CHAPTER 5

INVESTIGATION OF RC FRAME WITH PARTIAL INFILL
RETROFITTED USING MASONRY INSERTS

5.1 GENERAL

The results of the experimental investigation carried out on two-bay, two-storey partially infilled RC frame retrofitted using masonry inserts is presented. This frame was designated as S3MF tested to investigate the seismic performance of RC frames with captive-column defects strengthened by providing additional masonry inserts. The load-displacement response, specimen behaviour, and the crack pattern of the frame S3MF are discussed. Various parameters like lateral deflection, strength, stiffness, ductility, and energy dissipation capacity were considered for study on the behaviour of the frame.

5.2 LOAD-DISPLACEMENT RESPONSE (P-Δ)

The frame was subjected to lateral cyclic loads in a quasi-static pattern simulating seismic action. The history of sequence of loading for the frame S3MF is shown in Figure 5.1. The ultimate load of 147 kN was reached in the twenty-ninth cycle of loading. The load-displacement response of the
frame S3MF was recorded as plotted in Figure 5.2. At the ultimate base shear, the top-storey deflection was found to be 30.1 mm.

Figure 5.1 Sequence of Loading for the Frame S3MF

Figure 5.2 Load-Displacement Response of Specimen S3MF
5.3 SPECIMEN BEHAVIOUR AND CRACK PATTERN

In the frame S3MF strengthened using masonry inserts, the first structural crack developed at 70 kN of in-plane load at the top of front column in the bottom-storey. At 90 kN, a similar crack formed at the top of central column. The crack patterns indicated a combined effect of flexural and shear failure. These cracks continued to enlarge and the first infill crack developed in the bottom-storey at a base shear of 100 kN. This shear crack in both the bays appeared almost along the diagonal of the brick infill passing through the masonry inserts (Figures 5.4 and 5.5). Shortly after, another diagonal crack formed in the infill nearly parallel to the first and passing through the masonry inserts. Between these two set of cracks, a diagonal strut clearly formed (Figure 5.7).

At a load of 120 kN, a tension crack materialised above the mid-height of the front column (Figure 5.8) and cracks developed in the bottom of central and back column. The crack in the back column continued to enlarge and the frame reached its maximum lateral displacement of 30.1 mm at a base shear of 147 kN (Figure 5.2), without any cracks in the top-storey. From the failure pattern, it is observed that the additional masonry inserts have defended the column by allowing the compression strut in the masonry wall to travel along the wall plane, thus diverting away the critical shear force from the RC column. This shows that the strengthening scheme used with masonry inserts was successful in preventing the column shear failure due to captive-column effect, improving the strength of the specimen. Various stages of frame S3MF are shown in Figures 5.3 to 5.11. Figure 5.12 shows the frame at its maximum lateral displacement.
Figure 5.3 First Structural Crack at Top of Front Column

Figure 5.4 Diagonal Cracks Passing Through Masonry Inserts in Left Bay at 100 kN
Figure 5.5 Diagonal Cracks Passing Through Masonry Inserts in Right Bay at 100 kN

Figure 5.6 Parallel Diagonal Cracks Showing the Diagonal Strut Action
Figure 5.7 Diagonal Strut Action along the Left Bay

Figure 5.8 Tension Crack above Mid-Height of Front Column at 120 kN
Figure 5.9 Tension Crack in Central Column at 120 kN (Rear View)

Figure 5.10 Widening of Structural Cracks (Rear View)
Figure 5.11 Closer View of Diagonal Cracks through the Masonry Inserts
(Rear View)

Figure 5.12 Frame S3MF at Maximum Lateral Displacement
5.4 LATERAL DEFLECTION, STRENGTH AND STIFFNESS

Response envelope for the specimen S3MF given in Figure 5.13 showed the strength and stiffness characteristics of the specimen and also its general behaviour. The observed ultimate load of frame S3MF was 147 kN and the corresponding maximum lateral displacement was 30.1 mm. Base shear versus LVDT deflection at various levels of the frame S3MF is shown in Figure 5.14. In this Figure, it is observed that there is a uniform increase in the LVDT deflections till the frame reached its maximum lateral displacement. This shows a gradual reduction in strength of the frame without any critical failure in the bottom-storey columns.

![Figure 5.13 Response Envelope Curve for the Test Specimen S3MF](image_url)
Figure 5.14 Base Shear vs. LVDT Deflection of Specimen S3MF

The function of the deflection curves corresponding to LVDT1, LVDT2, LVDT3, and LVDT4 placed at various levels of the frame (Figure 2.15) are given by

\[ y = -0.34x^6 + 7.3862x^5 - 61.377x^4 + 242.61x^3 - 458.24x^2 + 366.02x \]
\[ (R^2 = 0.9325) \]  
(5.1)

\[ y = -0.0073x^6 + 0.2188x^5 - 2.6175x^4 + 15.974x^3 - 51.516x^2 + 89.049x \]
\[ (R^2 = 0.9943) \]  
(5.2)

\[ y = -0.0003x^6 + 0.0158x^5 - 0.3638x^4 + 4.0401x^3 - 22.504x^2 + 63.79x \]
\[ (R^2 = 0.9922) \]  
(5.3)
The relationships established can be utilised for estimating the lateral loads that can be experienced by buildings of similar nature strengthened with masonry inserts and for estimating the deflections at various levels of such buildings. From the estimated values, the effect of masonry inserts in preventing the formation of captive-column condition can be assessed. However for obtaining a generalised relationship, studies of similar nature have to be carried out with frames of different heights.

