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Comparative Study of Elastic Design and Performance Based Plastic Design Method of RC Moment Resisting Frame

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Abstract: *Performance based Plastic design method is a rapidly growing design methodology based on the possible performance of the building during earthquakes. It is very essential after the recent earthquakes to study the performance of structures so that the structures can be designed to withstand the different ground motions without losing its stability. In this study, RC moment resisting frames are designed by the Performance based Plastic design method and conventional elastic design method. It is then evaluated by Nonlinear static (Pushover Analysis) and Nonlinear dynamic analysis (Time history analysis) under different ground motions. Performance based Plastic design is a displacement based method which uses pre-selected target drift and yield mechanisms as design criteria whereas the elastic design method is based on the conventional force based limit state method. In the RC moment resisting frames, it is find that the nonlinear static pushover analysis shows formation of hinges in columns of the frame designed using elastic design approach leading to collapse, while the hinges forms in beams only and at the bottom of column in the performance based plastic design frame. This leads to increase performance which clearly indicates that the performance based plastic design method gives economical sections in terms of the optimum capacity utilization as compared with elastic design method. Also from the nonlinear time history analysis it can be seen that ground motions causes larger displacements and acceleration in the performance based plastic design frame as compared to elastic design frame.*

1. INTRODUCTION

It is noticed in the recent major earthquakes, that the seismic risk in urban areas is increasing and the infrastructure facility is far from socio-economically acceptable levels. Hence there is a new methodology developed by Lee and Goel (2001) named performance Based Plastic Design (PBPD) method. This method is based on the predicted performance of the structure during an earthquake. The methodology used here is direct design method which uses pre-selected target drift and yield mechanisms as key performance criteria from the very start, eliminating or minimizing the need for lengthy iterations to arrive at the final design that determine the degree and distribution of expected structural damage. It is based on the formulations derived from the capacity-spectrum method using Newmark–Hall (1982) reduction factors for the inelastic demand spectrum. The design base shear is calculated by equating the work needed to push the structure monotonically up to the target drift to the energy required by a corresponding Elasto-Plastic Single Degree of Freedom system to achieve the same state.

2. NON LINEAR STATIC PUSHOVER ANALYSIS

The static pushover analysis is becoming a popular tool for seismic performance estimation of existing and new structures. This analysis method, also known as sequential yield analysis or simply "Pushover" analysis has gained significant popularity during past few years. It is one of the three analysis techniques recommended by FEMA 356 and a main component of Capacity Spectrum Analysis method (ATC-40). The expectation from the pushover analysis is, it will provide sufficient knowledge on seismic demands applied through the design ground motion on the components and its structural system. By subjecting a structure to a monotonically increasing pattern of lateral forces a pushover analysis is performed, representing the internal forces which would be experienced by the structure when subjected to ground shaking. Under incrementally increasing loads various structural elements experiences a loss in stiffness. Using a pushover analysis, a characteristic nonlinear force-displacement relationship can be determined.

3. Nonlinear Dynamic Time History Analysis

The popularity of Non-linear structural analysis in earthquake resistant design is increasing day by day, mainly with the development of performance based earthquake engineering, the material nonlinearity of a structure is considered with regards to inelastic time history analysis is dynamic analysis. Considering the efficiency of the analysis, nonlinear elements are used to represent important parts of the structure, and the remainder is assumed to behave elastically. The result of this analysis is obtained by setting up an environment which imitates the real time earthquake ground motions and gives the real picture of the possible deformation and collapse mechanism in a structure. But, it is a very tedious and complex analysis, having a lot of mathematical calculations. Even though non-linear dynamic analysis is usually considered to be the most accurate of the existing analysis methods, it is cumbersome for design. However, the calculated response can be extremely sensitive to the characteristics of the individual ground motion used as seismic input; as a result several time-history analyses are essential using different ground motion records. The analysis had been carried out using the data from past earthquake ground motions.

