Title: Seismic performance of steel moment resisting frames considering horizontal and vertical seismic components

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ABSTRACT

Steel Moment Resisting Frames (SMRFs) are widely used to resist seismic loads. Different response parameters such as maximum roof drift, Maximum Inter-storey Drift (MID), and plastic rotation of different frame elements are used to assess their seismic performance. This study investigates the variability of MID at collapse, evaluates the effect of vertical seismic component and identifies the critical floors. A ten storey SMRF was considered as a case study. Incremental dynamic analysis (IDA) was conducted using five different ground motions considering both the horizontal and vertical components. It was observed that the storey experiencing the MID is not always the severely damaged storey. The vertical seismic component was found to significantly increase the column axial forces and vertical deflection of the beams, and, thus increases the state of seismic damage in the frame. The effect of the vertical seismic component on the MID was also investigated.

Keywords: Seismic performance, Steel moment resisting frames, Inter-storey drift, Incremental dynamic analysis.

INTRODUCTION

Steel moment resisting frames (SMRFs) are widely used as a lateral load resisting systems for mid to high-rise buildings. After 1994 Northridge earthquake, significant research was conducted to improve their seismic performance. Response parameters used to assess the global seismic performance of SMRFs include maximum roof drift, MID, base and storey shear forces. The local performance is

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usually monitored by examining the rotation of beams, columns and connections. Reported MID values at collapse have large variations in literature. FEMA356 [1] limits the MID for steel structures to 5%. FEMA 350 [2] defines collapse to occur at 10% inter-storey drift ratio for SMRFs of midrise buildings (4-12 storeys).The New Zealand loading standard NZS1170.5 [3] limits the MID to 2.5%. UBC 1997 [4] proposed MID ratios 2.5% and 2.0% for short and long period structures, respectively. The actual MID depends on many factors including design assumptions, characteristics of ground motion and effect of higher mode of vibration. Defining seismic performance by a single limiting value of MID does not allow identification of the severely damaged storeys.

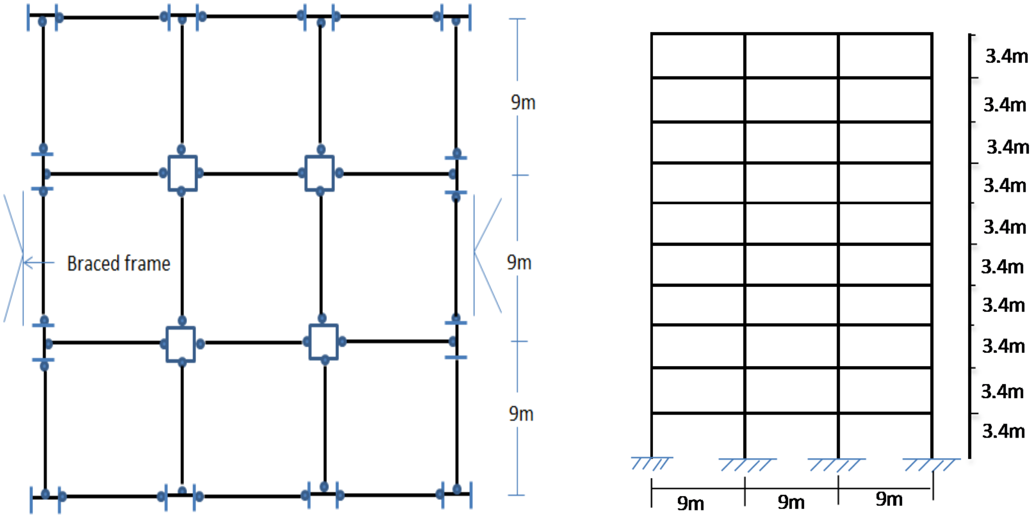
The damage due to vertical component of vibrations was observed to be very significant by many researchers [5-7]. The response of interior columns and interior beams of moment-resisting frames can be affected significantly [5, 6]. Labbafzadeh and Tehranizade [7] found that the increase in the column axial forces caused by the vertical excitation of near-field and far field earthquakes can reach 65% and 8%, respectively. The fluctuation of column axial force can also increase the column's rotational ductility demand and thus causes significant structural damage [8]. Recently several building codes require to account for the vertical seismic component by assuming the vertical design response spectra as 2/3 of the horizontal design spectra [1] [4]. Eurocode 8 [9] and the National Earthquake Hazards Reduction Program [10] include vertical spectrum defined independently from the horizontal spectrum.

