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Performance Evaluation of RC Frame Structure Through Incremental Dynamic Analysis

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Abstract

Objective: The objective of this paper is to assess the capacity and performance of the RC frame structure in different seismic zones of India through Incremental Dynamic Analysis. This study utilizes Incremental Dynamic Analysis (IDA) for capacity assessment of the RC frame structure in different seismic zones of India. **Method of Analysis:** A set of ground motion records is selected and scaled from low seismic intensity to high seismic intensity with site compatible response spectra. The nonlinear time history is applied to structure from lower demand to the demand up to which the structure is failing. **Findings:** This parametric study involves safety consideration of RC frames with variation in demand. The behavior and performance level of the structure in different seismicity have been studied. The results have been compared on basis of base shear versus roof displacement graph, inter-storey drift ratio and the hinge formation mechanism. **Application/Improvement:** The study will illustrate the behavior of the structure for seismic actions and the performance and damages to structure will be acquired. The results will show the proper response of the structure under different seismic loads.

Keywords: Earthquake, Demand, Ground Motion, Performance

Introduction

For seismic analysis of the structure the demand and the capacity of the structure plays important role. There are so many methods are evolved to evaluate the seismic capacity and demand of the structure for different seismic excitation. One of the common methods used for evaluation of the capacity of the structure is incremental dynamic analysis. Now a day, Incremental Dynamic Analysis (IDA) is emerging as an accurate tool to estimate the capacity of the structure[1]. It involves subjecting a structural model to a number of ground-motion records, each scaled to low severity to high severity. Although this analysis requires large number of inelastic time history analysis[2]. Because of the complexity of the IDA analysis, generally IDA[3] is done on simple model like SDOF. However, the exact response of the structure cannot be determined by the nonlinear time history analysis, incremental dynamic analysis is found to be more reliable and efficient. Rigorous calculations effort needed to perform incremental dynamic analysis, as well as selecting and scaling of the ground motion data for site compatibility. For incremental dynamic analysis there are no criteria to select the ground motion records. So it is very difficult to select the proper ground records for incremental dynamic analysis. It is very important that the selection of the ground motion data should be such that it should follows the ground hazard data of the specific site and scaling should be done in appropriate manner[4]. If the input ground data is not according to site hazard the response of the structure will be uncertain[5]. However, selection of ground data can reduce the uncertainty of the structural response[6].

The objective of this paper is to evaluate the capacity and performance of the structure in different seismic zones of India through Incremental Dynamic Analysis. A four storey RC frame structure is modelled and designed according to IS-456:2000 and seismic load combina-

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tions are provided as per IS-1893:2002. The structure is designed for all four major seismic zones and checked for capacity under incremental dynamic analysis.

2. Structure Modelling

2.1 Geometry and Structural Configuration

The four storey RC frame structure studied is symmetrical in plan in both the directions. The frame has four bays in both the directions; each bay is 6m long. Four storey structures have storey height of 3m each. The plan and the elevation of the frames are given in Figure 1 and Figure 2 respectively. The RC frame is bare frame with rigid diaphragm assigned for the slab action. The total dead and live loads assumed on the structure are $4kN/m^2$ and $3kN/m^2$ respectively. The frame is designed according to the IS-456:2000 and seismic loading according to IS-1893:2002(part-I). The frame is designed for all four zones i.e. Zone-V, Zone-IV, Zone-III, and Zone-II. The frames are designed for the medium soil type site conditions.

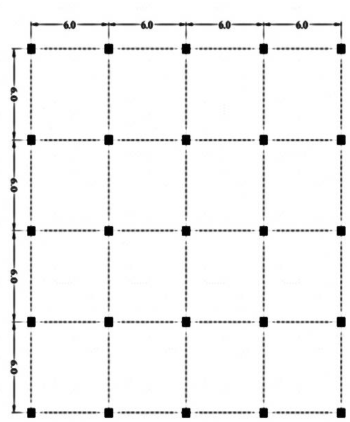


Figure 1. Plan of the RC frame structure.

Table 1. Material properties

Material	Properties
Concrete	f_{ck} = 30MPa υ = 0.2
Steel	f_y = 415MPa E_{st} = 200x10^3 MPa

f_{ck} - Characteristic compressive strength of concrete.

f_y - Yield strength of the steel.

υ - Poisson's ratio

E_{st} – Modulus of elasticity of the steel.

