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Seismic Vulnerability Assessment of R.C. Structure and Incremental Dynamic Analysis

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ABSTRACT - Incremental Dynamic Analysis (IDA) is a computational analysis method. The structural model of a RC building is treated with a suit of ground motions and using the scale factors intensity of ground motion is increasingly scaled. As much as the intensity increases the structure responds from elastic to nonlinear followed by structural collapse. Afterwards at the results lot of curves are generated. These curves represents the ground motion intensity levels versus the specified responses.

IDA executes a more no. of non-linear time history analysis. IDA requires more time for the analysis. But though range of structural responses from elastic to collapse are generated from IDA.

This research work focused on dealing with ZONE III placed RC MRF. The software used is SEISMOSTRUCT-2018 which is a finite element software used for the analysis. The structure used is a 12 storey, symmetric in plan structure, for the study of IDA. For spectral acceleration IDA curves are produced. There is selection of suit of twenty ground motion records. These ground motion records were then selected and scaled in SeismoMatch2018. Then these are applied to the buildings to perform the IDA in SEISMOSTRUCT 2018. For plotting of the fragility curves, spectral acceleration has been used. Guidelines of HAZUS MH MR-4 technical manual have been used for production of fragility curves.

KEYWORDS: Time history, Incremental Dynamic Analysis, SEISMOSTRUCT 2018, HAZUS MH MR-4

I. INTRODUCTION

IDA is a computational analysis method of earthquake engineering for performing a comprehensive assessment of the behavior of structures under seismic loads. Simulated building seismic responses obtained from IDA are represented by IDA curves that require a series of non-linear time history analysis with a suite of ground motions, during which the ground motions' intensities are increased using a specified scale factor. Therefore, IDA provides the buildings' seismic behavior for the whole range from elastic to collapse.

IDA is a parametric analysis method. It involves subjecting a structural model to one (or more) ground motion record(s), each scaled to multiple levels of intensity, thus producing one (or more) curve(s) of response parameterized versus intensity level. To establish a common frame of reference, the fundamental concepts are analyzed, a terminology is proposed, suitable algorithms are presented, and properties of the IDA curve are looked in for both single-dof and multi-dof structures. Also the summarization techniques for multi-record IDA studies and the association of the IDA study with the conventional static pushover analysis and the yield reduction R-factor are discussed. Finally, in the framework of performance-based earthquake engineering, the assessment of demand and capacity is viewed through the lens of an IDA study. (Vamvatsikos and Cornell 2002)

IDA was first given by Bertero in 1977 and at end of last century and at beginning of this century it has been subjected to sustainable development by researchers. This analysis method was adopted in the Federal Emergency Management Agency(FEMA2000a) and it is the state-of-art-method to predict the structural responses under seismic loadings. India as a developing country has the increasing population in the city and hence to accommodate the increasing population there is not sufficient space provided by the buildings.

This challenge is addressed by high-rise buildings as one of the remedies for mega cities and developing countries. Also high-rise buildings are sign of modern development and has aesthetics value for cities . Far more complex dynamic properties are exhibited by high-rise buildings which requires a complete understanding and thoughtful study before they can be confidently resided in. Now a days for several decades Reinforced concrete (RC) is a frequently used building material used to construct high-rise buildings. Amongst one of the most hazardous natural disaster is earthquake . They cause large amount of damage to humans and also in region which are defined as high-seismic zone by geologists. For seismic analysis various static and dynamic analysis methods were proposed.

Technology now a days has been developing very fast . Also seismology has been continuously advancing with this technology in this century , but though we are not able to estimate the future earthquakes , intensity of the attack and the time of attacking .Hence as a result old earthquake data are yet used for analyzing the buildings which results in robust buildings for earthquakes to happen in time to come.

Also there is ambiguous situation in design process. Same ambiguous situation is present in seismic loads , building material , building geometry and construction process which leads to use of probability for prediction of building responses. For evaluating behavior of structure under seismic action one of the method used is the IDA proposed by Vamvatsikos and Cornell. Different fragility curves are obtained as the result from this work. It obtains this result by gaining dynamic response of the structure for increasing seismic actions in this case the peak ground acceleration.

