Seismic Behaviour of Hybrid Fibre Reinforced Concrete Bare Frames

K.Ramadevi [#1], Dr.D.L.Venkatesh Babu [#2], Dr. R.Venkatasubramani [#3]
[# 1] Associate Professor,
Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore, India – 641 049
[# 2] Professor and Head,
Department of Civil Engineering, JSS Academy of Technology, Bangalore, India – 560 060
[# 3] Professor and Head,
Department of Civil Engineering, Sri Krishna College of Technology, Coimbatore, India – 641 042
[1] ramadharans@gmail.com
[2] vbkcm@rediffmail.com
[3] rvs_vlb@yahoo.com

Abstract - Fibers have been used to reinforce materials that are weaker in tension than in compression. Hybrid fiber reinforced concrete (HFRC) is the one in which more than one or two types of fibers are used as secondary reinforcement. By providing fibres in the critical zones, i.e., joints of the frames, it is possible to improve the performance of the frames against lateral loading. Hence an attempt is made to determine the behaviour of the hybrid fiber reinforced concrete bare frames against lateral cyclic loading. The fibers used here are polyolefin and steel fibers. Various tests were done on concrete cubes, cylinders and prisms with different dosage of fibers to determine the mechanical properties of HFRC and the test results are compared with control specimens. The hybrid fibres were used in the joints of the frame specimen. The percentage of fibers used is 0.75%, 1.5% & 2%. The cyclic load behavior of hybrid fiber reinforced concrete bare frames was experimentally investigated. The ultimate strength, Deflection, ductility factor and energy dissipation of HFRC bare frames with varying percentage hybrid fibres were compared with control bare frame specimen.

Keyword- Polyolefin fibre, Steel fibre, HFRC frames, Lateral cyclic load, Ductility

I. INTRODUCTION

The use of fibres in concrete is not a new concept. Asbestos fibres, straw, horsehair was 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 fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lends varying properties to the concrete. 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. It is found from existing review of literatures it is found that in the use of steel-synthetic fibre combination, Steel-Polypropylene blend is more frequent and Steel-Polyolefin blend is only few. Hence an attempt is made to study the behaviour of reinforced concrete infill frames with Steel - Polyolefin (70% -30%) fibres in its joints.

The forces in the columns, beams and shear walls (if any) under the action of seismic loads specified in the code, may be obtained by considering the *bare frame* building. However, beams and columns in the open ground storey are required to be designed for 2.5 times the forces obtained from this bare frame analysis.

In RC buildings, the portions at intersections of beams and column are called beam-column joints. Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are applied during earthquakes, joints are severely damaged. Repairing damaged joints is difficult, and so damage must be avoided by enhancing the strength of joints. Thus, beam-column joints must be designed to resist earthquake effects. It is planned to provide hybrid fibres in the joints of the frame specimen in various percentages (0.75%, 1.5% and 2.0%) and to verify the seismic performance compared to control frame.

II. MATERIALS USED

The details of materials used in this research work are as given below.

A. Cement

Ordinary Portland Cement of grade 33 and locally available fine aggregate and coarse aggregate was used. The physical properties of cement, fine aggregate and coarse aggregate are presented in Table I.

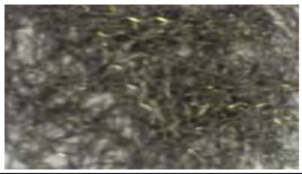
TABLE I
Physical properties of cement, fine aggregate and coarse aggregate

Property	Cement	Fine Aggregate	Coarse Aggregate
Fineness	1%	4.72	8.21
Consistency	30%	-	-
Initial setting time	80 mins	-	-
Specific gravity	3.18	2.62	2.78

B. Steel fibres

The steel fibers used here were of undulated/wavy type. These fibres are used to improve structural strength and to reduce crack widths. The steel fibres increases the flexural strength, improve ductility, fracture toughness and impact resistance. The properties of fibres used in this research work are shown in Table II.

