CHAPTER - 5

BEHAVIOUR OF REINFORCED CONCRETE BARE FRAME UNDER CYCLIC LOADING (CONTROL FRAME)

5.1 GENERAL

In this chapter the behavior of bare frame cast using Mix–1 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 RCBF1 cast using are IS: 456-2000 detailing subjected to cyclic loading. Similarly the test specimen RCBF2 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.

5.2 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 RCBF1 and RCBF2 is shown in Figure 5.1 and 5.5. The ultimate load of 36kN and 44kN were reached in the twelveth and fifteenth cycle of loading for RCBF1 and RCBF2. The load-displacement response of the frames RCBF1 and RCBF2 respectively were observed and plotted in Figure 5.2 and 5.6 respectively. At the ultimate base shear the top storey deflection was observed to be 81.2 mm for RCBF1 and 69.9 mm for RCBF2. Figure 5.3, 5.4 and 5.7, 5.8 show response envelope curve and base shear vs LVDT deflection curve for the specimens RCBF1 and RCBF2 respectively.
5.2.1 Load – Deflection Behavior of RCBF1

Figure 5.1 Sequence of Loading for the Frame RCBF 1

Figure 5.2 Load – Displacement Response of Specimen RCBF 1
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 = 0.418x + 4.449  
R² = 0.965  \hspace{1cm} (5.1)

y = 0.539x + 4.426  
R² = 0.964  \hspace{1cm} (5.2)

y = 0.696x + 5.217  
R² = 0.938  \hspace{1cm} (5.3)

y = 1.096x + 5.208  
R² = 0.938  \hspace{1cm} (5.4)

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.

5.2.2 Load – Deflection Behaviour of RCBF2

![Graph](image)

**Figure 5.5 Sequence of Loading for the Frame RCBF 2**
Figure 5.6 Load – Displacement Response of Specimen RCBF 2

Figure 5.7 Response Envelope Curve of Specimen RCBF 2
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,

\[ y = 0.576x + 4.465 \]
\[ R^2 = 0.981 \] \hspace{1cm} (5.5)

\[ y = 0.974x + 4.101 \]
\[ R^2 = 0.984 \] \hspace{1cm} (5.6)

\[ y = 1.307x + 4.105 \]
\[ R^2 = 0.984 \] \hspace{1cm} (5.7)

\[ y = 1.701x + 4.105 \]
\[ R^2 = 0.984 \] \hspace{1cm} (5.8)

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.

5.3 SPECIMEN BEHAVIOUR AND CRACK PATTERN

5.3.1 Behavior and Crack Pattern of RCBF1

The detailed behavior of specimen RCBF1 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 5.9 shows the cracks in the front column. In the control specimen RCBF1, first structural cracks began to form at a base shear of 14 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 24 kN, cracks are formed in the front top of the column as well as the beam-column joint region of the front column (Figures 5.10 and 5.11). 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 (Figures 5.12).

Figure 5.13 shows that the specimen RCBF1 reached a maximum lateral displacement of 81.2 mm, which corresponds to a base shear of 36 kN. 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 34 kN.
Figure 5.9 Cracks in front column

Figure 5.10 Flexural hinge formation and propagation of Diagonal shear cracks in front column
Figure 5.11 Flexural hinge formation and propagation of Diagonal shear cracks in front column

Figure 5.12 Shear cracks in front column
5.3.2 Behavior and Crack Pattern of RCBF2

The detailed behavior of specimen RCBF2 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 5.14 shows the cracks in the front column. In the control specimen RCBF1, first crack began to form at a base shear of 10 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 was 20 kN, cracks are formed in the front top of the beam as well as the beam-column joint region of the front column (Figures 5.15 and 5.16). At a base shear of 23 kN, the cracks formed in the top of the bottom of the beam region and wider cracks started propagating between beam and column (Figures 5.17).

Figure 5.18 shows that the specimen RCBF2 reached a maximum lateral displacement of 69.9 mm, which corresponds to a base shear of 44 kN. 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 23 kN initially and it leads to the formation of flexural hinges and shear cracks in the front columns at 44 kN.

![Figure 5.14 Cracks in the front column](image-url)
Figure 5.15 Flexural hinge formation and shear cracks in front column

Figure 5.16 Flexural hinge formation and propagation of Diagonal shear cracks in front top column
Figure 5.17 Overview of wider cracks in beam-column joint

Figure 5.18 Frame RCBF2 at Maximum lateral displacement
5.4 STIFFNESS

Stiffness is defined as the load required to cause unit deflection of the beam-column joint. The stiffness of test specimens RCBF1 and RCBF2 at each load cycle were shown in Figure 5.19 and 5.20 respectively. The stiffness was calculated as the amount of base shear required for causing unit deflection at the top-storey level.

