CHAPTER 7

BEHAVIOR OF EXTERIOR SIFCON
BEAM-COLUMN JOINTS

7.1 GENERAL

In order to study the behavior of beam-column joints with fibrous concrete in the fuse locations, an experimental investigation was taken up to study the effect of SIFCON in the fuse locations of conventional RC beam-column joints under static cyclic loading. Beam-column joints made totally with conventional RC, FRC and SIFCON were also investigated for comparison. The parameters like load carrying capacity, stiffness degradation, ductility and energy absorption capacity were assessed as before. The results of the investigation on the effect of SIFCON in the fuse locations of conventional RC beam-column joints are summarized in this chapter.

7.2 LOADING AND LOAD DEFLECTION BEHAVIOR

The specimens were subjected to cyclic loading (forward and reverse), simulating the load experienced during earthquakes. The experimental test setup is shown in Figure 4.18. The load was increased and decreased in stage of 3 kN for both forward and reverse cycle. The load sequence diagram for SIFCON beam-column joint specimen is shown in Figure 7.1. The specimens were subjected to cyclic loading to study the behavior in pre-cracking, cracking, post-cracking, ultimate and post ultimate stages. For beam-column joints with SIFCON in the fuse location, the maximum load observed was 51 kN in forward and 48 kN in reverse and the
ultimate deflection was recorded as 31.47 mm. For RC specimen the maximum load observed was 39 kN in forward and 36 kN in reverse respectively and the ultimate deflection was recorded as 24.25 mm. For FRC specimen the maximum load observed was 46 kN in forward and 42 kN in reverse and the ultimate deflection was recorded as 24.45 mm. For SIFCON specimen the maximum load observed was 66 kN in forward and 57 kN in reverse and the ultimate deflection was recorded as 33.15 mm. The deflections observed were always greater than that obtained in the previous cycles. The load-deflection plot for all the specimens were drawn and are shown in Figure 7.2 to Figure 7.5. The comparison of load-deflection response envelopes is shown in Figure 7.6.

Figure 7.1 Load sequence diagram for SIFCON specimen

Figure 7.2 Load-deflection response of conventional RC beam-column joint
Figure 7.3  Load-deflection response of FRC beam-column joint

Figure 7.4  Load-deflection response of RC specimens with SIFCON in fuse location

Figure 7.5  Load-deflection response of SIFCON beam-column joint
The first crack load of RC specimens with SIFCON in fuse location was found to be 21 kN whereas the corresponding values for conventional RC, FRC and SIFCON specimens were found to be 15 kN, 18 kN and 27 kN respectively. The ultimate load carrying capacity of RC specimens with SIFCON in fuse location was found to be 51 kN whereas the corresponding values for conventional RC, FRC and SIFCON specimens were found to be 39 kN, 46 kN and 66 kN respectively. The comparison of ultimate load for various specimens is shown in Figure 7.7.
7.4 STIFFNESS CHARACTERISTICS

For beam-column joints with SIFCON in fuse location, the stiffness was degraded from 14.2 kN/mm to 2.86 kN/mm and 12.3 kN/mm to 3 kN/mm during forward and reverse loading respectively. For RC specimens, the stiffness was degraded from 12.27 kN/mm to 1.9 kN/mm and 9.64 kN/mm to 2 kN/mm during forward and reverse loading respectively. For FRC specimens, the stiffness was degraded from 14 kN/mm to 2.75 kN/mm and 10 kN/mm to 2.57 kN/mm during forward and reverse loading respectively. For SIFCON specimens, the stiffness was degraded from 17.15 kN/mm to 2 kN/mm and 17.14 kN/mm to 2.53 kN/mm during forward and reverse loading respectively. It was observed that there was general degradation of stiffness for all the specimens with an increase in the load cycles. The variation of stiffness degradation with load cycles is shown in Figure 7.8.

![Figure 7.8 Variation of stiffness degradation with load cycles](image)

7.5 DUCTILITY CHARACTERISTICS

For specimens with SIFCON infuse location, the cumulative ductility was found to have increased from 0.95 during the first cycle of loading to 34.75 during the last cycle of loading. For RC specimens, the value was found to have increased from 0.51 during the first cycle of loading to 15.14 during the last cycle of loading. For FRC specimens, the value was
found to have increased from 0.4 during the first cycle of loading to 23.96 during the last cycle of loading. For SIFCON specimens, the value was found to have increased from 0.69 during the first cycle of loading to 46.34 during the last cycle of loading. The variation of cumulative ductility factor with load cycles is shown in Figure 7.9 and the comparison of cumulative ductility factor is shown in Figure 7.10. As can be observed, very large ductility values were recorded in the test for SIFCON beam-column joints. Similarly, the ductility values of specimens with SIFCON in fuse location were found to be more than that of conventional RC and FRC beam-column joints. This type of behavior will be of more advantage for structures located in seismic prone zones. The variation of ductility factor with load cycles for SIFCON beam-column joints is shown in Figure 7.11.

