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Incremental Dynamic Analysis for seismic Assessment of RC Building using SeismoStruct Software

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***Abstract*—IDA is a parametric analysis which predicts absolute structural responses and performances. Analysis is perform by properly defining structural model which is subjected to a suite of ground motion records and the intensity of these ground motions are scaled increasingly using scale factors. The intensity continues to increase when the whole structural responses range from elastic to the nonlinear followed by structural collapse. In the end, a number of curves depicting the specified responses versus the ground motion intensity levels are produced. IDA performs a large number of non-linear time history analysis. Although IDA is time consuming analysis, it can provide the whole range of structural responses from elastic to collapse.**

Present study deal with existing RC Moment resisting frame located in Zone III. 12 storey structure, symmetric in plan is used to study Incremental Dynamic analysis using seismostrut-2018. SeismoStruct 2018, a finite element program is used for the analysis. IDA curves are developed with respect to spectral acceleration (Sa (T1, 5%)).

Twenty real ground motion pairs were selected and scaled in SeismoMatch 2018, then applied to the buildings to perform the Incremental Dynamic Analysis (IDA). For the development of fragility curves, guidelines given by HAZUS MH MR-4 technical manual have been used. Spectral acceleration is considered for plotting the fragility curve.

***Keywords*— Incremental Dynamic Analysis, Time history, HAZUS MH MR-4, SEISMOSTRUCT 2018, etc.**

I. INTRODUCTION

The idea of incremental dynamic analysis (IDA) was firstly proposed by Bertero in 1977 and it has been subjected to substantial development by many researchers at the end of last century and the beginning of this century. The Federal Emergency Management Agency (FEMA 2000a) adopted this analysis method and is considered as the state-of-the-art method to estimate the structural responses under seismic loadings. Developing trend of mega cities leads to increase population in the city and there are not sufficient spaces provided by large number of buildings to accommodate the increasing population. High-rise buildings address this challenge as one of the solutions for the developing countries and mega cities. In addition, high-rise buildings give aesthetic to cities and they are signs of modern development. High-rise buildings exhibit far more complex dynamic properties that require careful study and a complete understanding before they can be confidently resided in. Reinforced Concrete (RC) is a common building material which have been used to construct high-rise buildings for several decades. Earthquakes are one of the most hazardous natural disasters that attacks human and cause large damages especially in regions where defined as high-seismic zone by geologists.

Various static and dynamic analysis method were proposed for seismic analysis. Although seismology has been continuously advancing during the century, it is not possible to predict future earthquakes' severity and time of attacking. Therefore previous earthquake data are still widely used to analyze buildings resulting in robust buildings for future earthquakes.

In addition to uncertainties in seismic loads, uncertainties associated with building material, design process, building geometry, and construction will also lead to the use of probability to predict building responses. Fragility curve assessment is one of the probabilistic methods which shows the conditional probability of exceeding a certain damage level. Fragility assessment has been widely adopted in earthquake engineering to understand the seismic performance of different building

To prevent the seismic risk, it is necessary to assess the vulnerability of existing structures. To do that, several methods have been proposed, starting from different approaches. One of the tool used to evaluate the performance of structures against seismic actions is the Incremental Dynamic Analysis (IDA) proposed by Vamvatsikos & Cornell.

The main aim of IDA is to obtain a measure of damage in the structure by increasing the intensity of the action record, in this case the peak ground acceleration. IDA allows obtaining the dynamic response of a structure for increasing seismic actions.

The main result of this work is the quantitative assessment of the expected randomness of the structural response, defined by its fragility curves.

II. LITERATURE REVIEW

Vamvatsikos D. and Cornell C. (2010) studied application of Incremental Dynamic Analysis to Performance-Based Earthquake Engineering (PBEE) and used it to define limit states such as immediate occupancy, collapse prevention.

Gaikwad et al. studied performance of incremental dynamic analysis of structures using SAP 2000 subjected to several scaled ground motions scaled using SEISMOMATCH 2018.

