CHAPTER 6

CONNECTION ASSEMBLY FOR SFCC PANELS

6.1 PREAMBLE

It is proposed to use SFCC panels as both load bearing wall panel and floor/roof slabs in low-rise buildings. In continuation with the studies on component behaviour of SFCC panel under compression, flexure and in plane lateral loading, development of connections to join the SFCC panels is essential to form buildings. In the present study, a simple prefab connection assembly is proposed to join the SFCC wall-to-wall and SFCC wall-to-floor/roof panels. The performance of the proposed connection assembly is studied by conducting experiment complimented with further numerical studies.

6.2 DEVELOPMENT OF CONNECTION ASSEMBLY FOR SFCC PANELS TO FORM BUILDINGS

Many prefabricated systems are developed and adopted in low and medium rise residential and community buildings. The connection between wall and floor/roof slab constitute a potential weak link in the structure to resist the combination of lateral and vertical loads requiring skilled man power. Hence, it is required to develop an effective connection system to join the wall panels to the floor/roof panels to form a building system. The proposed connection assembly consists of SFCC connecting panel to connect the top SFCC wall panel to bottom wall panel, which in turn is connected to SFCC floor panel by using ISA angles and bolts. The entire connection is developed in such a manner that the connecting components can be
prefabricated and assembled at site with ease. The schematic diagram of the proposed connection assembly is shown in Figure 6.1. The test specimen (Figure 6.1) represent an exterior wall and floor joint of low-rise buildings. The components of the test specimen consists of top and bottom SFCC wall panel, SFCC floor panel and connection assembly. The present study aims to investigate the behaviour of proposed connection assembly under combined axial and bending loads.

All units are in mm

Figure 6.1 Proposed connection assembly
6.2.1 Geometrical Details of Connection Assembly

The SFCC panel arrangement (Specimen 3 explained in Chapter 3), one which exhibited better performance under axial, flexural and in-plane lateral loads is adopted for fabrication of wall and floor/roof panels. The total height of test specimen is 2100 mm and the centre-to-centre distance between SFCC wall panels is 1000 mm. The size of SFCC wall panel is 685 mm wide, 1050 mm high and 130 mm thick (outer to outer). The width and span of SFCC floor panel is 685 mm and 860 mm respectively. The thickness of SFCC floor panel is similar to wall panel thickness (130 mm). The width of SFCC connecting panel is similar to that of SFCC wall panel and is 400 mm high. The thickness of SFCC connecting panel is 126 mm (outer to outer), which is less by 4 mm than the SFCC wall panel thickness and enables the SFCC connecting panel to fit exactly into SFCC wall panel. This connecting SFCC panel is inserted into the bottom portion of the top SFCC wall panel for 200 mm and the remaining 200 mm is inserted into the top portion of bottom SFCC wall panel to have a composite connection and are connected by using bolts. The entire SFCC wall panel is then connected to the SFCC floor panel by using M16 bolts and ISA (100 mm × 100 mm × 8 mm) angle arrangement as shown in Figure 6.1. The base of SFCC wall panel is embedded inside the concrete block and the base concrete block is then anchored to the reaction floor by using tie rods while testing. The connection between sheets in SFCC wall, floor and connecting panels are achieved by using 8 mm dia through-through mild steel studs of fy-250 MPa grade. The panel-to-panel connections are provided with16 mm dia HTS bolts of grade 8.8. To accommodate the 16 mm dia bolts, 20.5 mm dia holes are made in the sheet for the purpose of inserting hollow steel pipes to create holes during casting. The configuration, arrangement and the elevation drawing of bottom SFCC wall panel, top SFCC wall panel, SFCC floor panel, SFCC connecting panel and the provisions for holes are shown in Figures 6.2 to 6.5 respectively. In the bottom SFCC wall
panel, both the sheets are connected by using 14 nos. of 8 mm dia studs. The studs have stepped ends with dia of 7 mm and hence 7 mm dia holes are provided in the sheet (trough portion) at spacing as shown in Figure 6.2. At the bottom portion of the panel, 8 nos. of 20.5 mm dia holes are provided in the trough portion for inserting hollow pipes to accommodate 16 mm HTS bolts. The top portion of the bottom wall panel are provided with 6 nos. of 20.5 mm holes in the crest portion (@113 mm from the top edge) to accommodate hollow pipes and 16 mm HTS bolts for connecting the bottom SFCC wall panel to SFCC connecting panel.

