CHAPTER 7

BEHAVIOUR OF P.P.F.R.C. BARE FRAME UNDER CYCLIC LOADING

7.1 GENERAL

In this chapter the behavior of bare frame cast using Mix–3 concrete under cyclic loading have been enumerated. Here the parameters like load vs deflection, load carrying capacity, stiffness, ductility factor and energy dissipating capacity are discussed for the test specimen PPFRCBF1 cast using are IS:456-2000 detailing subjected to cyclic loading. Similarly the test specimen PPFRCBF2 cast using IS: 13920–1993 detailing were determined for parameters like load vs deflection, load carrying capacity, stiffness, ductility factor and energy dissipating capacity under cyclic loading.

7.2 LOADING AND LOAD DEFLECTION BEHAVIOUR

The bare frame was subjected to lateral cyclic loads in a quasi static pattern simulating seismic action. The history of sequence of loading for the bare frame PPFRCBF1 and PPFRCBF2 is shown in Figure 7.1 and 7.5. The ultimate load of 49kN and 54kN were reached in the seventeenth and eighteenth cycle of loading for PPFRCBF1 and PPFRCBF2. The load-displacement response of the frames PPFRCBF1 and PPFRCBF2 were observed and plotted in Figure 7.2 and 7.6 respectively. At the ultimate base shear the top storey deflection was observed to be 110.05 mm for PPFRCBF1 and 98.48 mm for PPFRCBF2. Figure 7.3, 7.4 and 7.7, 7.8 show response envelope curve and base shear vs LVDT deflection curve for the specimens PPFRCBF1 and PPFRCBF2 respectively.
7.2.1 Load – Deflection Behavior of PPFRCBF1

Figure 7.1 Sequence of Loading for the Frame PPFRCBF1

Figure 7.2 Load – Displacement Response of Specimen PPFRCBF1
Figure 7.3 Response Envelope Curve of Specimen PPFRCBF1

Figure 7.4 Base Shear vs. LVDT Deflection of Specimen PPFRCBF1
The function of the deflection curves corresponding to LVDT 1, LVDT 2, LVDT 3 and LVDT 4 placed at various levels of the frame (Figure 3.13) are given by,

\[ y = 0.422x + 9.049 \]
\[ R^2 = 0.917 \] (7.1)

\[ y = 0.552x + 8.761 \]
\[ R^2 = 0.923 \] (7.2)

\[ y = 0.766x + 9.002 \]
\[ R^2 = 0.915 \] (7.3)

\[ y = 1.215x + 8.762 \]
\[ R^2 = 0.923 \] (7.4)

7.2.2 Load – Deflection Behavior of PPFRCBF2

![Graph showing load-deflection behavior of PPFRCBF2](image)

**Figure 7.5 Sequence of Loading for the Frame PPFRCBF2**
Figure 7.6 Load – Displacement Response of Specimen PPFRCBF2

Figure 7.7 Response Envelope Curve of Specimen PPFRCBF2
The function of the deflection curves corresponding to LVDT 1, LVDT 2, LVDT 3 and LVDT 4 placed at various levels of the frame (Figure 3.13) are given by,

\[ y = 0.652x + 10.63 \]
\[ R^2 = 0.893 \]  \hspace{1cm} (7.5)

\[ y = 0.53x + 10.79 \]
\[ R^2 = 0.890 \]  \hspace{1cm} (7.6)

\[ y = 0.965x + 10.63 \]
\[ R^2 = 0.893 \]  \hspace{1cm} (7.7)

\[ y = 1.686x + 10.63 \]
\[ R^2 = 0.893 \]  \hspace{1cm} (7.8)

The relationships established can be utilized for estimating the lateral loads that can be experienced by buildings of similar nature and for estimating the deflections at various levels of such buildings. However for obtaining a generalized relationship, studies of similar nature have to be carried out with frames of different heights.
7.3 SPECIMEN BEHAVIOUR AND CRACK PATTERN

7.3.1 Behavior and Crack Pattern of PPFRCBF1

The detailed behavior of specimen PPFRCBF1 is described in the following section. The terms front, centre, and back are used to identify the location of columns with respect to the loading end. The term front refers to the member nearest to the loading jack, while the term back refers to the member farthest from the loading end.

