Performance Evaluation of R.C. Moment Resisting Symmetric Frame using Nonlinear Dynamic Analysis

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Abstract

Engineering structures are often very complex and difficult to analyze for their dynamic, or vibrational, behavior. With the immense loss of life and property witnessed in the last couple of decades alone in India, due to failure of structures caused by earthquakes, attention is now being given to the evaluation of the adequacy of strength in RC framed structures to resist strong ground motions. Modern performance-based design methods require ways to determine the realistic behavior of structures under such conditions. Enabled by advancements in computing technologies and available test data, nonlinear analyses provide the means for calculating structural response beyond the elastic range, including strength and stiffness deterioration associated with inelastic material behavior and large displacements. In general, the study of the inelastic seismic responses of buildings is important to provide economical design by making use of the reserved strength of the building as it experiences inelastic deformations. In the present paper, Performance evaluation of R.C.C. Symmetric frames located in Seismic Zone V is done using Non Linear Dynamic Analysis. It is widely recognized that Nonlinear Dynamic Analysis constitutes the most accurate way for simulating response of structures subjected to strong levels of seismic excitation. This analytical method is based on sound underlying principles and features the capability of reproducing the intrinsic inelastic dynamic behavior of structures. Thirteen Ground Motions are selected in present paper, in which there are seven past Indian ground motions and six artificial ground motions. For this paper 4, 6, 9 storey R.C.C frames is selected for performance evaluation. Due to faster solver system and fiber based concept among all software's SeismoStruct software is chosen to perform Nonlinear Dynamic Analysis. Finally, Performance evaluation is carried out in terms of displacement profile and drift limit from performance criteria mentioned in ATC-40 and Fema-356.
Keyword- Incremental Dynamic Analysis, Limit-State, Nonlinear Dynamic Analysis Performance-Based Earthquake Engineering

I. INTRODUCTION

Building codes require that structures should be designed to withstand a certain intensity of ground acceleration, with the intensity of the ground motion depending on the seismic hazard. Because of the high forces imparted to the structure by the earthquake, the structures are usually designed to have some yielding. The goal of earthquake engineering is to minimize loss of life due to the collapse of the yielding structure. However, the costs involved in replacing and rehabilitating structures damaged by the relatively moderate earthquakes have proven that the "Life-Safe" building design approaches are economically inefficient. As a result, the principle of "Performance Based Earthquake Engineering" (PBEE), which promotes the idea of designing structures with higher levels of performance standards across multiple limit states, has been proposed.

In performance based design, the response of structure is considered beyond elastic limit. Static and dynamic non-linear analysis is the analysis techniques used for performance based design. Elastic analysis gives a good indication of the elastic capacity of the overall structure and indicates where first yielding occurs. It can't predict failure mechanisms and account for redistribution of forces during progressive yielding. An inelastic analysis procedure helps to understand that how the building really works by identifying modes of failure & the potential of progressive collapse.

Many researchers have worked in the field of nonlinear dynamic analysis. Amr S. Elnashai Sep'2009 in his paper "Do We Really Need Inelastic Dynamic Analysis" concluded that there is not a single static curve that traces the entire dynamic curve progression. The paper examines the requirements for inelastic static and dynamic analysis applied to earthquake design and assessment. Another paper "Criteria for performance evaluation of RC building frames using non-linear time history analysis for performance-based design" Jiji Anna Varghese, Devdas Menon. A comprehensive review on performance evaluation of structures using non-linear time history analysis is presented in this paper. Non-linear material properties and the selection of ground motion and scaling procedures are discussed in detail. It was concluded that Response spectra generated for a suite of near-field and far-field ground motions shows an increase in response due to near-field earthquakes in the long period range.

II. NONLINEAR DYNAMIC ANALYSIS

Nonlinear dynamic analysis methods generally provide more realistic models of structural response to strong ground shaking and, thereby, provide more reliable assessment of earthquake performance than nonlinear static analysis. Nonlinear static analysis is limited in its ability to capture transient dynamic behaviour with cyclic loading and degradation. Nevertheless, the nonlinear static procedure provides a convenient and fairly reliable method for structures whose dynamic response is governed by first-mode sway motions. In general, the nonlinear static procedure works well for low-rise buildings with symmetrical regular configurations.