![Geometrical details of bottom SFCC wall panel](image)

**Figure 6.2 Geometrical details of bottom SFCC wall panel**
Similarly the sheets in top SFCC wall panel are connected by using 16 nos. of 8 mm dia mild steel studs and the provision for holes with the respective spacing are shown in Figure 6.3. At the distance of 113 mm from the bottom edge of top wall panel, 6 nos. of 20.5 mm holes are provided (crest portion) to accommodate 16 mm HTS bolts for connecting the top SFCC wall panel to the SFCC connecting panel. The top portion of the top SFCC wall panel is provided with 8 nos. of 20.5 mm dia holes (crest portion) to accommodate 16 mm HTS studs for connecting the top SFCC wall panel to the loading plate.

Figure 6.3 Geometrical details of top SFCC wall panel
The dimensions of SFCC floor panel is 685 mm × 860 mm × 130 mm. In SFCC floor panel, the sheets are connected by using 12 nos. of 8 mm studs. Hence 12 nos. of 7 mm dia holes are provided at the spacing as shown in Figure 6.4. At a distance of 45 mm from both the edges of sheet, 6 nos. of 20.5 mm holes are provided in the crest portion to accommodate 16 mm dia HTS bolts, which are used to connect the SFCC floor panel to SFCC wall panel by means of ISA angles of size (100 mm × 100 mm × 8 mm).

Figure 6.4 Geometrical details of SFCC floor panel
In SFCC connecting panel, the connection between sheets are achieved by 4 nos. of 8 mm dia mild steel studs and 12 nos. of 16 mm HTS bolts. Hence 4 nos. 7 mm dia holes and 12 nos. of 20.5 mm dia holes are drilled in the crest portion of sheets at a distance of 85 mm from both the edges as shown in Figure 6.5. The spacing between holes in the length direction is 230 mm. The fabricated sheets are shown in Figure 6.6.

![Figure 6.5 Geometrical details of SFCC connecting panel](image)

Three different types of hollow pipes are used and are given the designations as PIPE 1, PIPE 2, and PIPE 3. The locations of the pipe used are shown in Figures. 6.2 to 6.5. The geometrical details of the hollow pipes are given in Figure 6.7. The hollow pipe, PIPE 1 is stepped at the distance of 52.4 mm and have threaded ends of length 28 mm for placing the nuts and washer (Figure 6.8). PIPE 2 has smaller stepped ends of length 6.3 mm (Figure 6.8) and is used in SFCC connecting panel to maintain the spacing between the sheets and are retained after casting for creating the holes. PIPE 3 also has
smaller stepped ends of 3.5 mm and is used in SFCC floor panel. This pipe is also retained after casting and the purpose is to maintain the spacing between sheets and to create holes. The geometrical details of the stud is given in Figure 6.9. The diameter of the stud is 8 mm and is stepped to 7 mm at the spacing of 56.4 mm and have threaded ends at both the edges (Figure 6.10) to accommodate nuts and washers. The stepped ends at both the edges prevent the inward movement of sheets and maintain the desired spacing. The mild steel ISA angle of size (100 mm x 100 mm x 8 mm) and 700 mm length with \( f_y = 250 \text{ MPa} \) and \( f_u = 420 \text{ MPa} \) is used to connect the SFCC wall panel to floor panel. The mechanical properties of steel sheet presented in Section 5.4 of Chapter 5 is applicable for the present study.

a. SFCC wall panel  
b. SFCC floor panel  
c. SFCC connecting panel

Figure 6.6 Fabricated sheets for the components
Figure 6.7 Geometrical details of hollow pipes

Figure 6.8 Fabricated hollow pipes

Figure 6.9 Geometrical details of stud

Figure 6.10 Fabricated mild steel studs
6.2.2 Assembly of SFCC Wall and Floor panels

