EFFECT OF PLASTIC HINGE LENGTH ON SEISMIC RESPONSE OF HIGH RISE STEEL FRAMES

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ABSTRACT

This paper presents an analytical study on seismic response of high rise steel frames under earthquake loads at different percentage of plastic hinge length. This study aims to investigate the best value of plastic hinge length which gives the best response of steel frames in high rise building. Three steel frame models are presented in order to carry out this study, 12-storeys, 24-storeys and 36-storeys frame models. Three different input earthquake waves have been used as seismic loads. The main parameter has been considered in this study is the plastic hinge length. The presented steel frame models have been studied under six different cases of plastic hinge length, 1%, 5%, 10%, 15%, 20% and 25% of member length. The responses of the studied different steel frame models for the different cases have been presented as displacement at frame top, bending moment time history at frame base and hysteresis rotation-moment at first floor beam. The results show that the most effective percentage of plastic hinge length vary from 5% to 15%. At this range, the steel frame models can perform in the best response of displacements at frame top, rotations of beams, and moments at frame base.

Keywords: Nonlinear Response; Yielding Zones; Plastic Hinge length; Steel Frames; Earthquake Loads

1. INTRODUCTION

Ultimate deformation capacity calculation of structural members under earthquake loading still difficult task due to their nonlinear and complex behavior. The two main parameters affect the ultimate deformation capacity of structure component are the plastic hinge length and the ultimate curvature. Through the plastic hinge length, it can be dealt with tension stiffener and inelasticity of flexural behavior. Under great earthquake ground motions, the flexibility of steel moment-resisting frames may result in great beams and columns damage. In steel frames, the beams and columns stresses should be limited in design due to the weak seismic performance related to geometric nonlinearities and brittle failure of beam-to-column connections. Therefore, the stresses at beams and columns should be limited in design, and hence larger member sizes may be required. Limited ductility and low energy dissipation capacity due to beam deformations and column buckling is one of several reasons for the weak performance of steel frames as Nakashima et al (1988), FEMA (2000), and Omar (2014). After structural member at certain section has reached its maximum resistance in plasticity region, it deforms under any additional applied load, till the strain reaches the level of fracture/breakage. This period/phenomenon when it freely deforms without any resistance till breaking, is essentially hinge like behavior, and since it formed in plastic range, is called plastic hinge.
Figure 1. Steel frame models
Based on structural member response capacity, the plastic hinge length determination of steel structures is an important consideration which effect on design procedures. In the past decade, the carried out researches have shown that structures significant damages can be caused by great earthquake ground motions. The structure is expected to face these motions into its inelastic range of response through multiple excursions.

The plastic hinges can be formed in structure members when the structure subjected to great seismic action. The plastic hinge length of a steel member is an important demand parameter in assessing the response and damage of a structure to earthquakes or other loads causing the formation of plastic hinges. Therefore, it is essential that plastic hinge length of a steel member is considered.

Several research have been carried on proposed plastic hinge length such as Avery and Mahedran (2000), Peng et al (2008), Ribeiro et al (2015), and Scott and Fenves (2006).

In this paper, the effect of plastic hinge length on seismic response of high rise steel frames under three different input earthquake motions is presented. Three steel frame models are considered to represent high rise steel frame. The main parameter has been considered is the plastic hinge length. The responses of the studied frame models presented as displacement at frame top, bending moment time history at frame base and hysteresis rotation-moment at first floor beam. The results present the effect of plastic hinge length on the non-linear seismic response of the high rise steel frame.

2. METHODOLOGY AND STRUCTURAL MODEL

In this study, nonlinear dynamic time history analysis using finite element program (SeismoStruct 2016), is performed. Inelastic force-based plastic hinge frame element is considered. This plastic-hinge element, featuring a similar distributed inelasticity forced-based formulation, but concentrating such inelasticity within a fixed length of the element. The advantages of such formulation are not only a reduced analysis time (since fiber integration is carried out for the two member end sections only), but also a full control/calibration of the plastic hinge length (or spread of inelasticity), which allows the overcoming of localization issues. The number of section fibers used in equilibrium computations carried out at the element's end sections needs to be defined. The ideal number of section fibers, sufficient to guarantee an adequate reproduction of the stress-strain distribution across the element's cross-section, varies with the shape and material characteristics of the latter, depending also on the degree of inelasticity to which the element will be forced to. Hence, the plastic hinge length needs to be defined.

Three high rise steel frame models have been proposed, 12-storeys, 24-storeys and 36-storeys. The geometry of the different frame models is shown in Figure 1. The frame models have been initially designed using SAP2000 program to be with cross sections as shown. Six different alternative amount of plastic hinge length at the beams and columns are proposed to study the seismic response of the steel frame structure. The length of the plastic hinge of beams and columns is taken as a percent of member length starting from the face of the beams and columns. The proposed plastic hinge lengths are proposed gradually from 1% to 25% of member length.

