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Seismic Fragility Analysis of Regular and Vertical Setback R/C Frame Buildings

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ABSTRACT
The earthquake phenomenon represents one of the most devastating forces that causes not only loss to human life but cripples the economy of a nation as well. Hence it is necessary to study the vulnerability characteristics of structures subjected to such seismic excitations to reduce the socioeconomic impact of such a catastrophe. The study of behavior of RC structures subjected to seismic loads has always been a subject of interest owing to the large scale presence of such structures in the seismically prone areas.
In this report a brief review of seismic performance evaluation procedure of reinforced concrete buildings is presented. Capacity spectrum method (CSM) is adopted for evaluating seismic performance of reinforced concrete building for various parameters (hard, medium and soft soils) as per IS code 1893(Part 1):2002.
Further the methodologies for vulnerability assessment of different R.C buildings are presented. The applicability of HAZUS drift ratio based damage state thresholds for building designed as per IS 456-2000 code are also studied. Fragility curves were developed for buildings with setbacks on different stories and their damage probability is compared. Fragility curves were also developed for the buildings with and without infill walls and compared their damage states. The vulnerable characteristics of these buildings are analyzed and compared by developing the damage probability matrix. Setback buildings were found to be more vulnerable compared to regular building however setbacks building with provision of infill are found to perform as regular RC buildings.

I. INTRODUCTION

Background

Losses inflicted on modern buildings from recent earthquakes have shown the pressing need for investigation of the seismic safety of code-compliant buildings at various performance limit states. This need has stimulated significant research to develop methodologies for deriving fragility relationships, which are a key component in seismic loss assessment. The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to a scenario earthquake. The level of damage is directly associated with deaths, injuries, economic losses. Damage functions are to be developed to assess the damage level for given level of earthquake. The outcome of vulnerability assessment can be used in loss estimation. Loss estimation is essential in disaster mitigation, emergency preparedness. The aim of seismic performance of buildings is to estimate and depict the damage in structures due to a specified earthquake at a specific location. Various methodologies exist for estimating the seismic vulnerability and subsequent damage in seismic areas. The methodologies are used to develop various tools such as Damage probability matrices, vulnerability functions and fragility curves, from structural damages observed during earthquakes. A complete observed damage database would be necessary for developing such tools possible in high seismicity areas where post-earthquake surveys are available. In areas where the data is limited or incomplete, local expert opinion will be used to support observed data. Building modeling and non-linear structural analysis are other methods to stand in for the shortage of data. In areas without any available damage database, the information obtained in other similar areas was applied, but at the same time using an expert judgment. Accordingly, the probabilistic analysis of computer- generated structural responses, obtained by using nonlinear analysis procedures of representative buildings, has provided fragility functions.

II. LITERATURE REVIEW

General

To provide a detailed review of the literature related to assess the seismic performance of the structures in its entirety would be difficult to address in this chapter. A brief review of previous studies seismic performance evaluation of structures is presented is this section. This literature review focuses on evaluation of seismic performance of structures and past efforts most closely related to the needs of the present work.

Literature Review on Seismic Performance Evaluation

(Murat serdar kircil) the main aim of this study is to develop the fragility curves for mid-rise reinforced concrete frame buildings in Istanbul, which have been designed according to the 1975 version of the Turkish seismic design code, based on numerical simulation with respect to the number of stories of the buildings. Sample 3, 5 and 7 story building were designed according to the Turkish seismic design code. Incremental dynamic analysis were performed for those capacities, fragility curves were developed in terms of PSA,PGA and elastic spectral displacement for yielding and collapse damage levels with lognormal distribution assumption. It is observed from the fragility curves that there is an effect on fragility curve parameters due to the number of stories in the buildings. Regression analysis has been carried out to determine the relationship between the fragility curve parameter and the number of stories, and extended fragility curves were constructed with the help of the results of regression analysis. Furthermore, the maximum allowable inter-story drift ratio and spectral displacement values that satisfy the immediate occupancy and collapse prevention level requirements are estimated with respect to the number of stories of the building using constructed fragility curves and statistical methods.

(Alex H. Barbat) The seismic risk evaluation method used in this paper incorporates last generation methodologies for hazard, damage and risk estimation. They solved this problem by classifying the buildings in typological groups. The vulnerability of the different building classes is characterized by bilinear capacity spectra obtained by using CMS methods. The basic seismic hazard in the studied area is defined by 5% elastic response spectra starting from which demand 5 spectra are obtained. In this study the seismic micro zonation allows obtaining specific elastic response and demand spectra for the different soil types of the urban area. This paper concluded that Fragility curves are used to characterize the expected structural damage in a probabilistic way. Together with the performance of the building when submitted to a specific seismic action, they lead to damage probability matrices for each seismic zone which are the key result for calculating seismic risk scenarios. Here, the adopted method has been applied to Barcelona, which is a typical Mediterranean city, located in a low to moderate seismic hazard area. Capacity and fragility curves have been developed for about 97% of the residential building stock of the city, which is well represented by six building classes. Credible hazard scenarios in ADRS format have been used for the studied urban area. Significant damage is obtained for mid-rise and high-rise masonry buildings, due to the slenderness and low strength of these buildings. Reinforced concrete buildings with waffle slabs also show low seismic capacity leading to significant expected damage. Damage probability matrices have been obtained for the four seismic areas of the city, allowing development of representative risk scenarios, which are based on a complete and highly reliable database for the buildings of the city. Seismic risk scenarios have been developed based on a building-by-building analysis. These physical damage scenarios have been mapped according to different territorial or political areas of the city like districts, neighborhoods and census zones. They constitute excellent information sources and tools for risk management, emergency planning and also useful for civil protection, prevention and preparedness.