A 4 storey RC moment resisting frame is designed by the conventional elastic design method and Performance based Plastic design method. Then the frame is analyzed by the nonlinear static analysis (Push over Analysis) and nonlinear dynamic analysis (Time history analysis) with three different ground motions using ETABS (2007) software. Plan and elevations of RC moment resisting frame shown in figure.1 and figure.2

4. DESIGN OF RC MOMENT RESISTING FRAME DESIGNED USING ELASTIC DESIGN APPROACH

The ongoing Indian Standard Code (IS 456-2000 and IS 1392) makes use of the limit state procedure (which is a force based design) for the designing of RC structures to make sure a good earthquake resistant design which at times may fail in case of a major earthquake as it is based on elastic analysis. The dead and imposed loads are calculated using IS875, (parts I to V) and the seismic loads are calculated using IS1893:2002 based on Elastic Design Spectrum.

Table. 1 Seismic parameters of the frame

Soil Type	II
Elastic Spectral Acceleration " Sa / g"	2.5
Importance Factor "I"	1
Zone Factor " Z"	0.36
Natural time Period "T"	0.55 sec
Response reduction factor "R"	5

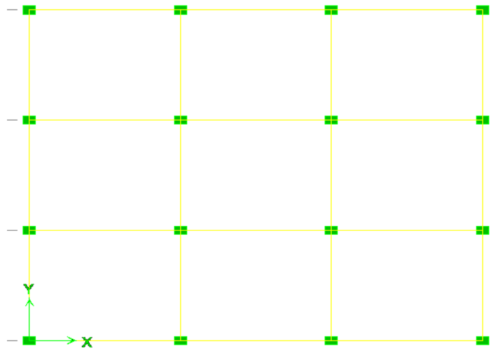


Figure.1 Plan of RC moment frame

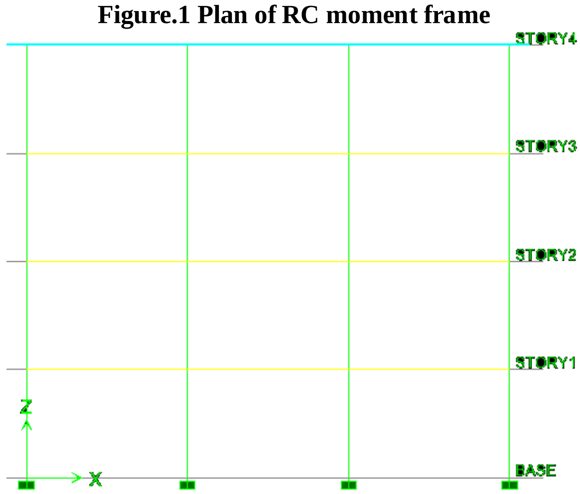


Figure. 2 Elevation of RC moment frame

5. DESIGN OF RC MOMENT RESISTING FRAME BY USING PBPD METHOD APPROACH

The main goal of performance based design i.e. a desirable and predictable structural response can be achieved by accounting in-elastic behavior of structures directly in the design process. Figure.3 shows the target and yield mechanism chosen for the frame while designing it using the performance based plastic design method. The hinges are to be formed at the bottom of the base column and in beams only. The beams are modeled to behave in-elastically, while the columns are modeled (or „forced") to behave elastically. The seismic Parameters used for the study were,

Table.2 Seismic parameters of the frame

Yeild drift ratio θy	0.5%
Target drift ratio θu	2%
Inelastic drift ratio θp= θu-θy	1.5%
Ductility factor μs= θu/ θy	4
Reduction factor due to ductility "Rμ"	4
Energy modification factor due to ductility" γ"	0.541

