Arab J Sci Eng (2014) 39:6959–6967
DOI 10.1007/s13369-014-1273-6

RESEARCH ARTICLE - CIVIL ENGINEERING

Behaviour of Hybrid Fibre-Reinforced Concrete Frames with Infills Against Lateral Reversed Loads

K. Ramadevi · D. L. Venkatesh Babu · R. Venkatasubramani

Received: 14 April 2013 / Accepted: 30 November 2013 / Published online: 18 July 2014

Abstract Infilled frame construction represents a common type of construction in urban areas. The frames carry gravity loads and earthquake loads while the infills provide a building envelope and or internal partitioning. In several moderate earthquakes, buildings with infills have shown excellent performance even though many such buildings were not designed and detailed for earthquake forces. It is seen that the masonry infills contribute significant lateral stiffness, strength, overall ductility and energy dissipation capacity during moderate earthquakes. By providing fibres in the critical zones, it is possible to improve the performance of the frames against lateral loading. Hence, an attempt is made by using hybrid fibres (a combination of Polyolefin and Steel fibres) in the joints of the frames in various proportions and to determine the behaviour of the hybrid fibre-reinforced concrete (HFRC) frames under lateral reversed load. The percentages of fibres used are 0, 0.75, 1.5 and 2 %. This research work presents the experimental results of RC frames and HFRC frames and also the comparison of the same using ANSYS.

K. Ramadevi (✉)
Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore 641 049, India
e-mail: ramadharans@gmail.com

D. L. Venkatesh Babu
Department of Civil Engineering, JSS Academy of Technical Education, Bangalore 560 060, India
e-mail: vbkcm@rediffmail.com

R. Venkatasubramani
Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore 641 042, India
e-mail: rvs_vlb@yahoo.com

Keywords Masonry infill · Polyolefin fibre · Steel fibre · HFRC frames · Lateral reversed load

الخلاصة

يمثل بناء إطار الإرتداد نوعا شائعا من البناء في المناطق الحضرية ، حيث إن هذه الأطر تحمل أحمال الجاذبية والأحمال الزلزالية في حين أن الارتدادت توفر غلافا للمبنى و/ أو تقسيما داخليا. وفي العديد من الزلازل المعتدلة أظهرت المباني مع ارتدادات أداء ممتازا بالرغم من أن العديد من هذه المباني لم تكن مصممة ومفصلة لقوى الزلزال. وينظر أن تسهم ارتدادات البناء بشكل كبير في الصلابة الجانبية، والقوة ، وقدرة تبديد الطاقة الشاملة خلال الزلازل المعتدلة. ومن خلال توفير الألياف في المناطق الحرجة ، فمن الممكن تحسين أداء الأطر ضد التحميل الجانبي. ولذلك تم إجراء محاولة باستخدام الألياف المختلطة (مزيج من البولي أوليفين و ألياف الفولاذ) في مفاصل أطر بنسب مختلفة وتحديد السلوك من أطر الخرسانة المسلحة بالألياف الهجينة تحت حمل جانبي معكوس. والنسب المئوية للألياف المستخدمة هي 0٪، 0.75 ٪ ، 1.5 ٪ ، و 2 ٪. ويعرض هذا العمل البحثي النتائج التجريبية من أطر الخرسانة المسلحة وأطر الخرسانة المسلحة بالألياف الهجينة ، وكذلك المقارنة بينهما باستخدام برمجية أنسيس.

1 Introduction

The use of fibres in concrete is not a new concept. Asbestos fibres, straw and horsehair were used in olden days. Also the use of hybrid/composite fibres came into being in the 1950s. Fibre-reinforced concrete is concrete containing fibrous material which increases its structural integrity. The performance of conventional concrete is enhanced by the addition of fibres in concrete. FRC contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres—each of which lends varying properties to the concrete. In addition, the character of fibre-reinforced concrete changes with varying concretes, fibre materials, geometries, distribution, orientation and densities.

The main reasons for adding steel fibres to concrete matrix is to improve the post-cracking response of the concrete i.e. to improve its energy absorption capacity and apparent ductility and to provide crack resistance and crack control. Also, it helps to maintain structural integrity and cohesiveness in the material.

The combination of more than one or two types of fibres in concrete forms hybrid fibre-reinforced concrete. The blends of two types of fibres combine the benefits of both fibres. The use of optimized combinations of two fibres in a concrete mixture produces a better composite than a concrete with single fibre.