Marra et al. used discrete rigid blocks interacting through nonlinear elastic damageable interfaces to model the global behaviour of a medieval masonry tower under seismic actions. The seismic vulnerability assessment is carried out by nonlinear static analysis (NSA) and incremental dynamic analysis (IDA), whose results are compared.

Rojit Shahi et al presents findings from an investigation which was aimed at determining what ground motion parameters are most suitable for use as IM whilst allowing the frequency content of the earthquake to vary in an IDA.

Hosseinpour et al. studied aim to overcome previous limitations and derive fragility curves for three RC (reinforced concrete) buildings with different number of stories under multiple earthquakes.

Melani et al. determined financial risk assessment on the basis of results of incremental dynamic analysis (IDA) of reinforced concrete frames analysed using nonlinear time history analyses on IDARC platform with a suite of 20 ground motion records used by Vamvatsikos and Cornell (2002) for mid-rise buildings

Seung -Wori Lee et al. proposes the procedure to estimate seismic fragility curves using an incremental dynamic analysis (IDA) rather than the method adopting a Capacity Spectrum Method (CSM).These is because IDA method can properly capture the structural response beyond yielding rather than the CSM and can directly calculate higher mode effects

III. SYSTEM DEVELOPMENT

A. Steps involved in Incremental Dynamic Analysis

1 Modeling of the building
2 Selection of intensity measure of earthquake like spectral acceleration, Peak ground acceleration
3 Selection of response measure like inter-storey drift ratio, base shear
4 Selection ground motions according to zone the building is situated in.
5 Generation of IDA curves by interpolation.
6 Plotting of Fragility Curves by HAZUS MH MR-4 technical manual.

B. Incremental Dynamic Analysis of G+11 story building and loading Details

A. Building Description

Floor Height = 3.06m
Column Dimension = (700x700) mm
Beam Dimension = (300x500) mm
Slab thickness = 110 mm
Building Location = Zone III
Boundary Condition = fixed on ground
Material properties = M25, Fe415
Size of Column 700X700 steel 4#20,
Size of Beam 300X500 steel 3#16 at top, 3#16 at bottom

B. Material used

SEISMOSTRUCT has eleven material models ranging from concrete, steel, fibered reinforced plastic to shape memory alloy. In this research, the nonlinear steel and nonlinear concrete models were used to model the RC buildings.

