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A Study on the Effectiveness of Bracing System for Lateral loading

Dhruba jyoti Borthakur[1], Dr. (Mrs) Nayanmoni Chetia[2]

[1]M.E Student, Department of Civil Engineering, Jorhat Engineering College, Jorhat, Assam, India
[2]Asstt. Prof., Department of Civil Engineering, Jorhat Engineering College, Jorhat, Assam, India

Abstract—*An attempt has been made to study the reduction in responses of a structure under lateral loading due to the incorporation of a bracing system. In practice a building structure is subjected to eccentric loading due to the placement of different nonstructural elements within and above the structure. Due to the effect of eccentric loading a building normally experiences lateral as well as torsional displacement under seismic loading. Bracing system in any form increases the overall stiffness of the system and hence acts as a control mechanism for both lateral and torsional movement of the structure. In this study a single storey steel frame model is analyzed in a shake table for three different loading conditions namely frame without any extra mass, frame with a central mass and frame with an eccentric mass. A pair of X bracing system is then introduced to the structure and analyzed for the same three conditions. Comparisons are made for different responses namely lateral displacement, velocity, acceleration and torsional movement of the frame at roof level with and without bracing system. From the study it is clear that the bracing system is effective for reducing the lateral movement as well as the torsional effect to a great extent. Model study shows that a bracing system results in a reduction in the displacement at roof level up to about 80% as compared to that of an unbraced frame.*

Keywords— Bracing system, response, torsional effect.

I. INTRODUCTION

Earthquake is a natural phenomenon, which is generated in earth's crust and thousands of people lose their lives due to earthquakes in different parts of the world. Building collapse or damages are the major causes of these heavy no of causalities. Lateral instability has always been a major problem specially in the areas with high earthquake hazard. Bracing system effectively reduces the lateral displacements and concentric, eccentric and knee bracing systems have been used over years.

When there exists an eccentric loading in building structure, Centre of mass and Centre of rigidity do not coincide. As a result, the structure experiences a response in a direction perpendicular to the excited force or torsional force. The torsional effect, being the most destructive one in a structure should be taken care of. Attempt has been carried out to study the effectiveness of different seismic control system in minimizing the torsional response of the structure.

Bracing is a highly efficient and economical method to laterally stiffen the framed structures. Bracing system allows obtaining a great increase of stiffness with a minimal added weight, and so it is very effective for existing structure for which the poor lateral stiffness is the main problem. Bracing is efficient because the diagonal bracing works in axial stress and therefore call for minimum member sizes by providing the stiffness and strength against horizontal shear. Thus bracing system reduces lateral movement as well as torsional motion of the structures under seismic loading.

Fig. 1: Practical example of bracing system

In this study a single storey shear frame model has been used. Responses have been recorded for three different conditions such as bare frame, frame with central mass and frame with eccentric mass. Tests were performed on a shake table. Then the results were verified analytically and calibration was achieved. A pair of X bracing system was attached to the bare frame and again analyzed for the three mentioned conditions.

II. LITERATURE REVIEW

Amini Moein A. et al (2012) studied the effect of bracing arrangement in the seismic behaviour of buildings with various concentric bracings by nonlinear static and dynamic analysis. In his study a set of regular multi-story steel buildings were considered with three kinds of x, v

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and chevron bracing, in two placements of 'two adjacent bays' and 'two non-adjacent bays' along the building height. Results show that in all cases, bracing arrangement in non-adjacent bays leads to lower stiffness but higher strength than in adjacent bays.

Hejazi F. et al. (2011) has done a study on the occurrence of soft storey at the lower level of high rise buildings subjected to earthquake. Also attempt has been made by adding bracing in various arrangements to the structure in order to reduce soft story effect on seismic response of building. Assessment was made to study the vulnerability level of existing multi-storied buildings so that they can be retrofitted to possess the minimum requirements. This will help in minimizing the impending damages and catastrophes.

Kevadkar M. D. and Kodag P. B. (2013) have done lateral load analysis of R.C.C. Building (G+12) by considering 3 models.The first model was without bracing and shear wall, second model with different shear wall system and third model with different bracing system. The computer aided analysis was done by using E-TABS to find out the effective lateral load resisting system during earthquake in high seismic areas. The performance of the building was evaluated in terms of Lateral Displacement, Storey Shear and Storey Drifts, Base shear and Demand Capacity (Performance point).

III. EXPERIMENTAL SET-UP AND MODELS

3.1 Shake table

Shake table is an electromechanical experimental setup which enables the study of basic issues related to vibration behavior such as damping, dynamic response magnification, resonance, structural vibration under support motions, normal modes, vibration isolation, vibration absorption, dynamics with soft or weak first storey under dynamic base motions. These tables have the capabilities for applying harmonic base motions and have the provision to mount the test structure at any desired angle with respect to the direction of applied base motion.

