5 e_{si} – 0.05 b_i, e_{si}-static eccentricity at floor i defined as the distance between the centre of mass and centre of rigidity
P-delta effect	Nothing has been mentioned about for which type of building this effect needs to be considered

4. Design Factor of Safety

The adequacy of structures has traditionally been evaluated using a factor of safety. A structure is adequate if it can perform its intended function satisfactorily. The design factor of safety, **FS**, is the ratio of resistance, R (i.e., capacity), the maximum load under which a system can perform its intended function, and the resultant stress, S (i.e., load or demand), placed on a system under design conditions:

$$F = \frac{R\ (\text{Capacity})}{S(\text{Demand})} \quad (2)$$

If, **FS ≥1** a margin of safety exists. Structures are typically designed to a factor of safety greater than one to provide a margin of safety. The margin of safety, *Z*, is the difference between capacity and demand or resistance and load:

$$Z = R - S = \text{Capacity - Demand} \quad (3)$$

This function is known as a limit state equation or a performance function. If capacity exceeds demand, $\boldsymbol{Z > 0}$, there is residual capacity and the system is in a survival state. If demand exceeds capacity, $\boldsymbol{Z < 0}$, the system is in a failure state. The condition $\boldsymbol{Z = 0}$ is the limiting state.

4.1. Risk

For the purposes of natural hazard risk analyses, risk can be defined as

$$R = P \times I \times E \times V \quad (4)$$

Thus, the target side is also characterized by two factors: the exposure 'E' and the vulnerability V. From the definition, it is obvious that vulnerability analysis is a key part of the risk assessment for natural hazards.

4.2. Uncertainty and Risk

Uncertainty can be described as either aleatory or epistemic. Aleatory uncertainty is attributed to natural variability over space and time or to inherent randomness. Aleatory uncertainty cannot be reduced by obtaining more information; therefore, aleatory uncertainty is sometimes also known as irreducible uncertainty. Epistemic uncertainty is uncertainty attributed to a lack of knowledge. Epistemic uncertainties can, in principle, be reduced by obtaining more information, although in practice it may be very difficult, expensive, or physically impossible to do so. Uncertainty in a quantity/reality is often a mixture of aleatory and epistemic uncertainty.

The probability of structural failure is a function of both uncertainty in the capacity and uncertainty in the demand. The capacity of a structure to withstand a load is a function of its geometry and material properties. These are fixed and can potentially be known, but it may be very difficult to evaluate them. Therefore, when evaluating the reliability of an existing structure, uncertainty in structural capacity is epistemic. If the strength of materials is also a function of environmental variables such as temperature, humidity, or moisture content, these are inherently variable and the uncertainty in structural capacity is both aleatory and epistemic. Similarly, uncertainty about what loads will be exerted on a structure can be either aleatory or epistemic.

4.3. Reliability

When there is uncertainty in capacity or demand, *R* and *S* take the form of random variables, and uncertainty in these variables is described by probability distributions: F (r) R and F (s) S. In the presence of uncertainty, the state of the system (failure or survival) can only be evaluated with some probability. Reliability, **r**, is the probability that the structure is in a survival state:

$$r = 1 - p_f \quad (5)$$

The term $\mathbf{p_f}$, is the probability of failure calculated from a joint probability density function for resistance and load:

$$\mathbf{p_f = p(z \leq 0) = p(FS \leq 1) = \iint_{R \leq S} f_{RS}(r, s) dr\, ds}$$

If R and S are independent, as is often assumed, then f RS (r s) = f R (r) f S (s). The safety margin, Z, is evaluated using the limit state equation. The density function is the derivative of the probability distribution function with respect to the random variable:

$$\mathbf{f_R(r)} = \frac{\partial F_R(R)}{\partial r} \text{ and } \mathbf{f_S(s)} = \frac{\partial F_s(s)}{\partial s}$$

Hence, a risk is a potential outcome with an adverse consequence of uncertain severity. This definition includes the term "potential outcome" to indicate that a risk is an outcome that may or may not be realized in the future. The term "adverse consequence" is used to indicate that the potential

5. Format for Probabilistic Risk Analysis

Analytical derivation of a vulnerability relationship includes hazard definition, reference structure, limit state definition, analysis method, uncertainty quantification, and probabilistic simulation method, as shown in Figure 4[22]. The seismic hazard used as an input to a structure should be defined considering the seismic nature of the region where the derived vulnerability curves will be applied. Analysis methods must be chosen carefully, because an overly simplified method, such as SDOF (Single Degree of Freedom) analysis or static analysis, rather than a nonlinear response history analysis, will not properly capture structural failure.