C. Load Applied on building

Live Load = 2KN/m2
Floor Finish = 1 KN/m2

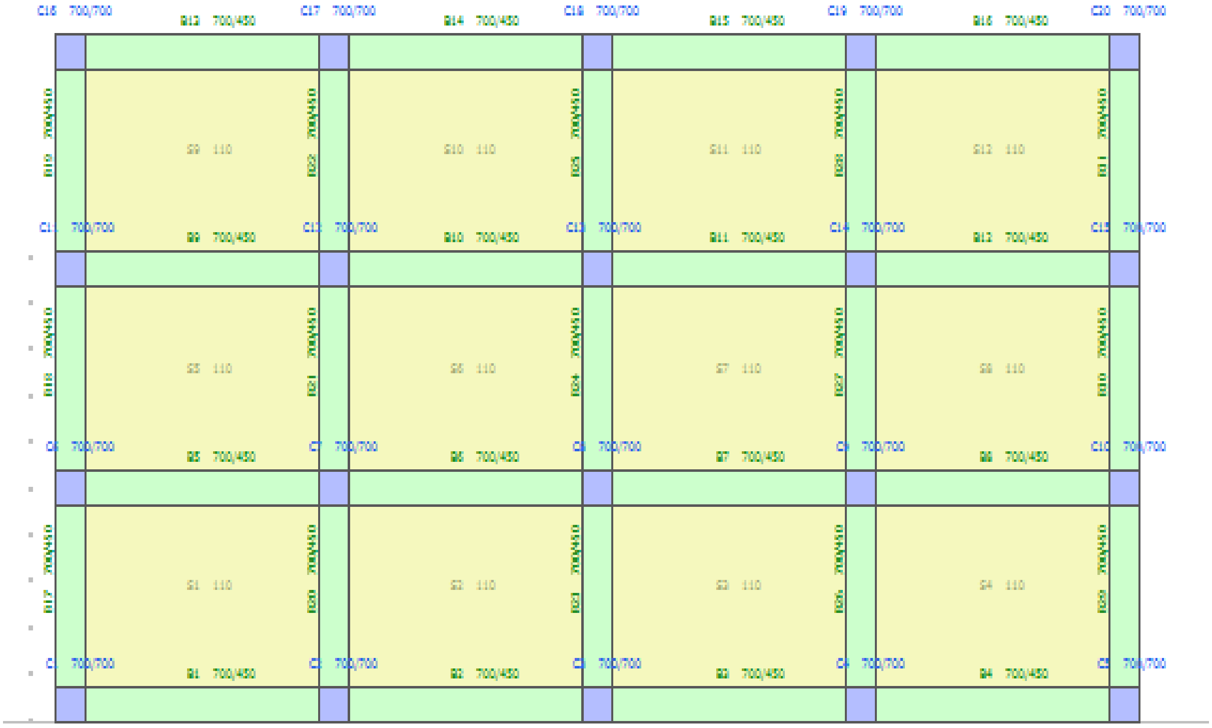

Fig 3.1 Plan of G+11 building (SeismoBuild Model)