TABLE III
Physical properties of fibres used

S.no	Fibre properties	Polyolefin fiber	Steel fiber
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 (Kgm^{-3})	920	7850
7	Young's Modulus	6 GPa	210 Gpa
8	Tensile Strength	550 Mpa	532 Mpa

C. Polyolefin fibres

The polyolefin fibres straight in shape were used for this research work. Polyolefin fibers are those fibers produced from polymers formed by chain growth polymerization of olefins (alkenes) and which contain greater than 85% polymerized ethylene, propylene, or other olefin units.

D. Superplasticizer

To improve the workability of the concrete mixture with two types of fibre blends, a superplasticizer Conplast SP 330 was used with a dosage of 0.8% by weight of cement.

III. TESTS ON COMPANION SPECIMENS

A. Proportioning of Concrete

The concrete mix of grade M25 with steel fibres and polyolefin fibres with different dosages (0.7% to 2%) was proportioned as per IS 10262-2009[1]. The mix proportion arrived for M25 grade concrete is shown in Table III.

TABLE IIIII
Mix proportion for M25 concrete

Cement Kg/m^3	Fine aggregate Kg/m^3	Coarse aggregate Kg/m^3	Water content Kg/m^3	Superplasticizer
425.75	649.498	1174.42	191.58	0.8% by weight of cement

B. Tests on companion specimens

The Compressive strength, Split tensile strength and Flexural strength of concrete are determined by casting cubes of size 150 x 150 x 150 mm, cylinders of size 300 x 150 mm and prisms of size 500 mm x 100 mm x 100 mm and allowed for 28 days curing and the test results were obtained for various percentage of fibers steel (70%) and polyolefin (30%) fibers. The results of Compressive strength, Split tensile strength and Flexural strength of control concrete and HFRC of various fibre dosages are plotted in Figure 1.