The objective of this study is to assess the seismic performance of SMRFs based on MID and also to investigate the effect of vertical seismic component on the MID.

ANALYTICAL MODEL

A ten storey SMRF is selected as a case study. The frame (Figure 1) is designed by Ozhendekci et al. [11] according to Turkish standard [12] which contains similar procedures provided by the AISC 316-89 [13]. As the structure is symmetric, a two-dimensional (2D) model of the moment resisting is developed using the software SeismoStruct [14].This software is based on fibre element approach. The modeling technique used in this study was already validated with the experimental results and documented in the SeismoStruct verification report [15]. Beams and columns are modeled using displacement based inelastic frame element. Each beam and column is divided into four and two elements to monitor the local damage at the ends of each element. The distributed dead and live loads are converted to equivalent point loads and applied at the two end nodes of beam element. The mass of the building is converted into lumped mass and applied at the two ends of each beam element. Bilinear material behaviour with 3% strain hardening is considered by distributed plasticity approach. The P-Δ effect is included in the analysis.

FEMA356 [1] proposed the limiting rotation of beam and column at different performance level. Local failure of beam and columns are assumed when the total chord rotation reaches at the ultimate chord rotation (θ_u) defined by FEMA356 [1].



(a) Plan view (b) Elevation

Figure 1: Plan view and elevation of 10- storey moment frame [11]

DYNAMIC ANALYSIS

The seismic performance of structures depends on variation on the seismic hazard parameters such as frequency content, event duration and effective number of loading cycles. As a result different ground motions scaled to same PGA do not cause same amount of damage to the structures. Five different ground motions, obtained from PEER ground motion database [16] are selected to conduct incremental dynamic analysis (IDA). Figure 2 shows the elastic response spectra considering 5% damping for the selected ground motions. Eigen value analysis was performed to determine the frequencies and mode shapes of free vibrations. The fundamental horizontal and vertical periods of vibrations are 2.385 sec. and 0.276 sec., respectively.

IDA was performed considering the horizontal seismic components of the five ground motions. The analysis was terminated when all three columns of the first floor reached the limiting rotation proposed by FEMA356. The frame is then reanalyzed while considering the vertical seismic component. The vertical component is scaled using the same scaling factor as the horizontal component to keep the V/H ratio constant.

DAMAGE DISTRIBUTION

Figure 3 compares the MID at failure while ignoring or considering the vertical seismic component. It is observed that vertical components of Imperial, and Tabas earthquake do not significantly affect the MID of different stories (0.62%-4.87%). MID of top two storeys are more effected due to Northridge earthquake. The value is decreased by 8.68%-10.1%. The vertical component of SanFernando earthquake decreases the MID of 1st-3rd storeys by 9.31%-17.27% and for 10th storey by 12.3%.

