CHAPTER 3
DETAILS OF SPECIMEN, TEST SETUP
AND TESTING PROCEDURE

3.1 GENERAL

Reinforced Concrete is the widely used construction material. The strength of concrete can be improved by adding fibres of different materials and volume. The most widely used stiff fibre is steel. Low volume fractions of fibres (less than 1%) are used to reduce shrinkage cracking. Moderate volume fractions (between 1% and 2%) increase flexural strength, fracture toughness and impact resistance. High volume fractions (greater than 2%) lead to strain hardening of the composites. The shape and length of the fibres also play a role in the effectiveness of fibres in improving the properties of the concrete. Few works have been done on hybrid fibre composites for volume fractions between 0.5% to 2%. Since the Steel-Polyolefin combination is recently been developing, it is aimed to use this hybrid fibre combination ranging between 0 to 2% in concrete elements.

This chapter presents the details of materials used, concrete mix design, properties of fibres used, specimens used, details of formwork, reinforcement details of specimens, test setup and testing procedure for beams, slabs and frames.
3.2 MATERIALS USED

Ordinary Portland Cement of grade 43 conforming to IS : 269-1976 had been used for concreting. Locally available graded crushed hard blue metal and uniformly graded sand available was used. For concreting and curing the specimens, potable water available in the campus had been used. To improve the workability, the Superplasticizer CONPLAST SP 330 was used.

The Steel fibres used in this research work are fibres of undulated/wavy type, purchased from Stewols India (P) Ltd, Nagpur, India. 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 Polyolefin fibres straight in shape obtained from Barchip Company 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. The base polyolefin is highly resistant to the majority of aggressive agents and will never oxidize when exposed to the conditions which cause steel to rust.

The steel and polyolefin fibres used in this research work are shown in Figure 3.1 and Figure 3.2. The properties of fibres used in this research work are listed in Table 3.1.
Table 3.1 Properties of fibres used in this research work

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Fibre properties</th>
<th>Steel fiber</th>
<th>Polyolefin fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surface texture</td>
<td>Undulated</td>
<td>Continuously Embossed</td>
</tr>
<tr>
<td>2</td>
<td>Shape</td>
<td>Wavy</td>
<td>Straight</td>
</tr>
<tr>
<td>3</td>
<td>Length (mm)</td>
<td>36</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>Size/Diameter (mm)</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>Aspect Ratio</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>Density (Kgm(^{-3}))</td>
<td>7850</td>
<td>920</td>
</tr>
<tr>
<td>7</td>
<td>Young’s Modulus (GPa)</td>
<td>210</td>
<td>8.2</td>
</tr>
<tr>
<td>8</td>
<td>Tensile Strength(MPa)</td>
<td>532</td>
<td>550</td>
</tr>
<tr>
<td>9</td>
<td>Melting point (°C)</td>
<td>1500</td>
<td>150-165</td>
</tr>
<tr>
<td>10</td>
<td>Specific Gravity</td>
<td>7.8</td>
<td>0.90-0.92</td>
</tr>
</tbody>
</table>

Figure 3.1 Steel fibres

Figure 3.2 Polyolefin fibres
3.3 CONCRETE MIX DESIGN

The mix design for M25 grade concrete was done as per IS 10262: 2009 and IS 456: 2000. The workability of the concrete mixture with two types of fibre blends was improved using Superplasticizer CONPLAST SP 330. The procedure for concrete mix design for M25 grade concrete is detailed in Appendix 1. The quantity and proportion of materials obtained was used for all specimens and is listed in Table 3.2. Table 3.3 presents the volume of fibres used and the percentage of hybrid fibres used.

Table 3.2 Mix proportion for M25 grade concrete

<table>
<thead>
<tr>
<th>Cement Kg/m³</th>
<th>Fine aggregate Kg/m³</th>
<th>Coarse aggregate Kg/m³</th>
<th>Water content Kg/m³</th>
<th>Superplasticizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>425.75</td>
<td>649.498</td>
<td>1174.42</td>
<td>191.58</td>
<td>0.8% by weight of cement</td>
</tr>
<tr>
<td>1</td>
<td>1.52</td>
<td>2.75</td>
<td>0.45</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3 Percentage of fibres used in concrete

<table>
<thead>
<tr>
<th>Percentage of fibres (%)</th>
<th>Steel fibre (70%)</th>
<th>Polyolefin fibre (30%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.75</td>
<td>0.525</td>
<td>0.225</td>
</tr>
<tr>
<td>1.50</td>
<td>1.05</td>
<td>0.45</td>
</tr>
<tr>
<td>2.00</td>
<td>1.4</td>
<td>0.6</td>
</tr>
</tbody>
</table>
3.4 TESTS ON MECHANICAL PROPERTIES OF HYBRID FIBRE REINFORCED CONCRETE

3.4.1 Details of the Specimens

The compressive strength of concrete was determined by casting cubes of size 150 mm x 150 mm x 150 mm, The split tensile strength and modulus of elasticity of concrete was determined by casting cylinders of size 300 mm height x 150 mm diameter. The flexural strength of concrete was determined by casting Prisms of size 500 mm x 100 mm x 100 mm.

