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Effect of Steel Bracing on Ultimate Strength and Stiffness of Reinforced Concrete Frames

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ABSTRACT: Infilled walls are normally considered as non-structural elements. However these walls are effective in carrying lateral loads. In this regard, an experimental investigation was planned and conducted to study the effect of braced Reinforced Concrete (R.C.) frames in contrast to the bare frames. All these frames were tested up to collapse and subjected to only horizontal loads to obtain an efficient and probable solution for soft storey. In comparison to bare R.C. frames, steel braced R.C. frames have an increase by a notable amount for stiffness and ultimate lateral load capacity. Central braced system is additional effectual than that of corner and diagonal braced system. For the similar load braced R.C. frames have considerable less deflection than that of the bare R.C. frames. The contribution of central and diagonal bracing in comparison to corner bracing is observed to be 20% and 50% correspondingly. The percentage increase in stiffness for braced frames in comparison to bare R.C. frame is 71.1%, 139.6% and 111.4% consonantly.

Keywords: Central braced frame, Lateral load, Soft storey, Diagonal bracing, R.C. Frame, Stiffness.

INTRODUCTION

Now–a-days in multi-storied structures soft stories are common at the parking level as there is absence of infill walls whereas the stories above are filled with partition walls. Such frames have less capacity to bear lateral loads. Considering all these factors, mild steel bracings with R.C. frames were tested under lateral loads to understand the behavior and contribution of such frames. In This study tests are conducted on eight numbers of different models of bare and braced frames as shown in Table 1.

Strength tor steel bars and high yield strength mild steel square bars are used. The behavior of frames have been studied with respect to

- Bracing system- bare frames and different types of braced R.C. frames.
- Strength, Deformation and Stiffness of frames.

Present work is predominantly experimental oriented and experiments have been performed on models up to failure. Studies have been carried out on single bay, single storey frames. For each frame, two models were tested and average value is considered for experimental loads and deflections.

Table 1. Description of various frames

Sr. No.	Frame Notation	Description
1	R1	Bare R.C. Frame
2	R2	Top corner steel bracing R.C. Frame.
3	R3	Top central steel bracing R.C. Frame.
4	R4	Diagonal steel bracing R.C. Frame.

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Portal frames tested up to have drawn attention of several investigators in the recent past for inherent structural advantage of such frames. Available literature attempts to evaluate the strength and stiffness of these frames. Infilled frames investigated by Wood (1958) through conducting several tests on concrete encased steel frames with brick and concrete infills. Experimental data were given on the behavior of panel walls and on the stiffening and strengthening effects of such panels on the resistance of structural frame works against racking loads. Benjamin et al. (1958, 1959) have tested many prototypes as well as models of R.C. frames with plain and reinforced concrete infill walls. Foundations were considered rigid. Results were reported category wise. They observed that there was no scale effect i.e. test can be performed on any scale model, results of scale models were found to be consistent with the prototype (Smith, 1966) studied the behavior of square frames and tried to compare the theoretical results with experimental ones and derived expressions for diagonal strength. It was suggested that the concept, that the infill acts as a diagonal strut of certain width along the loaded corners. To derive the effective width finite difference method was used. The difficulties of an exact analysis for R.C frames has emphasized by (Smolira, 1973) tested infilled with brickwork and also presented a simplified approach of analysis on the basis of the assumption of linear behavior of equivalent strut. The width of equivalent strut was taken as 1/3 rd of diagonal length. Detailed procedure for analysis was given in their paper. Tests were performed by (Mali and Saldoga, 1981) on Reinforced cement concrete frames with brick as infill. In addition to racking load, they applied a uniformly distributed vertical load, which caused pre-compression of wall. They reported cracking and failure behavior of infilled frames. Their experimental values were found to correlate well with theoretical values. A plastic theory had proposed by Liauw et al. (1983) for analysis of integral infilled frames. Theory is applicable to both single storey and multi-storey integral infilled frame and comparison of theoretical values with experimental results gave good agreement. Non-integral infilled frame problem was overcome by introduction of material with strong bond or shear connectors at the frame/infill interface. Dolšek and Peter (2001) studied complete failure of the first storey and the bottom two stories. It was demonstrated that a soft storey mechanism is formed in such structural systems if the intensity of ground motion is above a certain level. It is likely that collapse will occur if the global ductility of the bare frames, as well as the ductility of the structural elements, is low, and if the infill walls are relatively weak and brittle. The advanced bracing systems such as chevron-braced frames as per Dicleli et al. (2005) and eccentrically braced frames as per Berman et al. (2007) have been also developed in order to resist transverse dynamic loads. Eccentrically braced frames rely on the yielding of a link beam between eccentric braces, which provides ductility and energy dissipation under dynamic loads.