Figure 7.9 Shows Flexural Hinge formation and Propagation of Diagonal Shear Crack in the Front Column. The specimen PPFRCBF1, first structural cracks began to form at a base shear of 21 kN. These cracks started from the tension side of the beam column joint in the front columns of the bottom-storey.

When the base shears of 38 kN, cracks are formed in the front top of the column as well as the beam-column joint region of the front column (Figures 7.10). At a base shear of 26 kN, the cracks formed in the top and bottom of the column region as flexural hinges and diagonal shear cracks started propagating between them. The maximum widening of cracks occurs when the specimen is subjected to ultimate load (Figure 7.11, 7.12 and 7.13). Tensile cracks are developed in the front column when it is subjected to a load of 38kN (Figure 7.13).

Figure 7.14 shows that the specimen PPFRCBF1 reached a maximum lateral displacement of 110.05 mm at the top storey level which corresponds to a base shear of 49kN. Additionally, cracks developed in the back column of bottom-storey at the compression end because of diagonal strut action.

From the failure pattern, it is observed that the beam-column condition was formed at a base shear of 24 kN initially and it leads to the formation of flexural hinges and shear cracks in the front columns at 32 kN.
Figure 7.9 Flexural hinge formation and propagation of diagonal shear crack in the Front Column

Figure 7.10 Shear crack in front of beam - column joint
Figure 7.11 Widening of Structural cracks

Figure 7.12 Widening of Structural cracks (front view)
Figure 7.13 Tension crack above mid-height of rear left column

Figure 7.14 Frame PPFRCBF1 at Maximum lateral displacement
7.3.2 Behavior and Crack Pattern of PPFRCBF2

Figure 7.15 shows Diagonal shear cracks in the front column. The specimen SFRCBF2, first structural cracks began to form at a base shear of 24 kN. These cracks started from the tension side of the beam column joint in the front columns of the bottom-storey. At a base shear of 30 kN, the tension cracks are formed in the front column (Figures 7.15).

From the failure pattern, it is observed that the beam-column condition was formed at a base shear of 20 kN initially and it leads to the formation of flexural hinges and shear cracks in the front columns at 30 kN (Figures 7.16). When the base shears of 30 kN, tension cracks are formed in bottom of top front column as well as the beam-column joint region (Figures 7.17).

Figure 7.18 shows that the specimen SFRCBF2 reached a maximum lateral displacement of 98.48 mm at the top storey level which corresponds to a base shear of 54 kN. Additionally, cracks developed in the back column of bottom-storey at the compression end because of diagonal strut action.

Figure 7.15 Tension crack below the Mid-height of Front Column
Figure 7.16 Crack pattern in beam - column joint

Figure 7.17 Tension cracks below the beam
7.4 **STIFFNESS**

Stiffness is defined as the load required causing unit deflection of the beam-column joint. The stiffness of test specimen PPFRCBF1 and PPFRCBF2 at each load cycle is shown in Figure 7.19 and 7.20 respectively. The stiffness was calculated as the amount of base shear required for causing unit deflection at the top-storey level.
7.4.1 Stiffness Behavior of PPFRCBF1

The initial stiffness of the frame PPFRCBF1 was 1.85 kN/mm. In Figure 7.19, the stiffness was found to decrease from 1.85 kN/mm during the second cycle to 0.44 kN/mm during the seventeenth cycle of loading. In addition, it is observed that the stiffness of the frame condition during the eleventh cycle at a base shear of 33 kN, the frame exhibited a sudden stiffness degradation resulting in critical shear failure of bottom-storey columns due to the restriction of lateral displacement.