3.4.2 Concreting and Curing

The cube, cylinder and prism specimens were cast using concrete of control mix and also with varying percentages of hybrid fibres (0.75%, 1.5% and 2.0%). The specimens were demoulded 24 hours after casting and immersed in potable water available in the campus for curing to determine the 7th day and 28th day strengths respectively. The tests are done as per IS: 516-1959.

3.4.3 Slump Test

The fresh characteristics of concrete mixes were determined by conducting slump test based on IS: 516-1959. Slump test was done for the control mix and hybrid fibre reinforced concrete (HFRC) mixes with hybrid fibre dosages of 0.75%, 1.5% and 2.0% of concrete grade M25. The specimens were designated with alpha numeric values. The alphabet CC refers to the control mix. The terms 0.75H, 1.5H and 2H refers to the hybrid fibre reinforced concrete mixes with percentages 0.75, 1.50 and 2.0 respectively. The test results are shown in Table 3.4. Figure 3.3 shows the fresh concrete with hybrid fibres and Figure 3.4 shows the slump obtained
during the test. The slump values obtained are shown graphically in Figure 3.5.

![Figure 3.3 Fresh concrete with fibres](image1)
![Figure 3.4 Slump test](image2)

### Table 3.4 Slump test results

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Type of mix</th>
<th>Slump without Superplasticizer (mm)</th>
<th>Slump with Superplasticizer (mm)</th>
<th>Type of slump</th>
<th>Degree of workability as per IS:456-2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CC</td>
<td>100</td>
<td>-</td>
<td>True slump</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>0.75H</td>
<td>79</td>
<td>110</td>
<td>True slump</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>1.5H</td>
<td>72</td>
<td>102</td>
<td>True slump</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>2H</td>
<td>65</td>
<td>100</td>
<td>True slump</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Figure 3.5  Slump test results for fresh and HFRC concrete

The slump for HFRC mixes showed a significant decrease in workability. An average reduction of 29 mm in slump value was observed in HFRC mixes without the addition of Superplasticizer. A reduction in slump was observed due to the addition of steel-polyolefin fibres in to the concrete in various percentages. The addition of Superplasticizer CONPLAST SP 330 at a dosage of 0.8% by weight of cement increased the workability of all the HFRC mixes. Also the comparison of the measured slump values shows a decrease with the increase in fibre percentages.

3.4.4  Compressive Strength

The compressive strength of concrete cubes (f_{ck}) was evaluated after 7 days and 28 days curing. An average of 3 cubes for each test were used to estimate the compressive strength of control mix and mixes with hybrid fibre dosages of 0.75%, 1.5% and 2.0% of concrete grade M25. The specimens were designated with alpha numeric values. The alphabet CC refers to the control mix. The terms 0.75C, 1.5C and 2C refers to the hybrid
fibre reinforced concrete (HFRC) cube specimens with percentages 0.75, 1.50 and 2.0 respectively. The cube specimen during testing and after testing is shown in Figure 3.6 and Figure 3.7 respectively.

![Figure 3.6 Cube specimen during testing](image1)

![Figure 3.7 Cube specimen after testing](image2)

The results of compressive strength for various hybrid fibre mixes and control mix are presented in Table 3.5 and the comparison is shown in Figure 3.8. It was found that the compressive strength increased with an increase in the volume of fibres added. During testing, a good bonding of concrete and fibres was observed. Since the fibres were randomly oriented, the propagation of cracks were prevented thus causing an increase in load carrying capacity of the cubes. A comparison of compressive strength of cube specimens and hybrid fibre content is shown in Figure 3.9. It was found that the compressive strength increases with the increase in percentage of fibres. The specimen with 2.0% hybrid fibres showed maximum compressive strength of 35.3 N/mm² which is 30.74% more than that of control specimen.
Table 3.5  Compressive strength of cube specimens