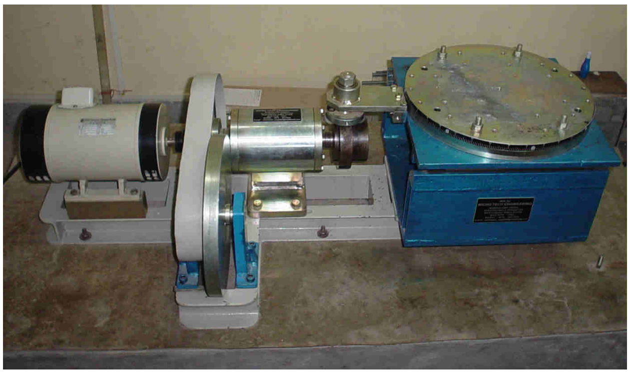

Fig. 2: Electric motor driven shake table

3.2 Steel frame models

A single storey shear frame model made up of mild steel with unit weight 7850 kg/m^3 was first studied. Young's modulas, E=200000 N/mm^4. Sizes of columns were 3mm × 25 mm and 400 mm high. The size of the slab was 300mm × 150mm, with 12 mm thickness.

Fig. 3: steel frame model 1 (without bracing system)

Fig. 4: Steel frame model 2 (with bracing system)

In the next study the model was attached with two pairs of X bracing system having cross sectional area of 50% of the total column cross section.

IV. RESULTS AND DISCUSSIONS

At first the model without bracing system was analyzed under a sinusoidal excitation of P_0 =1Sinωt in the shake table. The Natural frequency of vibration was found to be 6.4 Hz from the shake table and analytically it was found to be 6.44 Hz. Thus it is seen that error calculated was less than 3%. Hence it can be concluded that experimental results were in close proximity with analytical results.

Then the model was tested for three different conditions. Firstly, without any extra mass, secondly introducing an extra mass of weight 10% of the total structure at the center of the roof and in the third case by placing the extra mass in one corner of the roof. Different responses such as displacement, velocity and acceleration of the roof were then recorded for the sinusoidal excitation frequency ranging from 0 Hz to 10 Hz. Introduction of the eccentric mass results in a torsional movement of the structure.

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Fig. 5: Steel frame model 1 without any extra mass

Fig. 6: Steel frame model 1 with extra mass at the center

Fig. 7: Steel frame model 1 with extra mass at the corner

Fig. 8: Steel frame model 2 without any extra mass

In the later phase two pairs of X bracing system were introduced in the frame. The size of the bracings was 3mm X 12.5mm, 50% of the cross sectional area of the column. The frame was then analyzed for the same three conditions as the previous cases under the action of the same harmonic excitations. The displacement, velocity and acceleration responses were then recorded and compared with the previous results. Comparisons of different parameters for the braced and unbraced frame are plotted below.

Fig. 9: Steel frame model 2 with extra mass at the center

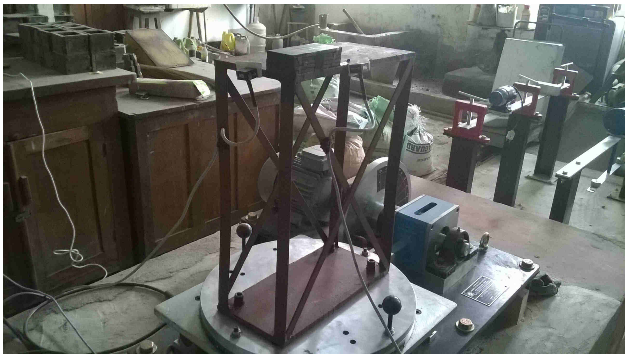

Fig. 10: Steel frame model 2 with extra mass at the corner

Comparisons of responces were made between braced and unbraced frame when no extra mass was attached to the roof of the frame and results are presented in Figs. 11, 12 and 13 respectively.

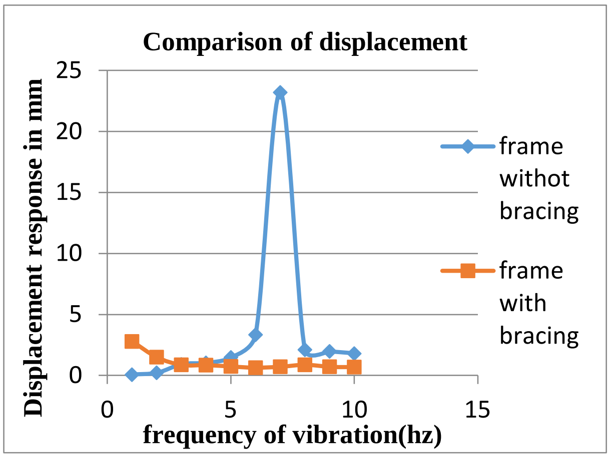

Fig. 11: Comparison of displacement with and without bracing for the frame without any extra mass.