The present study deals with the evaluation of R.C buildings using inelastic method (Pushover Analysis).Pushover Analysis is Non-Linear Static Analysis, so the Load-Deformation Curve can be obtained from ANSYS. Finite Element Software ANSYS 5.4 is used to perform the Non-Linear Static Pushover Analysis and cracking pattern can also be observed in ANSYS. Cracking Pattern provides the need for Strengthening required for particular Elements. Firstly, a symmetrical building is analyzed using ANSYS for the procedure development as per ATC-40. Then, Seismic Evaluation is performed on unsymmetrical building (L-shape), which is designed in the first part as without considering seismic effect and in the second part, Analysis is carried out on the same building designed seismically as per I.S 1893:2002. This paper is concluded that

1. ANSYS can be used as an effective tool for performing Pushover Analysis. It can be used to evaluate the seismic of both new and existing structural systems.
2. If the Performance Point lies within the elastic stage, the building can said to be safe. And if Performance Point lies in in-elastic range, strengthening is required in the affected members, as can be obtained from ANSYS cracking pattern. Limiting Value of Base Shear can also be found out from the Demand and Capacity Envelopes.
3. Seismic Evaluation by Non-Linear Static Analysis exposes design weaknesses that may remain hidden in an elastic approach. Such weaknesses include excessive deformation demands, strength irregularities, and overloads on potentially brittle points, such as columns and connections.

4. The unsymmetrical Building studied shows that a lot of retrofitting is required if seismic effect is not taken into design considerations. However, in case of analysis of seismically designed building, strengthening is needed at Beam-Column Joints because ductile detailing has not been incorporated.

(Nikos D Lagaros,) The main purpose this study was to examine the effectiveness of fragility analysis in order to assess the seismic performance of multi-story RC buildings designed based on modern codes. For this reason, a parametric study was performed considering two groups of buildings. In the first example, weak ground story and short column construction features were examined, while in the second example, six different designs were obtained that implemented different values of the behavior factor. Fragility analyses were shown to be an efficient tool for assessing the behavior of a structural system. Three significant findings were observed:
(i) The probability of exceedance of the slight damage state for the design earthquake is of the same order for all three designs. On the other hand, it was found that the probability of exceedance for the fully in filled design is one and three orders of magnitude less than that of the other two designs for the moderate and complete damage states, respectively.
(ii) Similar observations were noted for the structure designed for q=1 compared to those designed for larger values of the behavior factor. More specifically, the probability of exceedance of the moderate damage state for the Dq=1 design is one order of magnitude less than that of the other Dq=3 and Dq=6 designs, while for the complete damage state, the probability of exceedance for the Dq=1 design is two and three orders of magnitude less than the corresponding probability for Dq=3 and Dq=6 designs, respectively. (iii) Furthermore, an important observation of this study can be obtained by comparing the results of the two test examples studied. Through this comparison, it was found that the behavior, in terms of limit-state probability of exceedance for the design earthquake, of the bare design obtained for q=1 is similar to that of the fully in filled design obtained for q=3.5.

(Pavan Kumar.A (2010)) This paper gives brief explanation about the performance levels and different methods used for the seismic performance evaluation of the building, and concluded that pushover is the best method for the evaluation of the building. In this paper fragility functions (curves) are used for the evaluation of the building damage. Firstly he developed a pushover curve for the four story 2d building as a reference by using default and user defined hinge properties. The pushover analysis is carried with SAP 2000. The performance evaluation of frame is carried out for three different soil conditions. Secondly, he analyzes the 3D frames and developed a pushover curves. For analysis of the 3D building he used the procedure developed by the (fajfar et al), the method uses inelastic response spectrum and nonlinear static analysis. To validate the pushover procedure model with without shear wall is considered. The pushover analysis is carried with default and user defined properties and he observed that with default properties the capacity of the structure is slightly less than the user defined properties but behavior of the structure with default and user defined properties is same. Thirdly, he considered a 3 story building with and without infill and he developed fragility curves for 3 story bare frame. Finally he took two buildings and developed a fragility curves.

(M.M. Maniyar et al.), In this study, a methodology for obtaining the seismic yield and collapse capacities for a typical non-seismic RC frame building representative of a large inventory of buildings in developing countries including India is presented. A representative non-seismic RC frame building is modeled with appropriate material properties and hysteretic behavior. A set of twenty ground motions from large magnitude earthquakes recorded at medium distances from the source is used to conduct *Incremental Dynamic Analysis* (IDA) for assessing its seismic capacity. The seismic performance of the sample building is described in terms of yield and collapse capacities, which are derived from IDA curves. The yield capacity of the structure is defined as the level of *Intensity Measure* (IM; i.e. PGA or Sa) at which the IDA curve leaves the linear path. Similarly, the collapse capacity is defined as the IM level at which the IDA curve becomes horizontal. Results of IDA runs with the 20 ground motion records are used to assess the record-to-record randomness of response. Fragility curves defined as the probability of exceeding a damage level (yielding/collapse) at various levels of IM are then plotted for these two damage levels.

Probabilistic seismic performance assessment of the sample non-seismic RC frame building which is assumed to be located in Ahmadabad, India in this study reveals the following:
1. There is approximately 5% probability of collapse at a ground motion of PGA=0.12g and Sa=0.18g. These IM values are close to that of the ground motions (N12W and N78E) recorded at Ahmadabad in the event of Bhuj earthquake. The PGA of the recorded ground motions was 0.11g and the Sa derived at the fundamental period of the typical X direction frame of the sample building was 0.17g for the N12W record and 0.24g for the N78E record. The predicted 5% probability of collapse is also in fair agreement with the observed damage of such non-seismic RC frame buildings.