The stiffness of test specimen at each load cycle is shown in Figure 5.15. The initial stiffness of the frame S3MF was 25 kN/mm. It is observed in Figure 5.15 that the stiffness of the frame increased from 25 kN/mm during the first cycle to 37.5 kN/mm during the sixth cycle because of the presence of masonry inserts. After that there is a gradual degradation in stiffness due to the formation of structural and non-structural cracks in the bottom-storey. The stiffness decreased gradually from 37.5 kN/mm during the sixth cycle to 4.8 kN/mm during the twenty-ninth cycle of loading. The function of the stiffness curve for load cycles (x-values) ranging from 1 to 29 is given by

\[
y = -0.000007x^6 + 0.0007x^5 - 0.0281x^4 + 0.5486x^3 - 5.6121x^2 + 32.486x \\
(R^2 = 0.9968)
\]  

\[(5.4)\]

\[
y = 0.000005x^6 - 0.0004x^5 + 0.0121x^4 - 0.1455x^3 + 0.3614x^2 \\
+ 2.7859x + 19.973 \\
(R^2 = 0.9642)
\]  

\[(5.5)\]
5.5 DUCTILITY

In this study, the displacement ductility factors and the cumulative ductility factors of specimen frame S3MF were calculated as discussed in Section 3.5 of Chapter 3. The calculated effective stiffness and yield displacement of the specimen is given in Table 5.1. The variation of displacement ductility factors of the frame with load cycles is shown in Figure 5.16. The cumulative ductility factor at the ultimate cycle for the frame S3MF was found to be 20.32. Figure 5.17 shows the cumulative ductility factors for various load cycles. The function of the cumulative ductility factor curve is

\[ y = 0.00003x^4 - 0.0003x^3 + 0.0071x^2 + 0.0078x \]

\[ (R^2 = 1) \]
Table 5.1 Effective Stiffness and Yield Displacement of Specimen S3MF

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$V_y$ (kN)</th>
<th>$k_e$ (kN/mm)</th>
<th>$\Delta_y$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3MF</td>
<td>147</td>
<td>11.3</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Figure 5.16 Displacement Ductility Factors for Frame S3MF

Figure 5.17 Cumulative Ductility Factors for Frame S3MF
5.6 ENERGY DISSIPATION CAPACITY

The energy dissipation capacity and the cumulative energy dissipation capacity of the specimen frame S3MF were calculated as discussed in Section 3.6 of Chapter 3. The variation of energy dissipated by the frame during each cycle is shown in Figure 5.18 and the variation of cumulative energy dissipated by the frame is shown in Figure 5.19.

![Figure 5.18 Energy Dissipation Capacity of Frame S3MF](image1)

![Figure 5.19 Cumulative Energy Dissipation Capacity of Frame S3MF](image2)
The cumulative energy dissipation values were plotted against the corresponding cumulative displacement ductility factors to study the total energy dissipated by the frame with respect to ductility. The variation of cumulative energy dissipation characteristics of the test specimen S3MF is shown in Figure 5.20. From the graph, it is observed that the frame S3MF dissipated a total energy of 977.24 kN-mm which corresponds to a displacement ductility of 20.32. The function of the cumulative energy dissipation curve with respect to ductility is

\[
y = -0.0016x^5 + 0.094x^4 - 1.993x^3 + 16.579x^2 + 14.567x
\]

\[
(R^2 = 0.9995)
\]

(5.7)

Figure 5.20 Cumulative Energy Dissipation – Ductility Relationship of Frame S3MF
5.7 SUMMARY

This chapter presented the experimental investigations carried out on two-bay, two-storey, masonry-infilled RC frame with partial infill in the bottom-storey and retrofitted using masonry inserts. The frame designated as S3MF was subjected to quasi-static cyclic loads simulating seismic action. The load-displacement response, specimen behaviour, crack pattern, and mode of failure of the frame S3MF were observed. The observations show that the masonry inserts have defended the column allowing the compression strut in the masonry wall to travel along the wall plane, thus diverting away the critical shear force from the column. Various parameters like ultimate capacity, lateral deflection, stiffness, ductility, and energy dissipation capacity were calculated to study the effect of retrofit provided by the masonry inserts and to make a comparison with the other two specimens later.