In probabilistic performance assessment the relationship between the seismic demand and the seismic intensity has to be determined for different values of the seismic intensity measure. Usually, the top displacement is used as the engineering demand parameter and the spectral acceleration, i.e. the value in the elastic acceleration spectrum at the period of the idealized system, represents the intensity measure. Sometimes, it is convenient to use the peak ground acceleration as the seismic intensity measure.

Risk assessment is the process of obtaining a distribution of probabilities over potential outcomes. This is typically accomplished through some form of systems-level modelling. Fragility curves can also be developed to represent the probability of failure for given multiple failure modes and multiple loads.

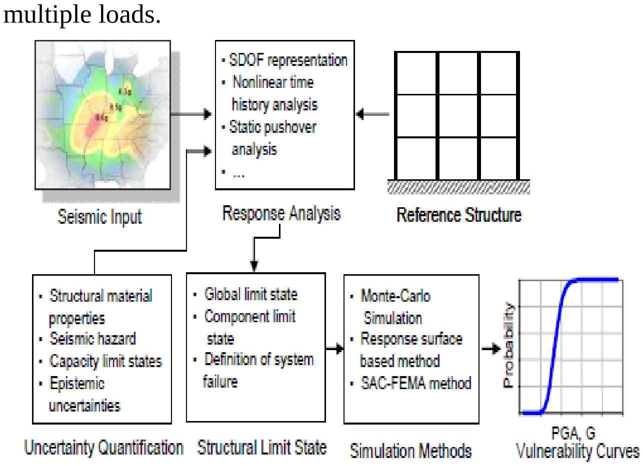

Figure 4. Components of Seismic Vulnerability Simulatio

5.1. Components of Probabilistic Risk Analysis

Seismic PRA (Probabilistic Risk Analysis) procedure has three components namely, (i) development of the site-specific input (ii) fragility analysis of structure and (iii) seismic risk evaluation of structures. Site-specific seismic input is provided in the form of response spectrum or a power spectral method of analysis is used for finding the seismic response of the structures. The power spectral density function is used as input when random vibration analysis of structures in the frequency domain is performed. The fragility analysis refers to the analysis of structures for finding their probabilities of failure for a given peak ground acceleration (PGA). Thus, the fragility curve is an indicator of risk/vulnerability of the structure associated with certain level of peak ground acceleration during earthquake. Rigorous fragility analysis is highly complex and computationally intensive. The complexity of the analysis is due to many factors such as consideration of soil structure interaction, non-linear effects in random vibration analysis, consideration of all probable failure modes and determination of failure criterion and different types of uncertainties involved in the risk analysis.

5.2. *Methodology of Probabilistic Risk Analysis*

The paper provide an analytical methodology to quantify hazard through system reliability for the probabilistic risk analysis of reference building as depicted in Figure 5 and Numerical simulation of 4-story reinforced concrete building in open sees is summarized as follows.

Step 1: Analytical Building Model

In the model, the nonlinear behavior is represented using the concentrated plasticity concept with rotational springs or distributed plasticity concept where the plastic behavior occurs over a finite length. The rotational behavior of the plastic regions in both cases follows a bilinear hysteretic response based on the Deterioration Model proposed by many researchers. All modes of cyclic deterioration are neglected. A leaning column carrying gravity loads is linked to the frame to simulate P-Delta effects [23].