2. For predicting the yielding and collapse damage states, Sa is found to be a better IM than the PGA. However, the band widths of flattened IDA curves using the two IMs were closer to each other, indicating that the difference in efficiencies of the two IMs in predicting the collapse damage state was less pronounced than for the yielding damage state. The drift demand for a specific damage measure varies with different ground motions. Being non-seismic and non-ductile, the drift capacity of the sample structure is very low. Hence, such buildings do not possess adequate ductility to resist the earthquake demands. Since the demands for yielding and collapse vary with different ground motions, assuming damage measure in terms of a predefined drift ratio or any similar EDP is not appropriate.
3. The hazard survival curve clearly shows the deficiency of this type of buildings against SE, DBE and MCE. There is no chance of survival of any of such building under probable MCE ground motions. Under probable DBE ground motions, the probabilities of surviving yielding and collapse are 30% and 75%, respectively. The probability of the building remaining elastic in probable SE ground motions is 85%. The predicted 15% probability of yielding under serviceability levels and 25% probability of collapse under design levels are deemed to be too high for modern structures. Therefore, there is an urgent need of appropriate retrofitting measures for such existing buildings to enhance their earthquake resistance over a period of time.

III. SEISMIC PERFORMANCE EVALUATION

General

In this chapter a brief review of the Intensity Measures, the Damage Measures, the methods that have been used for the performance evaluation and earthquakes considered presented in the current study.

Intensity Measures

An Intensity Measure (IM) is the reference ground motion parameter against which the probability of exceedance of a given limit state is plotted. Many IMs have been developed; each one may describe different characteristics of the motion, some of which may be more adverse for the structure under consideration. The use of a particular IM in seismic risk analysis should be guided by the extent to which the measure corresponds to damage to local elements of a system. There are two main classes of IMs: the empirical and the instrumental.

With regards to the empirical IMs, different macro seismic intensity scales are derived from mostly qualitative assessments of the damage rendered into a discrete numerical scale. Such intensity scales are: the Mercalli-Cancani-Sieberg Intensity Scale (MCS), the Modified Marcella Intensity Scale (MMI), the European Macro seismic Scale (EMS-98) etc. Macro seismic intensity scales have a wide range of applications and can be found in some fragility analyses both in the past and present; their use in detailed engineering-based assessments of fragility though, is limited.

Regarding the instrumental IMs, the severity of the ground shaking can be expressed as a value measured by an instrument or computed by processing of recorded accelerograms. The estimation of the severity of the earthquake is no longer subjective. The preferred IMs for use in building loss assessment are:

- Spectral acceleration, *Sa*
- Spectral displacement, *SD*
- Peak ground acceleration, PGA
- Peak ground velocity, PGV

These four IMs are used in building vulnerability from the last fifteen years. It is evident that for most regular structures and buildings where most of the mass participates in the first mode the *Sa* and/or *SD* are the preferred IMs. When the capacity spectrum method is used, and the performance of a structure is determined by the yielding and ultimate capacity, the full spectrum is essential. For mid-rise buildings whose fundamental periods (both elastic and inelastic) may lie in the velocity dominant portion of the elastic response spectrum, PGV may be the most appropriate IM.

Damage Measures

In the production of seismic fragility curves several Damage Measures (DM) may be used. Which of the DM is the most suitable depends on whether the seismic assessment of the members or of the building as a whole is of interest.
For the building as a whole:

- Chord Rotation
- The inter-storey drift ratio
- The global Park and Ang Damage Index (1985)
- The Softening Damage Index
- Composite DMs may be built up from the DMs of their components, taking into account the nature, importance, etc of the components as well as the statistical correlations/independence. For instance, Erduran and Yakut presented a methodology for damage assessment of in filled RC frame buildings, based on the damage suffered by the building elements. The weighted sum of the element damage was used to calculate the storey damage and from the weighted sum of the storey damage the building damage was calculated.

Seismic Performance Evaluation of Buildings

The seismic performance evaluation and retrofit of existing buildings pose a great challenge for the owners, architects, and engineers. The risk, measured in both lives and dollars, are high. Equally high is the uncertainty of where, when, and how large future earthquakes will be. The inherent complexity of concrete buildings and of their performance during earthquakes compounds uncertainty. Traditional procedures developed primarily for new construction are not wholly adequate tools for meeting this challenge.

Filiatrault et al, 1997 studied seismic behavior of two half scale reinforced concrete structures experimental and analytically. Performance based evaluation procedure provides insight about the actual performance of buildings during earthquake. The steps to be followed in seismic performance evaluation of structures and rehabilitation of structures are given below

1. Select the performance objective of the building as required by owner to achieve for given seismic hazard.
2. Review the existing building conditions by visual inspections, existing drawings, and tests on structure and perform preliminary evaluation of the building.
3. Formulate a strategy for achieving the desired performance objective for given level of seismic hazard.
4. Assess the performance of the retrofitted structure with any analysis procedures.
5. Check the performance of the structure with desired performance objective.
6. If performance objective is not achieved, formulate new strategy and assess the performance of the structure again. Do the above process till desired performance objective is achieved.

Performance Levels

Performance level describes a limiting damage condition which may be considered satisfactory for a given building and a given ground motion. Performance levels are qualitative statements of damage the structure going to experience in future prescribed earthquakes. Performance levels are described for structural components and nonstructural components. ATC 40, 1996 defines 6 levels of structural damage or performance levels and 5 levels of nonstructural damage [2]. The brief details of structural and non-structural performance levels are given in below tables

Table: Description of structural performance levels

Structural performance level	**Damage description**
Immediate occupancy(IO)	Very limited structural damage and risk to life is negligible. Vertical And lateral resisting system retains all pre-earthquakes characteristics.
Damage control	Range with more damage than IO and less than LS
Life safety (LS)	Significant damage to structural elements with some residual strength. Risk to life from structural damage is very low.
Limited safety	Range with more damage than LS and less than SS
Structural stability(SS)	Building is on verge of partial or total collapse. Significant degradation In stiffness and strength of lateral resisting system. Gravity load Resisting remains to carry gravity demand.