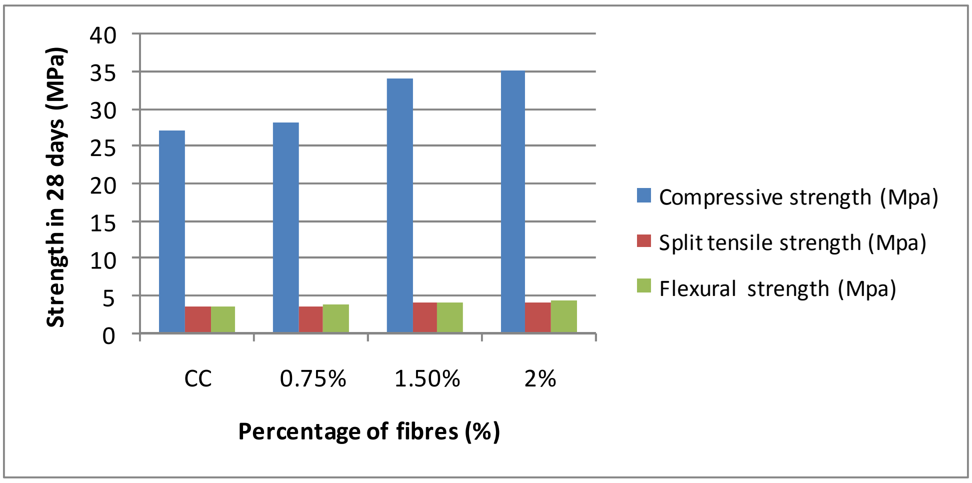


Fig. 1. Results of 28 days strength on companion specimens

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

IV. EXPERIMENTAL INVESTIGATION

A. Dimensions of Frame models and reinforcement details

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 [2]. The use of masonry infill increases the overall capacity of the system when compared to the system without masonry [3]. In this research work four different plane frame models without infills were considered. The strength of concrete used is M25 (f_{ck} = 25 N/mm^2) and the yield strength of steel is 415 N/mm^2. All the frame models were cast and tested experimentally under positive cyclic loading at the Structural Technology Centre of Kumaraguru College of Technology, Coimbatore, India. The frame specimen consists of two columns and a beam supported on a raft slab. The reinforcement of beam consists of 4 numbers of 10 mm dia bars top & bottom with a clear cover of 25 mm. The shear reinforcement includes stirrups of 8mm dia bars at 100 mm c/c spacing & the column reinforcement consists of 4 numbers of 12 mm dia bars. The raft slab reinforcement consists of 10 mm dia with 100mm c/c in both directions in two layers. According to IS 13920:1993, clause 6.3.5, flexural yielding may occur under the effect of earthquake forces over a length equal to 2d on either side of a beam section, where d is the effective depth of member[4]. The performance may be improved by utilizing transverse steel coupled with fibre reinforced concrete [5].Hence the HFRC bare frame models were cast with hybrid fibres of varying percentages (0%, .75%, 1.5% and 2%) in the joint zones of the frames i.e., at a distance of 2d for beams and 1.5d for columns, where d is the lateral dimension of the beam/column.

B. Loading scheme of frame specimens

The details of bare frame model specimen with HFRC zones and the complete test set up adopted for the frame model is as shown in Figure 2. 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 load (F) and the respective loads

(P – Axial load on columns: 30 kN and w – Uniformly distributed load on beam: 25 kN/m) as shown in Figure 2.

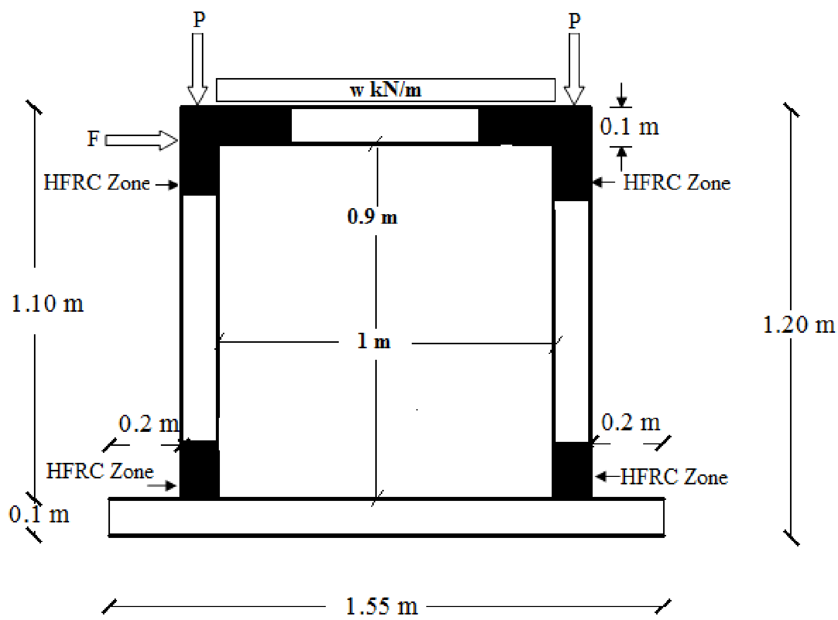
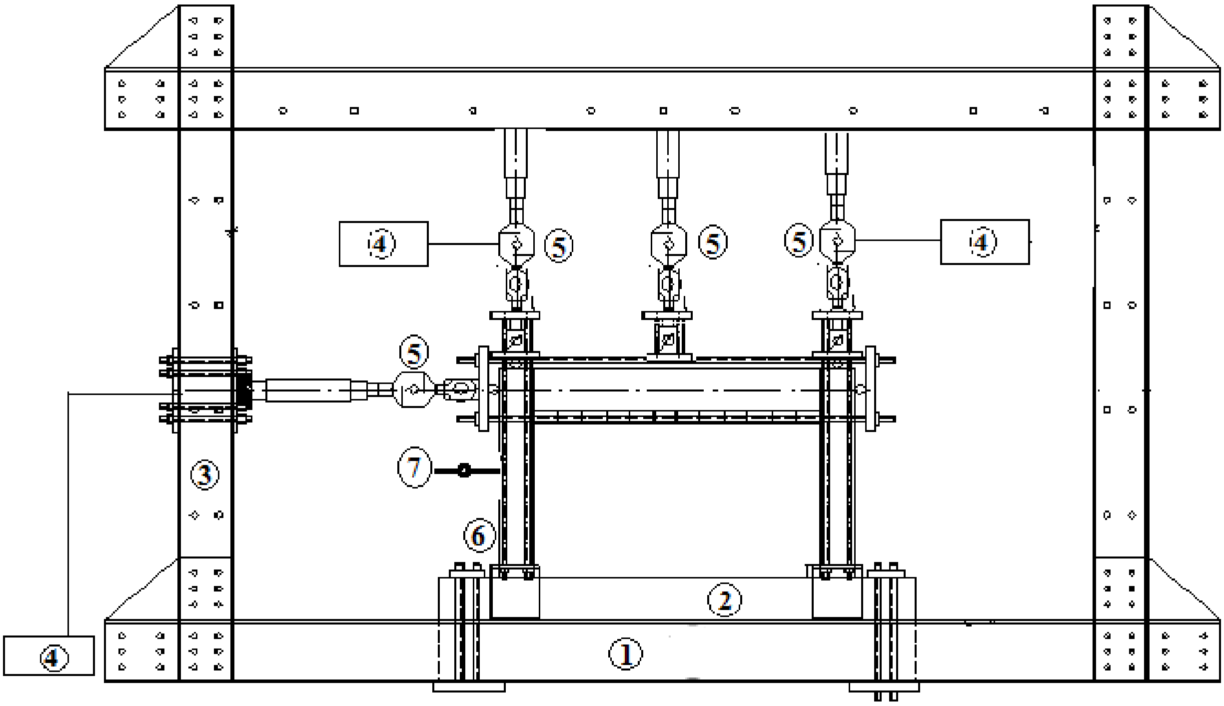


