Effects of Vertical Irregularity in Steel Braced Frames on Response to Earthquake

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Abstract: This paper deals with the irregular profile of braced steel frame building in vertical direction with shear link bracing systems. The underlying fact of the paper is the effect of seismic force in braced frames with different types of irregularities including mass irregularity, mass discontinuity and overhanging mass. For each successive model, the position of shear link bracings has been fixed to make the study effective. This study has investigated the vulnerable effect of irregular profiles in steel frame buildings. To attain the behavior of each frame, linear time history analysis method has been adopted for the present study. FEMA356 standard has been used here for linear time history analysis. Investigations on different frames exhibit that regular profile with symmetry in mass is more efficient while using overhanging mass is detrimental considering the time dependent displacements and accelerations.

Key words: Steel frame, shear link, time history analysis, irregular profile.

1. Introduction

Steel bracings have become a very common system to retrofit steel framed buildings for last few decades. It has become accustomed by reason of its affectivity on increasing strength, stiffness and ductile properties of structures. Earthquake rehabilitation has become a challenge nowadays. Steel bracing systems are the best means for the proper rehabilitation of existing structures which are prone to the earthquake loads. Use of shear links has made the method more effective to a noticeable extent. With the development of the concept of incorporating shear links with seismic bracings, researchers and structural engineers have already represented its credible performances compared to standard steel bracings systems. Based on a number of studies, it is clear that this system was developed for both steel and concrete structures [1, 2]. Research works are still going on to develop the

bracing pattern with or without links. Studies with vertical shear links depict that they provide more lateral stiffness to withstand the seismic force [1]. The bracings are provided not only in regular shaped framed structures but also in irregular shaped framed structures. These framed structures with or without shear links can be studied either experimentally or numerically. In case of experimental studies, shaking table test is often adopted. Shaking table test is a comprehensive test to determine the affectivity of certain frames; however, it is very costly and not widely available. Alternatively, numerical approaches are widely adopted.

A number of researches have already been conducted based on experimental studies and numerical analysis. For example, Hosseini et al. [3] discussed the pushover analysis of reinforced concrete building with vertical shear links steel braces. The goal of their study was to strengthen the frames providing steel bracings such as inverted “V” braces, inverted “Y” shear linked braces. Several models had

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been selected to conduct their study. Frames of 4, 8 and 12 story regular reinforced concrete building were analyzed to assess their properties and behaviors. They carried out the pushover analysis to evaluate the efficiencies of their models and it was found that the inverted Y-linked braces are good enough to resist earthquake force as the formation of first non-linear hinge has been found in shear links. Naik, Saleemuddin and Sangle [4] presented the seismic performance evaluation of reinforced concrete frames with irregular elevations using nonlinear static pushover analysis. Seismic performance of concentrically braced steel frames in multi-storey buildings with mass irregularity has been considered by Tremblay and Poncet [5]. Multi-storey frames having mass irregularity have been the focal concentration of their study. Seven incompatible frames limited to eight story have been reviewed in this study to obtain the effect of mass irregularity. The mass irregularity along the height has been evaluated. Equivalent static force method and response spectrum method have been adopted to compare the performance levels. Hossain et al. [2] discussed the seismic evaluation of a simple steel framed structure by pushover analysis. A simple steel structure has been developed to assess the nonlinear behavior of the certain structural frame. Although several research works have been reported, very limited studies for steel frames with vertical irregularities considering the use of shear links have been reported.

The aim of present research is to perform a comprehensive study of the substantial effects of using shear links in different types of steel frames which have vertical irregularity. Present research deals with a study which contains a number of cases to exhibit a notable behavior of the steel braced frames with shear links in different irregular type frames in the vertical direction. Vertical irregularities are considered because the structures are sometimes projected beyond the main frame to meet up the architectural requirement. Sometimes mass

irregularity and mass discontinuity along the vertical direction of structures are also observed. To investigate the behavior of irregular structures, linear time history analysis is carried out. The assessment of seismic force capacity has been determined for distinct cases. Furthermore, the consequences of using shear links on all types of frames have been reported. Four types of irregular framed structures have been considered in this study. Two of them comprise of mass irregularity; one is with mass discontinuity in upper story and the remaining frame is with an overhanging mass in higher story. Shear link braces have been used for individual systems. The shear link includes the bracing in the form of invert “Y”. Finally, a comparison has been made among the irregular frames which contain shear link bracing systems. These frames contain mass irregularity or discontinuity in mass. The outcome of the study shows the certain effects due to the mass irregularity/discontinuity or overhanging mass in a frame which is rehabilitated with shear link steel bracing or invert “Y” bracing. This is because the fact turns into a challenge for designer to opt for the optimum system for acceptable rehabilitation.