A detailed review of literature has been done in order to assess and evaluate the earlier works done on the behaviour of fibre-reinforced concrete frames with and without infills subjected to seismic loads.

Campione et al. [4] have studied the behaviour of high-strength fibre-reinforced concrete frames subjected to lateral forces including P-delta analysis. They found that a comparative performance may be obtained by utilizing less amount of transverse steel coupled with fibre-reinforced concrete.

Murty and Jain [1] have examined the influence of masonry infill walls on seismic performance of RC frame buildings. They found that the masonry infills contribute significant lateral stiffness, strength, overall ductility and energy dissipation capacity.

Suyambu Raja and Subramanian [6] have investigated the RC plane frame interactions with slab for seismic resistance that the infill and the slab also change the behaviour of the building under seismic action.

Eswari et al. [8] focused on Polyolefin–steel hybrid fibre reinforcing system and found that a hybrid fibre volume fraction of 2.0 % with 30–70 Polyolefin–Steel combine significantly improves the ductility performance of reinforced concrete specimens.

Tugce Sevil [9] carried out tests to determine the optimum steel fibre content (1, 2, or 4 % by volume) and to clarify the use of plasticizer or bonding agent in the mortar in the context of sticking ability, flexural, compressive and adhesion strengths. As a result, mortar with plasticizer and 2 % steel fibre (by volume) came out to be the optimum mortar mixture as strengthening material.

It is found from existing review of literatures that in the use of steel–synthetic fibre combination, Steel–Polypropylene blend is more frequent and Steel–Polyolefin blend is less so. Hence, an attempt is made to study the behaviour of reinforced concrete infill frames with Steel—Polyolefin (70–30 %) fibres in its joints.

The steel fibres used here are steel fibres of undulated/wavy type. These fibres are used to improve structural strength and to reduce crack widths. The steel fibres increase the flexural strength, improve ductility, fracture toughness and impact resistance. The polyolefin fibres straight in shape were used for this research work. Polyolefin fibres are those fibres produced from polymers formed by chain growth polymerization of olefins (alkenes) and which contain greater than 85 % polymerized ethylene, propylene or other olefin units.

2 Objective

- The main objective of this research work is to study the behaviour of RC infill frames provided with hybrid fibres (HFRC) in joint regions subjected to lateral reversed loads.
- To compare the results of HFRC frames with various hybrid fibre dosages and that of control frame.
- The fibres such as polyolefin and steel fibres of varying percentage (0, 0.75, 1.5 and 2 %) were used to determine the seismic behaviour of concrete frames.
- Comparison of the experimental results with ANSYS results.

3 Properties of Materials Used in this Research Work

The preliminary tests were done on cement, fine aggregate and coarse aggregate, and the test results were obtained. The mix proportion for M25 concrete (Cube compressive strength −150 mm at 28 days) is done based on the results obtained. The properties of materials used for concrete are tabulated in Table 1.

The percentages of hybrid fibres used in this research work are 70 % of steel fibre and 30 % of polyolefin fibres. The properties of both fibres are listed in Table 2.

The mix proportion for M25 grade concrete was calculated using IS:10262-2009. To improve the workability of the concrete mixture with two types of fibre blends, a superplasticizer Conplast SP 330 was used. The quantity and proportion of materials designed is listed in Table 3.

Table 1 Properties of Cement, FA and CA

Property	Cement	Fine aggregate (FA)	Coarse aggregate (CA)
Fineness	1 %	4.72	8.21
Consistency	30 %	–	–
Initial setting time	80 mins	–	–
Specific gravity	3.18	2.62	2.78

4 Preliminary Tests on Companion Specimens

The compressive strength, split tensile strength and flexural strength of concrete are determined by casting cubes of size 150 × 150 × 150 mm, cylinders of size 300 × 150 mm and prisms of size 500 mm × 100 mm × 100 mm and allowed for 28 days curing, and the test results were obtained for various percentage of fibres (polyolefin and steel fibres). The results of compressive strength, split tensile strength and flexural strength of control concrete and HFRC of various fibre dosages are tabulated in Table 4.

From the results, it was observed that the hardened concrete strength increases with the increase in hybrid fibre dosage. The comparison of the 28-day strength results shows an increase in compressive strength, split tensile strength and flexural strength for 2 % HFRC specimens compared to Control specimen (CC).