II. LITERATURE SURVEY

Wasekar S. B. , Chaudhari D. J described the vulnerability assessment of RC buildings .Guidelines given by Cornell (2002) have been used for that purpose. For the analysis, the RC buildings were modeled in ETABS 2015. Fragility Curves are generated and the time history analysis is carried out as per the FEMA P-58 guidelines. Fragility curves are then plotted after that vulnerability curve is generated as a result of time history analysis.

Vamvatsikos D. and Cornell C. performed the incremental dynamic analysis of 9 storey steel moment resisting frame. Twenty different time histories are applied to the structure to carry out IDA. Application of Incremental Dynamic Analysis to Performance-Based Earthquake Engineering (PBEE) is studied and limit states such as immediate occupancy, collapse prevention are defined.

Marra et al. used discrete rigid blocks interacting through nonlinear elastic damageable interfaces to model the global behavior 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. In addition, the non-dimensional horizontal-displacement threshold of 0.6% proposed by some building codes for existing masonry structures is aligned with NSA results and underestimates the capacity of the structure obtained by IDA.

Melani et al. determined financial risk assessment on basis of results IDA of reinforced concrete frames analyzed using NTHA on IDARC platform with a suite of 20 ground motion records used by Vamvatsikos and Cornell (2002) for mid-rise buildings. Results are interpreted to develop cumulative distribution functions for frames. Fragility curves are plotted for HAZUS damage states of conventional structures. Fragility curves thus drawn are for estimation of the expected annual loss (EAL) of low rise RC frames using quadruple integral formula based on probabilistic financial risk assessment framework.

III. METHOD OF ANALYSIS AND PROPOSED WORK

i] Stages of project work :

- a) Selection of the model of the building
- b) Design model in seismostruct
- c) Choosing IM (Intensity Measure) value ex: Peak ground acceleration , spectral acceleration
- d) Getting result in the form of inter-storey drift using IDA
- e) Ground motion records selection
- f) IDA curves creation
- g) By HAZUS MH MR-4 technical manual plot the fragility curves for the designed frames by performing IDA .



ii] Loading details :

- Live load = 2.5 kN/m²
- Floor finish = 1.5 kN/m²
- Dead load on slab = 0.110 X 25 X 1 = 2.75 kN/m²
- Total distributed load = 6.75 kN/m²
- Total load = 6.75 X 6 X 4 = 162 k N
- Load on innermost nodes = 40.5 X 4 = 162 k N = 16.2 ton
- Load on corner nodes = 162/4 = 40.5kN = 4.05 ton
- Load on outer nodes = 40.5 X 2 =81 k N = 8.1 ton

iii] Material details :

Material Properties	
Grade Of concrete	M25
Steel	Fe500

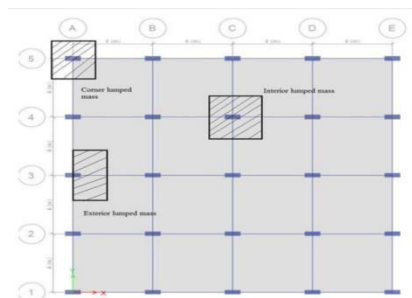


Fig.1.1 : Slab weight and live load carrying area to calculate lumped Mass

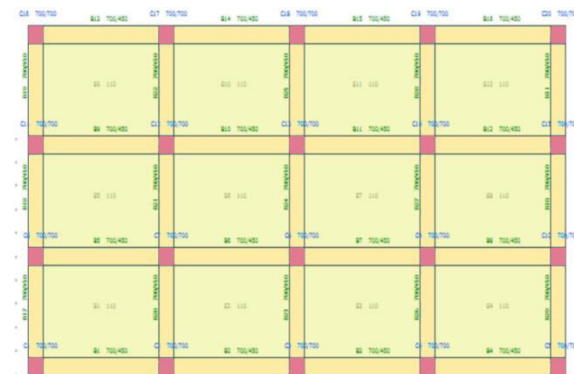


Fig. 1.2 : Plan

v] IDA (Incremental Dynamic Analysis) :

A graph of DM versus IM is called IDA curve. IDA curve can be plotted in two or more dimensions depending on the IM and at least one of them must be scalable. There are 2 types of IDA curves :

- a) Single record IDA curve
- b) Multi record IDA curve

- Steps Performed :
- 1) Building capacity is found out by using Incremental Dynamic Analysis
 - 2) Spectral acceleration to maximum inter storey drift graph from IDA is plotted.

