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Structural behavior of a single bay two-story basalt fiber reinforced concrete frame

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Professional paper

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This study focuses on structural design, which is a primary aspect of civil engineering. Investigating the behavior of reinforced concrete (RC) frame systems subjected to lateral loading and estimating the damage state of a structure still remain challenging tasks in civil engineering. Reinforced concrete is currently used in a majority of constructions and Conventional buildings remain vulnerable to seismic earthquakes. The aim of this research is to identify how well RC frames with basalt and steel fibers perform under cyclic loading. Steel and basalt fibers are chopped to a size of 2.5 cm. The reinforcements details are made according to IS 13920-2016. The concrete specimen used for this work is in the form of a single-bay, two-story frame, which is composed of reinforced concrete along with chopped steel and basalt fibers of two different proportions. Three frames are cast. One is a RC concrete frame with no fiber materials (conventional concrete) and the other two frames are cast with different proportions of fiber content. The basalt fiber is added to the specimens in proportions of 0.25 % and 0.50 %. The experimental outcome attained from the specimens of 0.25 % of basalt fibre has superior load-carrying capacity as well as minimum story drift than the other two frames. The ductile behavior of BFRC is increased compared to that in conventional ones. It is observed that the crack width of the BFRC is less when compared to that in the conventional concrete.

Key words:
concrete frame, fiber-reinforced concrete, basalt fibre, cyclic lateral loading, story drift

Stručni rad

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Ponašanje jednorasponskoga dvoetažnog betonskog okvira armiranog bazaltnim vlaknima

U ovom je radu fokus na projektiranju konstrukcije, što je primarni aspekt građevinarstva. Ponašanje sustava armiranobetonskih (AB) okvira izloženih bočnom opterećenju i procjena stanja oštećenja konstrukcije još su uvijek izazovni zadaci u građevinarstvu. Trenutačno se za većinu konstrukcija koristi armirani beton. U radu je prikazano istraživanje ponašanja AB okvira s bazaltnim i čeličnim vlaknima pod cikličkim opterećenjem. Čelična i bazaltna vlakna usitnjena su na veličinu od 2,5 cm. Detalji armiranja izrađeni su prema standardu IS 13920-2016. Uzorak korišten za oovo istraživanje u obliku je jednorasponskog, dvokatnog okvira koji je izrađen od armiranog betona s usitnjenim čeličnim i bazaltnim vlaknima u dvama različitim omjerima. Izvedena su tri okvira. Jedan je okvir od armiranoga betona bez vlakana (konvencionalni beton), a druga dva izrađena su s vlaknima različitih omjera. Omjeri bazaltnih vlakana su 0,25 % i 0,50 % te su dodani uzorcima. Ostvareni eksperimentalni rezultat na uzorcima s 0,25 % bazaltnih vlakana ima bolju nosivost kao i najmanji međukatni pomak u odnosu na druga dva okvira. Duktilnost okvira s BFRC-om povećana je u usporedbi s konvencionalnim okvirom. Uočeno je to da je širina pukotina pri uporabi BFRC-a manja u usporedbi s konvencionalnim betonom.

Ključne riječi:
betonski okvir, beton ojačan vlaknima, bazaltna vlakna, cikličko bočno opterećenje, međukatni pomak