The input waves have been applied at both fixed supports in order to investigate the effect of plastic hinge length under different input waves on the seismic response of the frame. The dynamic time history analysis used three input ground motion records obtained during the 1976 Friuli earthquake (6.5 Mw), the 1995 Kobe earthquake (6.9 Mw) and the 1989 Loma Prieta Earthquake (6.9 Mw). The input waves are restored at the wave’s packages with seismostruct software. The calculated responses for different records are compared. The accelerations of ground motions are shown in Fig. 2.

![Figure 2. Input ground motions](image-url)
Figure 3. Displacement time history at frame top 12-storey frame
Figure 4. Displacement time history at frame top 24-storey frame
Figure 5. Bending moment time history at frame base for 12-storey frame
3. ANALYSIS AND RESULTS

The seismic behavior of steel a high rise twelve storey steel frame is presented in this study. The steel frame is categorized according to the plastic hinge length into different models. Five different alternative amount of plastic hinge length at the beams and columns are proposed to study the seismic response of the steel frame structure. The length of the plastic hinge of beams and columns is taken as a percent of member length starting from the face of the beams and columns. The proposed plastic hinge lengths are proposed gradually from 1% to 25% of member length. Then, a study of nonlinear time-history analysis for all different models was carried out. The frame top point and the beam at first floor level were the target of response study.

It can be shown from the results that the different models have different behaviors according to the plastic hinge length, the input earthquake motion and the frame height. The time history of displacement at frame top point in direction of the input wave, for the 12-storey and 24-storey frame models, is shown in Figures 3 and 4. The maximum displacement at frame top changes from model to other due to amount of plastic hinge length. It can be shown that the 1% of plastic hinge length gives out of standing result, so it can be excluded from comparison. The better displacement response could be achieved around 5% plastic hinge length for 12-storey frame (0.065 m for Friuli, 0.094 m for Kobe and 0.053 m for Loma Prieta) and 10% for 24-storey frame (0.165 m for Friuli, 0.289 m for Kobe and 0.328 for Loma Prieta). The different in input waves has a slight effect on the displacement response. Hence, it can be considered that the main effective parameter is the percentage of plastic hinge length. Though, the percentage of 5% plastic hinge length gives the best displacement response, but the case of 15% the damping appears after time of 15 seconds and continues till end of wave while at 5% it looks like no damping through the whole wave applied and the displacement almost constant or increase is come cases.

It can be concluded that the displacement could be enhanced at the plastic hinge length with amount of 5% to 15% of member length, starting decreasing gradually by increasing the amount of plastic hinge length but without any damping till the end of wave. Thus, the optimum length of plastic hinge could be found in-between 5% to 15%, for getting better response of the displacements and rapid damping as well.

Figures 5 and 6 show the bending moment time history at support along the input wave, for the 12-storey and 36-storey frame models. For the 12-storey frame model, the best bending moment response occurs at 15% plastic hinge length with amount of 30.696 KN.m for Friuli earthquake, 49.043 KN.m for Kobe earthquake. While for Loma Prieta earthquake, the best bending moment occurs at 5% plastic hinge length with a magnitude of 39.753 KN.m. For the 36-storey frame, the bending moment reaches 99.868 KN.m. at plastic hinge length of 25% for the Friuli input wave. The percentage of plastic hinge length of 15% gives the best amount of moments for both Kobe and Loma Prieta input waves with amount of 127.442 KN.m. and 226.46 KN.m. respectively. It can be shown that at 15% plastic hinge length the response gives not only low amount of moments but also it gives longer periodic time which enhance the frame performance more than other percentage of plastic hinge length.

By blotting the hysteric relationship between the moment and rotation at the end of beam of first floor as in Figures 7, 8 and 9, it can be shown how the elasticity can be kept by changing the plastic hinge length. The figures show the hysteric curve M-θ relation at each case of plastic hinge length for the three studied frame models. It can be shown that the rotation can vary in closed range at plastic hinge length of 5% followed by percentage of 15% which has the minimum amount of moments. The minimum amount of moment can be reached at the plastic hinge length of 15% at most input wave cases and for different three types of frame models. That means, this percentage of plastic hinge agree with the last results of displacements and moment at frame base. Hence, it can be concluded that the plastic hinge length at amount from 5% to 15% of member length in this study can give most acceptable response of displacement, moment and rotation.
Figure 6. Bending moment time history at frame base for 36-storey frame
Figure 7. Moment-Rotation hysteric curve at first floor beam 12-storey frame
Figure 8. Moment-Rotation hysteric curve at first floor beam 24-storey frame
Figure 9. Moment-Rotation hysteric curve at first floor beam 36-storey frame
4. CONCLUSIONS

This paper presented the seismic response of three different storey steel frame models under load of three different input waves. The paper aims to investigate the effect of plastic hinge length on seismic response of steel frames, in order to find out the best values of plastic hinge length which gives the best response. The plastic hinge length changed from 1% to 25% of beams and columns. This investigation founded that the best plastic hinge length vary from 5% to 15% to give the best response. This range of plastic hinge length decreases the frame top displacement, decreases the bending moment at supports, and shows an early damping in response till the end of input wave. This investigation has open up several questions that need of further investigation about finding the equation governing the plastic hinge length for steel structures.

5. REFERENCES