5.4.1 Stiffness Behavior of RCBF1

The initial stiffness of the frame RCBF1 was 1.17 kN/mm. In Figure 5.19, the stiffness was found to decrease from 1.17 kN/mm during the second cycle to 0.44 kN/mm during the twelfth cycle of loading. In addition, it is observed that the stiffness of the frame condition during the sixth cycle at a base shear of 18 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 5.19 Stiffness of Test Specimen RCBF1
The function of the stiffness curve for load cycles (x-values) ranging from 1 to 12 is given by,

\[ y = -0.067x + 1.145 \]

\[ R^2 = 0.927 \]  \hspace{1cm} (5.9)

### 5.4.2 Stiffness Behavior of RCBF2

The initial stiffness of the frame RCBF2 was 1.75 kN/mm. In Figure 5.20, the stiffness was found to decrease from 1.75 kN/mm during the second cycle to 0.62 kN/mm during the fifteenth 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 5.20 Stiffness of Test Specimen RCBF2](image-url)
The function of the stiffness curve for load cycles (x-values) ranging from 1 to 14 is given by,

\[ y = -0.068x + 1.453 \]
\[ R^2 = 0.829 \]

(5.10)

5.5 **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, the force-displacement relationship is not actually bilinear, and certain assumptions have to be made.

5.5.1 **Ductility Factor of RCBF1**

The displacement ductility factor at the ultimate cycle for the frame RCBF1 was found to be 3.55. The Figure 5.21 Shows the ductility factor for Frame RCBF1.
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 RCBF1 was found to be 18.4. Figure 5.22 shows the cumulative ductility factors for various load cycles.
The function of the cumulative ductility factor curve is,

\[ y = 1.473x - 3.166 \]

\[ R^2 = 0.881 \]  \hspace{1cm} (5.11)

5.5.2 Ductility Factor of RCBF2

The displacement ductility factor at the ultimate cycle for the frame RCBF2 was found to be 3.83. The Figure 5.23 shows the displacement ductility factor for Frame RCBF2.

![Graph showing Ductility Factors for Frame RCBF2](image)

**Figure 5.23 Ductility Factors for Frame RCBF2**

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 RCBF2 was found to be 27.46. Figure 5.24 shows the cumulative ductility factors for various load cycles.
The function of the cumulative ductility factor curve is,

\[ y = 1.787x - 4.812 \]

\[ R^2 = 0.892 \] \hspace{1cm} (5.12)

**5.6 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.
5.6.1. Relative and Cumulative Energy Dissipating Capacity of RCBF1

Figure 5.25 Energy Dissipation Capacity of Frame RCBF1

Figure 5.26 Cumulative Energy Dissipation Capacity OF Frame RCBF1
Figure 5.25 Shows Energy Dissipation Capacity of Frame RCBF1. The energy dissipation values were plotted against the corresponding load cycle. The variation of cumulative energy dissipation characteristics of the test specimen RCBF1 is shown in Figure 5.26. From the graph, it is observed that the frame RCBF1 dissipated a total energy of 6917.62 kN-mm which corresponds to the maximum load cycle of the specimen.

![Cumulative Energy Dissipation - Ductility Relationship of Frame RCBF1](image)

Figure 5.27 Cumulative Energy Dissipation - Ductility Relationship of Frame RCBF1

The function of the cumulative energy dissipation curve with respect to ductility is,

\[ y = 511.5x - 1334 \]

\[ R^2 = 0.784 \]
5.6.2 Relative and Cumulative Energy Dissipating Capacity of RCBF2

Figure 5.28 shows Energy Dissipation Capacity of Frame RCBF2. The energy dissipation values were plotted against the corresponding load cycle. The variation of cumulative energy dissipation characteristics of the test specimen RCBF2 is shown in Figure 5.29. From the graph, it is observed that the frame RCBF2 dissipated a total energy of 10997.9 kN-mm which corresponds to the maximum load cycle of the specimen.

Figure 5.28 Energy Dissipation Capacity of Frame RCBF2

Figure 5.29 Cumulative Energy Dissipation Capacity OF Frame RCBF2
Figure 5.30 Shows Cumulative Energy Dissipation - Ductility Relationship of Frame RCBF2. The function of the cumulative energy dissipation curve with respect to ductility is,

\[ y = 676.1x - 2103 \]

\[ R^2 = 0.827 \]

(6.14)

**Figure 5.30 Cumulative Energy Dissipation - Ductility Relationship of Frame RCBF2**

### 5.7 SUMMARY

This chapter presented the experimental investigations carried out on single bay, two-storey Reinforced Concrete Bare Frame (RCBF). The frame designated as RCBF1 and RCBF2 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 RCBF1 and RCBF2 were observed. Other parameters like ultimate capacity, lateral deflection, stiffness, ductility, and energy dissipation capacity were calculated to study the behavior
of the bare frame and to make a comparison with fibrous bare frame specimens. The initial crack formation on specimen RCBF1 was 14KN and 20KN for RCBF2. The ultimate load carrying capacity of RCBF2 has increased to 22.22% and lateral deflection is reduced to 16.16% when compared to RCBF1. The Stiffness and Ductility factor of the specimen RCBF1 and RCBF2 was found to be 1.17kN/mm & 1.75kN/mm and 3.55 & 3.83 respectively. From the experiment, the total energy dissipated for RCBF1 and RCBF2 was found to be 6917.62 kN-mm and 10997.9 kN-mm which correspond to the maximum load cycle of the specimen.