1. Introduction

Basalt fiber RC is a novel technique for improving the structural behavior of concrete. Basalt fibers are mixed into conventional concrete and the structural behavior of single-bay, two-story concrete frame is then studied. The fundamental reaction of load carrying limit, hardness, flexibility, and energy scattering limit was determined. Three-straight RC frames with and without the shear wall in the center were exposed to a static cyclic horizontal load. The review described the whole loading limits, from the basic flexible period to the ultimate load. One of the edges was exposed to the horizontal turned around cyclic loading until it lost equivalent load carrying capacity, and the other shell was exposed to 80 % of the load relating to the failure load [1]. Steel fibers were used to determine the pre and post fatigue flexural properties of the specimen [2]. Spanish broom (natural fiber) is used to determine the cement composite parameters. Flax and hemp shaped broom fibers are used [3]. Glass fiber is used for determining the stiffness and ductility in polymer concrete. Fibers are used in 0 % and 1.5 % polymer concrete [4]. Fibers are used in 0.5 % and 0.1 % concrete for determining the mechanical behavior of the concrete [5]. Sisal Fiber (natural fiber) is used to determine the mechanical properties of concrete in the percentage of 0.05 % to 0.40 % [6]. The examples were retrofitted and exposed to a similar loading arrangement in the second stage. They were investigated in terms of hysteretic reaction, strength, flexibility, and ductility. The retrofitted frame, which was exposed to a lower level of difficulty in the first stage, showed better conduct [7]. Considering seismic earthquakes, specialists examined the measurable connection between the ductility requests and worldwide removal flexibility requests of considerable structures. Components with an assigned second curve relationship were considered for both shaft and section, and five-story and ten-story RC frame mathematical designs were developed [8]. Utilizing pushover examination and earthquake nonlinear powerful time-history investigation, the most extreme worldwide flexibility requests of the construction and the greatest curve of ductility request not entirely set in stone were determined [9]. The component curve flexibility of considerable construction gives a significant marker for controlling the level of elasticity. With an immediate speed increase, the arch ductility requests of sections and the removal flexibility requests of the design increment seismic assessment and danger, investigation of common place supporting the considerable structures are performed. Three specimens were separated with limit plan ideas considering shear limit, flexural limit, are assurance from the floor support to transfer the load. The time-history examinations are plotted against ground movement controls. Results represent temporary total scattering capacity for frames [10]. The presentation of three samples was investigated considering shear limit, flexural limit, and binding capacity. The related economic danger of structures with each of the three specimens is compared. The RC exposed specimen exhibition was completed in both examination and scientific works. The conclusion drawn from the outcomes is that the presentation of RC exposed mold in the investigation is identical to the exploratory review. Through the nonlinear examination, the acknowledgment rules such as safety and collapse pattern are estimated. The scientific outcomes show that yield load, ultimate load, and flexibility have undergone a 15 % difference in mix when compared with the conventional concrete. The logical strategy can provide helpful after effects of RC uncovered mold when contrasted with test review [11]. The majority of the examination was participating in seismic horizontal cyclic load in the frame; however, it did not consider the BFRC Frame. Therefore, this study examines the primary conduct of the supported considerable with the BFRC Frame [12-14].

The fundamental scope of this research is to determine the structural behavior of the RC frame with BFRC frame specimens, focusing on stiffness, ductility, energy absorption capacity, and crack pattern. This study presents a clear idea about the frame and its load dispersion behavior for practical purposes.

- To determine the feasibility of using a basalt fiber RC frame.
- To investigate the structural behavior of the BFRC concrete frame.
- To reveal the crack pattern of the RC and BFRC concrete frames.

2. Materials used

2.1. Concrete materials

For the current research, CHETTINAD (brand name) cement of 43 grade OPC per IS: 12269-2013 was utilized. The concrete specimen was tried according to the strategy given in IS: 4031-2019 and IS: 4032-1985 (reaffirmed 2019). Its properties are displayed in table 1. The locally accessible M-sand was utilized as a fine aggregate. Its properties are listed in table 2. Crushed granite coarse aggregate of a maximum size of 20 mm is used. The experiments were conducted to determine the properties of coarse aggregate as per Indian Standard Specifications IS: 383-2016. The physical properties of coarse aggregate are listed in table 3. Different sized Thermo-Mechanically Treated (TMT) bars were utilized as longitudinal support in different cases from the test sample. TMT bars were likewise utilized as shear supports in the footings, beams, and columns. TMT bars were tested and its mechanical properties are listed in Table 4. The re-bars of 6 mm, 8 mm, and 12 mm HYSD bars were utilized for support. The available drinking was used for both casting and curing the specimens, and it was confirmed by IS: 3025-1987 (reaffirmed 2019).