5 Experimental Programme

Infilled frame construction represents a common type of construction in urban areas. The frames carry gravity loads and earthquake loads, while the infills provide a building envelope and/or internal partitioning. The masonry infills contribute significant lateral stiffness, strength, overall ductility and energy dissipation capacity. Infills possess large stiffness and hence bear a significant share of the lateral force [1]. The use of masonry infill increases the overall capacity of the system when compared to the system without masonry [2].

In this research work, four different plane frame models were considered. The strength of concrete used is M25 ($f_{ck} = 25\,\text{N/mm}^2$, Cube compressive strength − 150 mm at 28 days) and the yield strength of steel is 415 N/mm^2 (Fe415). All the frame models were cast and tested experimentally under positive lateral reversed loading at the Structural Technology Centre of Kumaraguru College of Technology, Coimbatore, India. All the model frames were infilled with burnt clay brick masonry in cement mortar. The infill masonry is made with full-scale burnt clay bricks of size 220 mm × 105 mm × 70 mm.

The reinforcement of beam consists of four 10-mm-diameter bars top and bottom with a clear cover of 25 mm. The shear reinforcement includes stirrups of 8-mm-diameter bars at 100 mm c/c spacing and the column reinforcement consists of four 120-mm-diameter bars. The raft slab reinforcement consists of 10 mm diameter with 100 mm c/c in both directions in two layers. The dimensions and reinforcement details of the model frame adopted is shown in Fig. 1.

According to IS 13920:1993, clause 6.3.5, flexural yielding may occur under the effect of earthquake forces over a length equal to 2*d* on either side of a beam section, where *d* is the effective depth of member [3]. The performance may be improved by utilizing transverse steel coupled with fibre-reinforced concrete [4]. Hence, the HFRC frame models were

Table 2 Properties of fibre

S. no.	Fibre properties	Polyolefin fibre	Steel fibre
1	Appearance		
2	Length (Mm)	48	30
3	Shape	Straight	Wavy
4	Size/diameter (Mm)	0.7	0.6
5	Aspect ratio	39.34	60
6	Density (kg m^{-3})	920	7,850
7	Young's modulus (GPa)	6	210
8	Tensile strength (MPa)	550	532

Table 3 Mix proportion for M25 grade concrete

Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water content	Superplasticizer
425.75	649.498	1,174.42	191.58	0.8 % by weight of cement
1	1.52	2.75	0.45	–

Table 4 Preliminary test results

S. no.	Specimen ID	28 days strength in MPa		
		Compressive strength of cube	Split tensile strength of cylinder	Flexural strength of prism
1	CC	27.0	3.47	3.60
2	0.75 % HFRC	28.1	3.60	3.68
3	1.5 % HFRC	34.2	3.96	4.11
4	2 % HFRC	35.3	3.99	4.50

cast with hybrid fibres of varying percentages (0, 0.75, 1.5 and 2 %) in the plastic hinge zones of the frames i.e. at a distance of 2*d* for beams and 1.5*d* for columns. The infill frame with HFRC zones is shown in Fig. 2.

The following models were investigated in this research work:

1. RC frame with unreinforced masonry
2. 0.75 % HFRC frame with unreinforced masonry
3. 1.5 % HFRC frame with unreinforced masonry
4. 2 % HFRC frame with unreinforced masonry

The complete test set-up adopted for the frame model is as shown in Fig. 3. The columns and beams are square sections of size 0.1 m. The one-third scale model frames were applied with a monotonically increasing lateral displacement and the respective loads as shown in Fig. 3. The effectiveness of instrumentation set-up and the loading were checked initially by loading and unloading the frame with small loads (of the orders of 2.5 kN) till all the readings were repeatable. The frame was subjected to equivalent static lateral reversed loading. The loading sequences in the beginning were almost same.

The load increment for each cycle was 2.0 kN at all the stages. The deflections were measured at each increment and decrement of load. The formation and propagation of cracks, hinges and failure pattern have been recorded. All the frames were marked by points in the outermost column of the portal frame from which the dial gauge is placed at 25, 50 and 95 cm from the top of the raft slab before testing to measure the deflection of the outermost column.