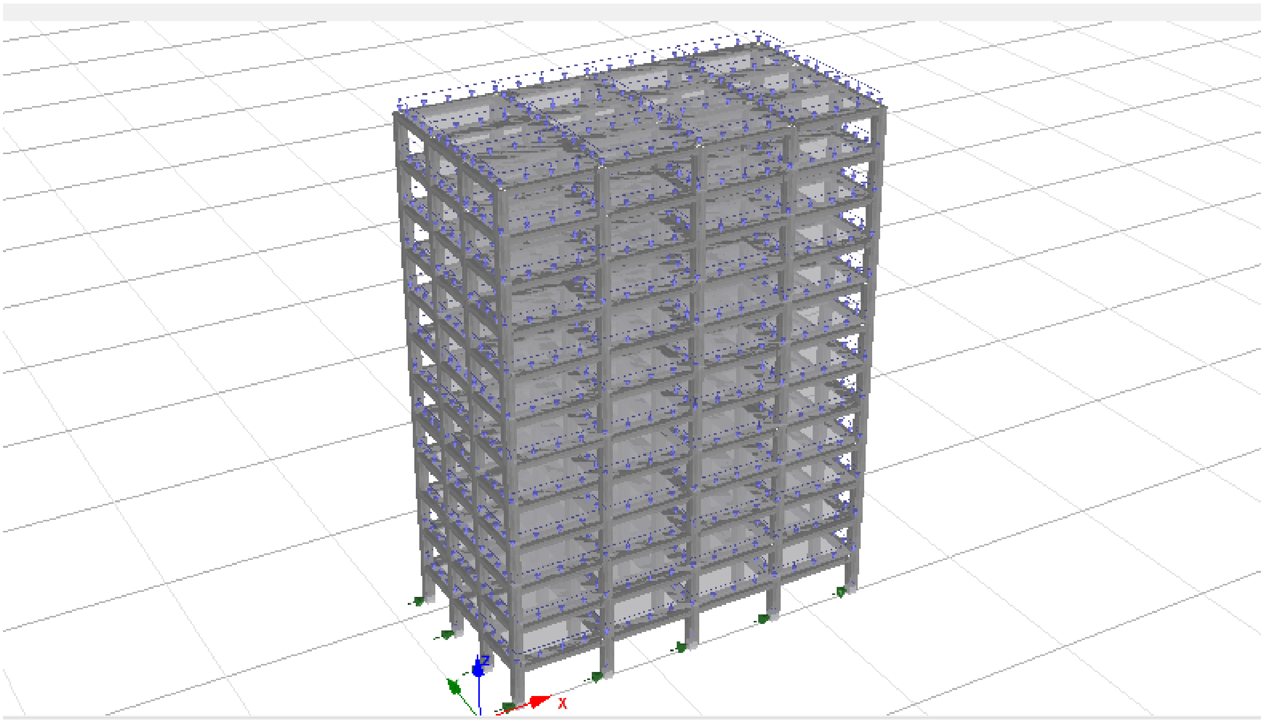

Fig. 3.2 Model of the building SeismoStruct model

D. Incremental Dynamic Analysis

In this chapter, building capacity is found out by using incremental dynamic analysis. Graph of spectral acceleration to maximum inter-storey drift from incremental dynamic analysis is plotted.

Time History used for analysis are listed below

TABLE I
CHARACTERISTICS OF THE SELECTED NATURAL GROUND MOTIONS

Eq No.	Earthquake Event	Event Date	PGA (g)	PGV (cm/s)
1	Big-Bear	28-Jun-1992	0.077	7.879
2	Palm-Springs	8-July-1986	0.101	8.64
3	Coalinga	2-May-1983	0.133	10.707
4	Whittier	1-Oct-1987	0.150	6.739
5	Coalinga	2-May-1983	0.173	18.264
6	Parkfield	27-June-1966	0.202	14.12655
7	Coalinga	2-May-1983	0.224	27.881
8	Northridge	17-Jan-1994	0.251	21.363
9	Loma-Prieta	18-Oct-1989	0.281	33.46
10	Northridge	17-Jan-1994	0.310	14.044
11	Imperial-Valley	15-Oct-1979	0.332	66.469
12	Imperial-Valley	15-Oct-1979	0.349	79.25
13	Parkfield	27-June-1966	0.375	17.806
14	Parkfield	27-June-1966	0.418	89.46
15	Parkfield	27-June-1966	0.429	113.112
16	Imperial-Valley	15-Oct-1979	0.438	51.48
17	Imperial-Valley	15-Oct-1979	0.473	41.145
18	Parkfield	27-June-1966	0.503	26.847
19	Northridge	17-Jan-1994	0.528	42.206
20	Parkfield	27-June-1966	0.565	31.798

E. IDA Curve

IDA curve visualizes the structural responses and shows structural behaviour subjected to ground motions. Buildings have different IDA curve shapes depending on their capacities (i.e. strength, stiffness, ductility) to resist seismic loads. In addition, researchers choosing different IM and DM values based on their research objectives, will resulting in different IDA curves.

Collapse of the IDA curves having hardening property is calculated from end part of the curve which become flat line. Finally, the IM values at collapse and different damage values indicates the seismic capacity of a building model. For example, curve (a) has the lowest value of IM and curve (d) has the highest value of IM among the four curves shown in Fig 3.2

Performance level or limit state of the IDA curves is an important part in assessing building seismic response. Buildings are usually evaluated at the limit states of the IDA curves and the fragility curves are constructed based on those limit states. Limit states are defined as collapse, immediate occupancy or other limit states depending on the performance type.

