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ORIGINAL RESEARCH

An experimental investigation on the ultimate strength of epoxy repaired braced partial infilled RC frames

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Abstract Due to earthquake, buildings are damaged partially or completely. Particularly structures with soft storey are mostly affected. In general, such damaged structures are repaired and reused. In this regard, an experimental investigation was planned and conducted on models of single-bay, single-storey of partial concrete infilled reinforced concrete (RC) frames up to collapse with corner, central and diagonal steel bracings. Such collapsed frames were repaired with epoxy resin and retested. The initiative was to identify the behaviour, extent of restored ultimate strength and deflection of epoxy-retrofitted frames in comparison to the braced RC frames. The performance of such frames has been considered only for lateral loads. In comparison to bare RC frames, epoxy repaired partial infilled frames have significant increase in the lateral load capacity. Central bracing is more effective than corner and diagonal bracing. For the same load, epoxy repaired frames have comparable deflection than similar braced frames.

Keywords Central braced frame · Epoxy resin · Lateral load · Soft storey · Retrofitted frame

Introduction

Nowadays, soft stories are common at the parking level in multi-storied buildings. There is elimination of infill walls in bottom storey, whereas the storeys above are filled with partition or shear walls. Such frames have less capacity to bear lateral loads. Based on an analytical investigation, Arshad and Alok (2008) had studied seismic performance and potential seismic damage of masonry infilled reinforced concrete (RC) framed building with soft storey. It was observed if the storey is partially infilled (in comparison to no infills); it decreases storey drift and deformations in the column and reduces the related damage to overall frame. Partially infilled RC frames were used as it is one of the best solutions to overcome the lateral strength problem for frames with soft storey. Many prototypes as well as models of RCC frames have been tested by (Benjamin and Williams 1958, 1959) with plain and reinforced concrete infill walls. It was concluded 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.

Based on the study of (Popov and Bertero 1975), it was found that the effectiveness of the epoxy repair is limited by the access to the joints surrounded by transverse beams and floor slab. This limitation can possibly be overcome by further advances in the vacuum impregnation technique. The effectiveness of vacuum impregnation epoxy inlet ports techniques was studied by French et al. (1990) to repair interior joints of beams and columns moderately damaged due to inadequate anchorage of continuous bars of beam. It was concluded that vacuum impregnation is an effective means of repairing large regions of damage with fewer reachable sides.

The effects of joint reinforcement arrangement were studied by Karayannis et al. (1998) on the efficiency of epoxy repair by pressure injection. Eleven of the tested one-way exterior joint specimens were repaired by epoxy injection and then retested. On the local retrofit of RC members, Mahmoud (2005) had investigated with the application of a new high-performance fibre-reinforced composite material

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Table 1 Description of various frames

Frame	Description
R4	Bare RC frame
R5	Corner top bracing frame filled with concrete
R6	Central top bracing frame filled with concrete
R7	Diagonal bracing frame filled with concrete
R8	Corner top bracing frame filled with concrete + epoxy resin
R9	Central top bracing frame filled with concrete + epoxy resin
R10	Diagonal bracing frame filled with concrete + epoxy resin

using a suitable epoxy adhesive. This technique enhances the strength and ductility compared with other methods of local retrofit, such as steel plates and FRP laminates. It was reviewed that the global retrofit of RC frames using direct internal steel bracing can increase the yield and strength capacities and reduce the global displacements of the frames.

For repairing and restoring superior strength (Bhikshma et al. 2010), repaired RCC beams with epoxy resin material (EexpacreteSne1) and the flexural strength increased significantly up to about 15 % for concrete beams compared to other epoxy resin materials. Deflections were lesser in reinforced concrete beams with epoxy resin compared to conventional concrete beams. The stress distribution for the relative stiffness was studied by Kanakambara Rao (2011) with aluminium frame and araldite AY103 with a hardener HY 951 as the infill material. The mutual interaction of the frame and the infill plays an important role in controlling the stiffness and strength of the infilled frame.

Considering all these factors, steel braced RC frames with concrete partial infill, which is one of the suggested possible solutions for soft storeys, were tested up to collapse. These collapsed frames were repaired by epoxy resin and were retested under lateral loads to understand the behaviour and contribution of retrofitted structure. This study consists of tests on 14 models of bare, braced and infilled frames subjected to lateral loads as shown in Table 1. For main reinforcement and bracings, high-grade steel bars and mild steel square bars are used for frames.