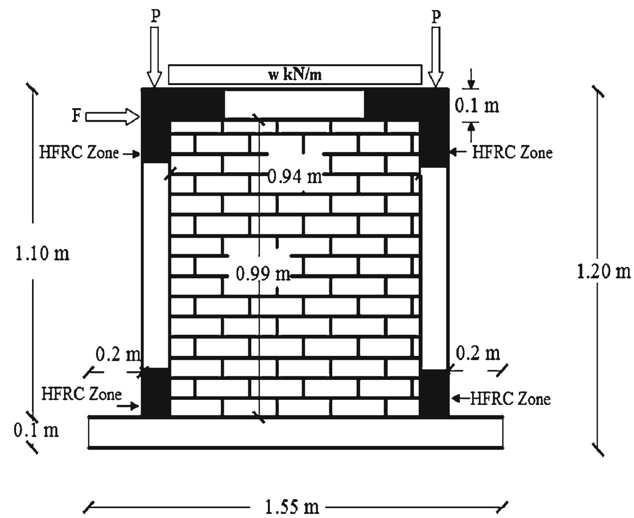


Fig. 2 Infill frame specimen with HFRC zones

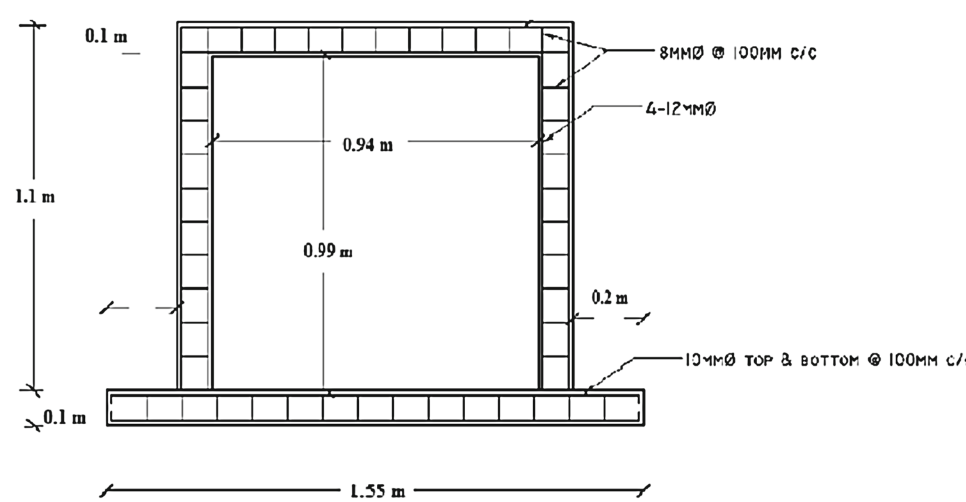


Fig. 1 Reinforcement details of the model frame

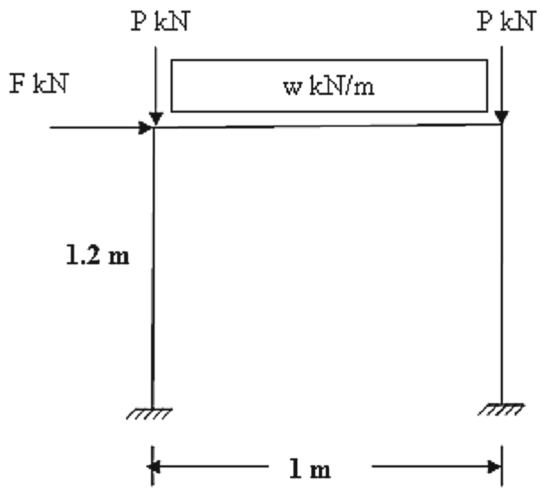


Fig. 3 Loading schemes of the frame specimens

Fig. 4 2 % HFRC frame specimen—load set-up

The complete load and deflection measurement set-up for 2 % HFRC frame specimen is shown in Fig. 4. All the frame specimens were tested till collapse. The ultimate load and the corresponding deflection were measured for all the frame specimens. The frame specimens before testing and after failure are presented in Fig. 5.

6 Experimental Results (Frames with Infills)

All the frame specimens were tested till collapse. The ultimate load and the corresponding deflection were measured for all the frame specimens. The results are tabulated in Table 5.

The capacity of the frame specimens was increased due to the presence of brick infills in the frame specimens [5]. The first crack was witnessed in the interface between brick infill and beam. The cracking occurred during loading reflect the fact that the infilled frame behaved as an integral unit. At failure, the infilled frame exhibited spalling of brick fragments. The formation of several cracks in the beam–column joints were observed after severe cracking of brickwork.

Major failures occurred in the beam–column joints and in the interface between beam–brick infill [6]. From the above table, it is seen that the ultimate load for the HFRC frames is increased when compared to that of the control frame, and the variation in deflection is also large.