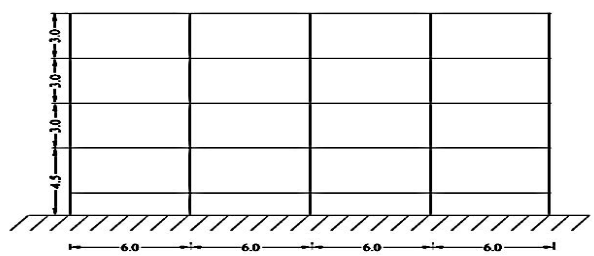


Figure 2. Elevation of the RC frame structure.

2.2 Modeling Approach for Inelastic Analysis

For inelastic analysis the RC frame structure models are assigned with the proper plastic hinges in structural members like beams and columns[7]. The beams are assigned to moment hinges only, and columns are assigned with the P-M-M hinges. The plastic hinges assigned to the elements are as per the FEMA-356 and ATC-40 specified[8,9]. The seismic response of the structure for higher modes is not considered as our structure model is low storey RC frame[10]. The effect of higher mode will be very less. The damping ratio is kept 5% as specified in IS-1893(2002). There have been many reports on the influence of gravity effect on the calculated seismic response. In the present study, the effect of gravity loads is taken into account.

3. Incremental Dynamic Analysis

Incremental Dynamic Analysis is the dynamic analysis for getting the proper structural response under given site earthquake condition. It measures the response and performance of the structure for given input ground motion at different levels. If large number of ground motion records used the method become more complex and accurate response of the structure can be obtained. Incremental dynamic analysis (IDA) was applied to obtain the relationship between the base shear force and the top story displacement or incremental dynamic push-over curve. Incremental dynamic analysis is an analysis in which dynamic time history is applied to the structure with varying the scale factor of the intensity of the time history. For using the incremental dynamic analysis, the selected ground motion data should be compatible to the response spectrum of the site.

4. Input Ground Motion

When nonlinear seismic analysis are carried, then it is required that the response spectra of the accelerograms used for design envelope the given target spectrum. The resulting analyses are considered to be conservative. The design spectrum is generally does not represent any actual seismic load but represents an envelope of possible spectral acceleration values. Figure 3 shows the elastic acceleration spectrum (S_a) of the six selected records and IS-1893:2002 elastic design spectrum. The details of the selected earthquake ground motion data is represented in Table 2 shows the details of the selected ground motion data. WAVEGEN software is used for conversion of the ground motion to medium soil spectrum.

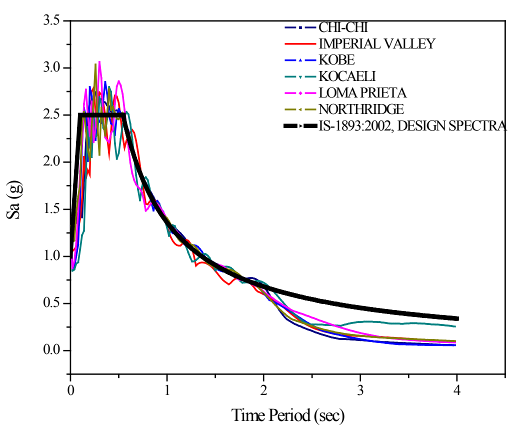


Figure 3. Spectrum compatible response spectra of selected ground motions for medium soil.

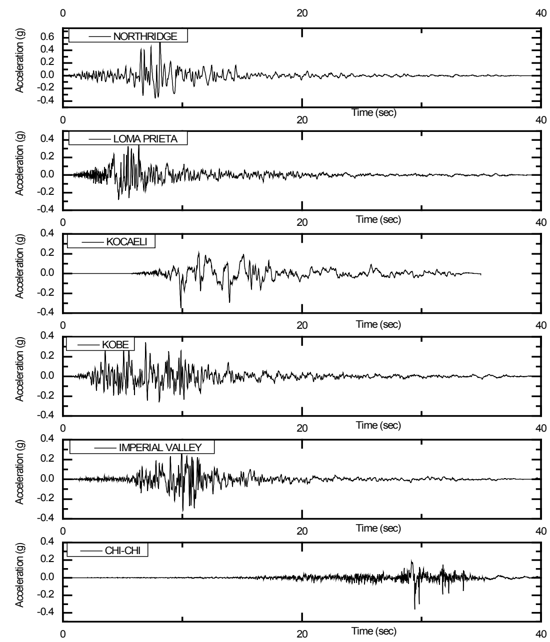


Figure 4. Acceleration time history of selected earthquake ground motion.