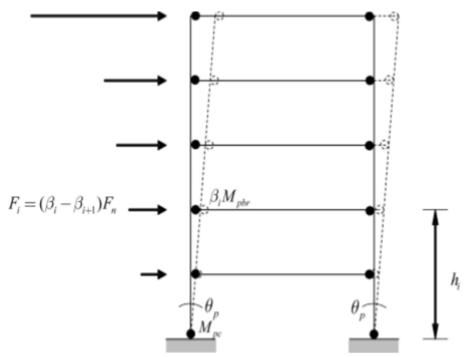


Figure.3 Target drift and yield mechanism

6. INELASTIC RESPONSE ANALYSIS OF THE RC MOMENT RESISTING FRAME DESIGNED USING ELASTIC DESIGN APPROACH

We first designed the RC moment resisting frame by the elastic design approach pertaining to the Indian Standard code using the ETABS software. For applying the static Pushover Force the Hinges are assigned in beams and column. Then the frame was analyzed by the nonlinear static Pushover analysis in ETABS. The entire frame is carried out up to the target drift in nonlinear static pushover analysis, by using design lateral force distribution. The failure mechanism of the frame obtained by ETABS is shown in figure.4. The results show formation of plastic hinges in some columns of floors which may result into total collapse of the entire frame Figure 4 The nonlinear Time history analysis of the frame when subjected to three different ground motions (Dharamshala, Bhuj, Elcentro Earthquake ground motions as shown in figure 4) was also carried out using the software. The acceleration and displacement response of this frame to these ground motions is shown in figures it could be seen in the acceleration and displacement responses of this frame that the peak values are obtained in harmonization with the ground motion.

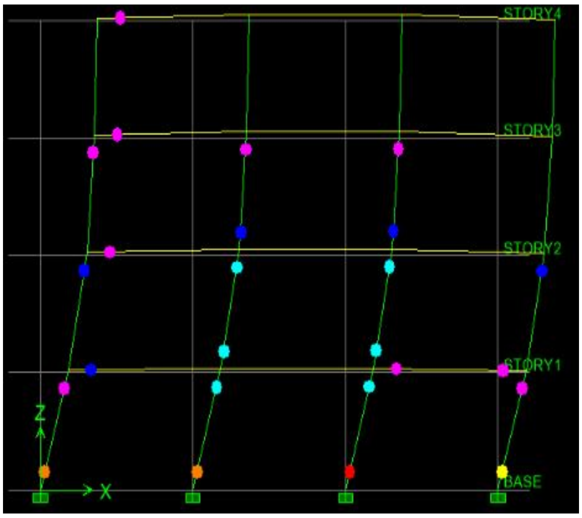


Figure.4 Formation of plastic hinges at step 7 in columns in elastic design.

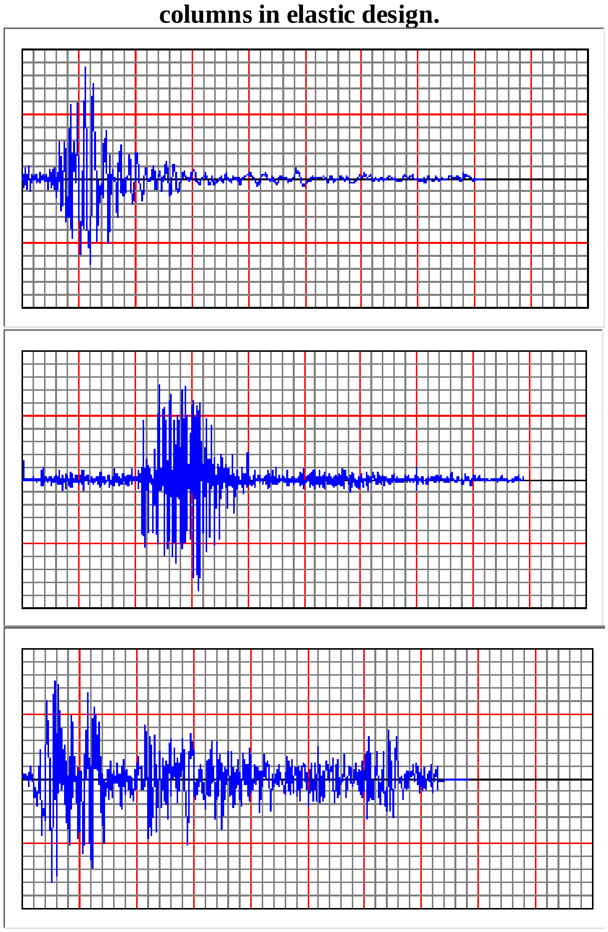


Figure.5 Earthquake ground motions (Dharamshala, Bhuj, Elcentro)

