Seismic Analysis of Steel Moment Resisting Frame with Different Target Drift

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Abstract : Steel moment resisting frame designed by performance based plastic design are carried out in this study. The design of moment resisting frame is usually governed by drift limits rather than strength because of their high flexibility. The purpose of this study is to evaluate the seismic performance of a 9 story steel moment resisting frame designed according to performance based plastic design with three different target drift limits 1%, 2% and 3%. Seismic analysis in this study has been carried out by non-linear static analysis (pushover analysis). The results of non-linear static analysis and an example of steel moment resisting frame designed by performance based plastic design are presented.

IndexTerms **– Steel moment resisting frame, Target drift, Performance based design, Pushover analysis.**

1. INTRODUCTION

Earthquakes are one of the most destructive calamities and cause a lot of causalities, injuries and economic losses leaving behind a trait of panic. It is known fact that the world is facing among all-natural disasters. The occurrence of an earthquake cannot be predicted and prevented, but the preparedness of the structure to resist earthquake forces become more important. India has experienced destructive earthquakes throughout its history. Most notable events of major earthquakes occurred in India, since 1819 to 2001. RC structures suffered heavy damage or even collapsed after recent earthquake. The observations behind such damage are, most of the buildings are not designed according to the current code regulations, Seismic behaviour is not taken into consideration in the architectural design and during selection of the structural system, Supervision in the construction phase is not adequate which in turn induces deficiencies like poor concrete quality, inadequate detailing of reinforcement etc. In past decades, several costly and destructive earthquakes have occurred. Current Indian codes do not address the evaluation of seismic resistance of building, which may not have designed for earthquake forces. An appropriate level of safety needs to be ensured for occupants of these buildings through strengthening measures, if found deficient. Therefore, it is necessary to assess the seismic performance and vulnerability of buildings for given seismic parameter. The performance-based design procedure, as briefly described herein, is aimed at achieving predictable and controllable behaviour of structures during design level seismic events. Three major factors are essential in achieving this goal:

1) A design lateral force distribution which reflects realistic story shear distribution along the height of the structure when subjected to severe earthquakes. The triangular force distribution used in most design codes is derived from elastic analysis and may not be valid in the inelastic state. Therefore, a design lateral force distribution derived from nonlinear dynamic analysis results and calibrated by representative ground motion records is more appropriate for performance-based design procedure.

2) A predictable global yield mechanism is more desirable so that the damage could be confined in pre-selected locations of the frame. In this regard, elastic design procedure cannot guarantee a predicable mechanism due to the predominantly inelastic nature of the structural response during severe earthquakes. Therefore, plastic design procedure is more suitable for purposes of performance-based seismic design because desirable yield mechanism is preselected. This design procedure was developed and successfully validated by Goel et al. through non linear dynamic analyses for the steel moment resistant frames (Leelataviwat et al. 1999; Lee and Goel 2001; Lee et al 2004).

3) A pre-designated target drift limit which can be incorporated in determination of the design base shear. To achieve the target building performance objectives (such as immediate occupancy, collapse prevention, etc.) for selected earthquake hazard levels the story drift is a good design parameter. Therefore, a design base shear based on selected target drift level, stiffness of the structure, ductility reduction factor, and structural ductility factor was used in this study. This design base shear was derived from modified energy balance equation and the proposed lateral force distribution (Leelataviwat et al. 1999; Lee and Goel 2001; Lee et al 2004).

1.1 NON-LINEAR STATIC ANALYSIS

In general, linear procedures are applicable when the structure is expected to remain nearly elastic for the level of ground motion or when the design results in nearly uniform distribution of non-linear response throughout the structure.

As the performance objective of the structure implies greater inelastic demands, the uncertainty with linear procedures increases to a point that requires a high level of conservatism in demand assumptions and acceptability criteria to avoid unintended performance. Therefore, procedures incorporating inelastic analysis can reduce the uncertainty and conservatism.