The plots between Load–Deflection and Load–Cycle number were obtained for each frame and shown in Fig. 6a. It is clearly observed that the ultimate load capacity and the corresponding deflection and cycle number increases with an increase in fibre dosage in the beam–column joints. It was observed that the HFRC models performed well when compared to the control specimen [7]. The energy dissipation characteristics of the frames with and without hybrid fibres are plotted in Fig. 6b. The experimental results of Load–Deflection behaviour of all frame specimens are represented in Fig. 6a and that for 2 % HFRC frame with infill using ANSYS 14 is shown in Fig. 7. The Load versus Cycle number plot is presented in Fig. 8.

7 Conclusions Based on Experimental Results

The experimental investigation on the structural behaviour of the frame specimens with and without hybrid fibres subjected to lateral reversed loading was found to be close to the analytical results using ANSYS software package. Based on the experimental results of this research work, the following conclusions were drawn for HFRC frames with infills subjected to lateral reversed loading.

- The load-carrying capacity of the infilled RC frame with hybrid fibre strengthening is more than that of infilled RC frames without fibre reinforcement.
- Separation of infill occurred at tension corners and crushing occurred at loaded diagonals due to high stress concentration.
- The percentage of fibres used was 0, 0.75, 1.5 and 2 %, and the results were found to be improving with an increase in fibre dosage.
- With the addition of hybrid fibres in the plastic hinge zones of the infill frames were found to perform well when compared to control frames.
- The load-carrying capacity for infilled frames increased with the increase in percentage of hybrid fibres, and it was 118.2 % for 2 % HFRC infilled frame compared to respective control frames