Fig. 2. Details of Bare frame specimen with HFRC zones

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 was repeatable. The frame was subjected to equivalent static positive lateral cyclic 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 cm, 50 cm & 95 cm from the top of the raft slab before testing to measure the deflection of the outermost column. The frames to be tested were placed in the loading frame of capacity 100 Tons. The reaction frame rigidly fixed to the test floor is used for loading arrangements.

Lateral cyclic loading was applied at the beam-column joint through a hand operated loading jack in which a load cell was fixed. A push pull jack of capacity 100 Ton was used to apply the lateral cyclic load. The applied load was measured using Linear Variable Differential Transformer (LVDT) connected from load cell to a 16 channel data acquisition system.

An axial load of 30 kN was applied to the columns of the frame individually using two loading jacks with load cells. Two numbers of single acting load cells of capacity 100 Tons were used for loading. The applied load was measured using pressure gauges. The beam was loaded with uniformly distributed load of 25 kN/m using a proving ring of capacity 5 tons. The loading arrangement for testing the frames is shown in Figure 3.



1. Test Floor
2. Base slab
3. Reaction Frame
4. Hydraulic oil pump unit
5. Load jack
6. Frame for test
7. Deflectometer

Fig. 3 Schematic view of Test Set-up of bare frame

C. Results and discussions

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 Figure 4.