There is selection of natural ground motions during this process. The time history data used for analysis can be given as follows :



Table 1.1 : Characteristics of the Selected Natural Ground Motions

Sr. 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	14.126 55
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	ImperialValley	15-Oct-1979	0.332	66.469
12	ImperialValley	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	ImperialValley	15-Oct-1979	0.438	51.48
17	ImperialValley	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

vi] IDA curves :

The structural response is visualize by the IDA curve and this IDA curve shows the structural behavior subjected to the ground motions. Depending on different building capacities (i.e. stiffness , strength , ductility) , these buildings have different IDA curve shapes to resist the seismic loads. Also the research work choosing distinct IM and DM value based on their objective will result in distinct IDA curves. When the end part of curve becomes flat line , collapsed IDA curve having hardening property is calculated from it. Also the IM value at collapse and the different damage values states the seismic capacity of the building model .

One of the main thing in assessing building seismic response is performance level or limit state of the IDA curves. Usually buildings are assessed at the limit states of the IDA curves and then the fragility curves are produced based on those limit states. There are 4 different types of IDA curves for four different behavior of softening to hardening .

vii] Fragility curve :

Fragility curve is mainly defined as the conditional probability which exceeds a specified limit state and examines 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.1.4 shows an ex. of a fragility curve. Fragility curve can be expressed as:

$$fDS (IM) = P (DS/ IM)$$

Where,

IM = the ground motion intensity measure.

DS = the damage state.

P= the probability of exceeding a damage level.

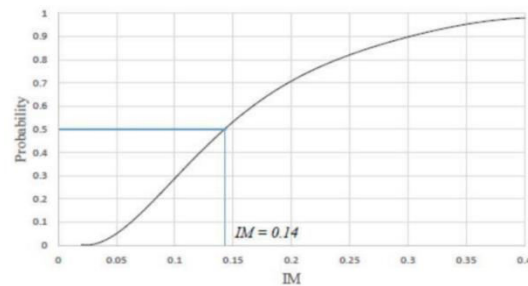


Fig. 1.4 Fragility curve of collapse limit state shows the way of Determining the probability of 50% of collapse . The probability from 0% to 100% of collapse may be determined from the curve.

Steps for creating fragility curve :

- 1] With the use of IDA(Incremental Dynamic Analysis) , analyze the building models.
- 2] Produce IDA curves for sixteen ground motions in both directions.
- 3] Determine the value of IM which are Sa(T1 , 5%) of the building responses from the IDA curves of 16 ground motions and these values are used as ground motion parameters in this fragility curves (i.e. horizontal axis) .
- 4] To obtain the fragility curve assumption (i.e. all variables log normally distributed) , natural logarithmic shall be taken Ln(X) for ground motion parameters.
- 5] Calculation of the mean and standard deviation for Ln (X) :

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

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

where ,

λ = mean of Ln(x)

ξ = standard deviation of Ln(x)

x= ground motion parameters could be Sa(T1 , 5%) , base shear or any IM of IDA curve

- 6] Calculating “s” of lognormal data :

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

- 7] Apply the standard normal distribution for the probability function and CDF which is denoted as Φ

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

8] Now plot the fragility curve between IM as horizontal axis and probability as vertical axis . IDA of G+11 building is carried out in SeismoStruct .For applied time histories , IDA curves are plotted . Collapse stage and yielding stage with respect to peak ground acceleration are determined for both the buildings.