According to Viswanath et al. (2011) many existing reinforced concrete buildings need retrofit to overcome deficiency to defend against seismic loads. The use of steel bracing systems for retrofitting and strengthening seismically insufficient reinforced concrete frames is a viable solution for enhancing earthquake resistance. The results of analytical and experimental investigations as per Jayaguru et al. (2011) for One-third scaled two-bay two-storey RC frames are with partial infill in the bottom storey and subjected to lateral cyclic loads. A local retrofitting strategy of strengthening RC structural elements with glass fiber reinforced polymer (GFRP) composites was adopted. Test results indicated that the retrofitted frame exhibited significantly higher ultimate strength and stiffness than the control frame (frame without retrofit). A reinforced concrete frame is modeled for finite element sensitivity analysis (Iftekharul Alam and Dookie, 2012) followed by direct differentiation method under both static and dynamic load cases. Later, the reliability analysis is performed to predict the seismic behavior of the frame. Rachana and Mohod (2012) stated that building damage by earthquake action is a serious problem. In this regard seismically deficient structures are studied by carrying out the Pushover analysis of frame structures using SAP Software. Building gets deformed because of the lateral and seismic forces acting on the structure. Dubey et al. (2013) conducted experiments to study the effect of braced and partially concrete infilled R.C. frames in comparison to the bare frames. All these frames were tested up to collapse for a possible solution of soft storey frames. It was observed that in comparison to bare R.C. frames, concrete partially infilled frames have an increase by a remarkable amount for lateral load capacity. Based on experimental observations, a mathematical model has been proposed to calculate theoretical ultimate load for braced and partially infilled R.C. frames.

MATERIALS AND METHODS

Experimental Setup

R.C. portal frame of single bay single storey with a welded base plate of 10 mm thick was mounted on a supporting girder and rigidly bolted with four bolts of 20 mm diameter. Horizontal load is applied to R.C. frame through column of reaction frame with the help of a jack. The models tested of each category are mentioned in Table 1. The details regarding dimensions, position of proving ring, loading jack and dial gauge are highlighted in Figure 1.The frame consists of two columns of height 400 mm and a beam with a span of 600 mm. The size of column is 60 mm x 100 mm and for beam it is 100 mm x 100mm. For measurement of load proving ring of capacity

10 kN was attached for bare frames and a hydraulic jack of 500 kN was utilized for rest of the frames. Dial gauge of range 20 mm was used to measure the horizontal displacement at the beam level. R.C. frames were cast by laying the moulds on the horizontal surface.

Materials for Models and Control Specimen

The following materials were used for the frame and bracing.

- For main reinforcement Ø8 mm, for ties and stirrups Ø6 mm were used for the R.C. frames. For bracings 10 mm square bars of mild steel was used.
- Cement, sand and coarse aggregate of 12mm in the ratio of 1:1.5:3 was used for concrete. Cubes of size 150mm × 150mm × 150mm were cast and tested to obtain the compressive strength after 28 days.

Test procedure

The R.C. frames were cast and after curing mounted on the reaction frame. The bolts were fully tightened to ensure the fixity of supports. The alignment of jack was checked along the beam axis. The initial reading on the proving ring and the dial gauge was recorded. The application of horizontal load was with the help of a screw/ hydraulic jack and horizontal displacement was noted down from dial gauge. The load was applied at a consistent rate. The loads and the deflections were recorded at regular intervals for each test set up. The load was applied continuously till it remains constant for a particular time on the loading gauge and then moves in a reverse order. This is known as plastic state. The collapse load analogous to this stage was recorded as an ultimate load. Load consequent to this stage was documented as an ultimate load.