Nonlinear dynamic analysis is required by some building codes and guidelines for buildings of unusual configuration or of special importance. This method is the most rigorous and provides the most reliable on building response and performance. Displacement and acceleration demands at each story along with the force demand for each member is determined accurately. It requires defining a complete hysteretic behaviour of the materials and set of natural records to perform dynamic response history analysis. There are two types of nonlinear dynamic analysis.

A. Non Linear Time History Analysis (NLTHA)

Nonlinear time history analysis is the most accurate method used to predict seismic responses of structures subjected to ground motions. Development of computer software causes to use this method widely in design new buildings and evaluating building performances during the past decade. To perform nonlinear time history analysis, ground motions directly applied to the model, it needs a suitable ground motions. Selecting ground motions should be accurate in nonlinear time history analysis.

B. Incremental Dynamic Analysis (IDA)

This analysis method was adopted by the Federal Emergency Management Agency (FEMA 2000) and is considered as the state-of-the-art method to estimate the structural responses under seismic loadings. IDA is a parametric analysis which predicts complete structural responses and performances. A properly defined structural model is subjected to a suite of ground motion records and the intensity of these ground motions are gradually increased using scale factors. Plotting between Intensity Measurement (IM) of the scaled ground motions and Damage Measurements (DMs) is called Incremental Dynamic Analysis.

III. METHODOLOGY

A. Description of Structure

Nine storey RC moments resisting frame with two bays of 6.0m width, typical storey heights of 3.20m and ground storey height of 4.0m is considered for the study. It was located in Zone-V and assumed to be constructed on firm soil condition. Response Reduction factor of 5 was used for design of special RC moment-frame. The loading considered was self- weight of beams, columns and slabs, floor finish and live load on slabs. The frame was then designed for load combination (a) 1.5(DL+IL) (b) 1.2(DL+IL±EL) (c) 1.5(DL±EL) as per IS Code. The design acceleration spectrums were used, which corresponds to IS 1893 (Part 1): 2002 for firm soil for 5% damping. The percentage of steel and sizes of beams and columns of nine storey frames are presented in Table I and II, respectively. Similarly for 4, 6 storey has been carried out.

Storey	Pt(%) for FBD				
	Size (mm)	Start		End	
		Bot.	Top	Bot.	Top
1	300x550	1.02	1.88	1.02	1.88
2	300x550	1.02	1.88	1.02	1.88
3	300x550	1.02	1.88	1.02	1.88
4	300x550	1.02	1.65	1.02	1.65
5	300x550	1.02	1.65	1.02	1.65
6	300x500	0.80	1.60	0.80	1.60
7	300x500	0.88	1.76	0.88	1.76
8	300x400	0.86	1.72	0.86	1.72
9	300x400	0.72	1.43	0.72	1.43

Table 1: Reinforcement Percentage for Beams: 9-Storey Frame

Storey	Exterior Column		Interior Column	
	Size (mm)	Pt(%)	Size (mm)	Pt(%)
1	550x550	2.60	550x550	3.01
2	500x500	2.30	500x500	2.80
3	500x500	2.30	500x500	2.30

4	450x450	2.83	500x500	2.30
5	450x450	2.48	450x450	2.83
6	450x450	2.48	400x400	3.14
7	400x400	3.14	400x400	2.30
8	350x350	3.00	350x350	2.63
9	350x350	3.00	350x350	2.63

Table 2: Reinforcement Percentage for Column: 9-Storey Frame

B. Description of Software

SeismoStruct software was used which is a commercial software, but it is free for research purposes. Also, it is graphical software and it does not need any program or script to write which is easier for the users. It is finite element package for structural analysis, capable of predicting the large displacement behaviour of space frames under static and dynamic loading, taking into account both material and geometric non linearity. SeismoStruct software works on fiber-based concept i.e. it discretized the element into small parts. The concrete and steel materials were modeled using built in models in SeismoStruct, For instance Bilinear Steel model and Mandar et al. nonlinear concrete model were implemented. The material properties are shown in Table III

Materials	Properties	Values
Concrete	Compressive Strength (MPa)	25(column), 20(beam)
	Tensile Strength (MPa)	3.5(column), 3.13(beam)
	Ultimate Strain (%)	0.35
Steel	Modulus of elasticity (MPa)	2.5e4(Column), 2.23e4(beam)
	Yield Strength (MPa)	415
	Strain Hardening (%)	0.5