The present work is predominantly experimental oriented and experiments have been performed on models up to failure. Though studies have been carried out on single-bay, single-storey frames for infilled frames, the same can be incorporated for multi-bay, multi-storied framed structures. For each frame, two models were tested and the average value is considered for experimental loads and deflections.

Experimental setup

RC 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 RC frame through column of reaction frame with the help of a jack. The models tested for each category are mentioned in Table 1. The details regarding dimensions, position of proving ring, loading jack and dial gauge are highlighted in Fig. 1. The frame consists of two columns of height 400 mm and a beam with a span of 600 mm. The size of the column is 60 × 100 mm and for beam it is 100 × 100 mm. 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. The steel skeleton of reinforcement is shown in Fig. 2.

After the testing up to collapse, frames R5, R6, and R7 were repaired by filling cracks with epoxy. Epoxy is a thermosetting polymer formed from the reaction of an epoxies "resin" with polyamine "hardener". Epoxy has a wide range of applications, including fibre-reinforced plastic materials and general purpose adhesives. Loose concrete is removed, and dirt or debris is cleaned to open up cracks or holes in the concrete before applying epoxy. The concrete is cleaned with a pH neutral cleaner using scrub brush to remove any remaining dirt from the damaged area, rinsed off with clean water and allowed to dry before applying epoxy. The most accurate method of proportioning is the use of pre-proportioned units supplied by the manufacturer. If such packaging is not available, the components may be mixed in the ratios established manually by laboratory tests. Though ratio for mix proportion of resin (araldite GY 257) and hardener (Aradur HY 140) was taken 1:0.5, as suggested by the manufacturer but manually checked for suitability of the initial and final setting time. The properties of the resin and hardener are mentioned in Table 2.

Materials for models

The following materials were used for the frame and epoxy.

- For main reinforcement ∅8 mm, and for ties and stirrups ∅6 mm were used for the RC frames. For bracings, 10-mm square bars of mild steel were used.
- Ordinary Portland cement of 53 grades, river sand and coarse aggregate of 12 mm in the ratio of 1:1.5:3 were used for concrete. Cubes of size 150 × 150 × 150 mm were cast and tested to obtain the compressive strength after 28 days. The partial infills of thickness 50 mm was made up with concrete.

Test procedure

The RC frames were cast and after curing mounted on the reaction frame. The bolts were fully tightened to ensure the

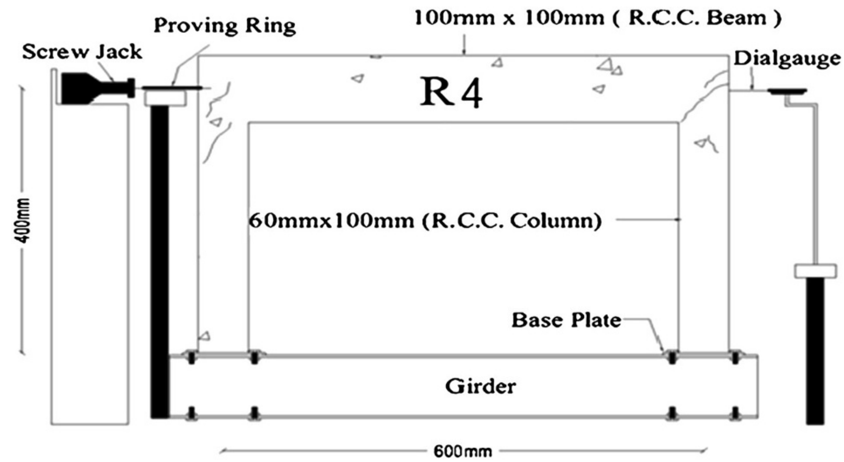

Fig. 1 Experimental set up

Fig. 2 Reinforcement details of frames

Table 2 The properties of epoxy resin and hardener

Property	Resin, araldite GY (257)	Hardener, aradur HY (140)
Colour (gardner)	≤1	≤10
Epoxy equivalent (g/eq)	183	95
Viscosity at 25 °C (Mpa s)	500	400
Gel time (min)	300	120
Application	Solvent free coatings, trowel ling compound	Automotive, industrial use, marine use

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 uniform 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 called as plastic state condition. The collapse load corresponding to this stage was recorded as an ultimate load (Fig. 3).

Observations and results

While conducting the experiments with bare RC frames, precautions were taken to keep the proving ring at its position as it was trying to lift itself. During application of load, crack formation and its propagation at different load levels were recorded. The final collapse modes were photographed for full details. The behaviour of frames has been studied with parameters, such as

- Partial infill system–bare frames and different types of braced partial infilled frames.
- Epoxy repaired cement concrete infill frames with similar braced frames.
- Strength, stiffness and deformation of frames.

