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Comparative study of elastic design method and performance based plastic design method based on Non-linear response analysis

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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. In this study, a fifteen storey steel moment resisting frames are designed by the Performance based Plastic design method and conventional elastic design method and evaluated by Nonlinear static (Push over Analysis) and Nonlinear dynamic analysis (Time history analysis) under eight different ground motions. 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. From the above studies it was found that the nonlinear static pushover analysis shows formation of hinges in columns of the frame designed using elastic design approach leading to collapse and formation of hinges in the beams of the Performance based Plastic design frame leading to increased 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.*

Keywords: *Performance based Plastic Design (PBPD), Target drift, Yield mechanism, Pushover Analysis, Time History Analysis.*

I. 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. There is an urgent need to reverse this situation and it is believed that one of the most promising ways of doing this is through the performance Based Plastic Design (PBPD) method (Lee and Goel, 2001) in which the structural design 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 for a particular danger level 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.

II. 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.

III. 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 15 storey steel 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 eight different ground motions using SAP 2000 V-15 software. Plan and elevations of steel moment resisting frame shown in figure.1

IV. DESIGN OF STEEL MOMENT RESISTING FRAME BY USING ELASTIC DESIGN METHOD

The ongoing Indian Standard Code (IS800:2007) makes use of the limit state procedure (which is a force based design) for the designing of steel 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.

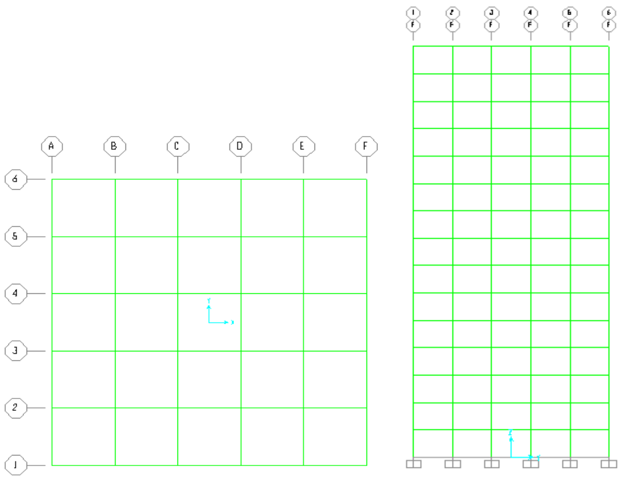

Figure: 1 Plan and elevation steel moment resisting frame

Soil Type	II
Elastic Spectral Acceleration " Sa / g"	0.921
Importance Factor "I"	1
Zone Factor " Z"	0.36
Response Reduction Factor "R"	5
Natural time Period "T"	1.476sec

Table: 2 the seismic parameters of the frame

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as per IS1893-2002

V. DESIGN OF STEEL MOMENT RESISTING FRAME BY USING PBPD METHOD

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.2 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, Yield drift ratio θy = 1%, Target drift ratio θu=3%, Inelastic drift ratio θp= θu- θy=2%, Ductility factor μs= θu/ θy=3, Reduction Factor due to Ductility Rμ= 2, Energy Modification Factor γ=0.75

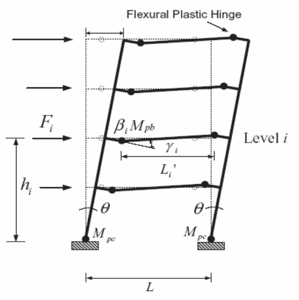

Figure: 2 Target and Yield mechanism (Goel-2010)

VI. INELASTIC RESPONSE ANALYSIS OF THE STEEL MOMENT RESISTING FRAME DESIGNED USING ELASTIC DESIGN APPROACH

We first designed the steel moment resisting frame by the elastic design approach pertaining to the Indian Standard code (IS800:2007) using the SAP2000 V-15 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 SAP2000 V-15. 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 SAP2000 V-15 is shown in figure.3. The results show formation of plastic hinges in some columns of floors which may result into total collapse of the entire frame Fig-3