![Figure 7.9 Variation of cumulative ductility factor with load cycles](image)

![Figure 7.10 Comparison of cumulative ductility factor](image)
7.6 ENERGY ABSORPTION CHARACTERISTICS

For specimens with SIFCON in fuse location, the energy observed has increased from 8 kNmm to 647 kNmm and 13 kNmm to 435 kNmm during forward and reverse loading respectively. For SIFCON specimens the energy observed has increased from 6 kNmm to 854 kNmm and 3 kNmm to 653 kNmm during forward and reverse loading respectively. The total energy observed by the beam-column joint specimen with SIFCON in fuse location is found to be 1847 kNmm whereas the corresponding values for RC, FRC and SIFCON beam-column joints were 983 kNmm, 1359 kNmm and 2672 kNmm respectively. The variation of cumulative energy absorption capacity with load cycles is shown in Figure 7.12 and the comparison of cumulative energy absorption capacity is shown in Figure 7.13. It can be seen that the SIFCON beam-column joints has not only carried higher loads, but also attained greater deflections till ultimate stage. This may be due to the incorporation of high volume fraction of fibers which lead to crack arresting and crack bridge mechanism in the matrix. As a result, the energy absorption capacity of
SIFCON beam-column joints was found to be high compared with other specimens.

![Graph showing variation of cumulative energy absorption capacity with load cycles]

**Figure 7.12** Variation of cumulative energy absorption capacity with load cycles

![Graph comparing cumulative energy absorption capacity for different specimens]

**Figure 7.13** Comparison of cumulative energy absorption capacity

### 7.7 WORK INDEX

For beam-column joint specimens with SIFCON in fuse location, the cumulative work index varies from 0.28 during the first cycle of loading to 27.33 during the last cycle of loading. For SIFCON specimens, the value varies from 0.16 during the first cycle of loading to 35.36 during the last cycle of loading. For RC and FRC specimens, the value varies from 0.2 to 13.17
and 0.13 to 19.08 respectively. The variation of cumulative work index with load cycles is shown in Figure 7.14 and the comparison of cumulative work index is shown in Figure 7.15.

![Figure 7.14 Variation of cumulative work index with load cycles](image)

![Figure 7.15 Comparison of cumulative work index](image)

### 7.8 HYSTERETIC DAMPING RATIO

The equivalent viscous damping ratio can be used to access the inelastic response of the system (Brezac 2002). The hysteretic damping ratio was calculated using the Equation (7.1) proposed by Jacobsen (1930); Berzac (2002) as follows:
\[ \xi_{\text{hyst}} = \left( \frac{2}{\pi} \right) R \]  

(7.1)

where \( R \) is the ratio of energies dissipated by a real system and rigid-perfectly-plastic system. Graphical representation for \( R \) is shown in Figure 7.16. The variation of hysteretic damping ratio with load cycles is shown in Figure 7.17. In general, it is observed that the hysteretic damping ratio increases with the increase in load cycles. This is due to the fact that at higher load cycles, the hysteresis loops are getting larger and that more energy is being absorbed.

Figure 7.16  Illustration for \( R \) used in hysteretic damping ratio

Figure 7.17  Variation of hysteretic damping ratio with load cycles
7.9 BEHAVIOR AND MODE OF FAILURE

SIFCON beam-column joints and RC beam-column joints with SIFCON in fuse location suffer less damage compared to conventional RC and FRC specimens. This is mainly due to the presence of fibres, which interlock the cracks by bridging the gap. Further, the formation of cracks does not take place at the early stages of loading as in the case of conventional RC and FRC specimens. Initially, the cracks were formed only at the junction of the SIFCON and concrete interface. However, further increase in the load results in the formation of numerous cracks. For all specimens, the failure has occurred in the beam portion of the beam-column joint as shown in Figure 7.18. SIFCON beam-column joints and specimens with SIFCON in fuse location have withstood a number of load cycles before the final collapse thereby exhibiting good ductile behavior.

Figure 7.18 Failure patterns of tested specimens
7.10 DISCUSSION OF RESULTS

1. The first crack load of SIFCON beam-column joints was found to be 80% more than that of conventional RC beam-column joints and 50% more than that of FRC beam-column joints.

2. The ultimate load carrying capacity of SIFCON beam-column joints was found to be 70% more than that of conventional RC beam-column joints, 40% more than that of FRC beam-column joints, and 30% more than that of RC beam-column joints with SIFCON in fuse location.

3. The ultimate load carrying capacity of RC beam-column joints with SIFCON infuse location was found to be 30% more than that of conventional RC beam-column joints.

4. The ductility factor of SIFCON beam-column joints was found to be 200% more than that of conventional RC beam-column joints, 90% more than that of FRC beam-column joints, and 30% more than that of RC beam-column joints with SIFCON in fuse location.

5. The energy absorption capacity of SIFCON beam-column joints was found to be 170% more than that of conventional RC beam-column joints, 95% more than that of FRC beam-column joints, and 45% more than that of RC beam-column joints with SIFCON in fuse location.

6. SIFCON hinges absorb nearly 90% and 35% of more energy than conventional RC and FRC beam-column joints respectively.
7. The work index of SIFCON beam-column joints was found to be 170% more than that of conventional RC beam-column joints, 85% more than that of FRC beam-column joints, and 30% more than that of RC beam-column joints with SIFCON in fuse location.