- 9] Fragility curve is plotted which denotes the extent of yielding and collapse with respect to PGA.

IV. RESULTS AND DISCUSSIONS

- 1) Design of buildings in SEISMOSTRUCT 2018
- 2) IS 1893-2000 gives the different loads which are taken for earthquake resistant design of the buildings
- 3) Incremental Dynamic Analysis is carried and time histories are applied to it.
- 4) For scaled time histories structures response like inter storey drift ratio , base shear is found out
- 5) For each time history applied IDA graph of spectral acceleration to inter storey drift ratio (%) is plotted.

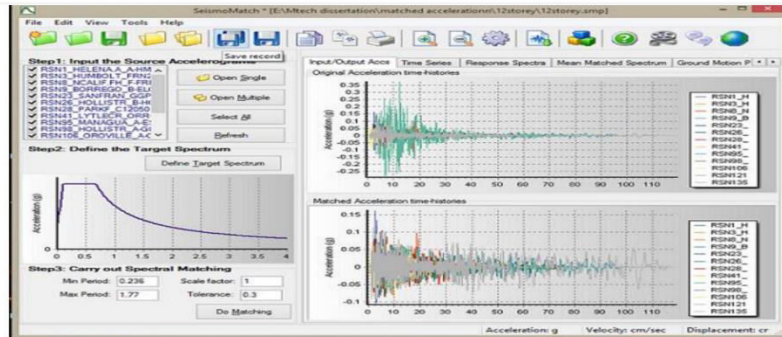


Fig. 3.14 Matching ground motions to the target spectrum steps using SEISMOMATCH 2018

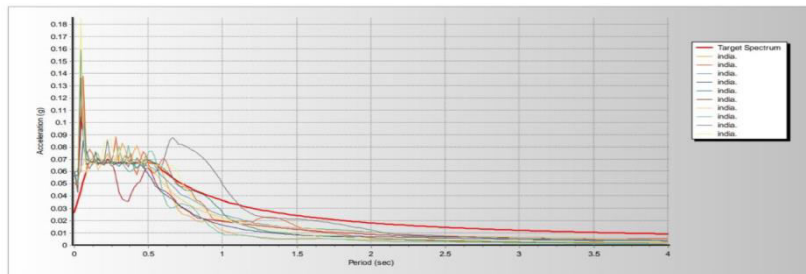


Fig. 3.16 Response spectrum for building, all ground motions matched to the building interval