5. Results

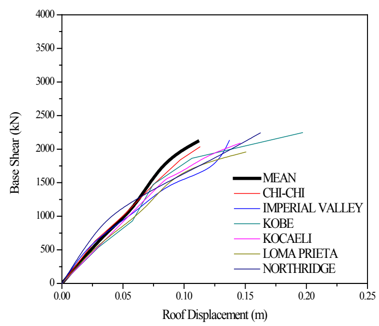
The results obtained from the incremental dynamic analysis of the four storey RC frame structure in different seismic zones have been discussed here. The results mainly contain the comparison of the base shear, roof displacement, inter-storey drift ratio and the hinge formation pattern of the structure.

Table 2. Details of the selected ground motions

SN.	Name of the Earthquake	Year	Recording Station	Dominant Period(sec)	PGA (g)
1	CHI-CHI	1999	TCU045	0.060	0.361
2	IMPERIAL VALLEY	1979	USGS STATION 5115	0.140	0.315
3	KOBE	1995	KAKOGAWA(CUE90)	0.160	0.344
4	KOCAELI	1999	YARIMCA(KOERI330)	1.400	0.349
5	LOMA PRIETA	1989	CDMG STATION 47381	0.220	0.369
6	NORTHRIDGE	1994	CDMG STATION 24278	0.260	0.568

5.1 Capacity Curve

The Figure 5 shows the capacity curve of the structures designed in different seismic zones. The capacity curve is plotted between the roof displacement and base shear. Figure 6 show that the structure designed for Zone-II has very less base shear capacity and fails so early. The roof displacement at failure is varying from 0.11m for structure designed for zone II to 0.20m for structure designed for zone-V seismicity.



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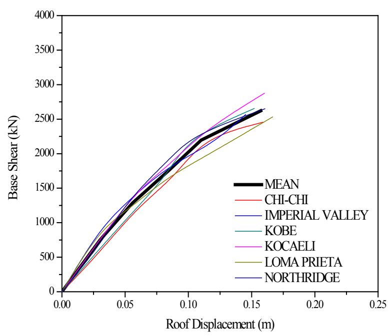

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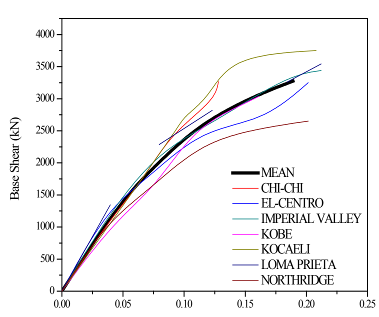

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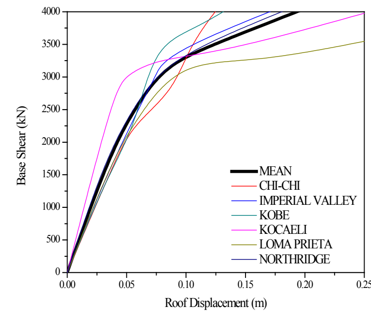

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Figure 5. Capacity curve of the RC frame structures for six ground motion records. (a) for Zone-II structure (b) for Zone-III structure (c) for Zone-IV structure (d) for Zone-V structure.

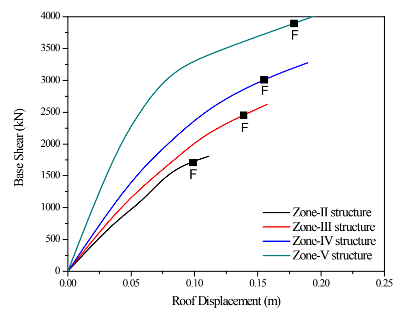
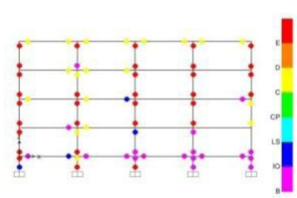


Figure 6. Mean capacity curve of RC frame structures F – Failure point of the structure.

5.2 Hinge Pattern Formation

Structural instability of the structures in different seismic zones is described below. The pattern of hinge formation will describe the critical section of the structure under different seismic loading condition. Figures 7–10 show the hinge pattern formed in structure at collapse.

The hinge pattern of the structure designed for different seismic zones shows that the top storey is more prone to the collapse during the seismic excitation. In the structures the beams are failing first then hinges are forming in columns.