<table>
<thead>
<tr>
<th>Cube specification</th>
<th>Compressive strength at 7 days (N/mm²)</th>
<th>Compressive strength at 28 days (N/mm²)</th>
<th>Percentage improvement of compressive strength (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>16.7</td>
<td>27.0</td>
<td>0.00</td>
</tr>
<tr>
<td>0.75C</td>
<td>18.9</td>
<td>28.1</td>
<td>4.07</td>
</tr>
<tr>
<td>1.5C</td>
<td>25.2</td>
<td>34.2</td>
<td>26.67</td>
</tr>
<tr>
<td>2C</td>
<td>27.4</td>
<td>35.3</td>
<td>30.74</td>
</tr>
</tbody>
</table>

Figure 3.8  Compressive strength of cube specimens
3.4.5 Split Tensile Strength

The cylindrical specimen of size 150 mm diameter and 300 mm length was placed in the compression testing machine of capacity 200 kN. The load was applied until failure of the specimens. The test setup for cylinder specimen and after testing is shown in Figures 3.10 and 3.11.

Figure 3.9 Compressive strength vs. fibre content

Figure 3.10 Cylinder during testing Figure 3.11 Cylinder after testing
The alphabet CCP refers to the control mix. The terms 0.75SP, 1.5S and 2SP refers to the hybrid fibre reinforced concrete (HFRC) cylinder specimens with percentages 0.75, 1.50 and 2.0 respectively.

**Table 3.6  Split tensile strength of cylinder specimens**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Split tensile strength at 28 days (N/mm²)</th>
<th>Percentage improvement of split tensile strength (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCP</td>
<td>2.63</td>
<td>-</td>
</tr>
<tr>
<td>0.75SP</td>
<td>2.84</td>
<td>7.98</td>
</tr>
<tr>
<td>1.5SP</td>
<td>3.47</td>
<td>31.94</td>
</tr>
<tr>
<td>2.0SP</td>
<td>4.0</td>
<td>52.10</td>
</tr>
</tbody>
</table>

**Figure 3.12  Split tensile strength of cylinder specimens**
Figure 3.13 Split tensile strength vs. fibre content

The results of split tensile strength (f_{sp}) for various hybrid fibre mixes and control mix are presented in Table 3.6 and the comparison is shown in Figure 3.12. The alphabet CC refers to the control mix. The terms 0.75S, 1.5S and 2S refers to the hybrid fibre reinforced concrete (HFRC) cylinder specimens with percentages 0.75, 1.50 and 2.0 respectively. During testing, the cylinder was compressed and the concrete was held together by the fibres. Hence the failure of the specimen was not sudden. In this test, an increase in strength was observed for HFRC cylinders and maximum split tensile strength of 3.99 N/mm² for 2.0% HFRC cylinder which is 52.10% more than cylinder without fibres was obtained. A comparison of split tensile strength of cylinder specimens and hybrid fibre content is shown in Figure 3.13.
3.4.6 Flexural Strength

The flexural strength ($f_b$) of concrete prisms was evaluated after 7 days and 28 days curing. An average of 3 prisms for each test were used to estimate the flexural strength of control mix, 0.75% HFRC mix, 1.5% HFRC mix and 2% HFRC mix. The prism specimens were designated with alpha numeric values.

The alphabet CC refers to the control prism. The terms 0.75P, 1.5P, 2P refer to the hybrid fibre reinforced concrete (HFRC) prism specimens with percentages 0.75, 1.50 and 2.0 respectively. The prism test setup and after testing are shown in Figures 3.14 and 3.15. The results of flexural strength for various hybrid fibre mixes and control mix are presented in Table 3.7 and the comparison is shown in Figure 3.16. A comparison of flexural strength of prism specimens and hybrid fibre content is shown in Figure 3.17.

![Figure 3.14 Test setup for prism](image1)

![Figure 3.15 Prism after failure](image2)
Table 3.7  Flexural strength of prism specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Flexural strength at 7 days (N/mm²)</th>
<th>Flexural strength at 28 days (N/mm²)</th>
<th>Percentage improvement of split tensile strength (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>1.24</td>
<td>3.60</td>
<td>0.00</td>
</tr>
<tr>
<td>0.75 P</td>
<td>1.27</td>
<td>3.68</td>
<td>2.22</td>
</tr>
<tr>
<td>1.5 P</td>
<td>1.70</td>
<td>4.11</td>
<td>14.17</td>
</tr>
<tr>
<td>2 P</td>
<td>1.95</td>
<td>4.50</td>
<td>25.00</td>
</tr>
</tbody>
</table>