RESULTS AND DISCUSSION

For bare R.C. frames ,while conducting the experiments, precautions were taken to keep the proving ring at its position as it was trying to lift itself. .The direction and progress of cracks at different load levels were recorded and shown in Figures 2 and 3 .The locations and extent of loss of contact between the frame and bracing were noted down. The final collapse modes were photographed for full details. The compressive strength of concrete mix cubes tested after 28 days was observed to be 24.2N/mm^2. The percent increase in lateral load capacity of steel braced frames R2, R3 and R4 in comparison to bare frame is 167.3%, 220.8%, and 301% correspondingly. The contribution of central and diagonal bracing in comparison to corner bracing is observed to be 20% and 50% analogously. The load deflection curves for R1, R2, R3 and R4 are shown in Figures 4 and 5 respectively. The comparison of experimental ultimate loads and stiffness for various frames is shown in Table 2. Figures 6 and 7, illustrate the crack pattern indicated by the red painted lines for all bare and braced R.C. frames correspondingly. The percentage increase in stiffness for braced frames in comparison to bare R.C. frame is 71.1%, 139.6% and 111.4% consonantly.

The behavior of braced R.C. frames subjected to lateral load was studied with different patterns of steel bracings such as corner, central and diagonal. It is observed that due to compressive force from diagonal compression band, tensile cracks are developed along tension column for all bare and braced R.C. frames. The possible plastic hinge locations are at column-beam juction and bottom of column. The cracks developed at various places are indicated on different frames as shown in Figures .It can be observed from photo plates that failure was predominately caused due to sway mechanism. The load Vs deflection comparison shows a considerable increase in lateral load capacity for braced frames than that of bare frames. The stiffness of braced frames was compared with the bare frames. In order to have comparative similarity for calculation of stiffness for all braced frames, the deflection for other two frames is considered corresponding to the ultimate load of frame R2.

Though diagonal braced system shows better results than that of the other two systems, practically it is difficult to implement diagonal bracing as it would hinder the movement of users around the space and thus central bracing system is additional effectual for soft storey frames. For shear walls which are used in all four corners of multi-storey buildings can be strengthen by using diagonal steel bracing with concrete infill, as its lateral strength contribution is remarkable.

Table 2. Comparison of ultimate load and stiffness for different frames

Frame	Experimental Ultimate Load kN	Contribution of bracing in comparison to bare frames (%)	Contribution of bracing in comparison to corner braced frames (%)	Stiffness (kN/M)	Percentage increase in stiffness for braced frames in comparison to bare frame
R1	9.35	-	-	772.72	-
R2	25	167.3	-	1322.7	71.1
R3	30	220.8	20	1851.8	139.6
R4	37.5	301	50	1633.9	111.4