The compressive strength of concrete was observed to be 24.2 N/mm^2. For mix proportion of resin and hardener with ratio of 1:0.5, the initial and final setting times were 30 and 90 min. The comparison of the ultimate load of RC frames R5, R6 and R7 with epoxy repaired frames R8, R9 and R10 as mentioned in Table 3 shows a decrease of 16.6, 24.42 and 11.7 %, respectively, in lateral load capacity. Figure 4 shows load versus deflection curve for bare RC frame. It can be concluded from Figs. 5, 6 and 7 that epoxy repaired frames have reduced amount of deflection for the similar value of load in comparison to braced frames. The percentage decrease in stiffness for epoxy repaired frames from similar braced infilled RC frame is 9.09, 24.42 and 27.08 % correspondingly.

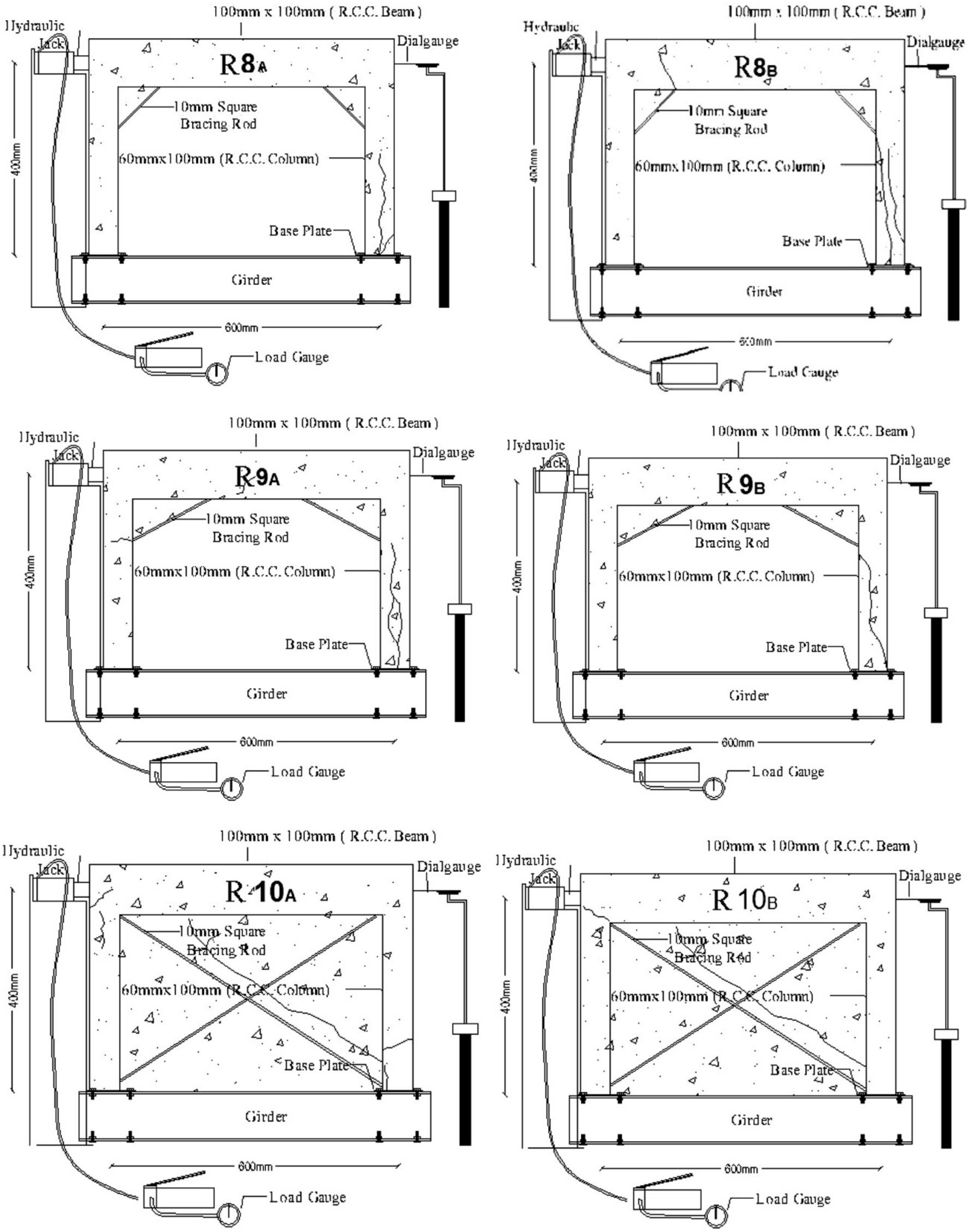

Fig. 3 Crack patterns for different epoxy repaired concrete infilled RC frames

Discussions

The behaviour of partial infilled braced RC frames subjected to racking load was studied with different patterns of bracings, such as corner, central and diagonal. Load was applied by a screw jack and measured on proving ring of capacity 10 kN on bare frames for precise results. As load carrying capacity of other frames was >10 kN, so