The inner surface of all the sheets are wiped clean from dust with the cotton waste and the excess oil/grease is removed using acetone. Similarly all the washers, nuts, bolts, studs and hollow pipes are cleaned using acetone. First the SFCC wall panel is assembled. The step by step assembling of SFCC wall and floor panels is illustrated in the photographs shown in Figure 6.11. Initially one of the sheets of bottom SFCC wall panel is placed on a levelled elevated wooden table. The hollow pipes (8 nos.) with stepped threaded ends (PIPE 1) are inserted in the bottom portion of the bottom SFCC wall panel (Figure 6.11a). The studs are inserted in the holes of the first sheet. After placing of the second sheet (Figure 6.11b), the studs are slightly tightened by using nuts and washers (Figure 6.11c). Then the top and bottom sheets of the SFCC connecting panel is inserted inside the top portion of the assembled bottom SFCC wall panel for a length of 200 mm (Figure 6.11d). Six numbers of hollow pipes (PIPE 2) are inserted inside the connecting panel and are kept just touching the holes (Figure 6.11e). On the projecting portion of the connecting SFCC panel, one of the sheets of top SFCC wall panel is placed (Figure 6.11f). The hollow pipes are inserted in the portion of the SFCC connecting panel, which is in contact with the top SFCC wall panel. Fully threaded 16 mm dia mild steel rods are inserted inside the hollow pipes (Figure 6.11g) in SFCC connecting panel and the nuts are slightly tightened against the washer placed in the sheets of bottom and top SFCC wall panels. The view of hollow pipes in the SFCC connecting panel is shown in Figure 6.11h. Then the other portions of the sheet in the top SFCC wall panel are connected by using mild steel studs and nuts. The assembled top and bottom SFCC wall panel by using SFCC connecting panel is shown in Figure 6.11i. The assembled SFCC floor panel is shown in Figure 6.12. The hollow pipes are used to create through holes in the panel and will be retained inside. All the studs and hollow pipes are equally snug tightened on both the sides. The
exterior of the specimens are painted by using red oxide to prevent the specimens from rusting. In this study, to facilitate the casting process, the top and bottom SFCC wall panels with the SFCC connecting panel are assembled together and then casting is carried out step by step.

a. Studs and hollow pipes inserted in the bottom SFCC wall panel

b. Placement of second sheet of bottom SFCC wall panel

c. Connecting the sheets of bottom SFCC wall panel with washers and nuts

Figure 6.11 Assembling of SFCC wall panels (contd...)
d. Connecting panel inserted into the bottom SFCC wall panel

e. Hollow pipes inserted into SFCC connecting panel

f. Connecting the top SFCC wall panel with sheet of SFCC connecting panel

Figure 6.11 Assembling of SFCC wall panels (contd…)

g. Insertion of fully threaded mild steel rods inside the hollow pipe

h. View of hollow pipes in SFCC connecting panel

i. Assembled SFCC wall panel (top and bottom SFCC wall panels using SFCC connecting panel)

Figure 6.11 Assembling of SFCC wall panels
6.3 CASTING OF SFCC WALL, FLOOR AND CONNECTING PANEL