Figure 3.16  Flexural strength of prism specimens
3.4.7 Modulus of Elasticity

The modulus of elasticity of concrete \( (E_c) \) was evaluated after 28 days curing of cylinder specimens. The cylinders were compressed in a Compression Testing Machine of capacity 2000 kN and the test was done as per IS: 516-1959. The cylinder was fixed to a compressometer along with a dial gauge at a specified gauge length. The test setup is shown in Figure 3.18.
Figure 3.18  Test setup to determine modulus of elasticity of concrete

An average of 3 cylinders for each test were used to estimate the modulus of elasticity of control mix, mixes with hybrid fibre dosages of 0.75%, 1.5% and 2.0% of concrete grade M25. The prism specimens were designated with alpha numeric values. The alphabet CC refers to the control specimen. The terms 0.75E, 1.5E and 2E refers to the hybrid fibre reinforced concrete (HFRC) cylinder specimens with percentages 0.75, 1.50 and 2.0 respectively. The stress-strain curves for the above specimens were plotted and the modulus of elasticity which is referred as secant modulus was obtained. The modulus of elasticity results for control mix and HFRC mix is shown in Table 3.8. The graphical representation of the modulus of elasticity is shown in Figure 3.19.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Type of mix</th>
<th>$E_c$ (N/mm$^2$)</th>
<th>% increase compared to control mix (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CC</td>
<td>17200</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.75 E</td>
<td>21200</td>
<td>23.25</td>
</tr>
<tr>
<td>3</td>
<td>1.5 E</td>
<td>23900</td>
<td>38.95</td>
</tr>
<tr>
<td>4</td>
<td>2.0 E</td>
<td>30900</td>
<td>79.65</td>
</tr>
</tbody>
</table>
Figure 3.19  Modulus of elasticity for control and HFRC mixes

3.4.8  Discussions

- The compressive strength of HFRC mix is higher when compared to control mix

- The compressive strength of the concrete increases with increase in fibre percentage. Enhancement of compressive strength ranges from 4.07% to 30.74% for HFRC mix

- The maximum Compressive strength is found to be 35.3 MPa for 2% HFRC mix which is 30.74% higher than the control mix

- The split tensile strength increases with increase in hybrid fibre percentage
• The maximum split tensile strength of 3.99 MPa is observed for 2% HFRC mix compared to control mix

• The enhancement in split tensile strength ranges from 7.98% to 52.1% for HFRC mixes

• The flexural strength increases with increase in hybrid fibre percentage

• The maximum increase in flexural strength was found to be 25% for 2% HFRC mix when compared to control mix

• The enhancement in flexural strength ranges from 2.22% to 25% for HFRC mixes

• The maximum value of modulus of elasticity of 30900 MPa is observed for 2% HFRC specimens

3.5 TEST ON RC AND HFRC BEAMS

3.5.1 Description of Formwork

For casting the beam specimens, wooden mould of size 2.1 m x 0.15 m x 0.25 m made of quality timber was made as shown in Figure 3.20.

Figure 3.20 Wooden moulds for casting beam specimen
3.5.2 Dimensions and Reinforcement Details of Beam

The beam specimen was made of size 2.1 m x 0.15 m x 0.25 m. High Yield Strength Deformed bars (HYSD) of 10 mm diameter were used as longitudinal reinforcements. The detailed design of beam is given in Appendix 2. The lateral reinforcement was provided using 8 mm diameter stirrups at 100 mm c/c spacing. A clear cover of 25 mm was provided at the bottom. The reinforcement details of the beam along the cross section and longitudinal section is shown in Figure 3.21.

Totally four number of beam specimens were cast out of which one is the control specimen and the other three beam specimens with hybrid fibre percentages equal to 0.75%, 1.5% and 2%. The steel fibres and polyolefin fibres were used conforming to the properties as stated earlier in Table 3.1.

![Figure 3.21 Longitudinal and cross section details of beam](image-url)
3.5.3 Casting and Curing of beams

The beams were cast in the Structural Technology Centre of Kumaraguru College of Technology, Coimbatore. An electrically operated concrete mixer was used for mixing of concrete. Concreting of the beams was done immediately after mixing and needle vibrator of 25 mm was used for concrete compaction. After 24 hours, the side planks of the mould were dismantled and the beam specimens were cured for 28 days by sprinkling water on the specimens covered with gunny bags. The casting and curing of beam specimens is shown in Figure 3.22(a) and Figure 3.22(b) respectively.