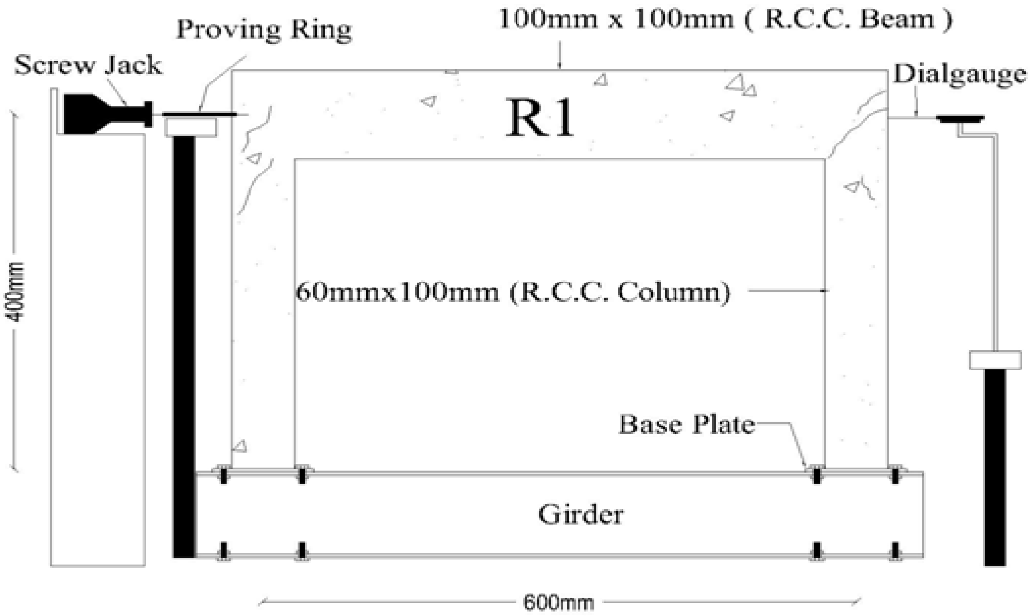

Figure 1. Details of Bare Frame

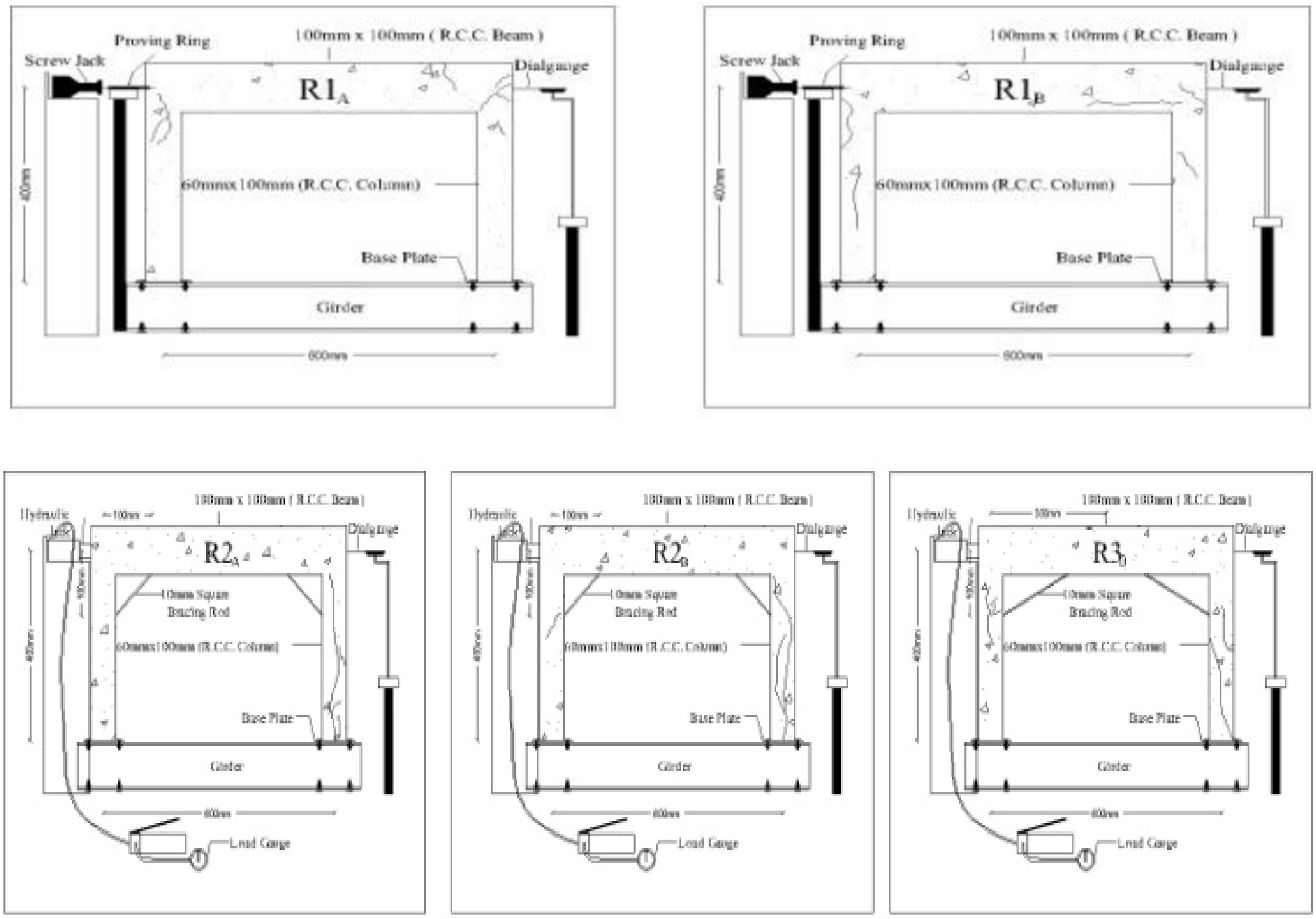

Figure 2. Crack pattern for frames R1 and R2

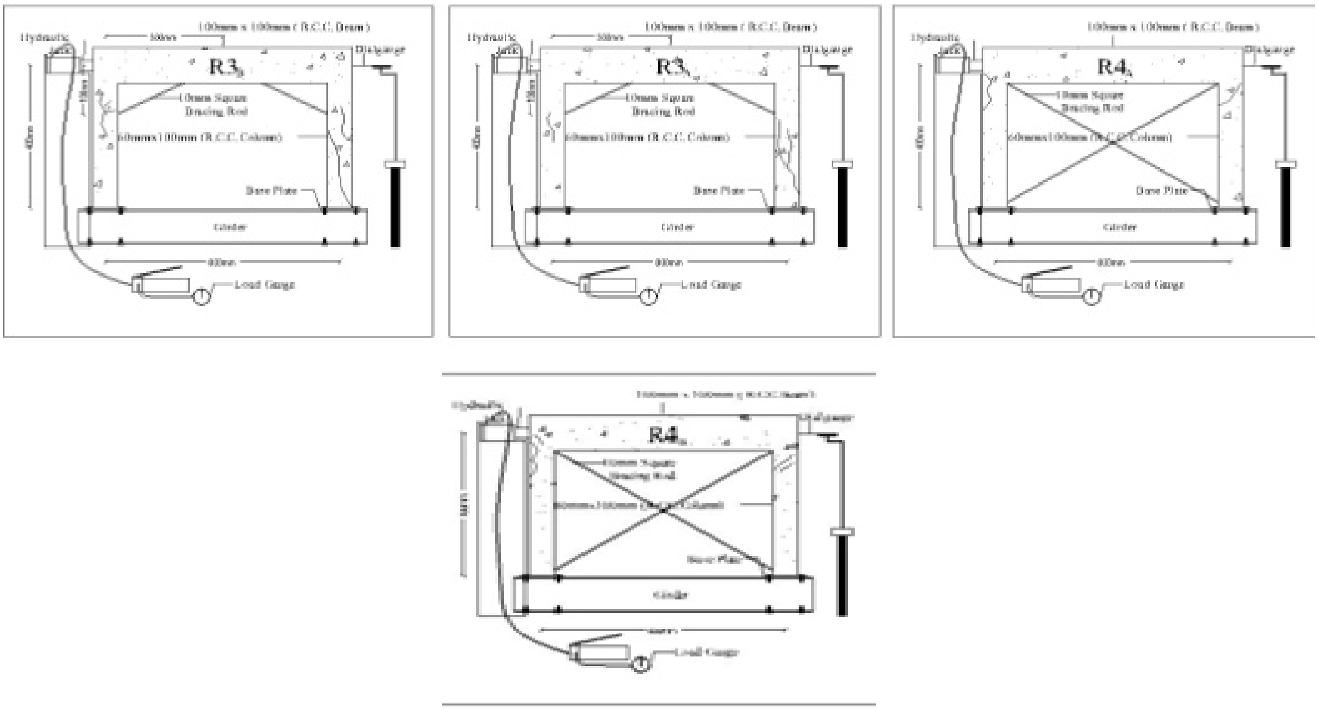

Figure 3. Crack pattern for frames R3 and R4

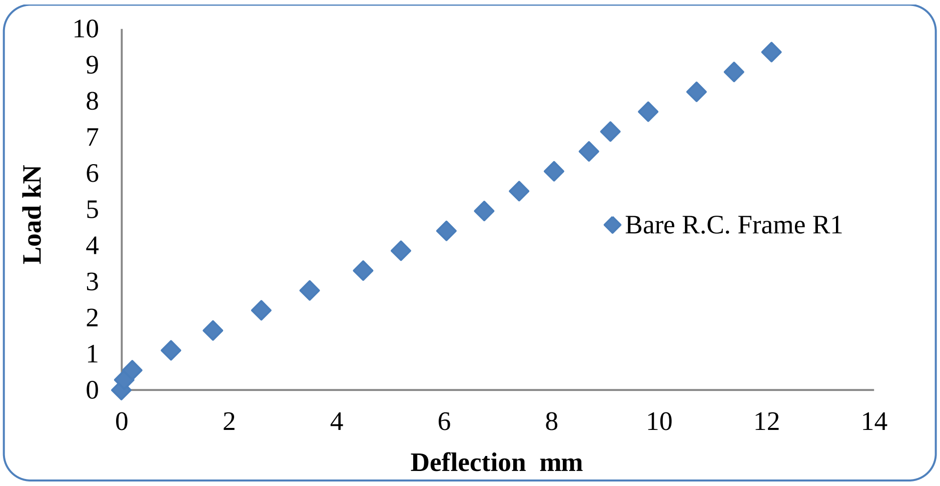

Figure 4. Load Vs Deflection Graph for Bare R.C. Frame R1

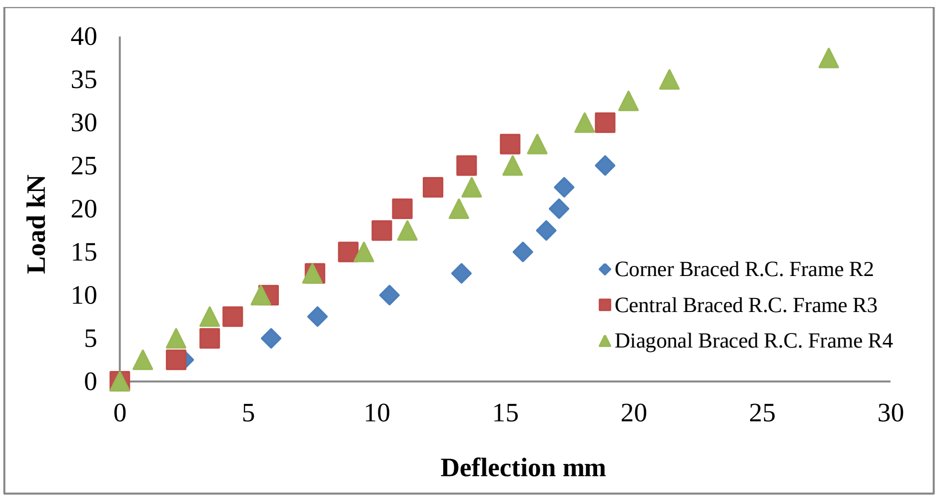

Figure 5. Load Vs Deflection graph for Braced frames

Figure 6. Top corner top bracing R.C. Frame

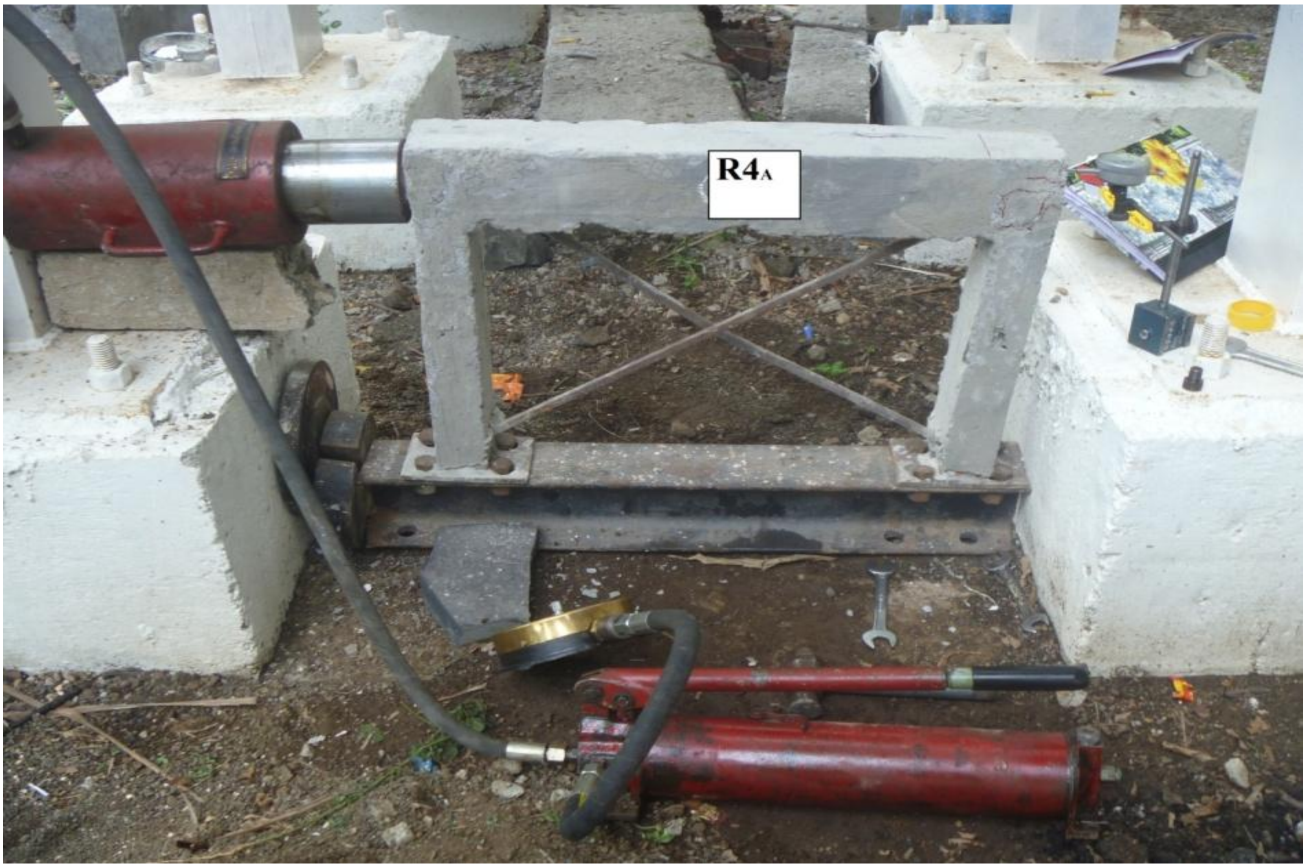