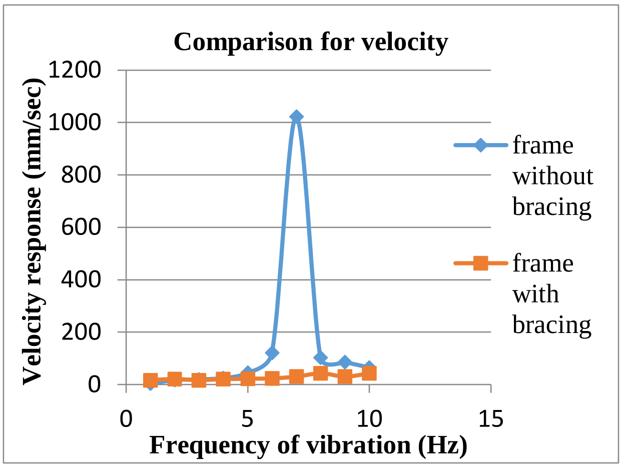

Fig. 12: Comparison of velocity with and without bracing for the frame without any extra mass.

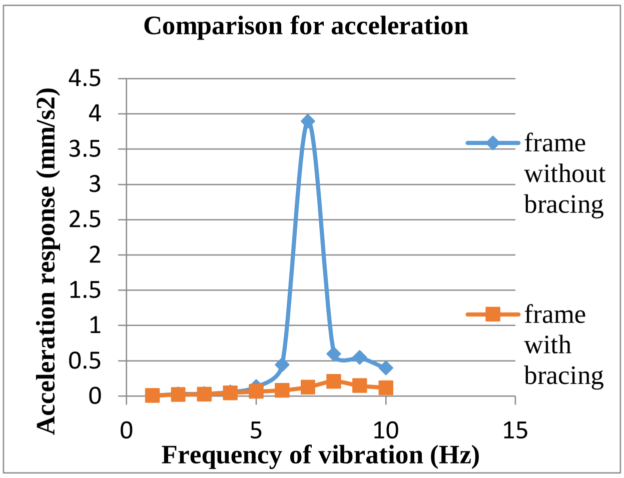

Fig. 13: Comparison of acceleration with and without bracing for the frame without any extra mass.

From the above comparison it is observed that incorporation of the bracing system will reduce the displacement up to 90% of the unbraced frame at resonant frequency. The bracing system reduces velocity by about 34 fold and acceleration by 29 fold to that of unbraced frame.

Similar studies were continued for frames with central and eccentric masses at the roof level and some of the results are presented in Fig. 14, Fig. 15, Fig.16 and Fig. 17.

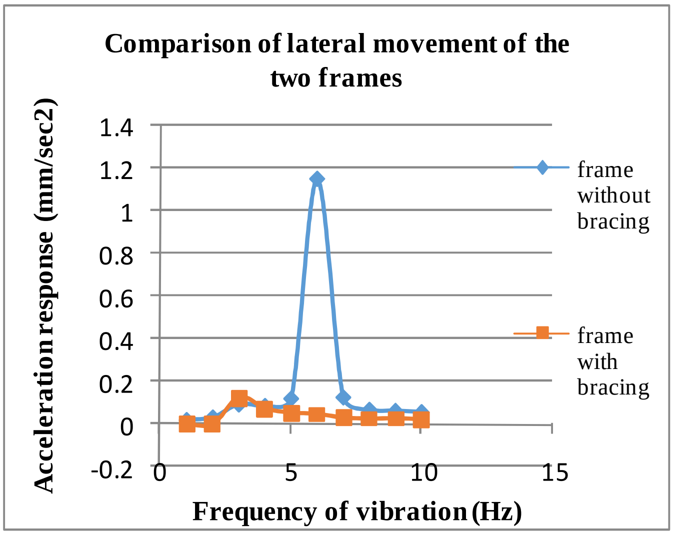

Fig. 14: Comparison of displacement along X direction with and without bracing for the frame with eccentric loading.