![Concreting of beam specimen](image1)

**Figure 3.22(a)** Concreting of beam specimen

![Beam specimens under curing](image2)

**Figure 3.22(b)** Beam specimens under curing
3.5.4 Beam Test Setup

The beams were simply supported (one end hinged and other end with Rollers) with an effective span of 1.8 m and subjected to a third point bending load as shown in Figure 3.23, with a distance of 0.6 m between the loads.

![Figure 3.23 Test setup for beam](image)

3.5.5 Testing Procedure

The beams to be tested were placed in the loading frame of capacity 100 tons under third point loading and the loading arrangement is shown in Figure 3.24. The end condition of the beam was kept as simply supported. All the beam specimens were white washed to facilitate marking of cracks. The beam was divided into number of grids before placing in the loading frame for the observation of crack pattern. The load cell was placed in the loading jack at the centre of the beam from which load imparted to the beam can be observed. A hand operated oil pump was used for load application. The load was applied at intervals of 5 kN and continued until collapse of the beam specimen. During the test, the load, deflections and the failure mode were measured at mid-span.
Figure 3.24  Loading arrangement for beam

In order to ensure proper response of data recording devices, and to check effectiveness of the instruments, the beams were loaded with small loads and unloaded. The beams were subjected to static loading. The deflections were measured at each increment of load. The cracks in the beams were also observed and marked on the beams simultaneously. Also the crack propagation and failure pattern of the beams were recorded.

For measuring the deflections under loading points, the deflectometers were placed. The load cell was connected to a 16 channel data logger, where the results can be viewed.

3.6  TEST ON RC AND HFRC SLABS

3.6.1  Description of Formwork

For casting the slab specimens, wooden mould of size 1 m x 0.3 m x 0.07 m was made of quality timber as shown in Figure 3.25.
3.6.2 Dimensions and Reinforcement Details of Slab

The one-way slab specimens were made of size 1 m x 0.3 m x 0.07 m. The main reinforcement consists of two numbers of 10 mm diameter bars and the distributive reinforcement was provided with 8 mm diameter bars at 135 mm c/c spacing. A clear cover of 20 mm was provided. Reinforcement of High Yield Strength Deformed bars (HYS) of 10 mm and 8 mm diameter had been used for slab specimens. The dimensions and reinforcement details of the slab are shown in Figure 3.26(a) and Figure 3.26(b).

Figure 3.25 Wooden mould for casting slab specimen

Figure 3.26(a) Dimensions of the slab specimen
Figure 3.26(b) Reinforcement details of slab

Totally four number of slab specimens were cast out of which one is the control specimen and the other three slab specimens with hybrid fibre percentages equal to 0.75%, 1.5% and 2%. The steel fibres and polyolefin fibres were used conforming to the properties as stated earlier in Table 3.1.

3.6.3 Concreting and Curing of slabs

An electrically operated concrete mixer was used for mixing of concrete. Concreting of the slabs was done immediately after mixing. After 24 hours, the side planks of the mould were dismantled and the slab specimens were cured for 28 days by sprinkling water on the specimens covered with gunny bags as shown in Figures 3.27(a) and 3.27(b).

Figure 3.27(a) Cast slab specimen  Figure 3.27(b) Slab under curing
3.6.4 Slab Test Setup

The slabs to be tested were placed in the loading frame of capacity 100 tons under third point loading and the test setup is shown in Figure 3.28.

![Test setup for slab](image)

**Figure 3.28 Test setup for slab**

The end condition of the slab was kept as simply supported. The slab was white washed and divided into number of grids before placing in the loading frame for the observation of crack pattern. The load cell was placed in the loading jack at the centre of the slab from which load imparted to the slab can be observed.

For finding the deflections under the two point loading, the deflectometers were placed one at the centre and one near support of the slab to measure the middle and support-deflection. The load cell was connected to a 16 channel data logger, where the results can be viewed.

3.6.5 Testing Procedure

The slabs to be tested were placed in the loading frame of capacity 100 tons under third point loading and the loading arrangement is
shown in Figure 3.29. The end condition of the slab was kept as simply supported. A hand operated oil pump was used for load application. During the test, the load, deflections and the crack pattern were observed at mid-span using transducers and dial gauges.

![Loading arrangement for slab](image)

**Figure 3.29  Loading arrangement for slab**

In order to ensure proper response of data recording devices, and to check effectiveness of the instruments, the slabs were loaded with small loads and unloaded. The slabs were subjected to static loading. The deflections were measured at each increment at each increment of load. The cracks in the slabs were also observed and marked on them simultaneously. Also the crack propagation and failure pattern of the slabs were recorded.