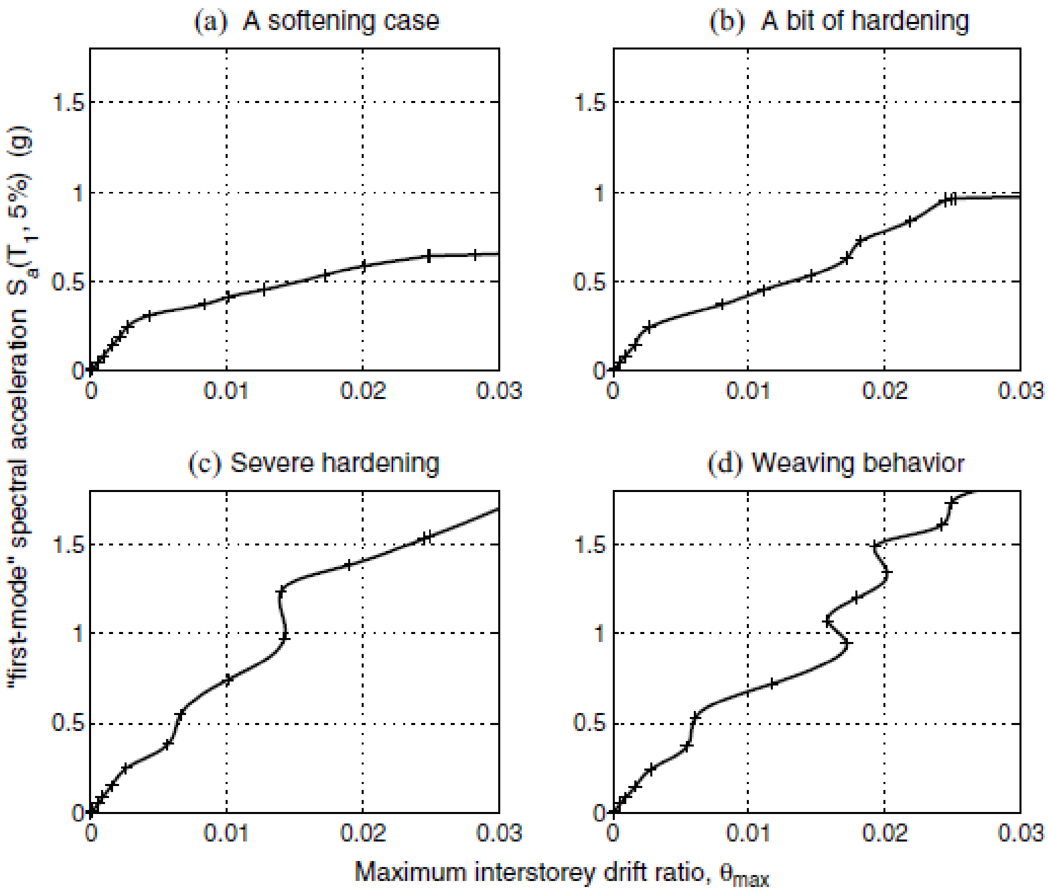

Fig 3.3 Four different behaviour of IDA curves (Vamvatsikos and Cornell,2005).

F. Fragility Curve

Fragility curve is defined as the conditional probability which exceeds a specified limit state and evaluates seismic vulnerability of the structure. Fragility curve shows the probability of structure damage as a function of ground motion intensity measure (IM) such as Peak Ground Acceleration (PGA), spectral acceleration at the fundamental building period with 5% damping 1 (T1,5%) or any other intensity measures. Fig 4-1 shows an example of a fragility curve. Fragility curve can be expressed as:

$$f_{DS}(IM) = P(DS/IM)$$

Where,
IM = the ground motion intensity measure.
DS = the damage state.
P= the probability of exceeding a damage level.
In this study, the analytical fragility curve method was used to develop fragility curve using IDA.

Procedure for Creating Fragility Curve
In this study, the following procedure was used to create the fragility curves
1. Analyze the building models using the IDA and create the IDA curves for the sixteen ground motions in both directions. Determine the value of IM which are
Sa (T1, 5%) of the building responses from the IDA curves of the 16 ground motions and these values are used as the ground motion parameters in the fragility curve (i.e. horizontal axis).
2. To obtain the fragility curve assumption (i.e. all variables log normally distributed), natural logarithmic shall be taken Ln(X) for ground motion parameters.
3. Calculate the mean and the standard deviation for Ln(x)

$$\lambda = \frac{\sum_{i=1}^{n} Ln(xi)}{n}$$

$$\xi = \sqrt{\frac{\sum_{i=1}^{n} (Ln(xi) - \lambda)^2}{n-1}}$$

Where,
λ = mean of *Ln(x)*.
ζ = standard deviation of *Ln(x)*.
x = ground motion parameters could be Sa (T1, 5%), base shear or any IM of IDA curve.