Many methods were presented to apply the Nonlinear Static procedure to structure. Those methods can be listed as;

1) Capacity spectrum Method CSM (ATC, 1996)
2) Displacement Coefficient Method. DCM (FEMA-273, 1997)
3) Modal pushover Analysis MPA (Chopra and Goel 2001)

This approach is also known as "pushover" analysis. A pattern of forces is applied to a structural model that includes non-linear properties (such as steel yield), and the total force is plotted against a reference displacement to define a capacity curve.

This can then be combined with a demand curve (typically in the form of an acceleration-displacement response spectrum (ADRS). This essentially reduces the problem to a single degree of freedom system.

Nonlinear static procedures use equivalent SDOF structural models and represent seismic ground motion with response spectra. Story drifts and component actions are related subsequently to the global demand parameter by the pushover or capacity curves that are the basis of the non-linear static procedures.

In Nonlinear Static Procedure, the basic demand and capacity parameter for the analysis is the lateral displacement of the building. The generation of a capacity curve (base shear coefficients v/s roof drift) defines the capacity of the building uniquely for an assumed force distribution and displacement pattern. It is independent of any specific seismic shaking demand and replaces the base shear capacity of conventional design procedures. If the building displaces laterally, its response must lie on this capacity curve. A point on the curve defines a specific damage state for the structure, since the deformation for all components can be related to the global displacement of the structure.

By correlating this capacity curve to the seismic demand generated by a specific earthquake or ground shaking intensity, a point can be found on the capacity curve that estimates the maximum displacement of the building the earthquake will cause. This defines the performance point or target displacement. The location of this performance point relative to the performance levels defined by the capacity curve indicates whether or not the performance objective is met. In this study modal pushover analysis is used and obtained capacity curve (base shear coefficients v/s roof drift).

2. Methodology

The steel moment resisting frame considered in this study is a 9-story building located in los Angeles. The plan and elevation of the building shown in Figure 1. In all cases, since the design of moment resisting frame in the two orthogonal directions was identical, only half of the structure is considered in the analysis.

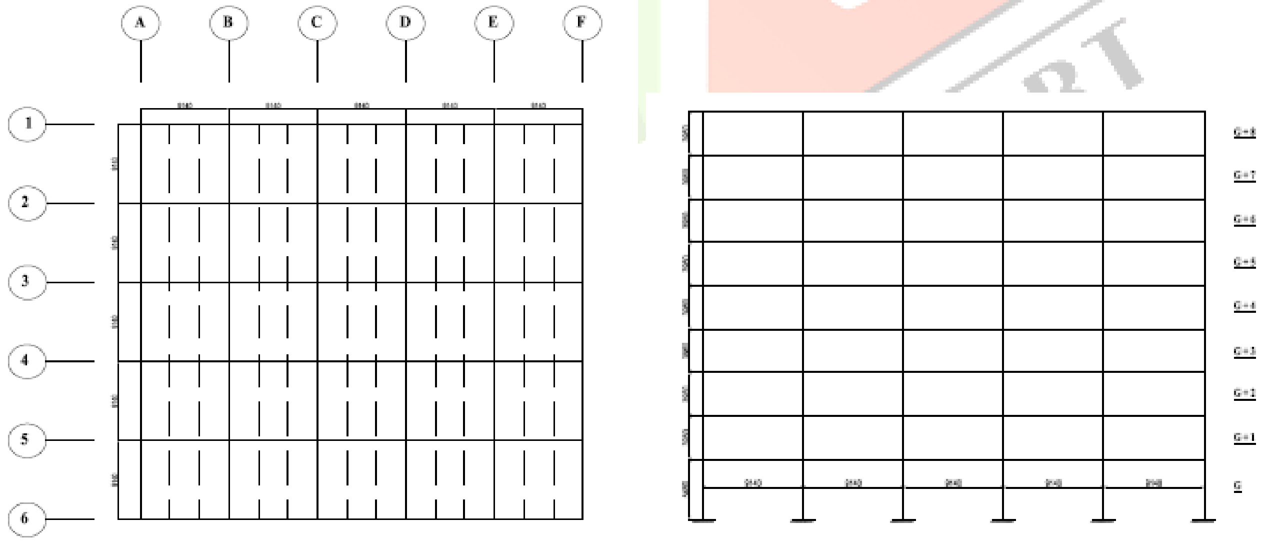

Figure 1. Plan and elevation of the steel frame

The target drifts of three structures were set at 1%, 2% and 3%. The design parameters of three structures with different target drifts were calculated as shown in Table 1, using the proposed equations based on UBC design spectrum with Z = 0.4, I = 1.0, and S3. The periods for the structures were estimated by using UBC formula. For the 9 story frames, the yield drift and the plastic rotation, θp, were taken as 1% (0.01) and 1% (0.01), respectively.