Table 3: Material Properties

C. Methodology of Nonlinear Time History Analysis

Nonlinear time history analysis is the most accurate method used to predict seismic responses of structures subjected to ground motions. Development of computer software causes to use this method widely in design new buildings and evaluating building performances during the past decade. To perform nonlinear time history analysis, ground motions directly applied to the model and it needs a suitable ground motions. There are two methods to obtain dynamic responses of a structural model, which are direct time integration and modal superposition. The nonlinear time history analysis presented herein belong to the direct integration method which is a second order differential equation. The equations of motion for a structural system represented by MDOF model are shown in following equation below. At each time step this equation is solved and displacements are calculated:

$$M\ddot{U} + C\dot{U} + KU = -MI\ddot{u}_g$$

where:
M = the mass matrix
C = the damping matrix
K= the stiffness matrix
$\ddot{u}_g$=earthquake ground acceleration
U =displacement calculated

In this study, a direct integration method was adopted to solve the equation of motion which is a second order differential equation. It is a common method used to solve dynamic response systems and it solves equation of motion numerically using discrete time stepping starting from zero to infinity. In this study, α-integration algorithm were selected in SeismoStruct software and it developed by Hilber et al (1977). This algorithm is based on the Newmark method (i.e. has the same finite difference expression and use the same γ and β parameters) by adding the parameter (α) to introduce numerical damping and improve second order accuracy and stability (Values of the three parameters shall be chosen to obtain high accuracy, numerical damping and analytical stability. The best choice for (α) is between [-1/3, 0] (this research used α = -0.1) and the other two parameters can therefore be determined using Eq. 2.2 and Eq. 2.3 (Hilber et al 1977).

$$\gamma = \frac{(1-2\alpha)}{2}$$

$$\beta = \frac{(1-\alpha)^2}{4}$$

D. Selection of Ground Motions

Selecting ground motions is major issue in nonlinear time history analysis. Factors affecting selection of ground motions are magnitude of earthquake, site condition, and peak ground acceleration. A set of 13 ground motions were used to perform nonlinear time history analysis on RC Frames. Out of which 6 artificial ground motions and 7 Indian Ground motions. The Artificial ground motions were matched to IS response spectra. The artificial ground motions were generated from SeismoArtif Software using Saragoni Hart function. The typical artificial ground motion and Indian Ground motion is shown in Figure 1 and Figure 2. Response Spectrum is shown in Figure 3 and Figure 4 respectively.

Sr. No.	*Earthquakes*	*Duration*	*Magnitude*
I1	*Uttarkashi Earthquake of Oct 20, 1991*	*36.16*	*6.5*
I2	*Kachchh Earthquake of Jan 26, 2001*	*133.53*	*7.0*
I3	*Chamba Earthquake of Mar 24, 1995*	*18.24*	*4.9*
I4	*Dharmsala Earthquake of Apr 26, 1986*	*20.08*	*5.5*
I5	*Chamoli Earthquake of Mar 29, 1999*	*24.34*	*6.4*
I6	*India-Burma Border Earthquake of Jan 10, 1990*	*62.84*	*6.1*
I7	*India-Burma Border Earthquake of May 06, 1995*	*28.58*	*6.4*