### 3.7 TEST SETUP FOR TWO-DIMENSIONAL RC AND HFRC FRAMES WITH INFILLS

#### 3.7.1 Description of formwork

For casting the base slab, columns and beam specimens, wooden mould made of quality timber was made as shown in Figure 3.30. The wooden mould for base slab of size 1.5 m x 1 m x 0.1 m, for column
of size 1 m x 0.1 m x 0.1 m and beam mould of size 1.1 m x 0.1 m x 0.1 m were fabricated. The inner surfaces of the moulds were coated thinly with mould oil before casting.

3.7.2 Dimensions and Reinforcement Details of Infilled Frame Model

The frame model is a simple portal frame structure. It consists of two numbers of columns of size 1 m x 0.1 m x 0.1 m and a beam of size 1.1 m x 0.1 m x 0.1 m over the columns. The frame was fixed at both ends to a raft slab of size 1.5 m x 1 m x 0.1 m ensuring fixity. The reinforcement of beam consists of 4 numbers of 10 mm dia. HYSD bars at top & bottom with a clear cover of 25 mm. The shear reinforcement includes stirrups of 8 mm dia. bars at 100 mm c/c spacing. The main reinforcement of column consists of 4 numbers of 12 mm dia. bars and lateral reinforcement with 8 mm dia. bars at 100 mm c/c spacing. The raft slab reinforcement consists of 10 mm dia. with 100 mm c/c in both directions in two layers. Totally four numbers of infilled frame specimens were cast out of which one is the control specimen and the other three frame specimens with hybrid fibre percentages equal to 0.75%, 1.5% and 2%. The steel fibres and polyolefin fibres were used conforming to the properties as stated earlier in Table 3.1.

Figure 3.30 Moulds used for casting frame
Figure 3.31 Reinforcement details of infill frame specimen
The reinforcement details of the frame are shown in Figure 3.31. The dimensions of the model frame adopted are shown in Figure 3.32. The details of modeling of frame specimens are given in Appendix 3.

### 3.7.3 Casting and curing of frames with infills

The infilled frame specimens were cast in the Structural Technology Centre of Kumaraguru College of Technology, Coimbatore. An electrically operated concrete mixer was used for mixing concrete. M25 grade concrete was adopted for casting of raft slab as well as beam and columns. The RC model frames were cast in the following order: The base slab was concreted first and after 24 hours, the side planks of the mould were dismantled. After three days, the columns and beams were cast to complete the frames and after 21 days the brick work for the infill frames was done. The base slab was cast with holes of size 3 inches at every 0.4 m span for bolting the slab with the test floor. The holes were made using 3 inch PVC pipes to get smooth surface. Also lifting hooks
were provided in diagonally opposite directions over the base slab to enable lifting of the frame specimens during testing.

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. Hence the HFRC frame models were cast with hybrid fibres of varying percentages (0.75%, 1.5% and 2%) in the plastic hinge zones of the frames i.e., at a distance of 2d (0.2 m) for beams and 1.5d (0.15 m) for columns from the beam-column joints as shown in Figure 3.33.

![Figure 3.33 Infill frame with HFRC zones](image)

The plastic hinge zones of the frames were cast using concrete enhanced with hybrid fibres and the other regions were cast with control mix simultaneously. The percentage of hybrid fibres used was 0.75%, 1.5% and 2%. Care was taken to mix the control concrete and concrete with hybrid fibres separately and the dimensions of the plastic hinge zones were
marked on the moulds. Concreting of the frames was done immediately after mixing and needle vibrator of 25 mm was used for concrete compaction. The concrete was filled in the column and beam moulds with hybrid fibre combination and control mix alternatively.

The concreting of base slab of infill frame specimen is shown in Figure 3.34 and the cast frame with infill under curing is shown in Figure 3.35.

Figure 3.34  Casting of infill frame specimen

Figure 3.35  Infill frame specimens under curing
The frames specimens were cured for 21 days and then the infill
was completed with bricks of third class standard and mortar of 1:3 was
adopted. Various properties like weight, moisture absorption and
compressive strength of the bricks were determined. Cement mortar 1:3
with a water-cement ratio of 0.45 was adopted for infilling the frame with
brick masonry. The brickwork was cured for 7 days. The infilled frames
under curing are shown in Figure 3.35. The properties of brick used for
infills are detailed in Table 3.9.