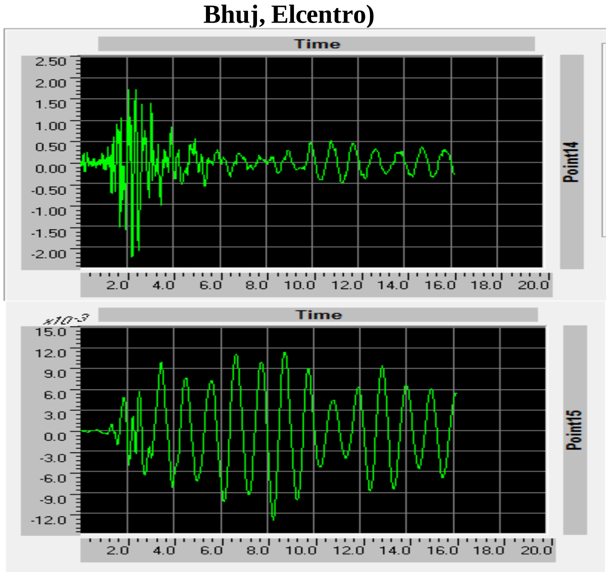


Figure.6 Dharamshala acceleration and displacement respose

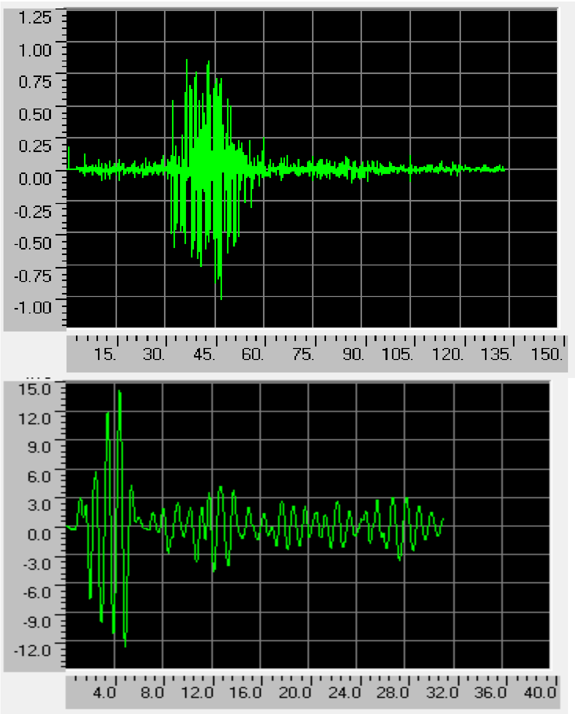


Figure.7 Bhuj acceleration and displacement respose

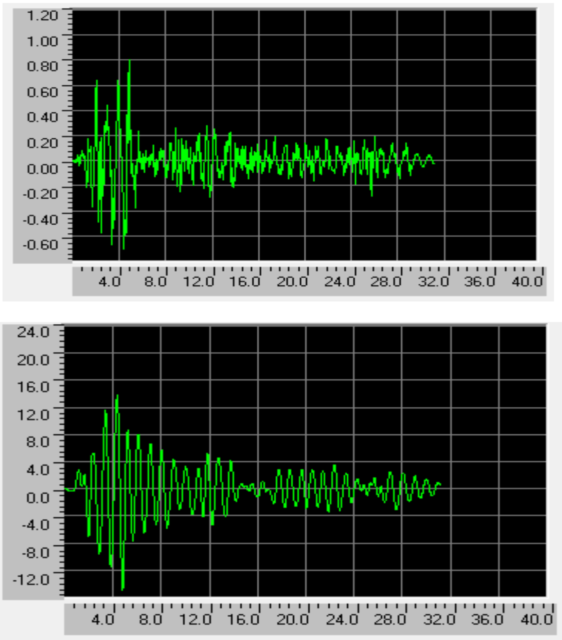


Figure.8 Elcentro acceleration and displacement respose

7. INELASTIC RESPONSE ANALYSIS OF THE RC MOMENT RESISTING FRAME DESIGNED USING PERFORMANCE BASED PLASTIC DESIGN APPROACH

The steel moment resisting frame was designed using lateral force distribution for the Performance Based Plastic Design method and then nonlinear static and time history analyses were carried out. In nonlinear static pushover analysis, the entire frame is carried out up to the target drift by using design lateral force distribution and thus the failure caused is shown in figure.9.