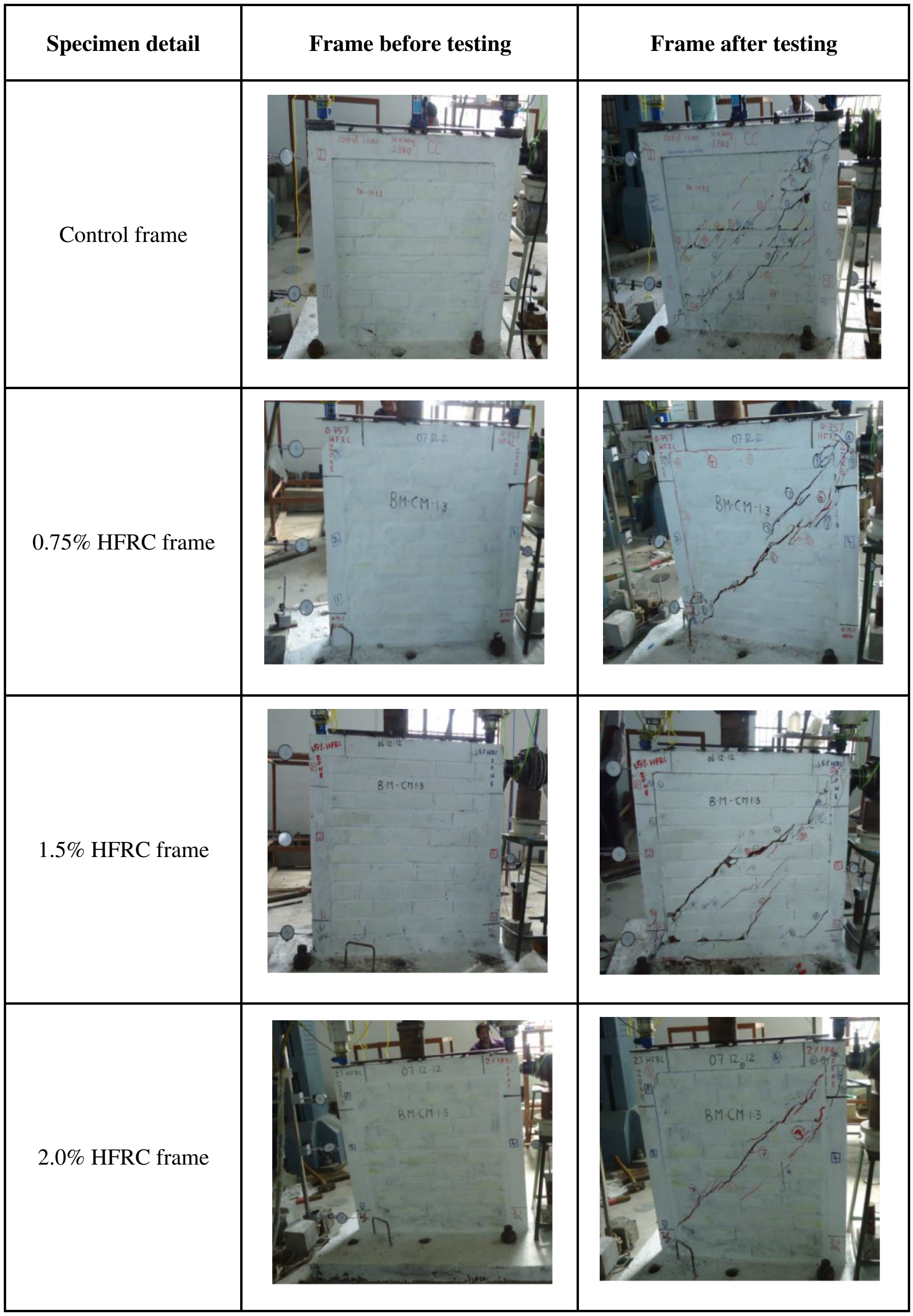
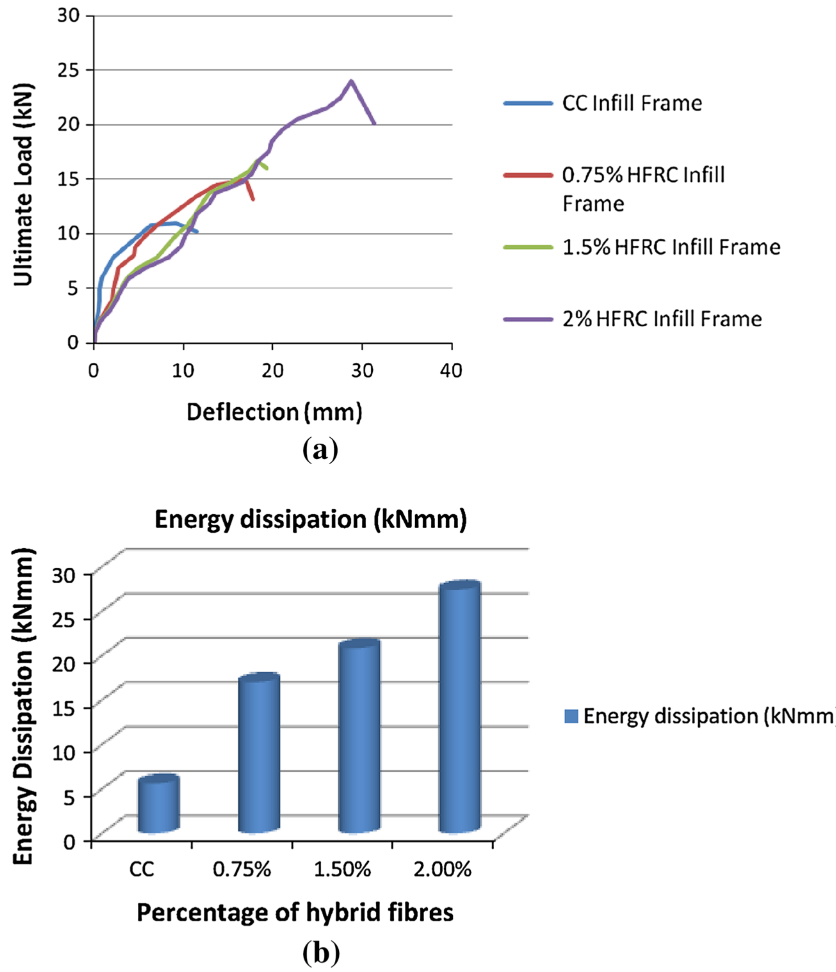


Fig. 5 2 % HFRC frame specimens—before testing and after failure

Table 5 Experimental results

Frame ID	% of hybrid fibre reinforcement	Experimental observations	
		Ultimate load (kN)	Deflection at ultimate load (mm)
CC	0	11.00	9.08
0.75 HFRC	0.75	15.00	16.95
1.5 HFRC	1.5	16.67	18.25
2 HFRC	2.0	24.00	28.76

Fig. 6 **a** Load–deflection behaviour of frame specimens. **b** Energy dissipation characteristics of various frame specimens



- Cracks in the infilled RC were found to be numerous and extensive and in the form of diagonal cracks.
- The deflection capacity of the frames were also increased due to the presence of hybrid fibres, and it was 216.7 % for 2 % HFRC infilled frame than the control frames.
- The number of cycles to failure increases with an increase in hybrid fibre percentage.
- The cumulative ductility factor for the HFRC frames increased with an increase in fibre percentage [8]. The cumulative ductility factor for 2 % HFRC infilled frame was 0.013 during first cycle of loading, and at ultimate load, it was 40.02.
- The energy dissipation capacity for 2 % HFRC infilled frame in first cycle was 0.098 and 186.856 kNmm during final cycle of loading.