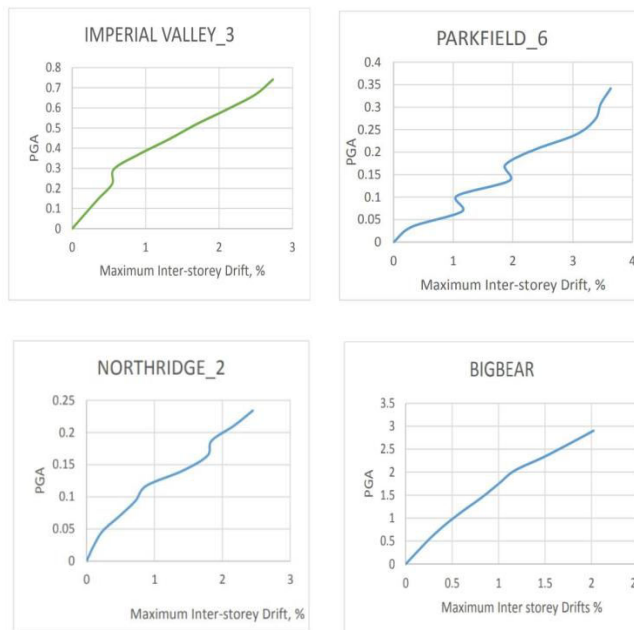


Fig. 1.5 : Single record IDA curves

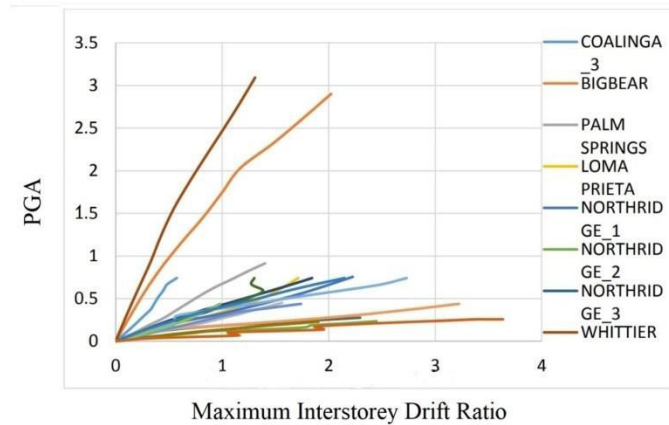


Fig. 3.21 Multi Record IDA curves for building

Thus these are some of the Single Record IDA curves and Multi Record IDA curves. While multi record IDA curves are the collection of single record IDA curves for a single building obtained from variety of ground motions, which are parametrized on the same IM and DM.

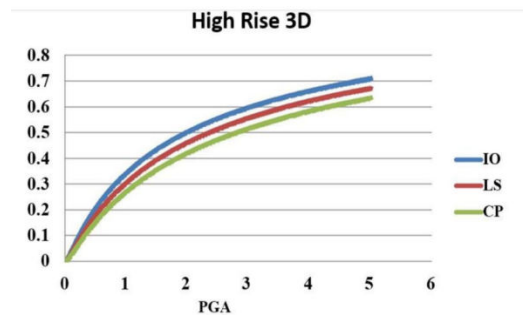


Fig. 3.23 Fragility curves of 3D high rise building by Time History Method

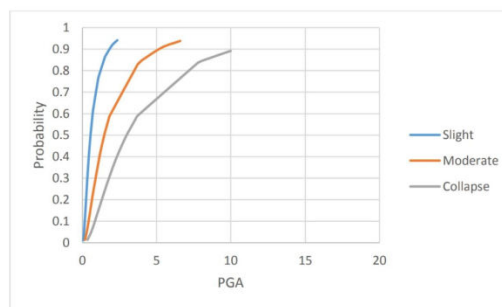


Fig. 3.24 Fragility curves of G+11 building by Incremental Dynamic Analysis Method

When the building collapses at smaller value IM and it has larger DM i.e. maximum inter storey drift it is the softening case. When DM value increased and decreased by increasing IM, the IDA curve is in nonlinear weaving and the case is of the hardening case.

While in the above case of plot of Multi-record IDA curve, this curves are weavy in nature in nonlinear region which shows that hardening is reached by the building.

Fragility curves are also plotted here, which denotes the extent of yielding and collapse w.r.t. spectral acceleration. For calculating fragility curves three limit states of 0.2, 0.5 and 1% is used. Building susceptibility i.e. whether this building is able to sustain the considered earthquake or not is found out using IDA.



V. OBSERVATION

1] For the RC structure taken in this study which is a G+11 building, this building is safe from all the earthquakes except at Parkfield, Big-Bear, and Whittier. Now here, 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 the building sustains the considered earthquake.

2] Fragility curves for G+11 building is plotted which denotes the percentage of yielding and collapse. These curves denotes the percentage of yielding and collapse with respect to the spectral acceleration of the considered earthquakes.

3] IDA curve helps in studying the behaviour of building under a particular earthquake and define the performance stages of the structure such as yield and collapse.

VI. CONCLUSION

1] With the use of incremental dynamic analysis, building susceptibility can be easily studied. Hence, we are able to find out that whether the building can fail to considered earthquake or not. If building is failing to the considered earthquake or failing to satisfy the criteria of serviceability, stiffness of structure needs to be increased by increasing column dimensions.

2] IDA is accurate than other analysis method, because response of the structure is plotted by applying actual available earthquake data. Hence, response obtained from building in IDA is actual response from the considered earthquake.

3] If the structure is of much importance like critical structure and high accuracy is needed, then only IDA should be preferred as IDA is tedious and very much time consuming than other available methods.

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