There is not considered (NC) option in performance level. This is option for owner weather to consider structural or nonstructural performance level. FEMA 273, 1997 defines same definitions of performance levels as described in ATC 40, 1996 but instead of structural stability (SS) FEMA 273, 1997 describes as collapse prevention (CP).

Table: Description of nonstructural performance levels.

Nonstructural performance level	**Damage description**
Operational	Nonstructural systems are in place and functional. All equipment and machinery will be in working condition
Immediate occupancy	Minor disruption of nonstructural elements and functionality is not Considered. Seismic safety status should not be affected
Life safety	Considerable damage to nonstructural elements. Risk to life from Nonstructural damage is very low.
Hazards reduced	Extensive damage to nonstructural damage. Risk to life because of collapse or falling of large and heavy items

	should be considered

Building performance level is combination of structural and nonstructural performance levels. There so many combinations of performance levels for owner to choose based on requirement. Building performance levels that commonly used are given in table 3.3. The building performance levels represented on pushover curve and load deformation curve are shown in figure

Table: Building performance levels

Building Performance Levels	**Combination of structural and nonstructural performance Level**
Operational	Immediate occupancy(S)+ Operational (NS)
Immediate occupancy	Immediate occupancy(S)+Immediate occupancy(NS)
Life safety	Life safety (S)+ Life safety(NS)
Structural stability (or) Collapse prevention	Structural stability (or) Collapse prevention (S)+Not considered

IV. Basic Safety Objective

As per ATC 40, 1996 Basic performance objective is defined as achieving life safety performance level for design earthquake (DE) and structural stability performance level for maximum earthquake (ME). As per FEMA 273,1997 guidelines basic safety objective is defined as achieving life safety performance level for basic safety earthquake~1 (BSE~1) and collapse prevention performance level for basic safety earthquake~2(BSE~2). The wide variety of building performance level can be combined with various levels of ground motion to form many possible performance objectives. Performance objectives for any building may be assigned using functional, policy, preservation or cost considerations.

V. Methods of Analysis for Seismic Performance Evaluation of Buildings

Basically two methods of analysis are available to predict the seismic performance of structures. Each method has its own advantages and limitations. The details of the two methods are given below.

VI. Elastic Method of Analysis

It is assumed that the structure will remain elastic under probable loads. So the strains and stress are linear along the depth of section. But to design a building to remain elastic for earthquake forces is uneconomical.

VII. Seismic Coefficient Method

In seismic coefficient method the maximum base shear is calculated based on the fundamental time period, importance factor, reduction coefficient. Lateral forces are distributed proportional to square of height. R factor is used to allow structure to go into inelastic to dissipate energy through yielding.

VIII. Linear Elastic Dynamic Analysis

This analysis required for Irregular buildings and Tall buildings. Dynamic Analysis can be time history analysis or response spectrum analysis. Sufficient number of modes must be considered in analysis such that total mass participation is at least 90%.Elastic Methods can predict elastic capacity of structure and indicate where the first yielding will occur, however they don’t predict failure mechanism and account for the redistribution of forces that will take place as the yielding progresses. Moreover, force-based methods primarily provide life safety but they can’t provide damage limitation and easy repair

IX. Inelastic Method of Analysis

Inelastic method of analysis incorporates material nonlinear behavior and geometric nonlinearity. Material nonlinearity is modeled using nonlinear stress-strain curve. Geometric nonlinearity is incorporated in structure by calculating secondary moment for each time step.

X. Inelastic Time History Analysis or Nonlinear Response History Analysis

In NRH analysis the reduced stiffness in nonlinear range is considered and the force deformation is not a single valued function. It depends on direction of motion as well. The inelastic time history analysis is the most accurate method to predict the force and deformation demands at various components of the structure. However, the use of inelastic time history analysis is limited because dynamic response is very sensitive to modeling and ground motion characteristics. It requires proper modeling of cyclic load deformation characteristics considering deterioration properties of all important components. Also, it requires availability of a set of representative ground motion records that accounts for uncertainties and differences in severity, frequency and duration characteristics. Moreover, computation time, time required for input preparation and interpreting voluminous output make the use of inelastic time history analysis impractical for seismic performance evaluation

XI. Nonlinear Static Analysis or Pushover Analysis

In pushover analysis the structure is subjected to monotonically increasing lateral loads until target displacement is reached. A predefined load pattern is applied and increased till yielding in one member occurs then the structure is modified and lateral loads are increased further. *Sermin et al*, *2005* [19] studied application of pushover of procedure for frame structures. He studied the effect of different lateral load patterns on capacity of structure. The pushover or capacity curve of the building is shown figure 3.1. Lateral loads are increased till structure reaches its ultimate capacity. The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis. The following are examples of such response characteristics are taken from *Krawinkler et al, 1998.*

1. The realistic force demands on potentially brittle elements, such as axial force demands on columns, force demands on brace connections, moment demands on beam-to-column connections, shear force demands in deep reinforced concrete spandrel beams, shear force demands in un reinforced masonry wall piers, etc.
2. Estimates of the deformation demands for elements that have to deform in elastically in order to dissipate the energy imparted to the structure by ground motions.
3. Consequences of the strength deterioration of individual elements on the behavior of the structural system.
4. Identification of the critical regions in which the deformation demands are expected to be high and that have to become the focus of thorough detailing.
5. Identification of the strength discontinuities in plan or elevation that will lead to changes in the dynamic characteristics in the inelastic range.
6. Estimates of the inter story drifts that account for strength or stiffness discontinuities and that may be used to control damage and to evaluate P-effects.
7. Verification of the completeness and adequacy of load path, considering all the elements of the structural system, all the connections, the stiff nonstructural elements of significant strength, and the foundation system