![Figure 7.19 Stiffness of Test Specimen PPFRCBF1](image)

The function of the stiffness curve for load cycles (x-values) ranging from 1 to 17 is given by,

\[ y = -0.094x + 1.851 \]

\[ R^2 = 0.947 \] (7.9)
7.4.2 Stiffness Behavior of PPFRCBF2

The initial stiffness of the frame PPFRCBF2 was 2.72 kN/mm. In Figure 7.20, the stiffness was found to decrease from 2.72 kN/mm during the second cycle to 0.54 kN/mm during the eighteenth cycle of loading. In addition, it is observed that the stiffness of the frame condition during the twelfth cycle at a base shear of 36 kN, the frame exhibited a sudden stiffness degradation resulting in critical shear failure of bottom-storey columns due to the restriction of lateral displacement.

![Stiffness of Test Specimen PPFRCBF2](image)

**Figure 7.20 Stiffness of Test Specimen PPFRCBF2**

The function of the stiffness curve for load cycles (x-values) ranging from 1 to 18 is given by,

\[ y = -0.135x + 2.722 \]

\[ R^2 = 0.950 \] (7.10)
7.5 DUCTILITY FACTOR

Ductility is defined as the ability of the structure or its components to sustain large inelastic deformations. In this study, displacement ductility factor at each cycle of loading was calculated as the ratio of peak displacement during the corresponding cycle to yield displacement.

In the analysis of nonlinear structures, the force-displacement relationship most frequently adopted is the ‘bilinear model’. This model is typically used for structures or structural elements with a linear force displacement relationship in both the elastic and the inelastic range. For concrete structures, unfortunately, the force-displacement relationship is not actually bilinear, and certain assumptions have to be made.

7.5.1 Ductility Factor of PPFRCBF1

The ductility factor at the ultimate cycle for the frame PPFRCBF1 was found to be 5.92. The Figure 7.21 shows the displacement ductility factor for Frame PPFRCBF1.

![Ductility Factor Graph](image)

**Figure 7.21 Ductility Factors for Frame PPFRCBF1**
Cumulative ductility factor up to any point is the sum of displacement ductility factors attained in each cycle of loading up to the cycle considered. This gives an idea about the overall ductility of the laterally loaded structure. The cumulative ductility factor at the ultimate cycle for the frame PPFRCBF1 was found to be 37.38. Figure 7.22 shows the cumulative ductility factors for various load cycles.

![Cumulative Ductility Factor Curve](image)

**Figure 7.22 Cumulative Ductility Factors for Frame PPFRCBF1**

The function of the cumulative ductility factor curve is,

\[ y = 2.023x - 6.833 \]

\[ R^2 = 0.847 \]  \hspace{1cm} (7.11)

### 7.5.2 Ductility Factor of PPFRCBF2

The displacement ductility factor at the ultimate cycle for the frame PPFRCBF2 was found to be 6.02. The Figure 7.23 shows the displacement ductility factor for Frame PPFRCBF2.
Cumulative ductility factor up to any point is the sum of displacement ductility factors attained in each cycle of loading up to the cycle considered. This gives an idea about the overall ductility of the laterally loaded structure. The cumulative ductility factor at the ultimate cycle for the frame PPFRCBF2 was found to be 35.44. Figure 7.24 shows the cumulative ductility factors for various load cycles.

**Figure 7.23 Ductility Factors for Frame PPFRCBF2**

**Figure 7.24 Cumulative Ductility Factors for Frame PPFRCBF2**
The function of the cumulative ductility factor curve is,

\[ y = 1.763x - 6.463 \]

\[ R^2 = 0.834 \] \hspace{1cm} (7.12)

7.6 RELATIVE AND CUMULATIVE ENERGY DISSIPATING CAPACITY

When the beam-column joint is subjected to cyclic loading such as those experienced during heavy wind or earthquake, some energy is absorbed in each cycle. It is equal to the work in straining or deforming the structure to the limit of deflection. The relative energy absorption capacities during various load cycles were calculated as the area of the load versus deflection diagram.