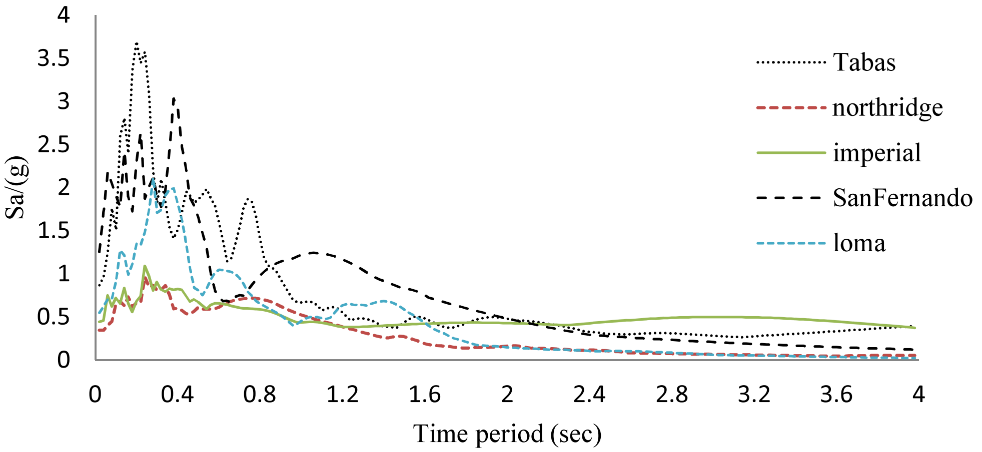


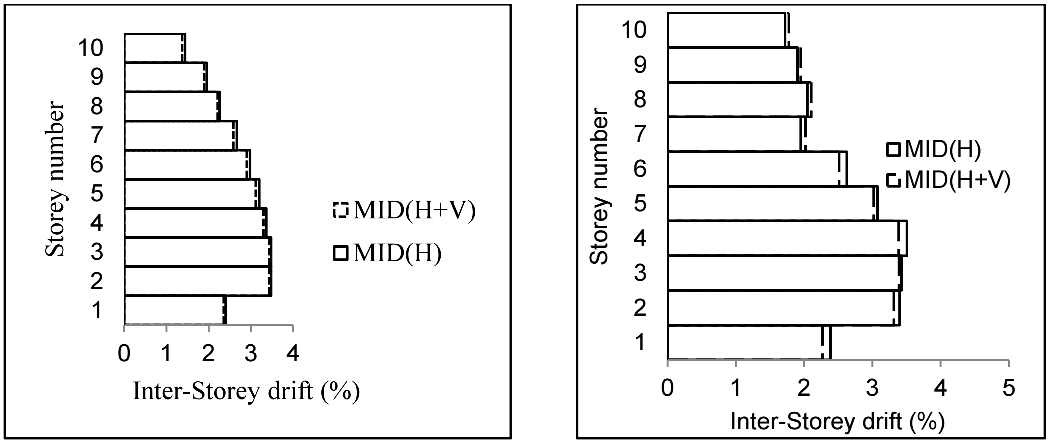
Figure 2: Elastic response spectral acceleration for horizontal seismic component

The significant effect is observed from 4th - 10th storey due to Loma earthquake where MID is decreased by 8%-21.6%. The values of MID varied from 3.41% to 5.44%. Figures 4-8 show the damage distributions due to different ground motions. The vertical seismic component causes the yielding of beams at the mid span. The seismic performance of columns is investigated based on rotation according to FEMA 356 [1]. It is observed that for all five ground motions the first storey is the severely damaged floor as three of the four columns have reached to failure though the MID does not occur at the first floor for any of the records.