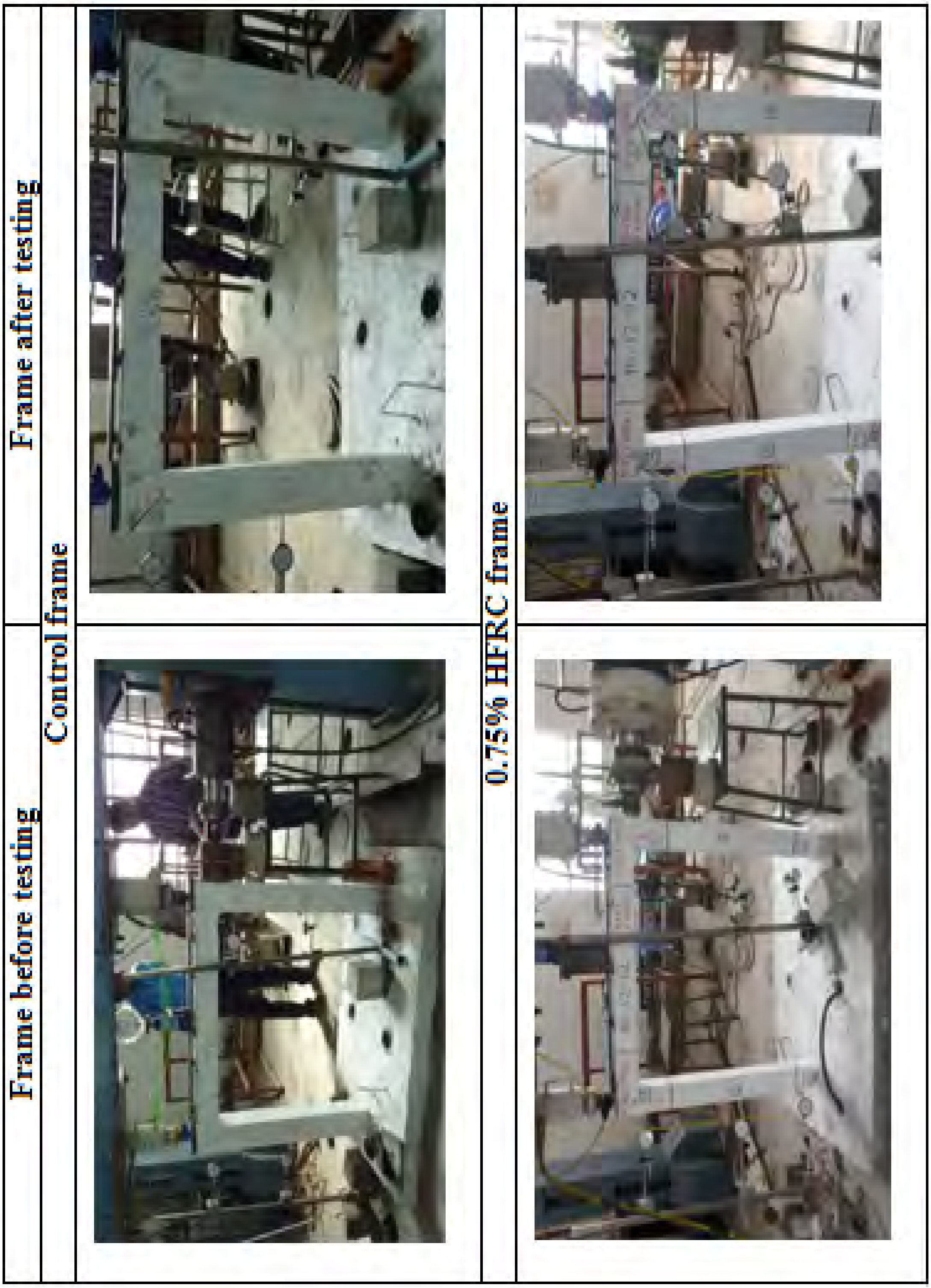


Fig 4(a) Control frame and 0.75% HFRC frame – Before and after testing

	Frame before testing	Frame after testing
1.5% HFRC frame		
2.0% HFRC frame		

Fig 4(b) 1.5% HFRC frame and 02.0% HFRC frame – Before and after testing

The experimental results are presented in Table IV and plotted in Figure 5.