4. Calculate *s* of the lognormal data

$$s = \frac{Ln(x) - \lambda}{\xi}$$

5. Apply the standard normal distribution for the probability function and CDF which is denoted as Φ

$$P(\leq D) = \emptyset(s)$$

6. Plot fragility curve between probability as vertical axis and IM as horizontal axis.
IDA of G+11 building is carried out in SeismoStruct. IDA curves are plotted for applied time histories. Generalized graph of both the buildings is also plotted. Yielding stage and collapse stage with respect to peak ground acceleration are determined for both the buildings.
Lastly, fragility curves denoting the extent of yielding and collapse with respect to peak ground acceleration is plotted.

III. RESULT AND ANALYSIS

In this study, incremental dynamic analysis is used to study the performance based analysis of the structure. First, the buildings are designed in SEISMOSTRUCT. Load combinations given in IS 1893-2000 are considered for the earthquake resistant design of building. While carrying out incremental dynamic analysis, number of time histories are applied. Response of the structure like inter-storey drift ratio, base shear is found out for the scaled time histories. IDA graph of spectral acceleration to inter-storey drift ratio (%) is plotted for every time history applied.
Given below are some Single Record IDA curves and Multi Record IDA curve where multi-record IDA curve is a collection of single-record IDA curves for a single building obtained from different ground motions, which are all parameterized on the same IM and DM