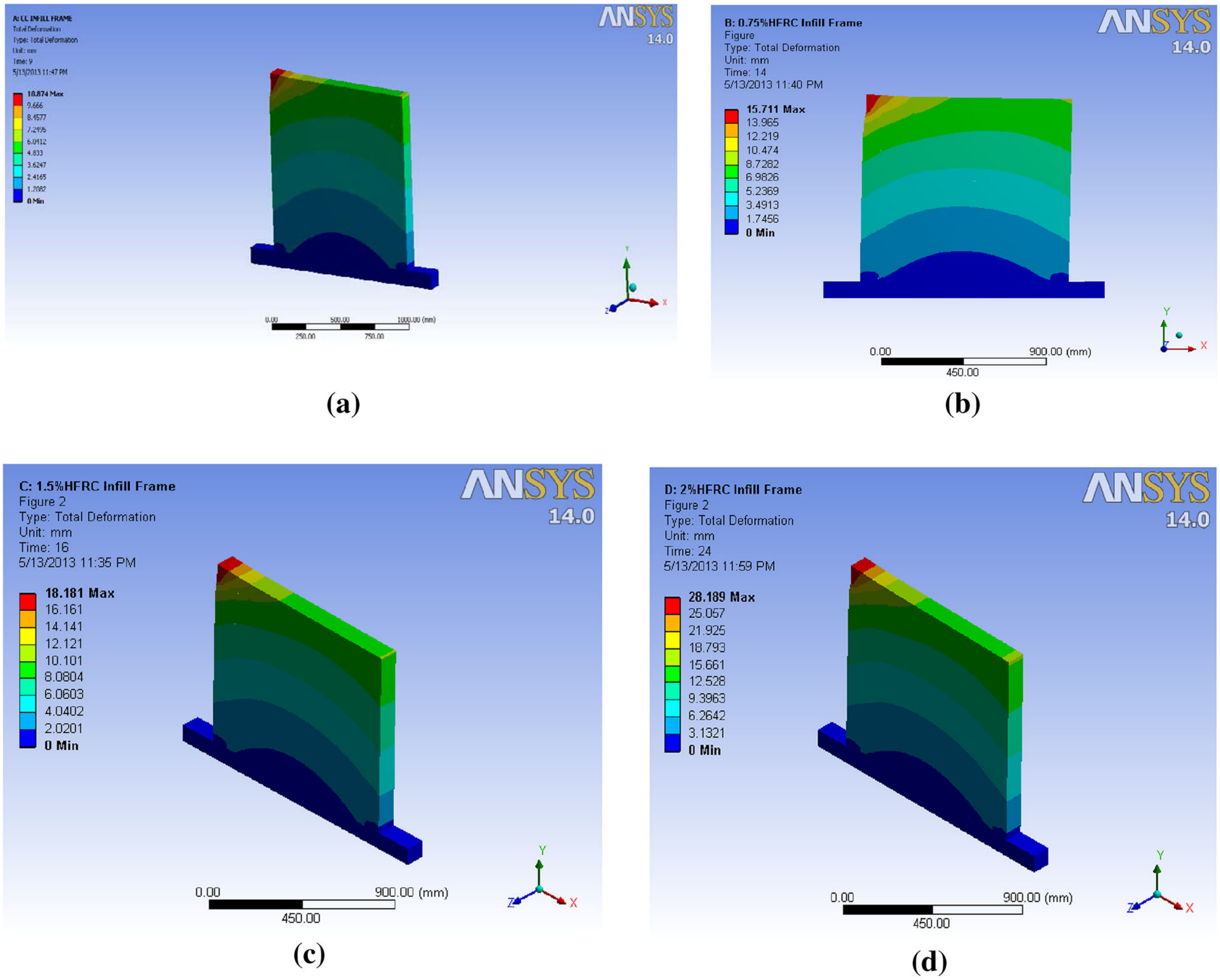
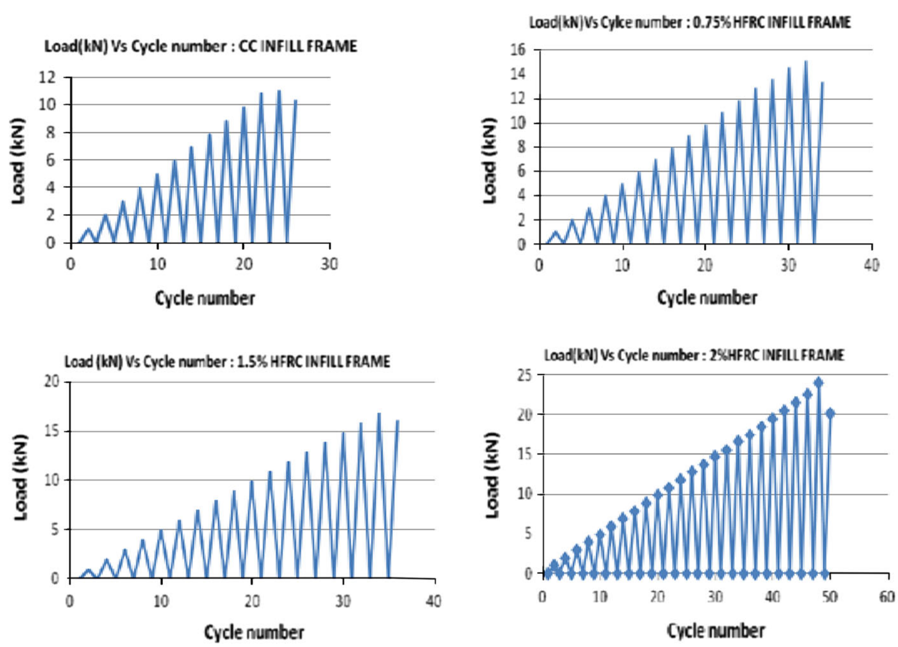