Table 1. Properties of cement

No.	Characteristics	Experimental value	As per IS: 8112-1939
1.	Consistency of cement	32 %	-
2.	Initial setting time	36 min	Should not be less than 30 min
3.	Final setting time	5 h and 10 min	Should not be more than 10 hrs
4.	Specific gravity	3.16	3.15

Table 2. Properties of fine aggregate

No.	Characteristics	Experimental value
1.	Specific gravity	2.7
2.	Water absorption	1 %
3.	Zone	Conforming III

Table 3. Properties of coarse aggregate

No.	Properties	Observed values
1	Fineness modulus	8.270
2	Specific gravity	2.720
3	Water absorption	1.37 %

2.2. Basalt fiber

Basalt fiber is obtained naturally from igneous rock in a molten state. A total of 25 mm of basalt fibers were used in this research, as shown in figure 1. The aspect ratio of the fiber is 833. Basalt fibers were purchased from a third-party vendor in Gujarat, who also provided the details concerning the physical properties. Basalt fibers are added in the ratio of 0.25 % to 0.50 % of the total volume of concrete. This is represented in the IDs of BFRC0 (0 % of Basalt fiber added in specimen also called as conventional concrete), BFRC1 (0.25 % of Basalt fiber added in specimen), and BFRC2 (0.50 % of Basalt fiber added in specimen).

Figure 1. Basalt Fiber

2.3. Concrete mix proportion

The mix was assigned according to IS: 10262-2019. In view of the exploratory outcomes, the mix extent of M20 was planned, and a concrete mix with a w/c proportion of 0.50 was ready. The details of the materials needed for 1m3 of cement are given in table 4.

Table 4. Properties of TMT bar

No.	Properties	Observed values
1	Modulus of elasticity	199 GPa
2	Ultimate tensile stress	544 N/mm^2
3	Yield stress	500 N/mm^2

One-fifth scale RC frame specimens were prepared for this project. Mold should be sufficiently stiff to withstand the stresses, which are developed by the handling and compacting of concrete while concreting. Mold preparations for the frame specimen are shown in Figure 2.

Figure 2. Mold for concrete frame specimen

Table 5. Materials required for 1 m^3 of concrete in kg

Grade	Cement	FA	CA	Water	W/C
M20	383	565.16	1229	191	0.50

2.4. Fabrication of reinforcement for frame specimen

The limit state method of configuration using IS 456:2000 was considered for the plan of column and segment independently and point by point according to IS13920:1993. Sufficient development length was provided in beam reinforcement and proper anchorage to the column. Fabrication of reinforcement was performed to cast two frame specimens; RC conventional frame and BFRC frame

Table. 6. Reinforcement Details of 1/5th scale down model

Members	**Size** [mm]	**Clear cover** [mm]	**Main steel bar**	**Distribution steel bar**
Beam	100 x 150	15	ø 8 mm (4 bars)	ø 6 mm / 100 mm
Column	200 x 100	15	ø 8 mm (4 bars)	ø 6 mm / 100 mm
Base beam	100 x 400	15	ø 12 mm (8 bars)	ø 6 mm / 100 mm