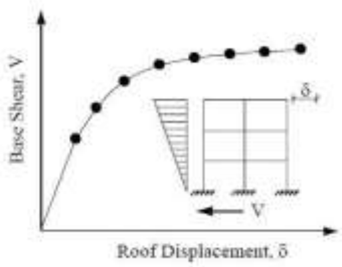


Figure:Pushover or capacity curve of the building (Sermin, 2005)

XII. Limitations of Pushover Analysis

A carefully performed pushover analysis will provide insight into structural aspects that control performance during severe earthquakes. For structures that vibrate primarily in the fundamental mode, such an analysis will very likely provide good estimates of global as well as local inelastic deformation demands. It will also expose design weaknesses that may remain hidden in an elastic analysis. Such weaknesses include story mechanisms, excessive deformation demands, strength irregularities, and overloads on potentially brittle elements, such as columns and connections. Although pushover analysis possesses a lot of advantages, it has several limitations also.

1. Pushover analysis is approximate in nature and based on static loading, so it cannot represent dynamic phenomena in large accuracy. It may not detect some important deformation modes that may occur in a structure subjected to severe earthquakes, and it may exaggerate others.

2. Limitations are imposed also by the load pattern choices. Whatever load pattern is chosen, it is likely to favor certain deformation modes that are triggered by the load pattern and miss others that are initiated and propagated by the ground motion and inelastic dynamic response characteristics of the structure. Thus, good judgment needs to be employed in selecting load patterns and in interpreting the results obtained from selected load patterns.

3. Pushover analysis will give reasonable results when the structure is vibrating in fundamental mode. But its accuracy decreases when the higher modes become important in particular structure

XIII. Estimation of In-elastic Displacement

The structure undergoes inelastic displacement for severe earthquake. Linear analysis methods cannot predict the inelastic displacement. Nonlinear response history analysis gives exact behavior of the buildings under severe earthquakes. Nonlinear response history analysis is very sensitive to ground motions and building characteristics. The other method which uses inelastic static analysis (pushover analysis) is effective way of estimating inelastic displacement.

XIV. 14. Capacity Spectrum Method

ATC 40, 1996 has developed a simple iterative procedure to estimate seismic inelastic displacement for given level of earthquake. For seismic evaluation of existing structures the procedure can be easily implemented. This procedure requires pushover curve which is obtained from nonlinear static analysis of structure. Demand spectrum has to be developed for the given site considering level of earthquake (Serviceability earthquake (SE), Design earthquake

(DE), and Maximum earthquake (ME)). This are defined based on percentage chances of probability of exceeding particular ground motion during 50 year time period. IS1893 defines two levels of earthquakes (Design basis earthquake (DBE), Maximum considered earthquake (MCE)). The procedure to estimate seismic inelastic displacement as per ATC 40, 1996 procedure is given below.

1. Develop design demand spectrum (Sa vs T) for the given site considering soil effects, level of earthquake.
2. Convert demand spectrum (Sa vs T) into acceleration –displacement response spectrum (ADRS) format.
3. Develop the capacity curve i.e., pushover curve obtained with incremental invariant lateral load pattern applied to structure until structure reaches ultimate capacity.
4. Convert capacity curve into capacity spectrum which is representation of capacity curve in acceleration-displacement response spectra (ADRS) format.
5. Bilinear representation of capacity spectrum is needed to estimate the effective damping β_{eff} and appropriate reduction of spectral demand associated with displacement dpi.
6. Calculate the effective viscous damping β_{eff} associated with maximum displacement dpi i.e. hysteretic damping represented as equivalent viscous damping plus inherent viscous damping
7. Calculate spectral reduction factors SRA, SRV which are required to reduce 5% damped elastic design response spectrum to account for yielding
8. Draw demand spectrum in ADRS format on the same plot as the capacity spectrum as shown in the figure 3.2
9. If reduced demand spectrum intersects the capacity spectrum at initially assumed displacement dpi then it is the performance point. Performance point is the inelastic displacement of the structure for the given level of earthquake.
10. If reduced demand spectrum does not intersects the capacity spectrum at initially assumed displacement dpi then assume next displacement based on judgment. Repeat steps 5 to 8 until convergence is achieved. The plot showing capacity spectrum method is given in figure

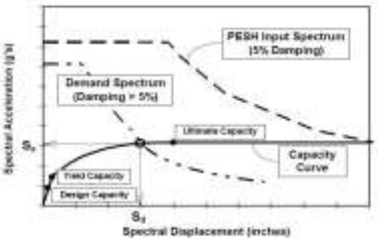


Figure :Capacity spectrum method (HAZUS MH MR 4)

XV. Seismic Vulnerability and Fragility Analysis of Buildings

Seismic Vulnerability of Building

Earthquake risk assessment is needed to estimate the casualties, losses (direct losses, economic losses, social impact) and to mitigate the risk associated. Earthquake risk is depends on hazard, vulnerability, and exposure. A significant component of a loss model is a methodology to assess the vulnerability of the built environment. The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to a scenario earthquake. There are two methods of assessing vulnerability of given building type. Empirical methods developed based on observed damage in past earthquakes. Analytical methods developed by simulation done on computer model. *Lang et al, 2002* studied seismic vulnerability of existing buildings in Switzerland. He developed analytical capacity curves for masonry building reinforced buildings. Damage grades were defined on capacity curves.

XVI. Fragility Curves of Building

Fragility curves describe the probability of damage to building. Building fragility curves are lognormal functions that describe the probability of reaching, or exceeding, structural and nonstructural 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.