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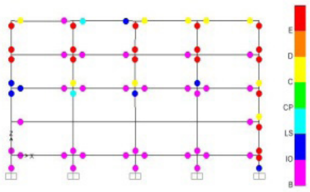

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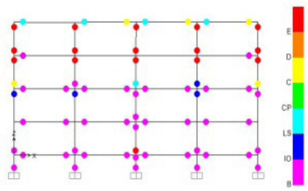

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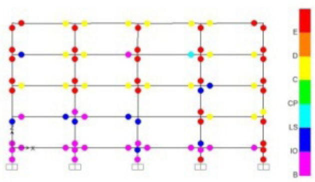

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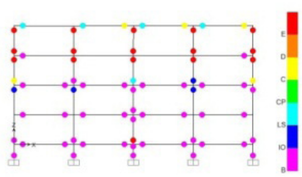

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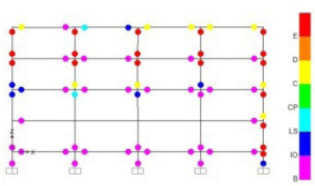
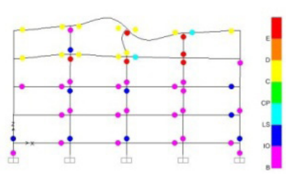


(f)

Figure 7. Hinge pattern of the Zone-II structure at collapse.



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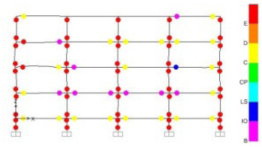

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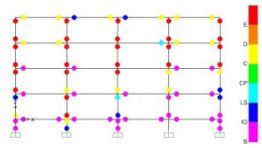

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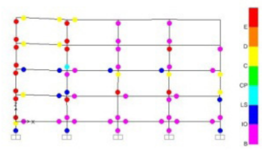

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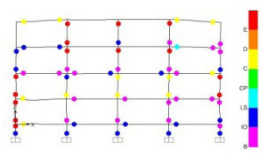

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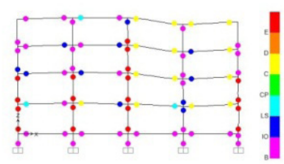

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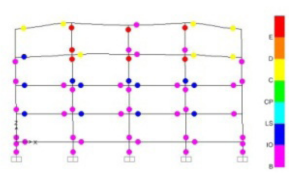
Figure 8. Hinge pattern of the Zone-III structure at collapse.



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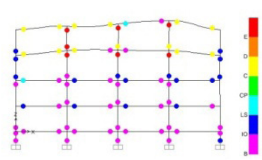

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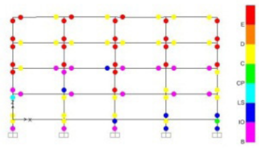

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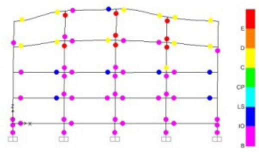

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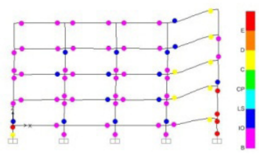

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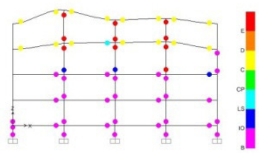

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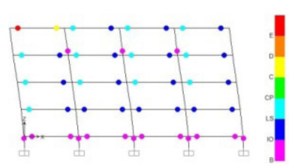
Figure 9. Hinge pattern of the Zone-IV structure at collapse.



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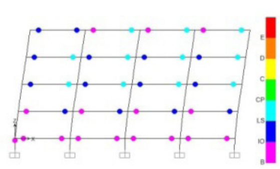

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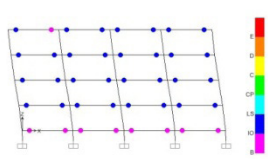

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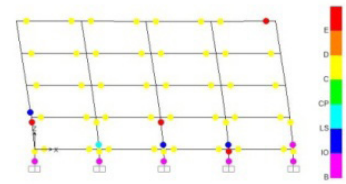

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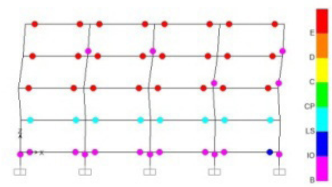

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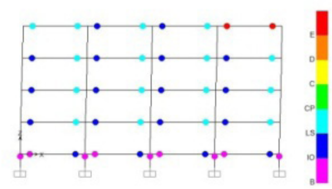

(f)

Figure 10. Hinge pattern of the Zone-V structure at collapse for Figures 7, 8, 9, and 10
(a) for Chi-Chi Earthquake , (b) for Imperial Valley Earthquake (c) for Kobe Earthquake (d) for Kocaeli Earthquake (e) for Loma Prieta Earthquake (f) for Northridge Earthquake.