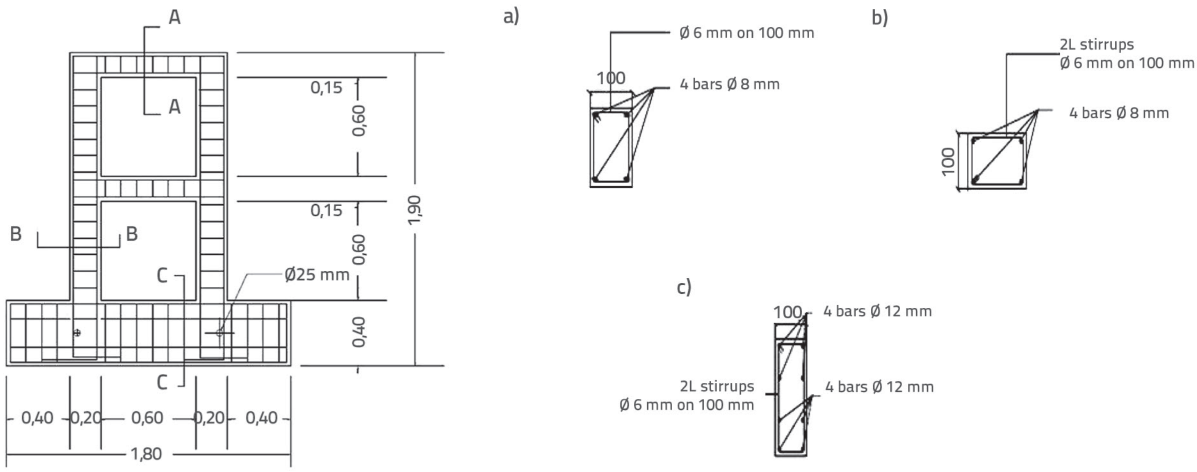

Figure 3. Frame reinforcement details: a) Section A-A; b) Section B-B; c) Section C-C

specimens. The reinforcement details for the 1/5th scale model of the real framed structures are listed in Table 6. Fabrication of reinforcement for the frame specimen is shown in Figure 3.

2.5. Casting of RCC frame specimen

The frames are highly vulnerable during earthquakes [13]. The challenging task of civil engineers is to construct structures that withstand earthquakes. The frames were cast in a horizontal position and later tilted vertical for panel construction. Before placing the mold on the test floor, it should be cleaned and the surface should be levelled. The wooden molds were oiled and appropriately adjusted to the correct aspect on the considerable stage. Created support for the frame was set inside the shape, keeping up with appropriate cover. The gusset plate is welded at both the standard story level. In the lab, coarse and fine aggregates were mixed in dry state in the mixer machine, after that cement and water was also added in the mixer machine for uniform mixing for approximately three minutes. The fresh concrete was placed into the molds for the respective mix, in three layers, and compacted with manual blows. After 24 hours, the formwork was removed and examples were cured for a total of 28 days. Reinforcement kept in the mold is shown in Figure 4. Projections of RCC frame examples are displayed. RCC Frame examples subsequent to de-molded specimens are also displayed.

Figure 4. Mold with rebar arrangement

3. Testing

Mechanical behavior of basalt fiber RC is also determined as per the IS 516:1959. Every example was tried under cyclic loading in the lab. The specimen was held by the foundation bed block. The hydraulic jack was mounted laterally in the loading frame and a hand-operated hydraulic jack with a 100 kN capacity was used to test the specimens.

3.1. Compressive strength

This compression testing is used to determine the capacity of the concrete to withstand the load without failure. Cube specimens of 150 mm X 150 mm X 150 mm are cast and tested after a 7-day and 28-day curing period, respectively. As per IS 516:1959 for conventional and BFRC. For the fiber mix proportioning ID of BFRC1, the maximum compressive strength is 30.443 N/mm^2, which is higher than that of the conventional concrete, shown in Figure 5. Optimum percentage of fiber mix proportion is 0.25 % of Basalt is the better one.

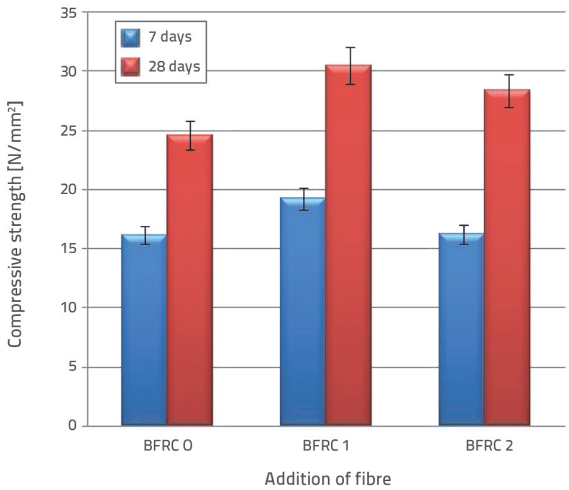

Figure 5. Split tensile strength test

3.2. Split tensile strength testing

Split-Tensile test on conventional concrete and BFRC specimens of 150 mm diameter and 300 mm height are casted. These conventional and BFRC specimens were evaluated using IS516:1959 references to determine the concrete quality after curing of 7th and 28th day.