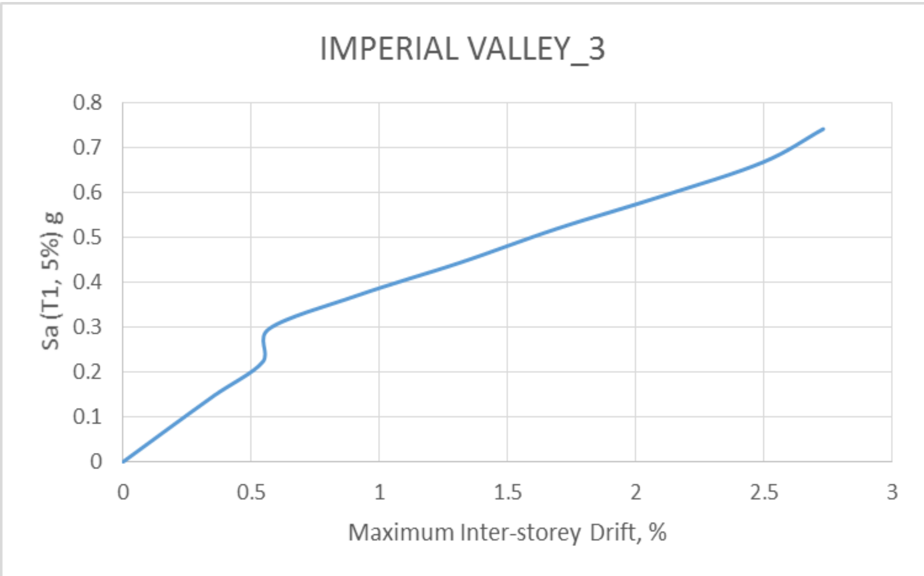

Fig 4.1 Single Record IDA curve of Imperial Valley

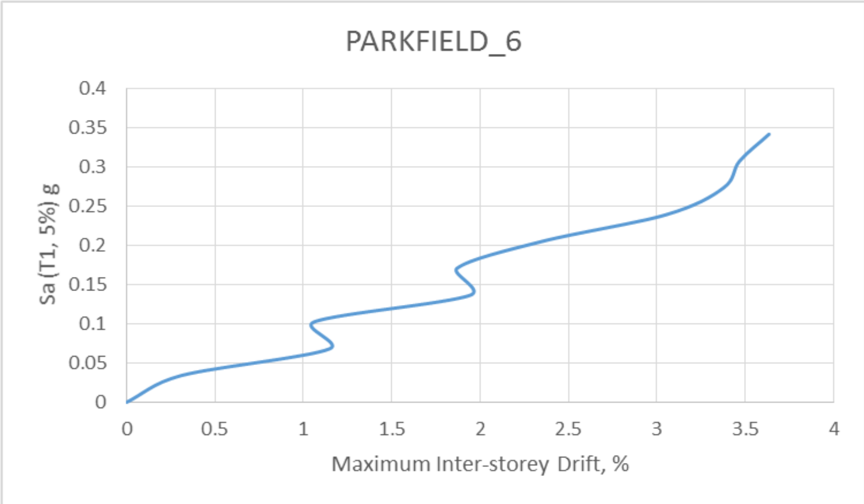

Fig 4.2 Single Record IDA curve of Parkfield

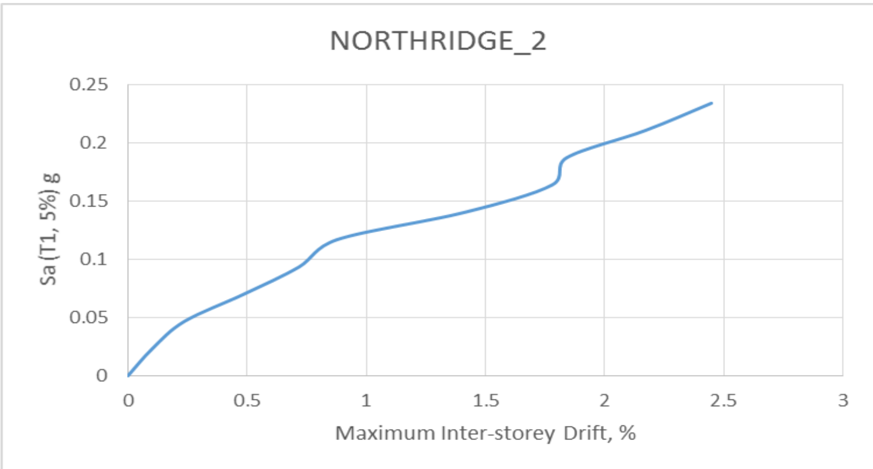

Fig 4.3 Single Record IDA curve of Northridge

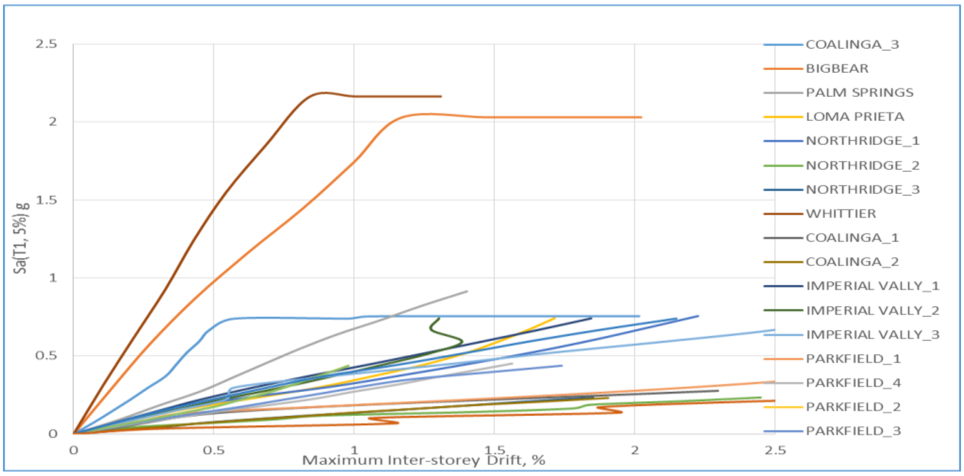

Fig 4.4 Multi-record IDA curve of 20 ground motions

Softening case means building collapses at smaller value IM and it has larger DM i.e. maximum inter-story drift. In contrast, hardening means that IDA curve in the nonlinear region weaving which means DM value increased and decreased by increasing IM**.**