The fragility curves distribute damage among slight, moderate, extensive and complete damage states. For any given value of spectral response, discrete damage-state probabilities are calculated as the difference of the cumulative probabilities of reaching, or exceeding, successive damage states. The probabilities of a building reaching or exceeding the various damage levels at a given response level sum to 100%. Discrete damage-state probabilities are used as inputs to the 23 calculation of various types of building-related loss. Each fragility curve is defined by a median value of the demand parameter (e.g., spectral displacement) that corresponds to the threshold of that damage state and by the variability associated with that damage state [3]. The typical fragility curve is shown in figure

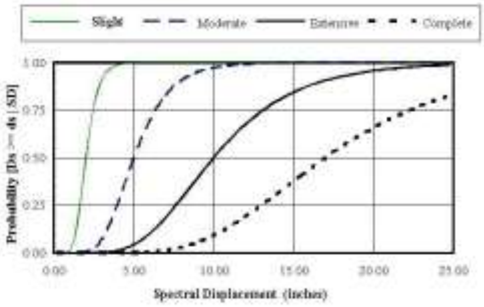


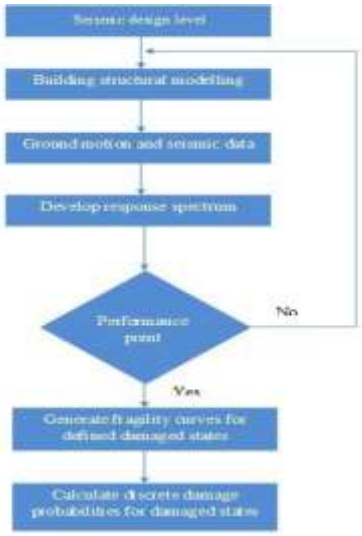
Figure: Log-normally distributed seismic fragility curves (HAZUS-MHMR1)

XVII. Building Type and Classification

Buildings are classified both in terms of their use, or occupancy class, and in terms of their structural system, or model building type. Damage is predicted based on model building type, since the structural system is considered the key factor in assessing overall building performance, loss of function and casualties. Occupancy class is important in determining economic loss, since building value is primarily a function of building use 24 Buildings are classified based on structural characteristics like number of stories as

1. Low-rise (1-3 stories),
2. Mid-rise (4-7 stories)
3. High-rise (8+ stories)

Building classification is done based on the material used for construction: steel frame, concrete frame, brick masonry burned and unburned, stone masonry and mud wall.



XVIII. Calculation of Cumulative Damage Probabilities of Particular Damage State

The damage function is assumed to be lognormal function. To define a probability distribution median and standard deviation values are required. For a given median spectral displacement Sd,ds and standard deviation β for a particular damage state ds, design level the conditional probability of being in or exceeding is defined by

$P[ds/sd] = \varphi[(1/\beta ds) \ln(Sd/Sd,ds)]$

Where,

Sd,ds=Median value of spectral displacement at which the building reaches the threshold of damage state, ds

βds= Standard deviation of the natural logarithm of spectral displacement for damage state, ds

φ= Standard normal cumulative distribution function.

Sd= Given peak spectral displacement.

P[S/Sd]=Probability of being in or exceeding slight damage state, S

P[M/Sd]=Probability of being in or exceeding moderate state, M

P[E/Sd]=Probability of being in or exceeding extensive state, E

P[C/Sd]=Probability of being in or exceeding collapse damage state, C

XIX. Calculation of Discrete Damage Probabilities of Damage States

The probability of discrete damage state ds is given below

Probability of Complete damage state P[C] =P[C/Sd]

Probability of Extensive damage state P[E] =P[C/Sd]-P[E/Sd]

Probability of Moderate damage state P[M] =P[E/Sd]-P[M/Sd]

Probability of Slight damage state P[S] =P[M/Sd]-P[S/Sd]

Probability of No damage state P[N] =1-P[S/Sd]

Table Guidelines for selection of damage state medians

Damage State, ds	Range of possible loss ratios	Probability of long-term building closure	Probability of partial or full collapse
Slight	0%-5%	P=0	P=0
Moderate	5%-25%	P=0	P=0
Extensive	25%-100%	P=0.5	P=0
Collapse	100%	P=1	p>0

In using the acceptance criteria of the NEHRP guidelines users must be aware and account for each of the following four issues.

The load deformation curve used as per NEHRP guidelines is given in figure

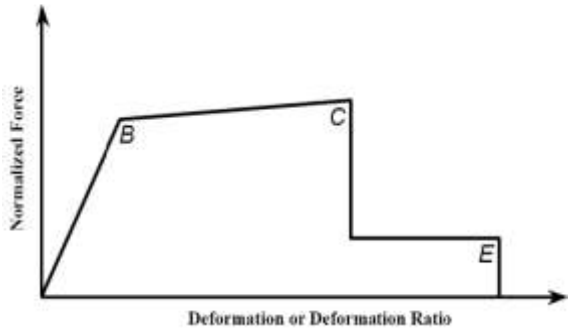


Figure:Idealized component load versus deformation curve

XX. Development of Damage State Variability βds

Lognormal standard deviation βdsvalues describe the total variability of fragility-curve damage states. Three primary sources contribute to the total variability of any given state namely, the variability associated with the capacity curve, βc the variability associated with the demand spectrum βd and the variability associated with the discrete threshold of each damage state $\beta T,ds$

$\beta ds = \{(conv[\beta c,\beta d])^2 + (\beta T,ds)^2\}^{(1/2)}$

HAZUS gives standard deviation values based on the following criteria

1. Building height group - Low-rise buildings, Mid-rise buildings, High- rise buildings
2. Post-yield degradation of the structural system – Minor, Major and Extreme degradation
3. Damage-state threshold variability –Small, Moderate or Large variability
4. Capacity curve variability –Very small, Small, Moderate or Large variability.