Test results are shown in Figure 6. BFRC1 maximum split-tensile strength is 3.197 N/mm^2. BFRC1 (0.25 % of Basalt) specimen gives the better result, higher than that of the conventional concrete. BFRC2 gives the higher percentage of strength increment, but economically, BFRC1 provides better result. BFRC1 provides 33.3 % more than conventional concrete.

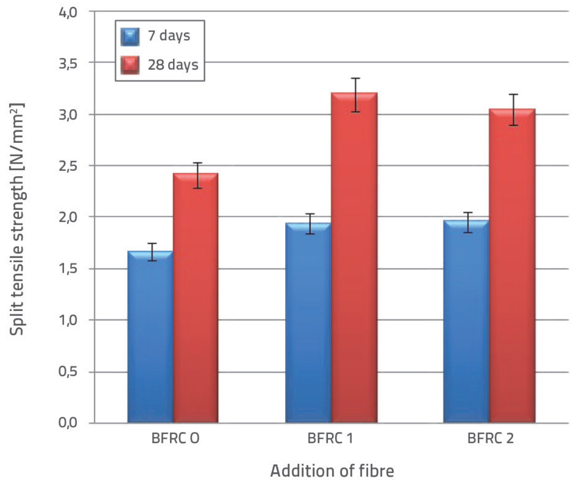

Figure 6.Split tensile strength test results

3.3. Flexural strength testing

For measuring the flexural strength of concrete, 100 mm X 100 mm X 500 mm plain concrete and BFRC specimens are cast and tested These BFRC and control specimens are tested in a Universal testing machine in accordance with IS 516:1959 to determine the concrete quality achieved on the 7th and 28th day of sufficient curing. BFRC maximum flexural strength is 5.495 N/mm^2. The BFRC 1 gives a better result higher than that of the BFRC and conventional concrete as shown in Figure 7. The BFRC1 contributes in increasing the flexural tensile strength by 42.6 % than that of conventional concrete.

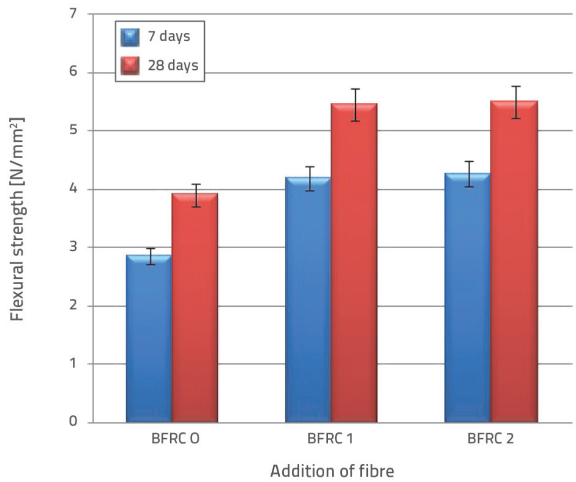

Figure 7. Flexural strength test results

3.4. Cyclic loading

For cyclic loading, observations were taken at load intervals of 5 kN up to the load of 40 kN. For the first cycle, lateral loading was applied at the top of the beam end, and then the load was reduced to zero, which is called the forwarding cycle and the deflection due to the application of lateral loading was noted.

Observations were taken at incrementing intervals of 5 kN. Similarly, in the second cycle, the load was again raised to 10 kN and then reduced to zero. For each cycle, the load was raised to 5 kN interval and reduced to zero. For the last cycle, the load was raised to the ultimate failure load.

3.5. Loading arrangement

The 1/5th scale down model examples were tried in a loading frame. The mold was placed in the middle of the foundation bed block. The motivation for establishing bed blocks is to stand firm on the section in vertical position, as well as, for the placement of diaphragm measurements at various areas. RCC framed specimens with test arrangements are displayed in Figure 8.