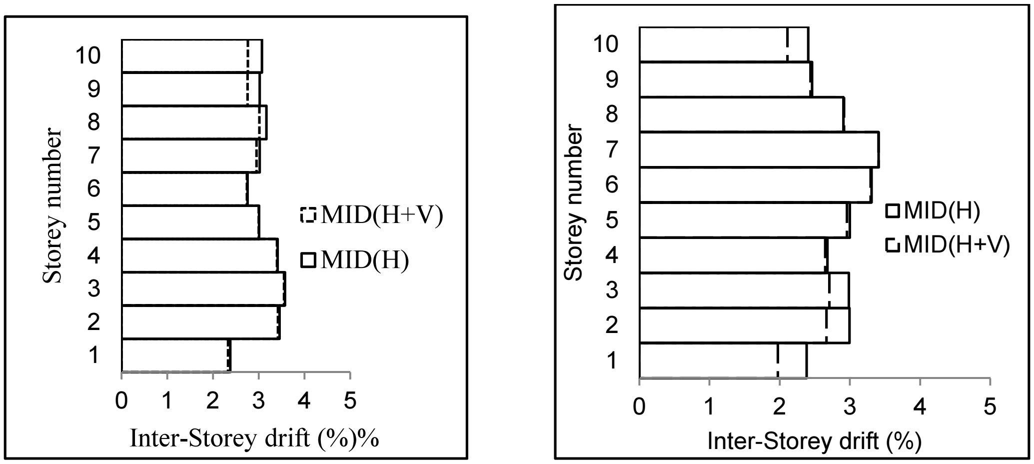
EFFECT OF THE VERTICAL SEISMIC

For all five ground motions, the average percentage of contribution of vertical motion to the column axial forces varied from 9.70%-20.58% for exterior column and 31.24%-53.86% for the interior columns. It indicates that the internal column axial forces are significantly affected by the vertical seismic component. Although the vertical component did not significantly influence the MID of different stories, significant increase in the column axial forces increased the rotation ductility demand for the columns.

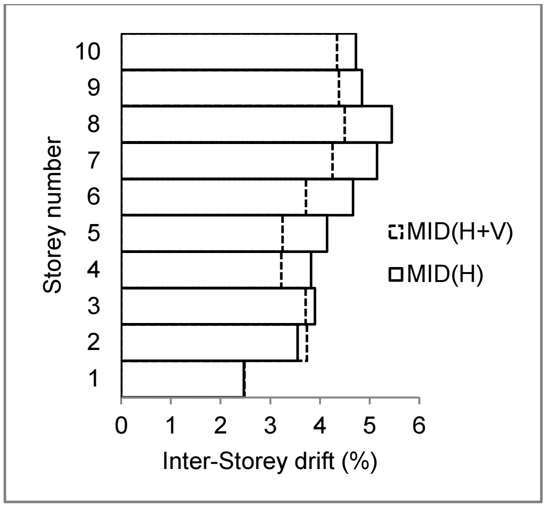
The dynamic analyses showed that beams are highly affected by the vertical motion. The vertical component caused the beams to have high vertical deflections. The effect is more pronounced in the top five storeys. The ninth storey beams have the highest vertical deflection (1.92% of the span) due to Loma earthquake.



(a) Imperial earthquake Sa(T1) =0.349g (b) Tabas earthquake at Sa(T1) =0.351g

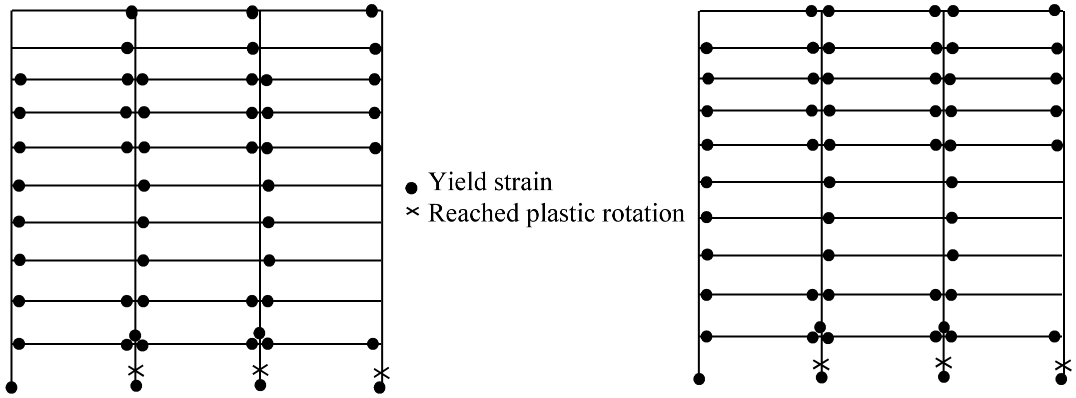


(c) Northridge earthquake Sa(T1) =0.424g (d) San Fernando earthquake at Sa(T1)=0.339g