The nonlinear Time history analysis of the frame when subjected to eight different ground motions (Athens, alkion, Cap-mendocino-2,elcentro Ionian, kalamata, Northridge Olympia Earthquake ground motions as shown in figure 5&6) 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

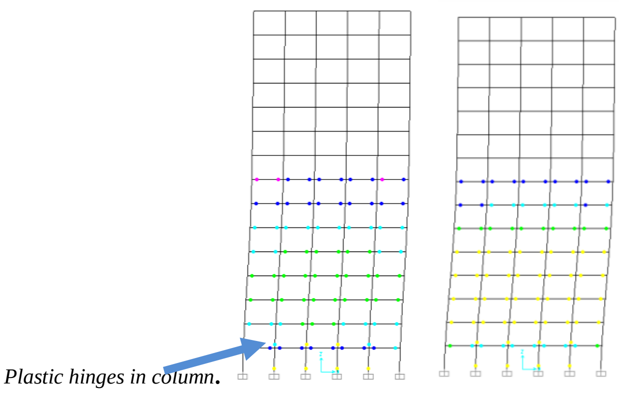

Figure: 3 Formation of Plastic hinges at step 8 &11 in the frame designed using elastic design approach

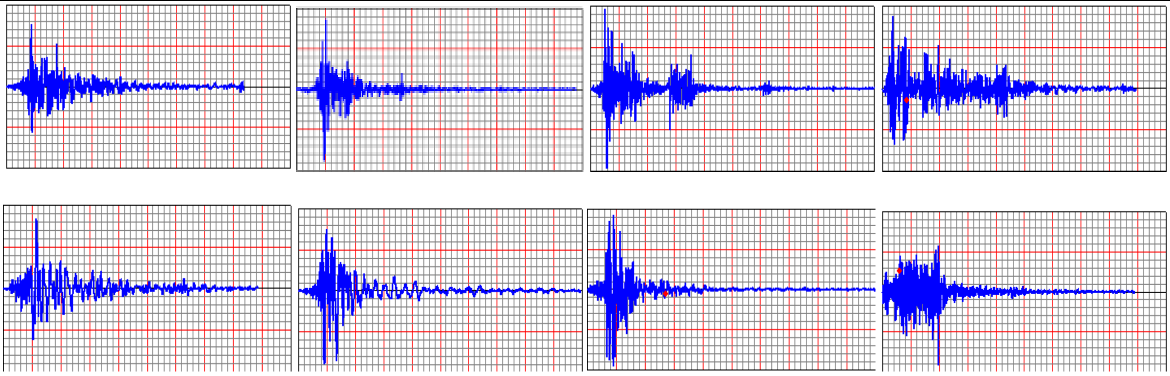

Figure: 4 Earthquake ground motions (Athens, Alkion, Cape Mendocino, Elcentro, Ionian, Kalamata, Northridge, Olympia*)*

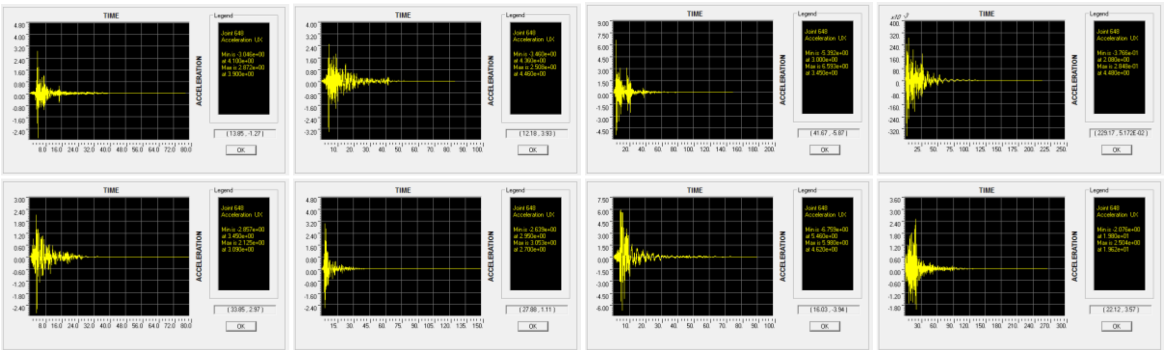

Figure: 5 Acceleration response (Athens, Alkion, Cape Mendocino, Elcentro, Ionian, Kalamata, Northridge, Olympia) of the frame designed using elastic design approach