Table 1. Design Parameters of the 9-Story Frames.

Number of Stories	Period (sec.)	C e	Target Drift	Assumed Yield Drift	θp	γ	α	V/W
9	1.285	0.635	0.01	0.01	0.01	0.75	1.50	0.179
9	1.285	0.635	0.02	0.01	0.02	0.56	3.01	0.073
9	1.285	0.635	0.03	0.01	0.03	0.44	4.52	0.038

Three design cases of the 9 story moment resisting frame are considered in this study. The members of the structure were designed by plastic design procedure and AISC-LRFD Specification [AISC 1994]. A572 GR.50 steel was used for all beams and columns in this study. The yield strength is 345 MPa; modulus of elasticity is 200 GPa. The final member sizes of the frames designed by the performance based plastic design procedure are shown in Table 2 through Table 4.

Table 2 Cross section details of the 9 story moment resisting frame with 1% target drift.

Story level	Beams	Exterior column	Interior column
1	W40*149	W14*500	W14*665
2	W40*149	W14*500	W14*665
3	W40*149	W14*455	W14*665
4	W40*149	W14*455	W14*665
5	W40*149	W14*426	W14*665
6	W36*135	W14*426	W14*665
7	W33*130	W14*342	W14*550
8	W30*116	W14*342	W14*550
9	W30*90	W14*257	W14*426

Table 3 Cross section details of the 9 story moment resisting frame with 2% target drift.

Story level	Beams	Exterior column	Interior column
1	W30*90	W14*283	W14*398
2	W30*90	W14*283	W14*398
3	W30*90	W14*283	W14*398
4	W30*90	W14*283	W14*398
5	W27*84	W14*257	W14*370
6	W27*84	W14*257	W14*370
7	W24*76	W14*211	W14*311
8	W24*76	W14*211	W14*311
9	W21*55	W14*176	W14*233

Table 4 Cross section details of the 9 story moment resisting frame with 3% target drift.

Story level	Beams	Exterior column	Interior column
1	W24*55	W14*159	W14*257
2	W24*55	W14*159	W14*257
3	W24*55	W14*159	W14*257
4	W24*55	W14*159	W14*257
5	W24*55	W14*145	W14*233
6	W21*48	W14*145	W14*233
7	W21*48	W14*145	W14*233
8	W21*48	W14*145	W14*233
9	W18*40	W14*109	W14*159

2.1 NONLINEAR STATIC ANALYSIS

Nonlinear static analysis is one of the methods available for evaluating buildings against earthquake loads. The results of this analysis obtained using SAP 2000 program which is general-purpose structural analysis program for static and dynamic analyses of structures. A two-dimensional model of the structure is developed in SAP2000. Beams and columns are modelled as frame elements by defining plastic hinges at both ends of beams and columns. Dead load are applied on the frame during pushover analysis.

Figure 2 shows the base shear coefficients versus roof drift plots of 9 story frame with target drifts obtained from pushover analysis. It can shown that design base shear coefficients of the frames are very close to the values assumed in the design procedure. Figure 3 through 5 shows the locations of the inelastic activity in the all the frames at 2% roof drift. All the frames developed the strong column weak beam mechanism and all plastic hinges occurred only in the beams and at the column bases.