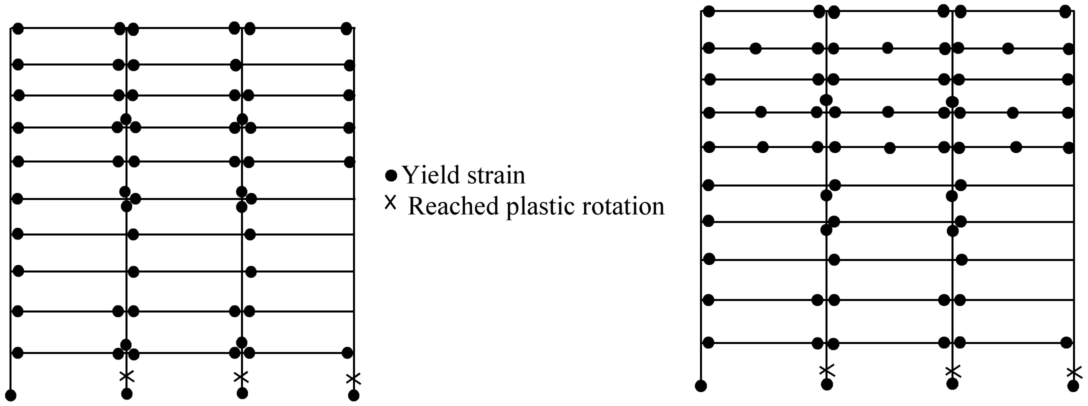
(e) Loma earthquake at Sa (T1)=0.596g

Figure 3 Comparison of MID for horizontal and both horizontal and vertical component of earthquakes



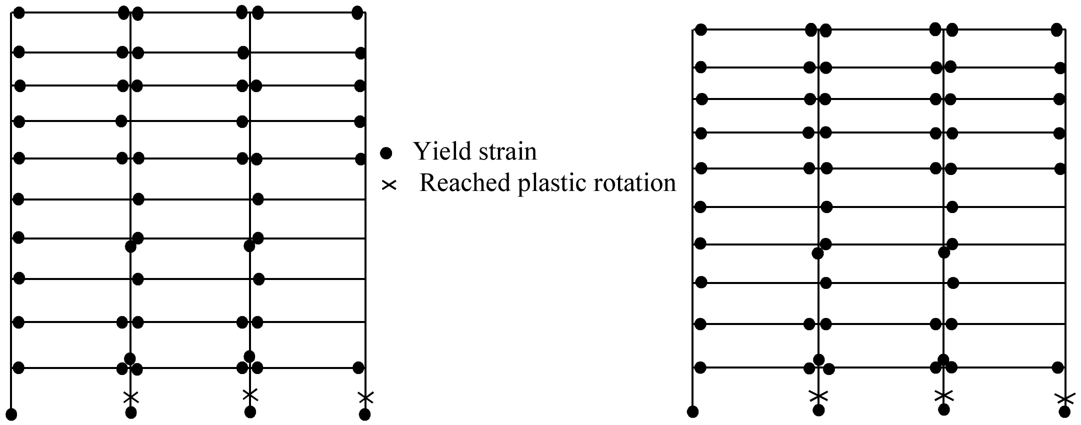
(a) (b)

Figure 4: Damage distribution due to Imperial earthquake at Sa(T1) =0.349g (a) horizontal component (b) both horizontal and vertical component



(a) (b)

Figure 5: Damage distribution due to Northridge earthquake at Sa(T1) =0.424g (a) horizontal component(b) both horizontal and vertical component



(a) (b)

Figure 6: Damage distribution due to SanFernando earthquake at Sa(T1)=0.339g (a) horizontal component (b) both horizontal and vertical component.