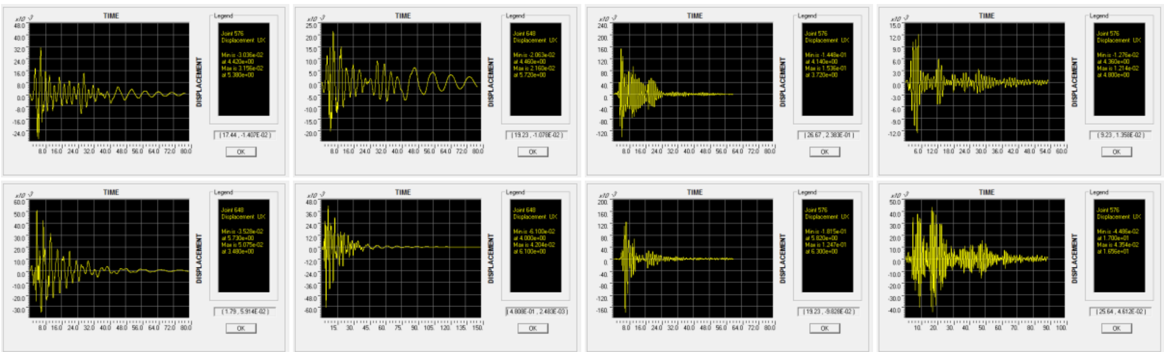

Figure: 6 Displacement response (Athens, Alkion, Cape Mendocino, Elcentro, Ionian, Kalamata, Northridge, Olympia) of the frame designed using elastic design approach

VII. INELASTIC RESPONSE ANALYSIS OF THE STEEL 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.7.

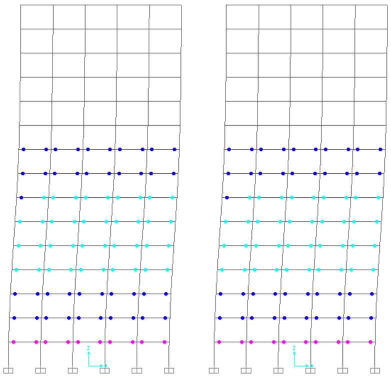

Figure: 7 Formation of Plastic hinges at step 10 &11 in the frame designed using PBPD approach

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 eight different ground motions (Athens, alkion, Cap-mendocino-2,elcentro Ionian, kalamata, Northridge Olympia Earthquake ground motions as shown in figure 8&9) was also carried out using the software. The acceleration and displacement response of this frame to these ground motions is shown in figure