rest of the frames were tested with a hydraulic jack of 500 kN. The partial infilled braced RC frames were tested up to collapse. Afterwards, the major cracks were filled with cement slurry and curing done for 7 days. The ratio for mix

Table 3 Comparison of ultimate load and stiffness for various frames

Frame	Ultimate load (Wu) kN	Percentage decrease in lateral load for epoxy repaired from similar braced frame	Stiffness (kN/M) of frames	Percentage decrease in stiffness of epoxy repaired from similar RC frames
R4	9.35	–	772.72	–
R5	30	–	1,562.5	–
R6	35	–	2,067.6	–
R7	85	–	5,208.3	–
R8	25	16.6	1,420.4	9.09
R9	27.5	21.42	1,562.5	24.42
R10	75	11.7	3,797.4	27.08

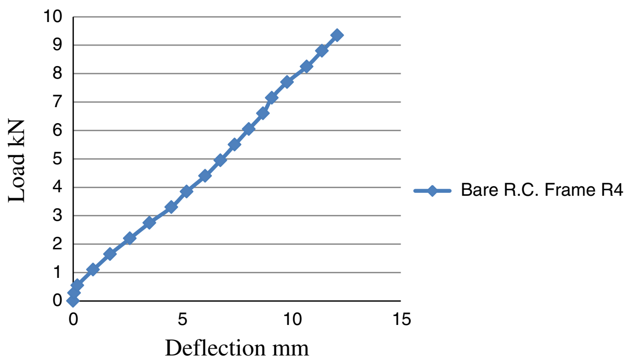

Fig. 4 Load vs deflection graph for bare RC frame R4

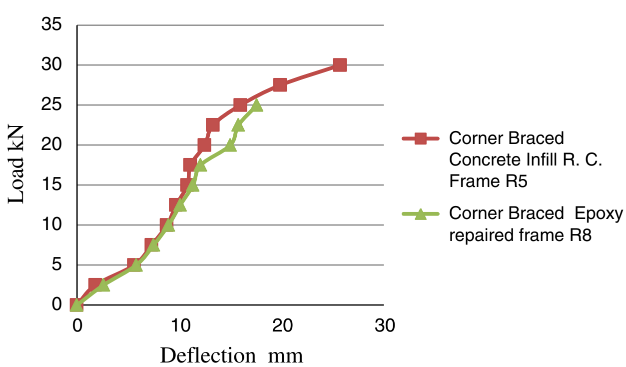

Fig. 5 Load vs deflection graph for R5 and R8

proportion of resin and hardener was taken 1:0.5, as suggested by manufacturer and manually checked for suitability of the initial and final setting time. The cracks within the deficient RC frames were filled with epoxy by grouting, pouring and using brush and allowed to harden for 24 h before testing. Safe handling of epoxy was accomplished using disposable gloves and working in a