Table 4: Details of Ground Motion

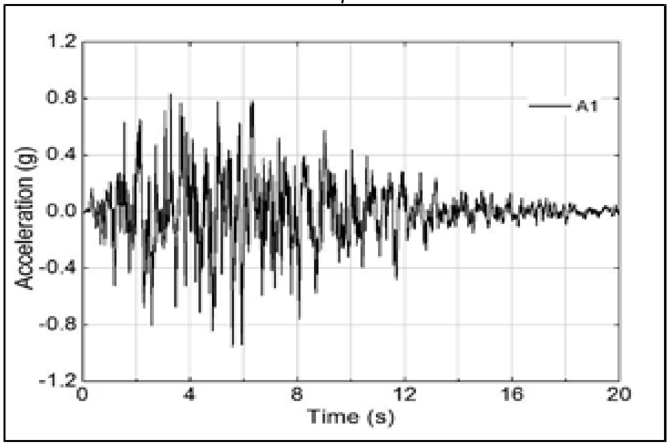

Fig. 1: A typical artificial ground motion A1

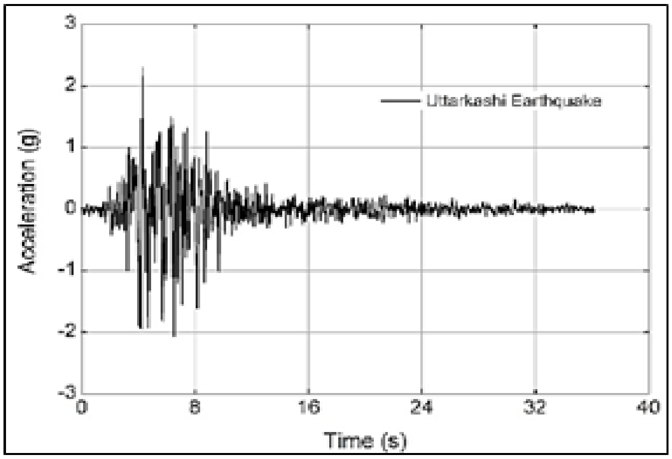

Fig. 2: A typical Indian ground motion I1

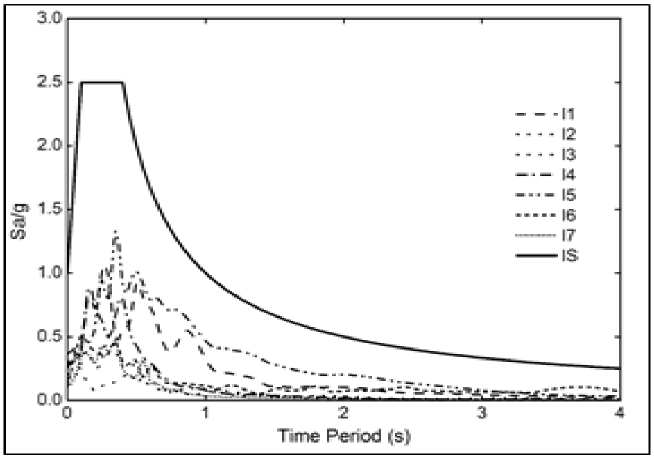

Fig. 3: Acceleration Response Spectra of Seven Indian Ground Motions

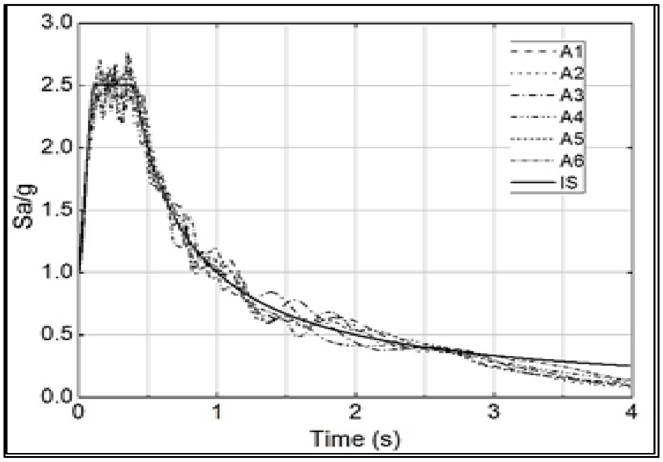

Fig. 4: Pseudo Acceleration Response Spectra of six artificial ground motion

IV. RESULTS AND DISCUSSIONS

The nonlinear time history analysis was studied to examine the response of the 4, 6, 9 storey RC frames subjected to varied earthquake excitations. In order to examine the structural response maximum interstorey drift ratio is selected as damage measure. Relative Displacements at each storey is determined accurately after analysis. It should be noted that interstorey drift ratio was computed as difference in a relative displacements of two intermediate floor levels divided by storey height. Inter Storey Drift Profile of 4 storey for Artificial and Indian ground motions are shown in Figure 5 and Figure 6 respectively. Inter Storey Drift profile of 6-storey for artificial and Indian ground motion are shown in Figure 7 and Figure 8 respectively. Inter Storey Drift profile of 9-storey for artificial and Indian ground motion are shown in Figure 9 and Figure 10 respectively.