XXI. Modelling and Dynamic Analysis of RC Buildings

Seismic Performance Evaluation of 2D Frame

The seismic performance evaluation of building is carried for design based earthquake (DBE) as per IS 1893-2002 under three different soil conditions. The seismic performance of building is evaluated using capacity spectrum method (CSM). The intersection point of capacity spectrum and demand spectrum such that capacity equals demand is performance point. Performance point is the inelastic displacement that the structure is going experience for the given level of earthquake. A 5-storyed RC building of storey height 3 meters and bay width 4 meters is considered for the study. The details of the building are as follows. The structure is located in Zone V and it is evaluated for three different soil conditions. The material Properties are M30 Grade concrete, Fe 415 steel for the yield strength of the longitudinal and transverse reinforcement. Beam of size 300X400mm and column of 400X400mm was chosen.

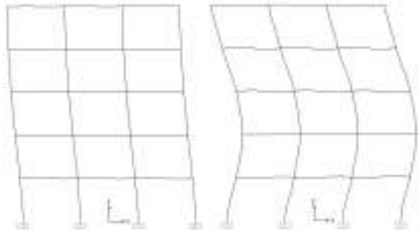


Figure:Mode shapes of the 5 storey building.

SAP2000 Calculation of Performance Point of 2D Frame

The seismic performance evaluation of the structure is carried out for three soil conditions. The performance evaluation is carried out zone V DBE level of earthquake. In Sap 2000 response spectrum as per IS 1893-2002 can be given as input parameter. The seismic performance evaluation can be performed easily in SAP 2000.

Zone V, soil type I

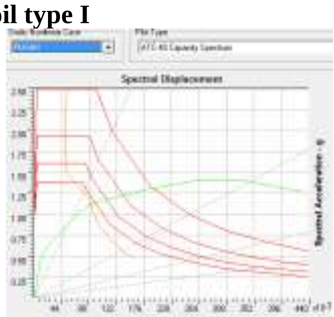


Figure :Performance point of 2D frame for zone V, DBE, soil type I

Spectral displacement =91 mm, Roof displacement =117 mm
Drift ratio =0.78% <1% (Immediate occupancy)

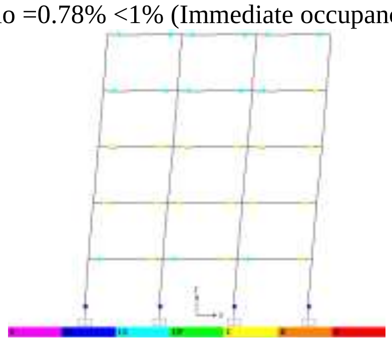


Figure:Member level performances of 2D frame for zone V, DBE, soil type I

Zone V, soil type II

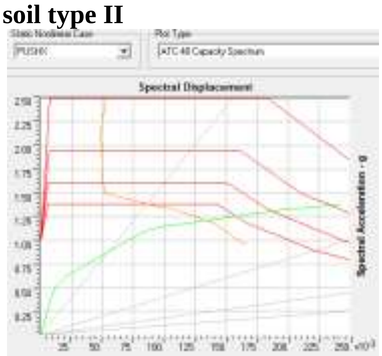


Figure:Performance point of 2D frame for zone V, DBE, soil type II

Spectral displacement =133 mm, Roof displacement =173 mm
Drift ratio =1.15% (lies between 1%-2%) (Damage Control)

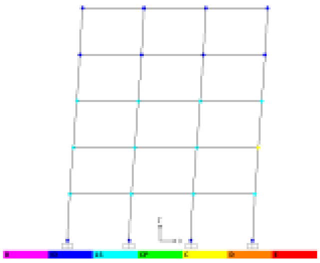


Figure: Member level performances of 2D frame for zone V, DBE, soil type II

Zone V, soil type III

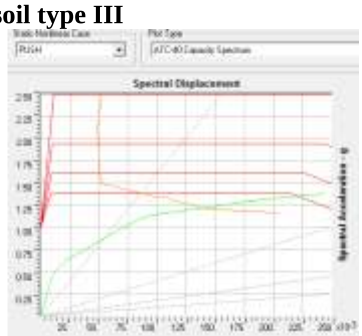


Figure Performance point of 2D frame for zone V, DBE, soil type III Fragility Analysis of R.C Buildings

XXII. Seismic Fragility Analysis with Setbacks at Different Stories

Vertical Geometric Irregularity

A structure is considered to be Vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.

The seismic fragility analysis of 10-storey bare frame is performed with vertical setbacks introduced at different stories. Fragility is defined by median value of the demand parameter (e.g., spectral displacement, roof displacement, PGA) that corresponds to the threshold of that damage state. The damage state variability values are taken from HAZUS for C1H, high code design structure. The fragility curves are developed for varied input parameters representing the damage state (Spectral displacement, roof displacement, Spectral acceleration, Peak ground acceleration). In this study fragility curves are developed considering roof displacement as demand parameter.

XXIII. Variations of Collapse Damage State Median (Sds) with Setback at Different Stories

For considering the variation in collapse damage state of median roof displacement, ten storey bare frames with setbacks at different stories are considered. All these frames are of equal storey height of 3 meters and equal bay width of 4 meters. For all these frames fragility analysis were carried out and collapse damage state medians were obtained. A graph is drawn showing the variation in collapse damage state median with setbacks at different stories.
From the graph (figure 6.2), damage state median is minimum for 5th storey setback which causes more seismic damage to the frame compared to the setbacks at remaining stories for earthquake of same intensity which will be clearly explained in the section

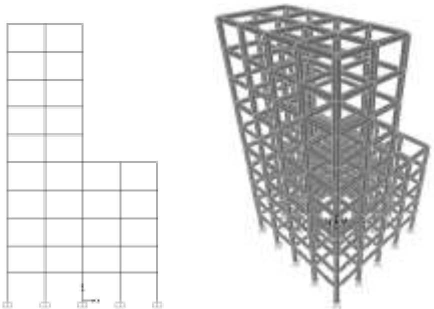


Figure:Building with Vertical setback at 6th storey

Width of top storey= 8m
Width of ground storey=16m
16/8=2>1.5 Hence, as per IS 1893, Part 1 the structures are vertically geometric irregular structure