Fig. 7 **a** ANSYS results of control frame with infill after testing. **b** ANSYS results of Infill frame with 0.75 % HFRC after testing. **c** ANSYS results of Infill frame with 1.5 % HFRC after testing. **d** ANSYS results of Infill frame with 2 % HFRC after testing

Fig. 8 Load (kN)–cycle number curves



References

1. Murty, C.V.R.; Jain, S.K.: Beneficial influence of masonry infill walls on seismic performance of RC frame buildings. In: Proceedings of the Twelfth World Conference on Earthquake Engineering, Auckland, 1790 (2000)
2. Moubarak, A.M.R.; El-Din Fahmy Taher, S.: Effect of reinforcing patterns on the behaviour of masonry walls in R.C frames. Arab. J. Sci. Eng. **34**(1B), 37–56 (2008)
3. IS 13920: 1993.: Code of practice ductile detailing of reinforced concrete structures subjected to seismic force, India
4. Campione, G.; La Mendola, L; Zingone, M.: Seismic behaviour of fibre reinforced concrete frames. In: Proceedings of the Twelfth World Conference on Earthquake Engineering, held at Auckland, Paper no. 0040 (2000). http://www.iitk.ac.in/nicee/wcee/article/0040.pdf
5. Suresh Babu, R.; Venkatasubramani, R.: Seismic strengthening of low rise buildings using brick inserts (Retrofit)—experimental investigation on 2D and 3D framed structures. Int. J. Adv. Eng. Sci. Technol. **2**(1), 073–084 (2011)
6. Suyambu Raja, A.; Subramanian, K.: Experimental investigation on three dimensional RC infilled frame—RC plane frame interactions with slab for seismic resistance. Am. J. Appl. Sci. **5**(4), 328–33 (2008)
7. Rajaram, P.; Murygesan, A.; Thirugnanam, G.S.: Experimental study on behaviour of RC beam column joints subjected to cyclic loading. Int. J. Appl. Eng. Res. **1**(1), 49–59 (2010)
8. Eswari, S.; Raghunath, P.N.; Suguna, K.: Ductility performance of hybrid fibre reinforced concrete. Am. J. Appl. Sci. **5**(9), 1257–1262 (2008)
9. Tugce Sevil, T.; Baran, M.; Bilir, T.; Canbay, E.: Use of steel fiber reinforced mortar for seismic strengthening. Constr. Build. Mater. **25**(2), 892–899 (2011)