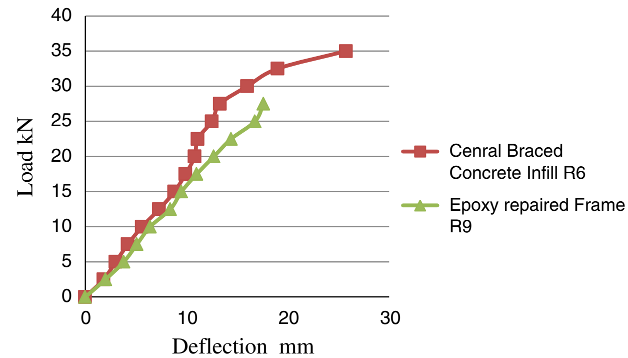

Fig. 6 Load vs deflection graph for R6 and R9

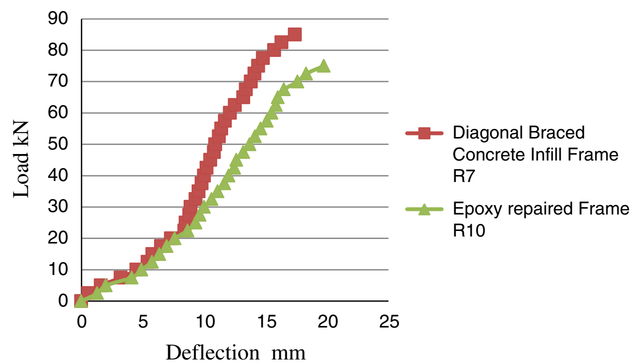

Fig. 7 Load vs deflection graph for R7 and R10

well-ventilated area with use of safety eye glasses. The repaired frames were tested using the same procedure. In general, concrete material crushed at the corners with major cracks developed along tension column and predominately sway mechanism can be observed in Figs. 8, 9 and 10 for different frames. The stiffness of epoxy repaired frames was compared with the similar braced infilled frames. To have comparative similarity for calculation of stiffness, the ultimate load of epoxy repaired frame was considered for similar frames. Though full corner braced infilled system shows better results than that of the other two systems, practically it is difficult to implement for soft storey frames as it would hinder the movement of users around the space, and thus central bracing system is more effective with moderate ultimate strength. Epoxy can be used as a binding material which has been widely used for patching or repairing surface defects of different types of concrete structures. It forms a good bond with old concrete surface and rebar which is one of the prime requirements of a good repair works. Epoxy repaired partial infill frames have significant lateral load carrying capacity and the deflection under control in comparison to bare RC frames.

Fig. 8 Epoxy repaired, with partial concrete infill corner braced frame

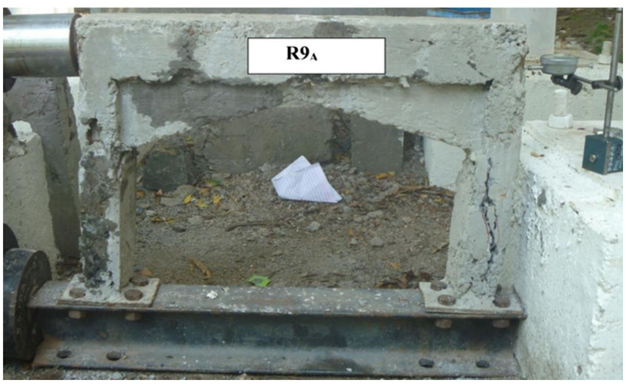

Fig. 9 Epoxy repaired, with partial concrete infill central braced frame

Fig. 10 Epoxy repaired, with concrete infill diagonal braced frame

Conclusions

The purpose of this study was to evaluate the strength of epoxy repaired RC frames than those studied by previous researchers, as well as to add to the database of strengthening test results to lead to changes or acceptance in design codes and standards. To study the ultimate load two bare, six partially infilled and epoxy repaired partially infilled RC frames were constructed and tested up to collapse.

Based on the results of the investigation, the following findings and conclusions are presented for epoxy-retrofitted frames.

- If the infill is stronger than frame, the failure mode corresponds to sway mechanism with major tension cracks along tension column, and for braced RC infilled frames possible plastic hinge locations are at column-beam junction and bottom of column.
- The initial and final setting time for epoxy is 30 and 90 min with ratio of 1:0.5 for resin and hardener. Safe handling of epoxy can be accomplished using disposable gloves, eye glasses and working in a well-ventilated area.
- Based on a comparison with the braced infilled RC frames, epoxy-retrofitted frames have shown a decrease of 16.6, 21.42 and 11.7 % in lateral load capacity. It specifies that the strength is restored for deficient frames up to a significant level.
- From load versus deflection curves, it is concluded that epoxy repaired frames have maximum deflection under control in comparison to bare RC frames.
- Practically, the partially infilled centre braced system may be a viable solution which may not affect architectural or interior function with moderate strength than that of corner and diagonal bracing partially infilled system for soft storey frames.
- The percentage decrease in stiffness is 9.09, 24.4 and 27.08 % for epoxy repaired frames from similar braced infilled RC frames, respectively. It specifies that the frames are stiffened up to considerable level after epoxy application

However, a limited number of tests (two for each frame) were carried out on various frames. The researchers recommend further testing to increase the database for epoxy retrofitted soft storey RC frames.

Conflict of interest The authors declare no competing interests.

Authors' contributions SKDD prepared the experimental model, carried out the experiments, and drafted the manuscript. SYK had given the idea, participated in designing the experimental model, helped in the interpretation of experimental output, and also helped in drafting the manuscript. Both authors read and approved the final manuscript.

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