Figure 7. Diagonal bracing R.C. Frame

CONCLUSION

With a limited number of tests (two for each frame) carried on various frames as mentioned in the Table 1, the following conclusions may be made.

- If the braced frames are stronger than bare frame, the failure mode corresponds to sway mechanism with major tension cracks along tension column for R.C. frames and for braced R.C. frames possible plastic hinge locations are at column-beam juction and bottom of column.
- The percent increase in lateral load capacity of steel braced frames R2, R3 and R4 in comparison to bare frame is observed to be 167.3%, 220.8%, and 301% correspondingly. The contribution of central and diagonal bracing in comparison to corner bracing is observed to be 20% and 50% analogously.
- All braced frames have considerable less deflection in comparision to bare frames. Steel bracing is cost-effective, occupies a lesser amount of space and has flexibility to design for meeting the required strength and stiffness.
- Practically the center braced system may be a viable solution, which may not affect architectural or inner function than that of diagonal bracing system for soft storey frames.
- The percentage increase in stiffness for braced frames in comparison to bare R.C. frame is 71.1%, 139.6% and 111.4% consonantly.
- For shear walls use of diagonal steel bracing will be additional effectual, as its lateral strength contribution is notable.

DECLARATIONS

Author's contribution

All authors contributed equally to this research paper.

Competing interests

The authors declare that they have no competing interests.

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