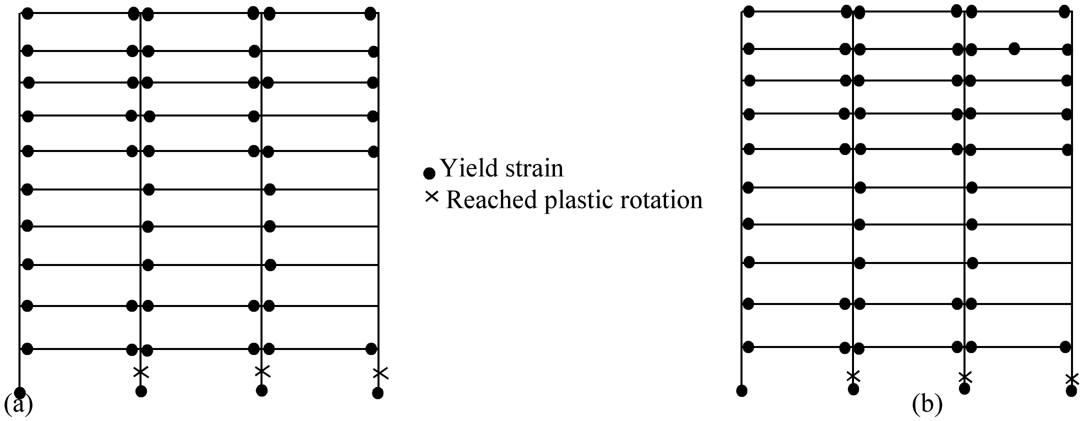


Figure 7: Damage distribution due to Tabas earthquake at Sa(T1) =0.351g (a) horizontal component (b) both horizontal and vertical component.

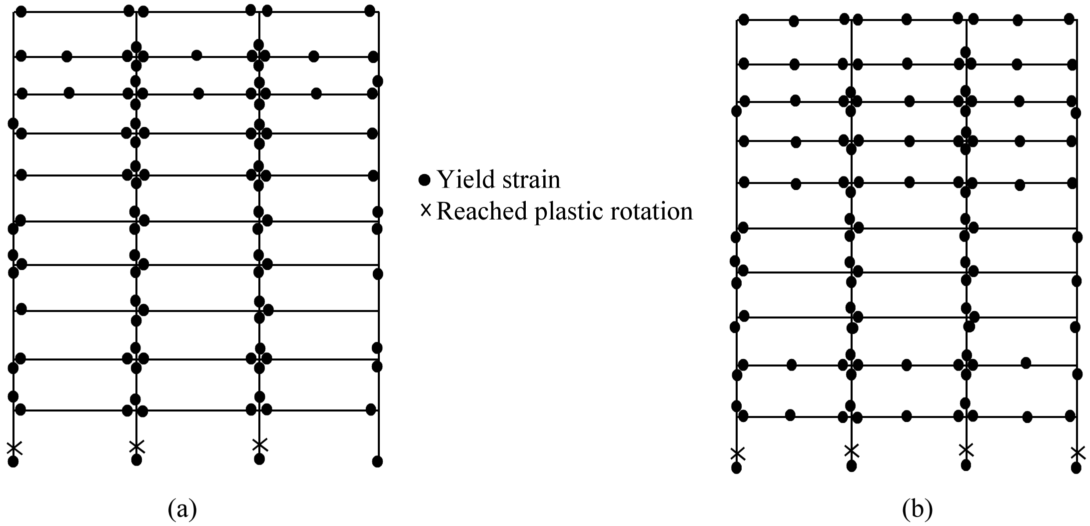


Figure 8: Damage distribution due to Loma earthquake at Sa (T1)=0.596g (a) horizontal component (b) both horizontal and vertical component

CONCLUSION

Nonlinear incremental dynamic analyses were performed considering five different ground motions to examine variations in the MID, understand the effect of vertical motion on MID and the seismic performance of the SMRFs. The following conclusion can be drawn from the study:

1. The MID of a building varies along the height of the building and also with the different ground motions. Vertical seismic component also significantly affects the MID. The storey experiencing the MID during the nonlinear dynamic analysis is not the severely damaged storey. Local damage cannot be identified using a single value of MID at collapse.
2. IDA shows that the vertical component of earthquake significantly increases the column axial force, and, thus reduces the ductility. It also significantly increases the vertical deflection of beams. Neglecting the vertical motion may not be always conservative.

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