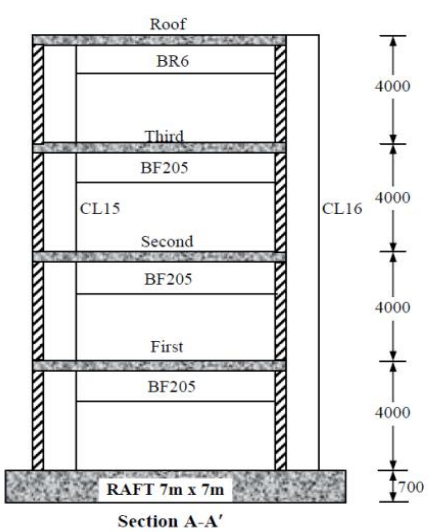

Figure 5. Overall Geometry of the Structure

Step 2: Pushover Analysis

Conventional pushover analysis is carried out to determine the ground motion intensity the building must be subjected to for it to displace to a specified inter-story drift ratio using SAP/E-TABS software's of latest version. The general procedure for the implementation of the probabilistic Capacity Spectrum Method (CSM) [24] is as shown in Figure 6.

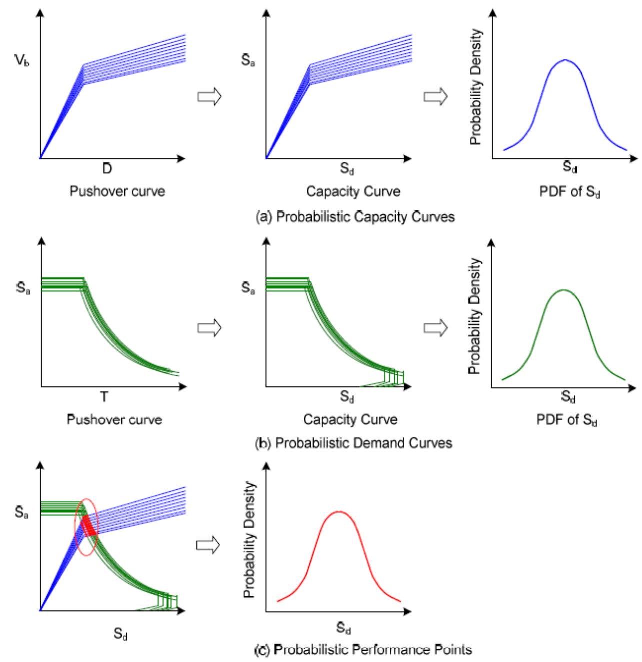

Figure 6. General procedure of the probabilistic CSM

Step 3: Define Damage State Indicator Levels (Failure Criteria and Performance Limit States)

The top storey displacement is often used by many researchers as a failure criterion because of the simplicity and convenience associated with its estimation. The limit states (immediate occupancy, life safety, and collapse prevention) associated with various performance levels of reinforced concrete frames as mentioned in FEMA 356 [17] and the damage state indicator levels are defined depending on progressive collapse starting from yielding and rotation to instability, which has been tabulated in Table 5 [25].

Table 5. Damage State Indicator Levels

Slight Damage	Hinge yielding at one floor
Moderate Damage	Yielding of beams or joints at more than one floor
Extensive Damage	Hinge rotation exceeds plastic rotation capacity
Collapse	Structural Instability

One of the most challenging steps in probabilistic risk analysis is the determination of damage parameters and their corresponding limit states. These parameters are very essential for defining damage state as well as determining the performance of RC building under a seismic event. Therefore, realistic damage limit states are required in the development of reliable fragility curves, which are employed in the seismic risk assessment packages for mitigation purposes.

Step 4: Incorporate the Uncertainty

Conduct a vulnerability analysis of reference RC building located in Zone-IV/Zone V of IS: 1893-2002 with uncertainty.

Step 5: Building Fragility Curves

Develop an analytical fragility estimates to quantify the seismic vulnerability of RC frame building

6. Conclusions

The methodology proposed and outlined in this article is for the probabilistic seismic risk evaluation of building structure, used as a guideline for seismic vulnerability assessment based on non-linear static analysis (pushover analysis) using any sophisticated software. Keeping uncertainty in consideration, probability of failure to quantify the seismic vulnerability of a given building structure may be achieved, provided failure criteria and performance limit states are known for different types of earthquakes. For the risk evaluation of building structure, normally either permissible top storey drift values based on different structural performance levels or different damage states depending on various damage indicator levels, are the main failure criterion to obtain building fragility estimates (probability of failure) in case of probabilistic risk evaluation. The salient features of IS: 1893(Part 1)-2002 codes were also discussed with respect to seismic risk of building structure in a probabilistic manner.

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