5.3 Interstorey Drift Ratio

Interstory drift is one of the predominant engineering response measure and indicator of physical performance of the structure. Generally, the interstorey drifts of structures as relative lateral displacement between two consecutive floors.

Here the results have been shown at the collapse levels. Figure 11,the first graph shows the interstorey drift ratio of RC structure in Zone II, Zone-III and Zone-IV when subjected to the performance point of the seismic zone II structure. In Figure 11(a) the interstorey drift ratio of the structure designed for zone-II seismicity is 2.56% whereas at same roof displacement the structure designed for zone-III, IV and V shows less interstorey drift ratio. The damage to structure when designed for higher zone will be less.

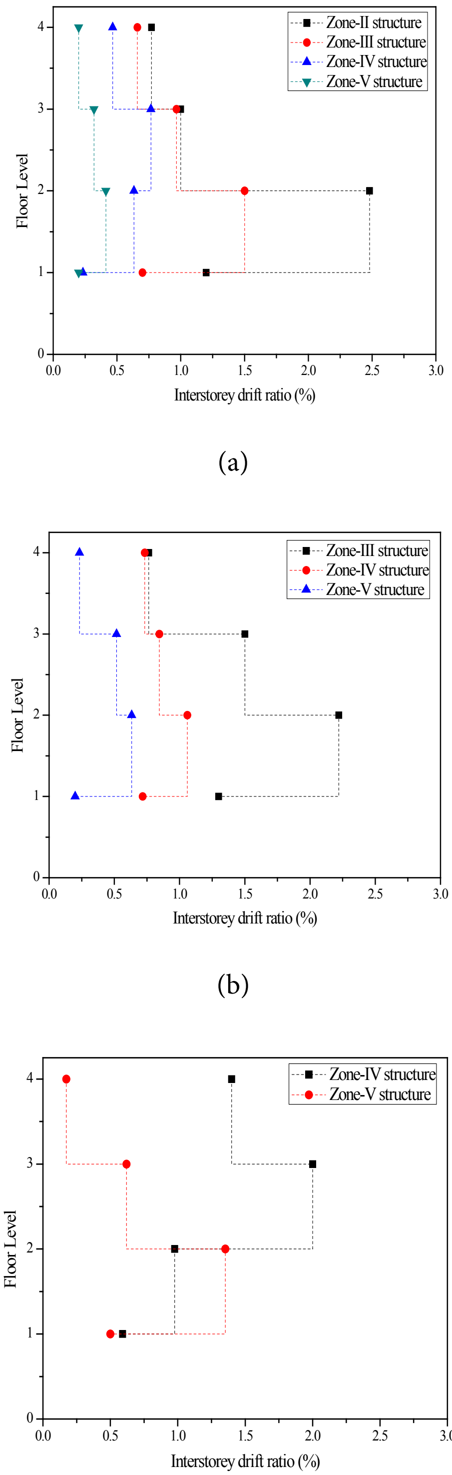

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Figure 11. Interstorey drift ratio of the structure in different seismic zones. (a) At zone-II seismicity (b) At Zone-III seismicity (c) At Zone-IV seismicity

6. Conclusion

From the analysis of the four storey RC structure models through incremental dynamic analysis following conclusions can be described.

- The structure designed for the zone-V shows much higher performance as compared to structure designed for low seismic demands.
- The inter-storey drift ratio of lower storey is more.
- IDA depicts more realistic results and gives the exact behavior of structure. The hinge formation will help in identifying the collapse pattern of the structure and the critical section of the structure.
- From capacity curve shows that for different ground motion the behavior of structure is also changing with respect to ground motion. So it is necessary to analysis the structure according to the site specific analysis of particular structure.

Finally, the analysis shows that the design of structure for high capacity is proving more stable and safer. Over-estimating the structure will give less damage to structure as well as lives. However over-estimating will not be economical but on performance consideration the structure should be designed for higher demands.

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