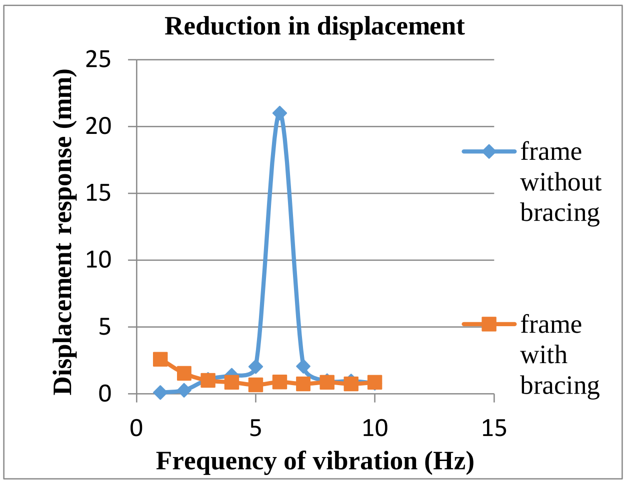

Fig. 15: Comparison of velocity along X direction with and without bracing for the frame with eccentric loading.

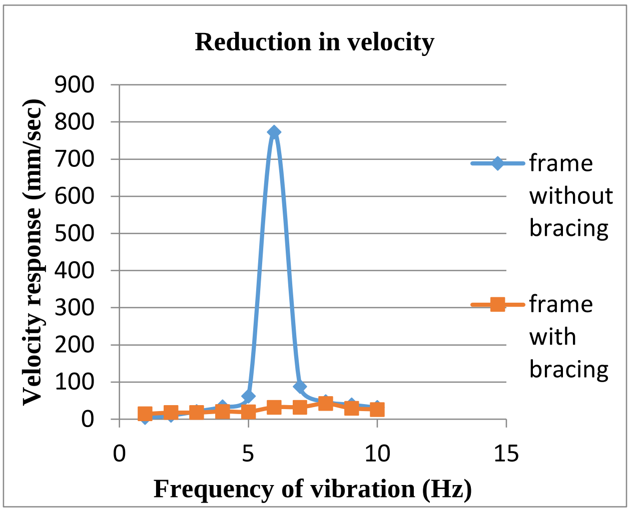

Fig. 16: Comparison of acceleration along X direction with and without bracing for the frame with eccentric loading.

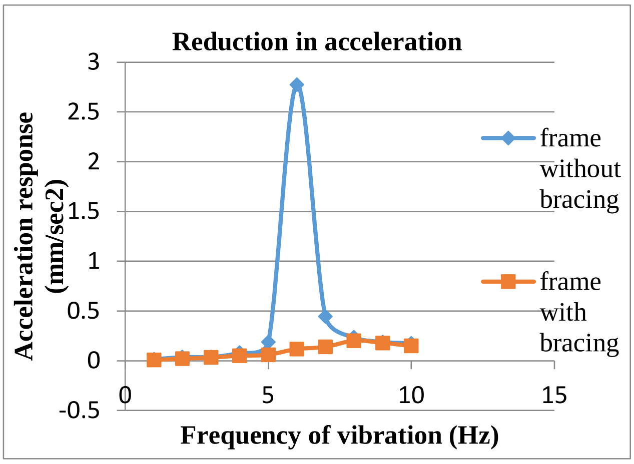

Fig. 17: Comparison of displacement in y direction (torsional movement) with and without bracing for the frame with eccentric loading.

From the above comparison it is observed that the bracing system reduces the displacement up to 80% to that of unbraced frame at resonant frequency.

The displacement in the Y direction was compared for the both cases, and the reduction in the torsional movement due to the incorporation of the bracing system can be computed.

From Fig. 17 it is clear that incorporation of the bracing system will results in a considerable reduction in the torsional movement. For this particular case the bracing system reduces the lateral displacement by 88% when the frame is eccentrically loaded.

Table.1 and Table.2 represents the reduction in displacement along x and y direction respectively due to the introduction of the bracing system when the frames are eccentrically loaded.

TABLE 1: Comparison of displacement along X direction for the braced and unbraced frame under eccentric loading

frequency of vibration (Hz)	displacement of the unbraced frame (mm)	displacement of the braced frame(mm)
1	0.09	2.589
2	0.279	1.538
3	1.077	1
4	1.401	0.87
5	2.044	0.668
6	21	0.882
7	2.071	0.756
8	0.979	0.861
9	0.96	0.756
10	0.8	0.861

TABLE 2: Comparison of displacement along Y-direction for the braced and unbraced frame under eccentric loading

Frequency of vibration (Hz)	Displacement of the unbraced frame (mm)	Displacement of the braced frame(mm)
1	0.018	0.002
2	0.03	0.004
3	0.092	0.126
4	0.084	0.074
5	0.118	0.055
6	1.149	0.049
7	0.125	0.032
8	0.066	0.028
9	0.061	0.029
10	0.055	0.025

V. CONCLUSION

From the experimental results following conclusions can be made. It is observed that lateral movement decreases up to 80% due to the incorporation of the bracing system. Likewise, reduction in velocity and acceleration is also noted. In case of the braced frame, peak response at the roof level at resonant frequency decreases up to a minimum value. Bracing system also results in reduction of torsional movement of the structure up to a greater extent.

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