Table 3.9  Properties of brick used for infills

<table>
<thead>
<tr>
<th>Size of brick (mm)</th>
<th>220 x 105 x 105</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>3.237</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>10.00</td>
</tr>
<tr>
<td>Compressive strength (N/mm²)</td>
<td>3.485</td>
</tr>
<tr>
<td>Type of bond adopted</td>
<td>English bond</td>
</tr>
</tbody>
</table>

3.7.4  Lifting and Erection of Frames with Infills

Lifting of frame specimens was done using overhead crane of
capacity 5 tons and moved to the test floor of capacity 200 tons.
The lifting hooks provided on the base slab during casting enabled proper
lifting of the frames with cranes. The base slab of the frame specimen was
kept on the test floor ensuring proper alignment of the bolt holes in the
specimen and the test floor. The bolts were inserted in the base slab and
were tightened properly.
3.7.5 Frame Test Setup

The schematic view of the test setup adopted for the infilled frame model is shown in Figures 3.36. The frames were considered to cantilever from the base. White washing of the frame specimens was done to enable visibility of cracks and failure pattern clearly. All the frames were marked by points in the outermost column of the portal frame from which the dial gauges were placed at 25 cm, 50 cm and 95 cm from the top of the raft slab before testing.

1. Test Floor 2. Reaction Frame 3. Test Frame 4. Load jack

Figure 3.36 Schematic view of test setup of infilled frame

The testing system consisted of strong floor of capacity 200 tons, reaction frame, loading equipment, instrumentation and data acquisition system. The specimens with stiff reinforced concrete base slab were bolted to the rigid test floor. Specimens were tested under lateral cyclic loading simulating seismic action. Lateral load was applied to
specimens at the beam-column joint level, using a hydraulic push & pull jack with LVDT (Linear Variable Differential Transformers) connected to the transducer. The applied load increment was 2 kN at each cycle for all the frame specimens. The frame was loaded up to the first increment load, then unloaded and reloaded to the next increment of load. This positive cycle load pattern of loading was followed for all the frames tested. Axial load of 20 kN was applied to both the columns and a uniformly distributed load of 5 kN/m was applied to the beam.

3.7.6 Loading Arrangement

The columns and beams were of square sections of size 0.1 m. The model frame was subjected to a concentrated vertical load for each column and a uniformly distributed load on the beam. The model frames were subjected to positive lateral cyclic loads and the loading scheme is shown in Figure 3.37.

![Figure 3.37 Loading scheme of frames with infill](image)

**F** - Lateral cyclic load, **P** - Axial Load of 20 kN on the column, **w** - UDL of 5 kN/m on beam
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 tons 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 20 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 5 kN/m using a proving ring of capacity 5 tons. The testing setup for frames is shown in Figure 3.38.

Figure 3.38 Test setup for infill frame
3.7.7 Instruments for Measuring Deflection

The frames were marked by points in the outer most column of the infill frame at 25 cm, 50 cm and 95 cm from the top of the base slab where the dial gauges were placed before testing. Dial gauges of leastcount 0.01 mm were used to measure the deflections in the outermost column of the frame at marked points. The data acquisition system used for recording loads is shown in Figure 3.39.

![Data acquisition system to measure load and displacement](image)

**Figure 3.39** Data acquisition system to measure load and displacement

3.8 TEST SETUP FOR TWO-DIMENSIONAL RC AND HFRC BARE FRAMES

3.8.1 Description of formwork

The size of the bare frame specimens were adopted similar to that of the infill frame specimens. For casting the base slab specimens, columns and beam specimens, wooden mould made of quality timber was made. The wooden mould for base slab of size 1.5 m x 1 m x 0.1 m, for column of size 1 m x 0.1 m x 0.1 m and beam mould of size 1.1 m x 0.1 m
x 0.1 m were fabricated. The inner surfaces of the moulds were coated thinly with mould oil before concreting.

3.8.2 Dimensions and Reinforcement Details of Bare Frame Model

The frame model is a simple portal frame structure. It consists of two numbers of columns of size 1 m x 0.1 m x 0.1 m and a beam of size 1.1 m x 0.1 m x 0.1 m over the columns. The frame was fixed at both ends to a raft slab of size 1.5 m x 1 m x 0.1 m ensuring fixity. The reinforcement of beam consists of 4 numbers of 10 mm dia. bars at top & bottom with a clear cover of 25 mm. The shear reinforcement includes stirrups of 8 mm dia. bars at 100 mm c/c spacing & the column reinforcement consists of 4 numbers of 12 mm dia. bars as main reinforcement and lateral stirrups of 8 mm dia. bars at 100 mm c/c spacing. The raft slab reinforcement consists of 10 mm dia. with 100 mm c/c in both directions in two layers. The percentage of steel-Polyolefin (70-30) fibres used in the joints of the frames is 0.75%, 1.5% and 2%. The dimensions of the bare frame specimen adopted are shown in Figure 3.40.