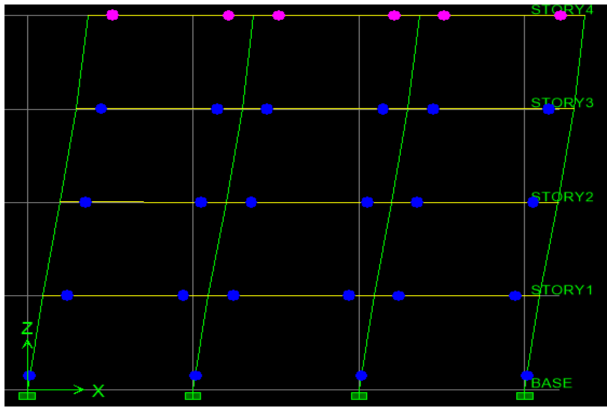
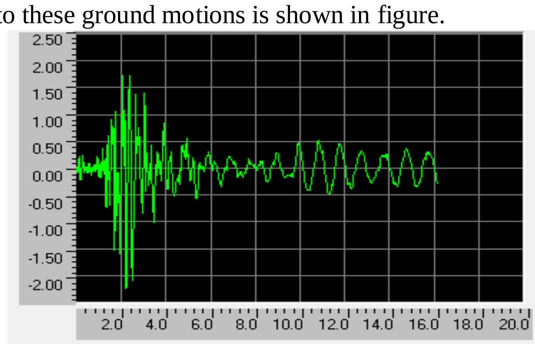


Figure. 9 Formation of plastic hinges (yield mechanism) in PBPD frame at step 8.

It could be clearly seen in figure that hinges are formed in beams only which converts the whole structure into a mechanism and avoids the total collapse. The nonlinear Time history analysis of the frame when subjected to three different ground motions (Dharamshala, Bhuj, Elcentro as shown in figure 10,11,12) was also carried out using the software. The acceleration and displacement response of this frame to these ground motions is shown in figure.