7.6.1. Relative and Cumulative Energy Dissipating Capacity of PPFRCBF1

![Energy Dissipation Capacity of Frame PPFRCBF1](image)

Figure 7.25 Energy Dissipation Capacity of Frame PPFRCBF1
Figure 7.26 Cumulative Energy Dissipation Capacity OF Frame PPFRCBF1

Figure 6.25 shows Energy Dissipation Capacity of Frame PPFRCBF1. The energy dissipation values were plotted against the corresponding load cycle. The variation of cumulative energy dissipation characteristics of the test specimen PPFRCBF1 is shown in Figure 7.26. From the graph, it is observed that the frame PPFRCBF1 dissipated a total energy of 17865.32 kN-mm which corresponds to a maximum load cycle of the specimen.

Figure 7.27 Cumulative Energy Dissipation – Ductility Relationship of Frame PPFRCBF1
Figure 7.27 shows Cumulative Energy Dissipation - Ductility Relationship of Frame PPFRCBF1. The function of the cumulative energy dissipation curve with respect to ductility is,

\[ y = 889.7x - 3490. \]
\[ R^2 = 0.760 \quad (7.13) \]

7.6.2 Relative and Cumulative Energy Dissipating Capacity of PPFRCBF2

Figure 6.28 shows Energy Dissipation Capacity of Frame PPFRCBF2. The energy dissipation values were plotted against the corresponding load cycle. The variation of cumulative energy dissipation characteristics of the test specimen PPFRCBF2 is shown in Figure 7.29. From the graph, it is observed that the frame PPFRCBF2 dissipated a total energy of 18086.59 kN-mm which corresponds to a maximum load cycle of the specimen.

![Energy Dissipation Capacity of Frame PPFRCBF2](image)

Figure 7.28 Energy Dissipation Capacity of Frame PPFRCBF2
Figure 7.29 Cumulative Energy Dissipation Capacity OF Frame PPFRCBF2

Figure 7.30 Cumulative Energy Dissipation - Ductility Relationship of Frame PPFRCBF2
Figure 7.30 shows Cumulative Energy Dissipation - Ductility Relationship of Frame PPFRCBF2. The function of the cumulative energy dissipation curve with respect to ductility is,

\[ y = 834.9x - 3576. \]
\[ R^2 = 0.733 \]  
(6.14)

7.7 SUMMARY

This chapter presented the experimental investigations carried out on single bay, two-storey PolyPropylene Fibre Reinforced Concrete Bare Frame (PPFRCBF). The frame designated as PPFRCBF1 and PPFRCBF2 were subjected to quasi-static cyclic loads simulating seismic action. The load displacement response, specimen behavior, crack pattern, and mode of failure of both the frames PPFRCBF1 and PPFRCBF2 were observed. Also other parameters like ultimate capacity, lateral deflection, stiffness, ductility, and energy dissipation capacity were calculated to study the behavior of the Polypropylene fibre reinforced concrete bare frame and to make a comparison with reinforced concrete bare frame specimen. The initial crack formation on specimen PPFRCBF1 was 21KN and 20KN for PPFRCBF2. The ultimate load carrying capacity of PPFRCBF2 has increased to 10.20\% and lateral deflection is reduced to 11.74\% when compared to PPFRCBF1. The Stiffness and Ductility factor of the specimen PPFRCBF1 and PPFRCBF2 was found to be 1.85KN/mm & 2.72KN/mm and 5.92 & 6.02 respectively. From the experiment, the total energy dissipated for PPFRCBF1 and PPFRCBF2 was found to be 17865.32 kN-mm and 18086.59 kN-mm which correspond to the maximum load cycle of the specimen.