2. Methodology

Specifications of materials used in the numerical analysis have been adopted from the manual of American Institute of Steel Construction (AISC) [7]. The details of the member specifications are listed in Table 1. The loading conditions have been adopted from UBC97 [8]. The adopted properties of frame can be observed in Table 1. In all frames, the beams and columns of same sizes have been provided. The materials and sections are kept same for braces as well. All types of material section and property have been adopted as per AISC. Frames with irregularity in mass, discontinuity in mass and overhanging mass along height have been considered for the present study. Bracing with shear links has been added as well to observe the behavior and strength of the dissimilar

steel frames with certain irregularities. Four irregular steel frames have been considered for the study. Fig. 1 (model-1) depicts the frame which is vertically irregular and asymmetry as well. The 6 story frame having a mass irregularity in every 2 floors has been taken for seismic analysis. Fig. 2 (model-2) depicts a frame that has mass discontinuity at fourth story. Fig. 3 (model-3), on the other hand, depicts an overhanging mass in fourth floor. This overhanging

mass is the key point of distinction compared to the other frames. The bay width and story height of each model are kept constant (see Table 1).

To understand the variations of behaviors of different frames, time history analysis has been conducted. This method is mainly adopted in case of existing structures and to find the response against acceleration of real earthquake. El Centro earthquake data have been used in present study to incorporate time

Table 1 Details of members used.

Members	Configuration
Beam size	W16x40
Column size	W21X83
Bracing size	Pipe 5 std.
Link beam size	W6X9
Total story	6
Bay width	5m
Story height	3 m

Fig. 1 Model-1.

Fig. 2 Model-2.

Fig. 3 Model-3.

Fig. 4 El Centro earthquake data.

history analysis. The behavior of structures can be comprehended from the force-displacement curve which is recognized as capacity curve. From Fig. 5, El Centro earthquake data can be observed.

3. Results

The analysis of all the frames has been carried out following the provisions of FEMA356 [6] for linear time history analysis. The analysis proclaims inherent consequences about the behavior of the selected frames. The main intent of the research includes the computation of displacement under seismic loading. Table 2 depicts the lateral displacements of considered frames. It can be observed that displacement is in model-1 while maximum is in model-3. From Table 3, modal mass participation ratios can be obtained. Dynamic load effect seems to be larger in model-2 and model-3. 80% mass participation requires higher

modes in model-2. But, in model-3, the frequency is less while the mass participation reached 80%. Table 3 delineates the modal frequencies of models. The frequency of model-1 is the highest. Lowest frequency values are noted in model-3. One more thing can be deliberated from this table. The differences of frequencies are very close for model-2 and model-3. Fig. 5 deliberates the story drifts of the building. Smaller values of story drifts can be noticed in model-1. It can also be seen that the story drift values of model-2 and model-3 are close till six meters. The differences get increase after six meters. Higher value is noted for model-3. After 4th story (15 meters), the story drift of model-2 gets increased. This is due to the mass discontinuity. Figs. 6-11 depict time dependent displacements and time dependent accelerations of following models. The graphs are generated in staad.pro software.

Table 2 Lateral displacements obtained from time history analysis.

Model	Maximum displacement of frames (mm)
Model-1	6.176
Model-2	7.681
Model-3	7.851

Table 3 Modal mass participations ratios (obtaining 80% mass).

Model	Mode	Frequency (Hz)	Participation (x) (%)
Model-1	19	13.351	82.962
Model-2	26	11.829	80.184
Model-3	20	9.764	82.293

Table 4 Frequencies (Hz) of models in first five modes.

Mode	Model-1	Model-2	Model-3
1	2.133	1.783	1.767
2	2.991	2.231	2.191
3	4.037	2.861	2.578
4	4.833	3.698	3.496
5	5.003	3.888	3.821

Fig. 5 Story drifts ratios (%) of different models. **Fig. 6** Time dependent displacements of model-1.

Fig. 7 Time dependent accelerations of model-1.

Fig. 8 Time dependent displacements of model-2.

Fig. 9 Time dependent accelerations of model-2.

The graphs denote time in seconds along horizontal and denote displacements (mm)/ accelerations (m/s^2) along vertical axis. It can be noted that the time dependent displacements of the models are 1.93 mm at 1.9 seconds and -2.59 mm at 2.03 seconds; 2.12 mm at 4.35 seconds and -2.04 at 4.31 seconds; 2.4 mm at 4.36 seconds and -4.72 at 2.05 seconds respectively. It is also reported that the time dependent accelerations of the models are 3.14 m/s^2 at 2.04 seconds and -2.24 mm at 1.9 seconds; 4.77 m/s^2 at

2.16 seconds and -3.42 m/s^2 at 1.9 seconds; 4.55 m/s^2 at 2.16 seconds and -2.94 m/s^2 at 4.36 seconds respectively. It is substantial that the time dependent displacements have higher values for model-3. But the time dependent acceleration has higher value in model-2.

4. Conclusion

A numerical analysis has been carried out to investigate the effect of vertical irregulars of steel

frame with shear linked steel braces. Different types of irregularities have been considered and time history analysis has been carried out. The differences between lateral displacements due to seismic load have also been noticed. The findings of the study are summarized below:

- The frame with overhanging mass (model-3) is the most critical with respect to the irregularities considered in the present study while model-1 is the safest one;
- Model with discontinuity in mass is also susceptible to vulnerable effects to a good extent;
- Discontinued and overhanging mass reduces the frame stiffness to a good extent.

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