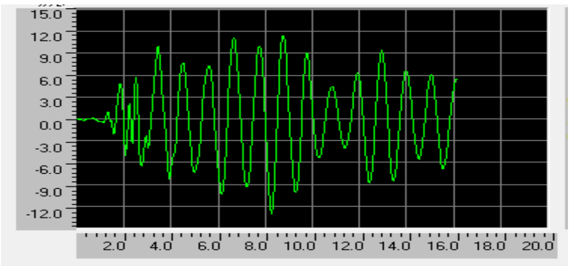


Figure.10 acceleration and displacement due to Dharamshala EQ record

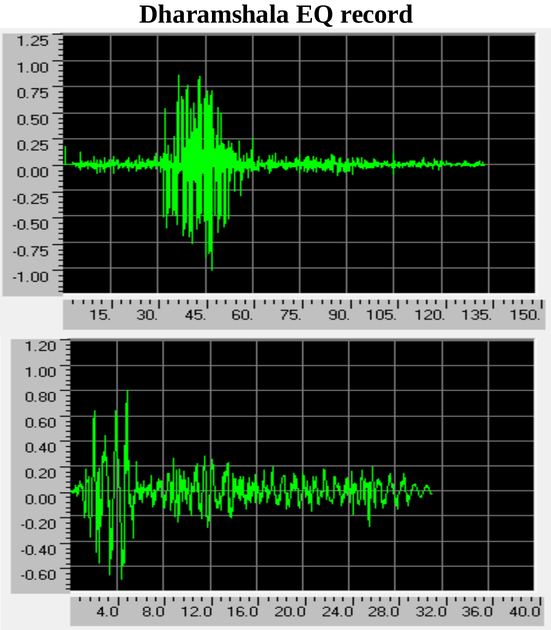


Figure.11 Acceleration and displacement due to Bhuj EQ record

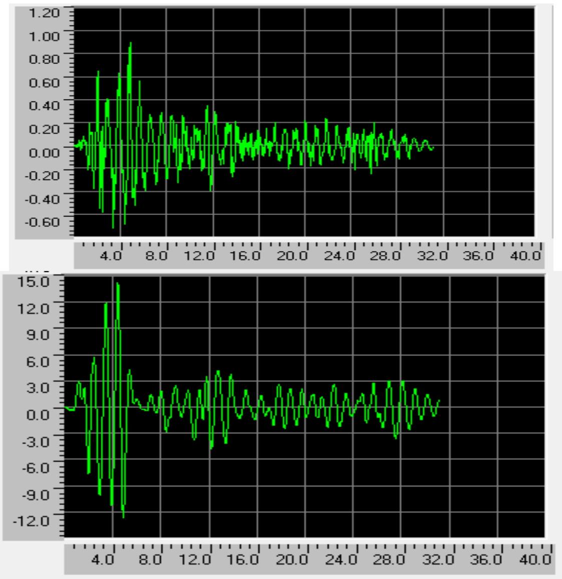


Figure.12 Acceleration and displacement due to Elcentro EQ record

The displacement and acceleration responses of frame designed using elastic design approach and performance based plastic design approach with respect to eight different ground motion are presented in Table.3 for Nonlinear dynamic time history analysis.

Table.3 Acceleration and displacement

Ground motions	Displacement(mm)		Acceleration	
	Elastic design	PBPD design	Elastic design	PBPD design
Bhuj	139.5	278	5.112	12.38
Elcentro	14.2	42.02	0.2984	0.721
Dharamshala	11.4	40.39	0.4926	0.828

From above table it has been found that PBPD has Increase in the acceleration and displacement responses as compared to the frame designed using conventional elastic design approach which leads to a higher hysteretic energy dissipation. The increased hysteretic energy dissipation of the frame indicates that the structure utilizes its capacity lying in the plastic zone. The increased hysteretic energy dissipation of the frame indicates that the structure utilizes its capacity lying in the plastic zone. The reason is that the PBPD method is based on the “strong column weak beam” concept and the beams fails first. As the structure turns into a mechanism due to formation of hinges in beams only it undergoes large deformation before failure.

8. RESULTS AND CONCLUSION

1) The Structure is designed taking into consideration its inelastic properties, this leads to the optimum utilization of the sections.
2) For the model studied, Nonlinear Time history analysis result shows that PBPD frame has 58.7%, 58.6% and 40.5% increased acceleration and 49.82%, 66.2% and 71.77% increased displacement for selected ground motion as compared to Elastic design frame which leads to higher hysteretic energy dissipation.
3) The increased hysteretic energy dissipation of the frame indicates that the structure utilizes its capacity lying in the inelastic zone. For the model studied, Non Linear Static (Pushover) analysis shows very good behavior of the PBPD frame under static pushover loads as compared to elastic design frame.
4) No unexpected plastic hinges were observed in the columns of the PBPD frame as compared to elastic design frame.
5) The hinges are formed in beams only which converts the whole structure into a mechanism and avoids the total collapse.
6) Static pushover loads because large displacements in the PBPD frame as compared to elastic design frame; the structure did not lose stability.

7) It can be thus concluded that the PBPD method is superior to the elastic design method in terms of the optimum capacity utilization.

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