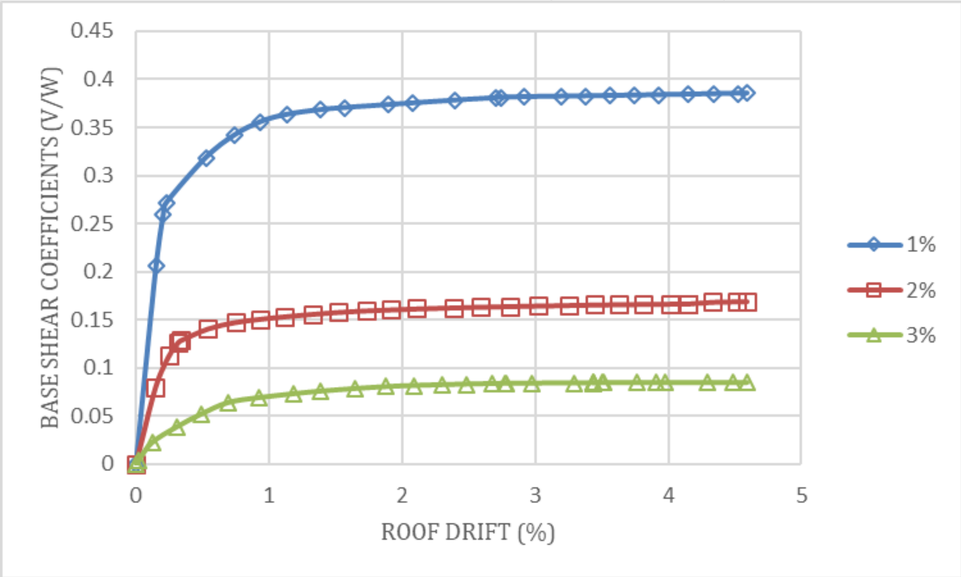

Figure 2. Base Shear Coefficient versus Roof Drift of 9 Story Frame

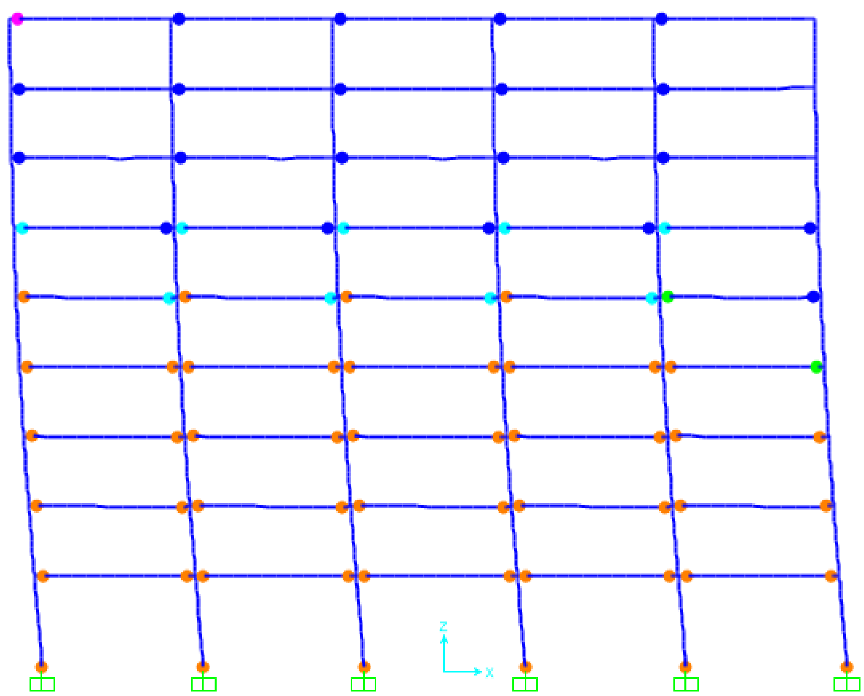

Figure 3. Hinge location of 9-story frame with 1% target drift

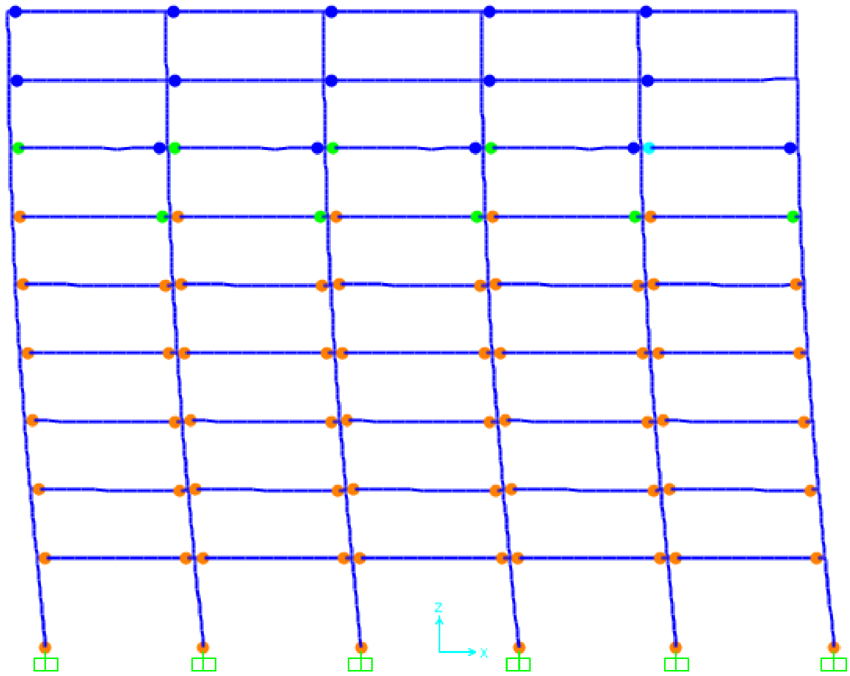

Figure 4. Hinge location of 9-story frame with 2% target drift

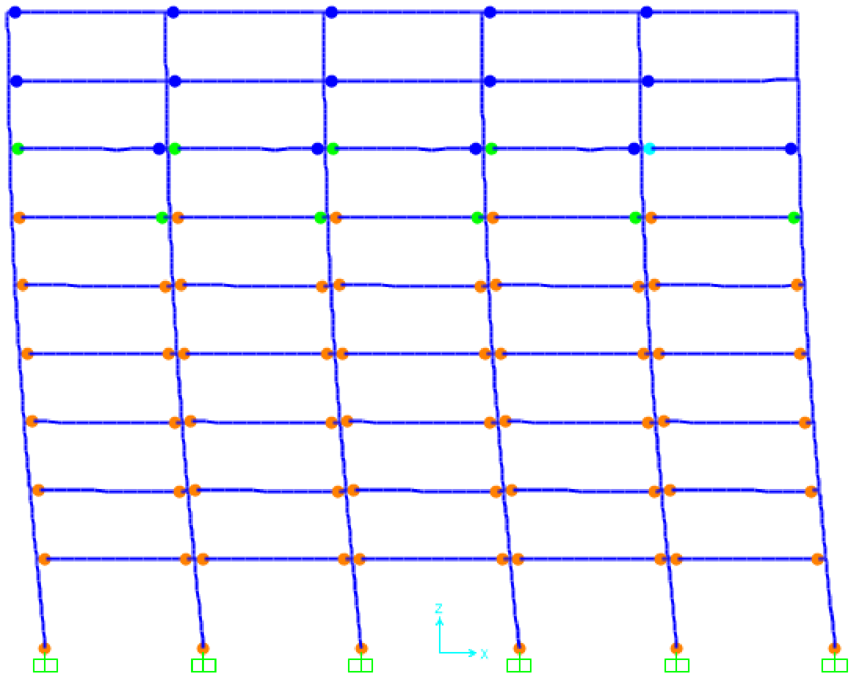

Figure 5. Hinge location of 9-story frame with 3% target drift

3. Conclusion

1. The use of plastic design theory leads to structures that meet a pre-selected performance objective in terms of yield mechanism and target drift.
2. The story drift (target drift) and pre-selected yield mechanism are specified as design parameters in the design procedure. Thus, it is not necessary to check the ultimate drift explicitly. The results from inelastic static analyses in the parametric study showed that the yield drifts and the design base shear coefficients of the frames were very close to the values assumed in the design procedure.
3. The proposed design procedure prevents structures from developing undesirable mechanisms, such as soft-story mechanism. The results of the parametric study show that the frames designed by the proposed procedure develop strong

column-weak beam mechanism and all plastic hinges occurred only in the beams and at the column bases with the later forming last, confirming the reliability of the proposed design procedure.

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