In above plot of Multi-record IDA curve, curves are weavy in nature in nonlinear region which clearly shows that hardening is reached by building

Fragility curves denoting the extent of yielding and collapse with respect to spectral acceleration are also plotted. Three limit state of 0.2, 0.5 and 1% is used to calculate fragility curves.
Building susceptibility i.e. whether the building can sustain the considered earthquake or nor is found out using IDA.

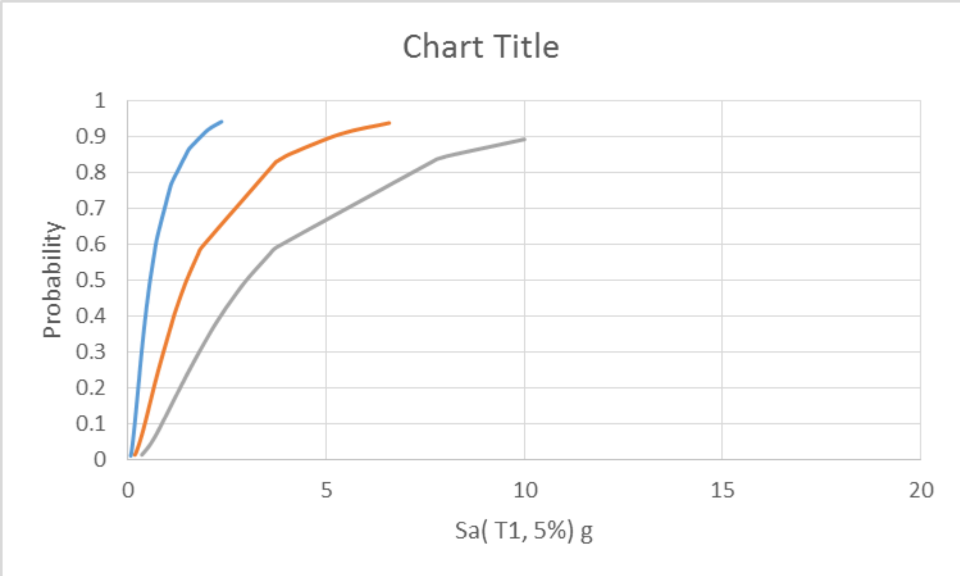

Fig 4.5 Fragility curves of 20 storey RC Building at different Limit states.

Following are the observations and conclusions that can be drawn from the study

1. Observations

1. IDA curve helps in studying the behavior of building under a particular earthquake and define the performance stages of the structure such as yield and collapse.
2. For the G+11 building considered in this study, building is safe from all the earthquakes except Parkfield, Big-Bear, and Whittier. If the yield and collapse acceleration of the structure for the considered earthquake is more than the original un-scaled acceleration, we can say that building sustains the considered earthquake.
3. Fragility curves denoting percentage of yielding and collapse for G+11 building is plotted. These curves denote the percentage of yielding and collapse with respect to spectral acceleration of the considered earthquakes.

V. CONCLUSION

Building susceptibility can be easily studied using incremental dynamic analysis. We can find out whether the building can fail to the considered earthquake or not. If building is failing to the considered earthquake or failing to satisfy the criteria of serviceability, stiffness of the structure needs to be increased by increasing column dimensions.
Incremental dynamic analysis is accurate than other analysis methods because response of the structure is plotted by applying actual available earthquake data. So, response obtained from building in incremental dynamic analysis is actual response from the considered earthquake. If the structure is of much importance like critical structure and high accuracy is needed, then only incremental dynamic analysis should be preferred as Incremental dynamic analysis is tedious and very much time consuming than other available methods.

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