3.8.3 Casting and Curing of bare frames

The bare frame specimens were cast in the Structural Technology Centre of Kumaraguru College of Technology, Coimbatore. An electrically operated concrete mixer was used for mixing concrete. M25 grade concrete was adopted for casting of raft slab as well as beam and columns. The RC model frames were casted in the following order: The base slab was concreted first and after 24 hours, the side planks of the mould were dismantled. After three days, the columns and beams were casted to complete the frames cured for 28 days. The base slab was casted
with bolt holes of size 3 inches at every 0.4 m span for bolting the slab with the test floor. The holes were made using 3 inch PVC pipes to get smooth surface. Also lifting hooks were provided in diagonally opposite directions over the base slab to enable lifting of the frame specimens during testing.

![Dimensions of bare frame specimen](image)

**Figure 3.40** Dimensions of bare frame specimen

![Bare frame specimen with HFRC zones](image)

**Figure 3.40(a)** Bare frame specimen with HFRC zones
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. Hence the model HFRC bare frame were 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 2d (0.2 m) for beams and 1.5d (0.15 m) for columns from the beam-column joints as shown in Figure 3.40(a).

The joints of the frames were cast using concrete enhanced with hybrid fibres and the other regions were cast with control mix simultaneously. The percentage of hybrid fibres used was 0.75%, 1.5% and 2%. Concreting of the frames was done immediately after mixing and needle vibrator of 25 mm was used for concrete compaction. The concrete was filled in the column and beam moulds with hybrid fibre combination and control mix alternatively.

![Figure 3.41 Casted bare frame specimen](image)
Figure 3.42  Bare frames under curing

The casted bare frame specimen is shown in Figure 3.41 and the frames under curing are shown in Figure 3.42.

3.8.4  Lifting and Erection of Bare Frames

Lifting of frame specimens was done using overhead crane of capacity 5 tons and moved to the test floor of capacity 200 tons. The lifting hooks provided on the base slab during casting enabled proper lifting of the frames with cranes. The base slab of the frame specimen was kept on the test floor ensuring proper alignment of the bolt holes in the specimen to the test floor. The bolts were inserted in the base slab and were tightened properly.

3.8.5  Bare Frame Test Setup

The complete test setup adopted for the bare frame model is shown in Figure 3.43. The frames were considered to cantilever from the base. White washing of the frame specimens was done to enable visibility
of cracks and failure pattern clearly. The test Setup consisted of the following arrangements:

- Support arrangement
- Loading arrangement
- Load measurements
- Deflection measurements

All the frames were marked by points in the outer most column of the portal frame from which the dial gauges were placed at 25 cm, 50 cm and 95 cm from the top of the raft slab before testing. The testing system consisted of strong floor of capacity 200 tons, reaction frame, loading equipment, instrumentation, and data acquisition system. The specimens with stiff reinforced concrete base slab were bolted to the rigid test floor. Specimens were tested under lateral cyclic loading simulating seismic action. Lateral load was applied to specimens at the beam-column joint level, using a hydraulic push & pull jack with LVDT (Linear Variable Differential Transformers) connected to the transducer. The applied load increment was 2 kN at each cycle for all the frame specimens. The frame was loaded up to the first increment load, then unloaded and reloaded to the next increment of load. This positive cycle load pattern of loading was followed for all the frames tested. Axial load of 20 kN was applied to both the columns and a uniformly distributed load of 5 kN/m was applied to the beam and a monotonic increasing lateral cyclic load was applied at the beam-column joint.
1. Test Floor   2. Reaction Frame   3. Test Frame   4. Load jacks

Figure 3.43  Schematic view of test setup of bare frame

3.8.6  Loading Arrangement

The columns and beams of bare frame specimens were square sections of size 0.1 m. The model frame was subjected to a concentrated vertical load for each column and a uniformly distributed load on the beam. The model frames were applied with a monotonically increasing lateral displacement and the respective loads and the loading scheme is shown in Figure 3.43.

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 tons 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.

![Location of load jacks with load cells for bare frame](image1)

**Figure 3.44** Location of load jacks with load cells for bare frame

![Hydraulic pumps used for loading](image2)

**Figure 3.45** Hydraulic pumps used for loading

An axial load of 20 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 5 kN/m using a proving ring of capacity 5 tons. The closer view of location of load jacks is shown in Figure 3.44 and the hydraulic pumps used for loading is shown in Figure 3.45.