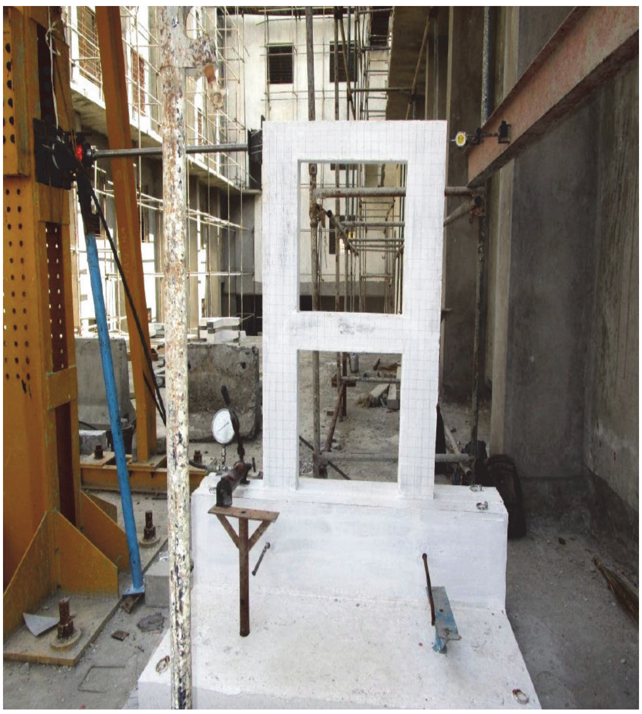

Figure 8. RCC frame specimen with test setup

4. Results and discussion

The deformations for each one of the specimens under cyclic loading were determined here. The typical load deflection curve for an M20 concrete specimen is displayed in Figure 13. The load deflection behavior of an RCC Specimen is shown in figure 13.a. The load deflection behavior of a BFRC specimen is shown in Figures 13.b and 13.c. Load avoidance bend shows the cyclic conduct of RCC and BFRC frames example, and the BFRC frame decreases the redistribution in each cycle on account of the RCC. It is inferred that the BFRC frame decreases the avoidance qualities of the edges and furthermore expands an ultimate load. During cyclic loading, when removing the load, the deflection value comes to zero. During reloading, more energy is absorbed to create the crack. This might cause an ultimate load.

4.1. Stiffness behavior

On account of the supported edge, the hardness of the joint diminishes when the joint is exposed to cyclic loading. This decrease in flexibility is because of the commencement of small cracks inside the joint, and at certain times, there is rapid exhaustion of the furthest reaches of the materials. This increases the defects within the joints, resulting in a decrease in hardness. The hardness of the edge is not entirely set in stone by utilizing the angle of the deviation. Stiffness is characterized as the amount of energy needed to cause unit deflection of the specimen. The system for computing stiffness is as per the following:

- A tangent line was drawn for each cycle of the hysteric curves at a load of P = 0.75 Pu. where Pu is the maximum of that cycle.
- Determined the slope of the tangent drawn to each cycle, which gives the stiffness of that cycle.

From Figure 9, the framed specimen with BFRC has higher stiffness than the conventional specimen. Thus, BFRC1 shows greater stiffness and less stiffness degradation than that of the RCC.