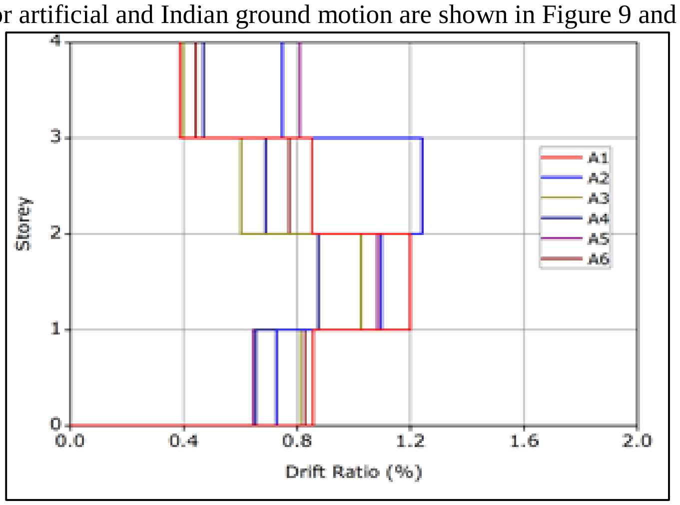

Fig. 5: Inter-storey Drift Profile of 4 storeys for 6 Artificial Ground motions

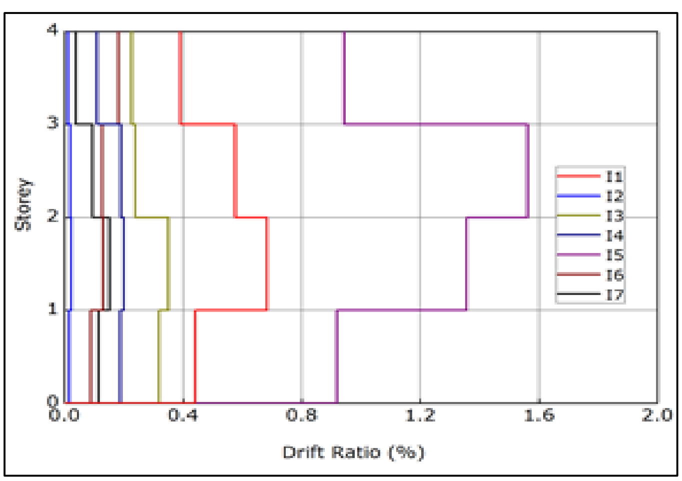

Fig. 6: Inter-storey Drift Profile of 4 storeys for 7 Indian Ground motions

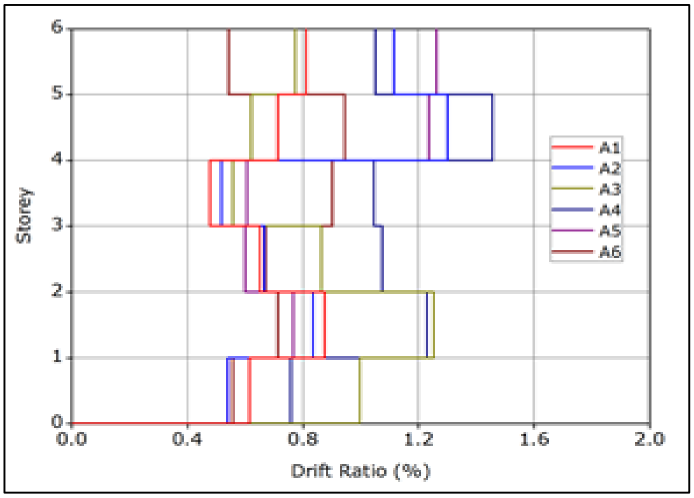

Fig. 7: Inter-storey Drift Profile of 6 storeys for 6 Artificial Ground motions

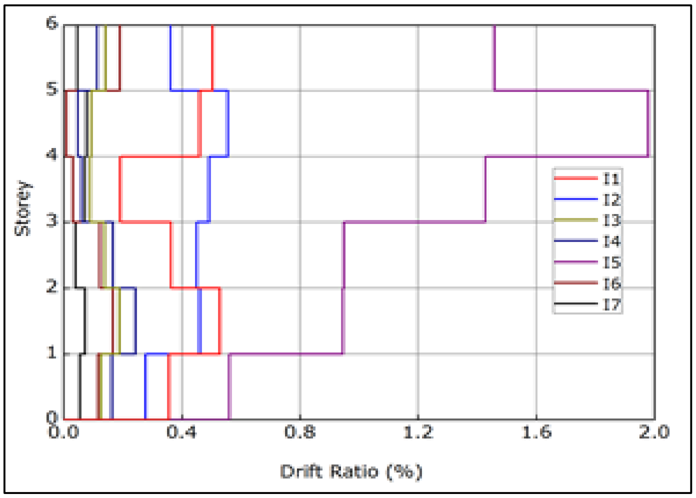

Fig. 8: Inter-storey Drift Profile of 6 storeys for 7 Indian Ground motions

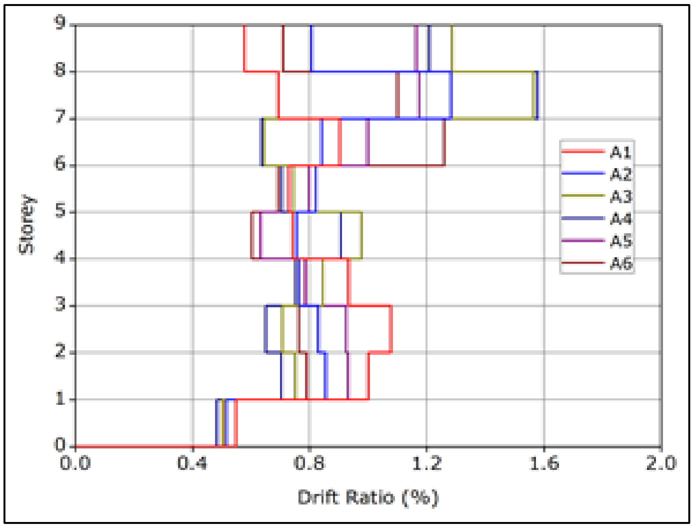

Fig. 9: Inter-storey Drift Profile of 9 storey for 6 Artificial Ground motions

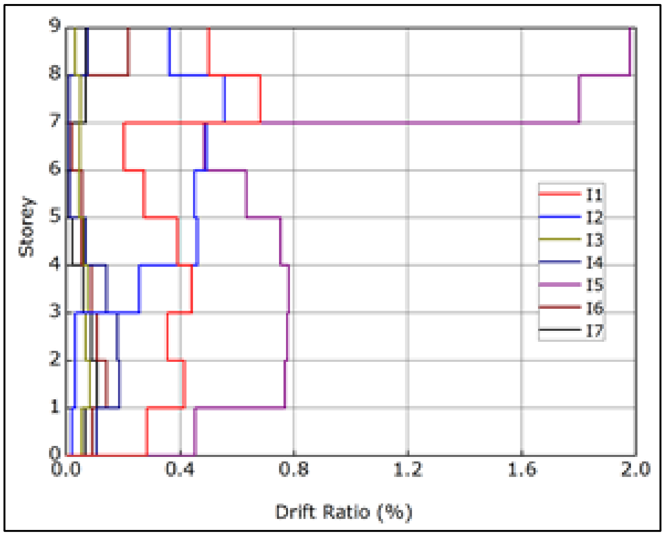

Fig. 10: Inter-storey Drift Profile of 9 storeys for 7 Indian Ground motions

V. Conclusions

The main aim of the paper was evaluating the performance of RCC moment resisting frames designed as per IS code provisions. Illustrative frames of 4, 6 and 9 storey with two bays were designed as per IS code guidelines. To evaluate the performance, the nonlinear time history analyses of these frames were carried out using Seismostruct software. The results of time history analysis are plotted in terms of inter-storey drift profile for thirteen ground motions. The linear drift limit as per IS: 1893 (Part 1): 2002 is 0.4% and frames were designed with response reduction factor of 5. Hence target drift limit for frames comes out to be 2%. It is observed from the plots that target inter-storey drift limit of 2% is not crossed in any of the frames. Hence it can say that frames shows satisfactory performance under dynamic loading.

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