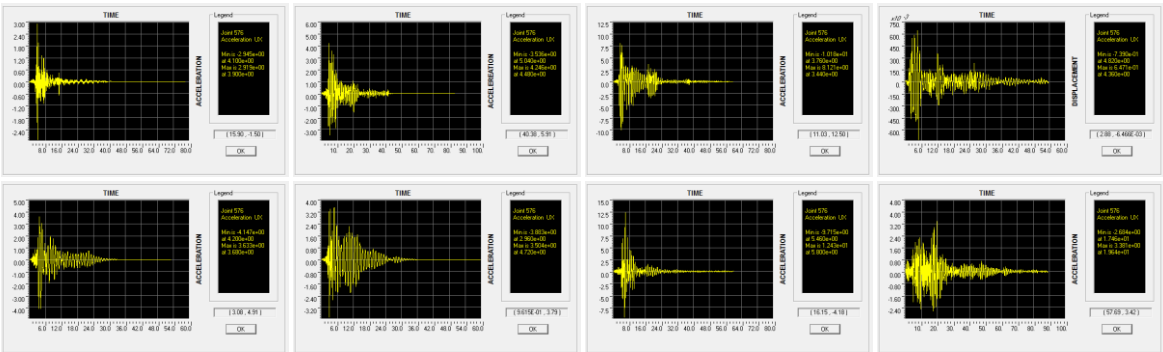

Figure: 8 Acceleration response (Athens, Alkion, Cape Mendocino, Elcentro, Ionian, Kalamata, Northridge, Olympia) of the frame designed using performance based plastic design approach

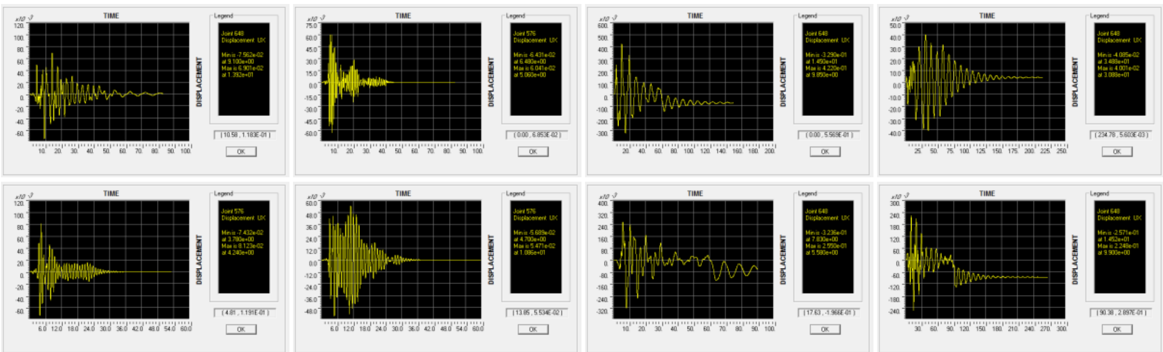

Figure: 9 Displacement response (Athens, Alkion, Cape Mendocino, Elcentro, Ionian, Kalamata, Northridge, Olympia) of the frame designed using performance based plastic design approach

VIII. ACCELERATION AND DISPLACEMENT

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.4 for Non linear dynamic time history analysis**.**

Ground Motion	Elastic Design		Performance Based plastic design	
	Acceleration	**Displacement(mm)**	**Acceleration**	**Displacement(mm)**
Athens	2.872	31.56	2.919	69.01
Alkion	2.508	21.6	4.246	60.41
Cape-mendocino-2	6.593	153.6	8.121	422
Elcentro new	0.2848	12.14	0.647	40.01
Ionian	2.125	50.75	3.633	81.23
Kalamata	3.053	42.04	3.504	54.71
Northridge	5.98	124.7	12.43	255
Olympia	2.504	43.54	3.381	224.8

Table: 4 Acceleration and displacement values of elastic design frame and PBPD frame

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

IX. CONCLUSION

The Structure is designed taking into consideration its inelastic properties. This leads to the optimum utilization of the sections.

For the model studied, Non linear Time history analysis result shows that PBPD frame has 1.61%, 40.93%, 18.82%, 55.98%, 41.51%, 12.87%, 51.89% and 25.94% increased acceleration and 54.27%, 64.24%, 63.60%, 69.66%, 37.52%, 23.16%, 51.10% and 80.63% increased displacement for selected ground motion as compared to Elastic design frame which leads to higher hysteretic energy dissipation. 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.

No unexpected plastic hinges were observed in the columns of the PBPD frame as compared to elastic design frame. The hinges are formed in beams only which converts the whole structure into a mechanism and avoids the total collapse.

Static pushover loads cause large displacements in the PBPD frame as compared to elastic design frame; the structure did not lose stability.

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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