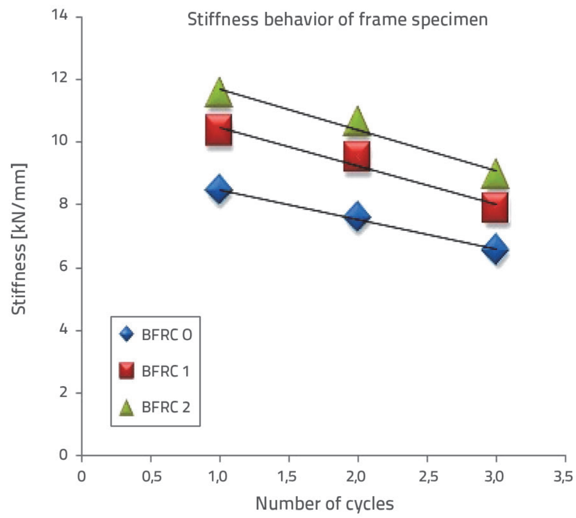

Figure 9. Stiffness behavior of the specimens

4.2. Cumulative energy absorption capacity

The point at which specimen is exposed to lateral cyclic loading, for example, during a weighty wind or earthquake, some energy is invested in each load cycle. This is equivalent to stressing or twisting the design to the furthest reaches of avoidance. The general energy retention limits during different load cycles were determined as the amount of the region under the hysteric circles from the high diversion chart. The energy retained during the RCC framed specimen was determined to be 139.3 kN-mm. The energy retained during the BFRC framed specimen was determined to be 178.6 kN-mm. The energy retention limits for each cycle and each example are shown in Figure 10.

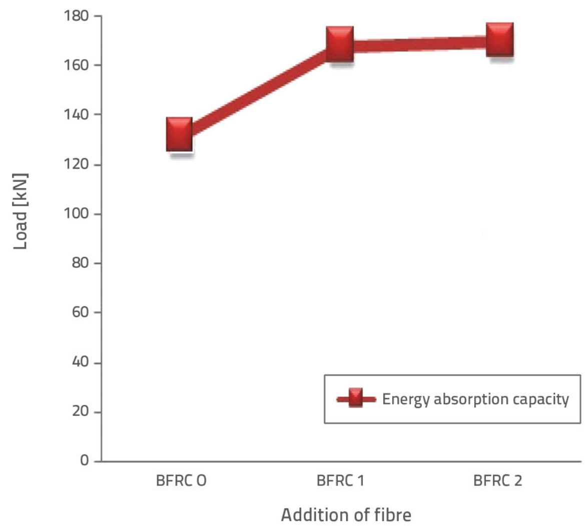

Figure 10. Comparison of energy absorption capacity

4.3. Frame crack pattern

The crack patterns of RCC and BFRC frame specimens under various loadings for various specimens are shown in Figures 11.a and 11.b. For RCC, forward cyclic loading is shown in Figures 11 and 14, and for BFRC, forward cyclic loading is shown in Figures 12 and 15.

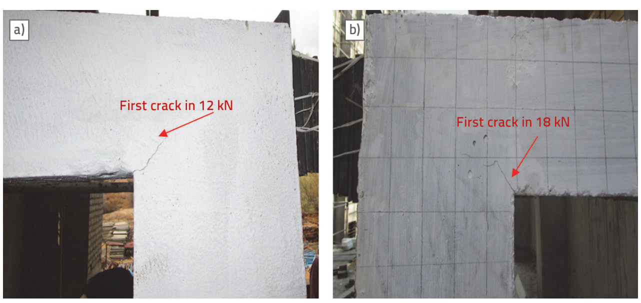

Figure 11. First crack in the: a) Conventional; b) BFRC Frame specimens

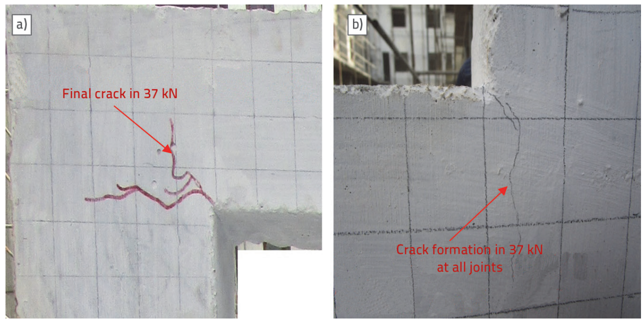

Figure 12. Final crack in the BFRC1 Frame specimens

The entire frame specimen showed the same failure pattern with the first crack developing at the joint face under cyclic loading. The first crack was initiated at 12 kN at the beam-column joint junction of the RCC Specimen and at 18 kN for the BFRC1 specimen. A few hairline cracks were developed in the second cycle, but during unloading, the crack propagation stopped. On further loading in the third cycle, specimens were loaded to failure, cracks started to widen, and the specimens failed at ultimate load. All specimens showed the same crack pattern and failure pattern, but the ultimate load and crack width varied from one specimen to another.