TABLE IV
Experimental results on Frame specimens with and without hybrid fibres

Frame ID	% of Hybrid Fibre Reinforcement in Bare frames (%)	Experimental Results	
		Ultimate Load (kN)	Deflection at Ultimate Load (mm)
CC	0	5.67	14.47
0.75HFRC	0.75	9.67	26.98
1.5HFRC	1.5	13.73	31.8
2HFRC	2.0	16.67	43.38

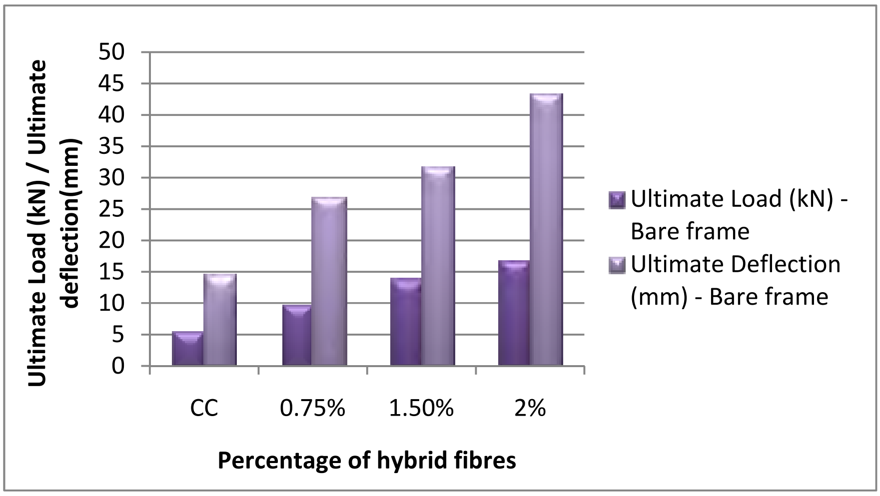


Fig. 5. Results of Bare frame specimens after testing

The capacity of the frame specimens was increased due to the presence of brick infills in the frame specimens [6]. 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 [7] and in the interface between beam-brick infill. 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 plot between Load and Cycle number was obtained for each frame. 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.

The plot between Load – Cycle number behaviour for 2.0% HFRC bareframe specimen is presented in Figure 6.

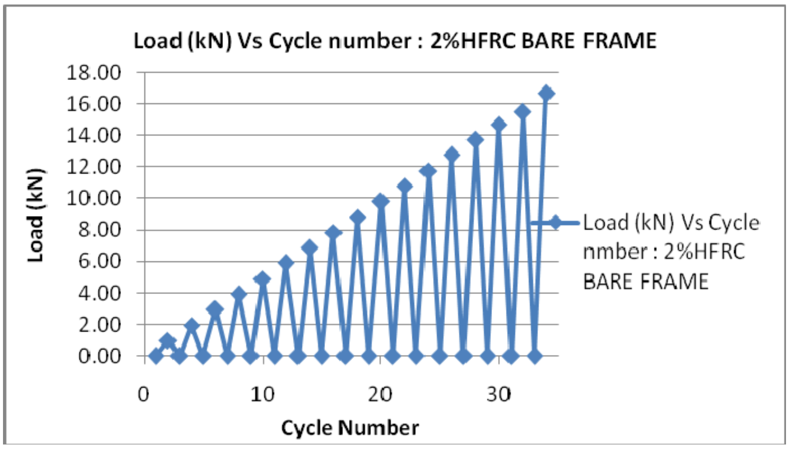


Fig. 6. Load – Cycle number behaviour of 2.0% HFRC bare frame

V. CONCLUSION

The experimental investigation on the structural behaviour of the bare frame specimens with and without hybrid fibres subjected to positive cyclic loading was obtained and compared. Based on the experimental results of this research work, the following conclusions were drawn.

- The load carrying capacity of the RC bare frame with hybrid fibre strengthening is found to be more than that of infilled RC frames without fibre reinforcement.
- The percentage of fibres used was 0%, 0.75%, 1.5% and 2% and the results were found to be increasing with an increase in fibre dosage.
- The employment of hybrid fibres in the plastic hinge zones of the bare frames were found to perform well when compared to control frames.
- The load carrying capacity for bare frames increased with the increase in percentage of hybrid fibres and it was 65.98% for 2% HFRC bare frame and compared to control frame [9].
- The deflection capacity of the frames was also increased due to the presence of hybrid fibres and it was 66.64% for 2% HFRC bare frame than the control frame.
- The number of cycles increases with an increase in hybrid fibre percentage.

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