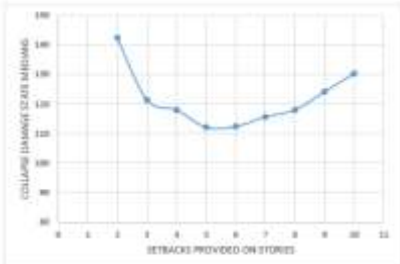


Figure: Variations of damage state medians (Sds) with setbacks at different stories

XXIV. CONCLUSIONS

Seismic vulnerability assessment for regular RC buildings and vertically geometric irregular buildings with and without infill's has been studied for various seismic intensity areas and soil conditions. The fragility curves for the above mentioned buildings have been developed for the various performance levels defined by hazes manual. Demand spectra have been obtained based on the inputs from IS1893 (part 1):2002 code for corresponding soil conditions in high seismic intensity area. Capacity spectrum has been developed for the corresponding buildings using pushover analysis and performance points are obtained from the intersection of demand spectrum and capacity spectrum using capacity spectrum method. It can be observed from the results that

1. The regular RC buildings located on soft soils have been found more vulnerable when compared to medium and hard soils due to amplification of waves in soft soil.
2. The probability of damage in RC buildings is found to be high when setbacks were introduced at middle storey compared with RC buildings with setbacks at other stories.
3. Also it is observed that setbacks introduced at middle storey of RC buildings the probability of damage is 20% more than the RC buildings without infill's.
4. Further it can be observed that RC buildings with infill walls are seismically more resistant than RC buildings without infill walls for all damage states.
5. The seismic resistance of the setback buildings having setback at middle storey can be improved similar to that of regular RC building by providing infill to the setback walls.

XXV. SCOPE FOR FUTURE WORK

1. Since adequate amount of earthquake data is not available, response spectrum analysis has been carried out for vulnerability assessment of RC buildings. The obtained results can be quantified in future by generating artificial accelerograms for the analysis.
2. Incorporating the results of seismic fragility analysis in geographic information based systems to assess loss estimation and risk estimation.

REFERENCES

[1.] Alexandra Papailia.,(2011). "Seismic fragility curves for reinforced concrete buildings", *M.Tech Dissertation,* University of Patras, Greece.

[2.] Applied Technology Council, (1996). "Recommended methodology for seismic evaluation and retrofitting of buildings." *ReportNo.ATC-40,* Redwood City, California.

[3.] Barbat A.H.,Lagomarsino S.,and Pujades L.G.,(2002). "Vulnerability assessment of dwelling buildings".projects,REN 2001-2418-C04-01 and REN2002-03365/RIES Universitat Politdecnica deCatalunya, Barcelona, Spain, University of Genoa, Italy.

[4.] Barbat A. H., Pujades L.G., and Lantada N., (2008).Seismic" damage evaluation in urban areas using capacity spectrum method: Application to Barcelona".*Soil dynamics and Earthquake Engineering*,28,851-865.

[5.] Bureau of Indian Standards. (2000). "Plain and Reinforced Concrete –Code of Practice *IS456:2000*.,"New Delhi.

[6.] Bureau of Indian Standards. (2002). "Criteria for Earthquake Resistant Design of Structures *IS1893(Part.I):2002*", New Delhi.

[7.] Chopra A.K., (2007). "Dynamics of Structures-Theory and Application to Earthquake Engineering", Prentice Hall, New Jersey.

[8.] Chopra, A.K. and Goel, R.K. (2002). "A modal pushover analysis procedure to estimate seismic demands for buildings," Earthquake Engineering and Structural Dynamics,31,561-582.

[9.] Federal Emergency Management Agency. (1997). "NEHRP guidelines for the seismic rehabilitation of buildings" *Report No. FEMA 273*, Washington, D. C.

[10.] Federal Emergency Management Agency. (2000). "Prestandard and commentary for the seismic rehabilitation of buildings." *Report No. FEMA 356*, Washington, D. C.

[11.] Ivan A., (2008). "Condition Assessment of Reinforced Concrete Buildings", *M.Tech Dissertation*, IIT Bombay, India.

[12.] Kircher C.A., Aladdin A.N., Onder K., and William T.H., (1997). "Development of building damage functions for Earthquake Loss Estimation*", Earthquake Spectra*, Vol 13, No.4, 663-682.

[13.] Kirchil M.S., and Polat Z., (2006). "Fragility analysis of mid-rise RC frame buildings", *Engineering Structures*, Vol 28, 1335-1345.

[14.] Lang K., (2002). "Seismic Vulnerability Assessment of Existing buildings", *Doctoral of Technical Sciences*, Dissertation ETH No.14446, Imperial College, London.

[15.] M. Altug Erberik., (2008). "Fragility-based assessment of typical mid-rise and low-rise buidings in turkey", Vol 30, 1360-1374.

[16.] M.M. Maniyar, R.K. Khare, R. P. Dhakal. **"**Probabilistic Seismic Performance

Evaluation of Non-Seismic Rc Frame Buildings”.

[17.] Nikos D Lagaros (2008).” Probabilistic fragility analysis: A tool for assessing design rules of RC buildings”, earthquake engineering and engineering vibration Vol.7, No.1, pg.no:45-56.

[18.] Pavan kumar “Fragility analysis of reinforced concrete building” M.tech dissertation, IIT Bombay, June 2010.

[19.] Sermin O., (2005).“Evaluation of Pushover Procedures for Frame Structures”, *PhD Thesis*, Middle East Technical University.