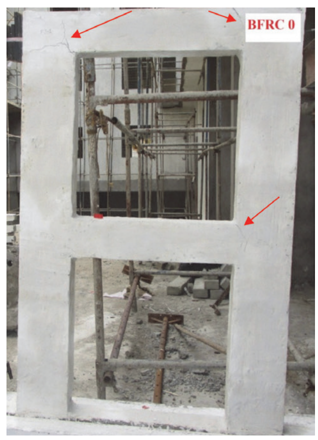

Figure 14. Crack pattern of RCC frame

Figure 15. Crack pattern of BFRC frame

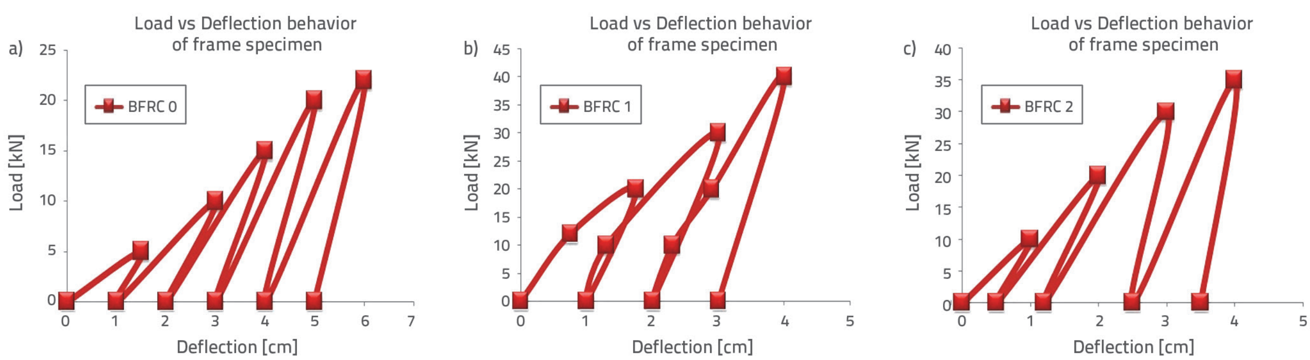

Figure 13. Load vs Deflection behavior of frame specimen

5. Conclusions

The experimental investigation was conducted on 1/5th scale-down models of a single-bay, two-storied bare reinforced concrete (RC), and basalt fiber reinforced concrete (BFRC) frame model. With the results obtained; the following conclusions are drawn:

- The compressive strength attained at 28 days for all grades of BFRC under ambient curing is greater than that of the RCC frame.
- BFRC1 is economical and provides good compressive strength, which is 8.7 % higher than that of BFRC0 (conventional concrete) specimens.
- Hence, an increase in the concentration of basalt fiber results in an increase in tensile strength. BFRC1 gives a 33.3 % higher tensile strength compared to that of BFRC0.
- BFRC1 showed better flexural strength as well. This test results clearly showed in to have 42.6 % higher flexural strength than that of the traditional concrete.
- The BFRC specimen had higher stiffness than that of the conventional specimen. However, BFRC1 showed better results economically, whereas BFRC2 was uneconomical.
- The BFRC1 specimen showed a 28.2 % higher cumulative energy storing capacity compared to that of BFRC0. BFRC 2 also showed better result than that of BFRC0, but poorer than that of the BFRC1 specimen result.
- The load-deflection figures of BFRC1 specimens were better compared to that of BFRC0 specimens. The BFRC examples showed better execution under a horizontal cyclic loading, maximum of 40kN, corresponding to a 3mm less deflection.
- The BFRC frame shows higher stiffness when compared to the conventional RCC frame specimen.
- Because of the development of cracks, the BFRC frame can bear a higher load compared to the RCC frame specimen.

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