The mix ratio and the procedure for preparing FC is explained in Section 3.4 of Chapter 3. The fresh density of FC achieved is 1120 kg/m$^3$. The SFCC wall and floor panels are placed on a levelled surface and are provided intermediate shuttering using tie rod assembly along the length to prevent bulging. In this study, the entire SFCC wall panel (G+1) with SFCC connecting panel is assembled together and the casting is carried out sequentially. The specimens ready for casting are shown in Figure 6.13. The bottom SFCC wall panel, SFCC connecting panel and SFCC top wall panel are cast on three different days with an interval of about 24 hrs to prior casting. The sequence of casting is depicted in Figure 6.14. The total height of SFCC wall panel for G+1 storey is 2100 mm. The individual height of SFCC wall panel is 1050 mm. The height of SFCC connecting panel is 400 mm, out of which 200 mm is inserted into the bottom most uncast portion of top wall
panel and the another 200 mm into the top most uncast portion of bottom wall panel. First the casting is carried out for the bottom SFCC wall panel upto the height of 850 mm. After 24 hours of casting, the casting is continued in the SFCC connecting panel for a height of 400 mm. Again after 24 hours of casting SFCC connecting panel, the top SFCC wall panel is cast and SFCC floor panel is cast separately. FC is manually poured into the panel as shown in Figure 6.15. After casting of the SFCC panels, a concrete block of size (1100 mm × 300 mm) is cast around the base of bottom SFCC wall panel for a height of 285 mm using M35 concrete with the mix proportion as given in Table 5.2 of Chapter 5. The wooden formworks are fabricated and assembled around the panel. Two steel reinforcement grids consisting of 2 nos. of 12 mm dia main rods and 7 nos. of 6 mm dia cross ties are fabricated and placed on both the sides of SFCC wall panel (Figure 6.16) in the wooden formwork. Two steel hollow tubes of 50 mm dia are fabricated and placed at 1000 mm c/c as shown in Figure 6.17 to provide through holes in the block. The top of the hollow steel tube is plugged with nylon to prevent accidental falling of concrete into the tubes. The concrete block with holes at 1000 mm c/c is used to anchor the entire SFCC wall panel to the reaction floor by using tie rods. After 24 hours of casting, the formwork is demoulded and the concrete block is water cured for 28 days. The finished panel with the base concrete block is shown in Figure 6.18. FC cubes of size (100 mm × 100 mm × 100 mm) and cylinders of size 100 mm dia and 200 mm length are cast from each batch used for casting the SFCC wall, connecting and floor panels to check their strength on the day of testing the panels. The cubes and cylinders are demoulded after 24 hours and are covered with plastic sheets. SFCC wall and floor panels are covered by polythene sheets for 28 days. Concrete cubes and cylinders made of the material used for the concrete block are also cast and cured in water for 28 days. The experiment is carried out on the 48th day of casting the panels. The average dry density of FC on the day of testing is found to be 1050 kg/m³. The cubes and cylinders are tested from each batch.
for their compressive and split tensile strength on the day of testing the connection assembly. The material properties of FC and base concrete block are presented in Table 6.1.

Figure 6.13 Specimens ready for casting
Figure 6.14 Sequence of casting
Figure 6.15 Manual pouring of FC

Figure 6.16 Placing of reinforcement in the wooden formwork
Figure 6.17 Placing of steel circular tubes at 1000 mm c/c

Figure 6.18 Finished panels with concrete block
Table 6.1  Properties of FC for density 1050 kg/m$^3$ and base concrete block

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$f_{ck}$ (MPa) (48 days)</th>
<th>$f_t$ (MPa) (48 days)</th>
<th>Modulus of elasticity $E$ (MPa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cube</td>
<td>Cylinder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom wall panel</td>
<td>5.36</td>
<td>0.78</td>
<td>4060</td>
<td>0.23</td>
</tr>
<tr>
<td>Connecting panel</td>
<td>5.31</td>
<td>0.75</td>
<td>4068</td>
<td>0.20</td>
</tr>
<tr>
<td>Top wall panel and floor panel</td>
<td>5.30</td>
<td>0.72</td>
<td>4182</td>
<td>0.21</td>
</tr>
<tr>
<td>Base concrete block (M35)</td>
<td>53.21</td>
<td>3.45</td>
<td>36,473</td>
<td>0.2</td>
</tr>
</tbody>
</table>

6.4  ASSEMBLY OF EXPERIMENTAL SET-UP FOR STUDIES ON CONNECTION ASSEMBLY

The schematic diagram of the experimental set-up is shown in Figure 6.19. The centre-to-centre distance between SFCC wall panels is 1000 mm. The step-by-step assembly of the experimental set-up is depicted in Figures. 6.20 a-j. The reaction frame consists of beam and columns. The reaction floor below the frame consists of grid of holes of dia 72 mm at every 500 mm intervals. These holes are utilized to fix the wall panel to the reaction floor to apply compression loading. The base of SFCC wall panel is embedded inside the concrete block of size (1100 mm × 300 mm) and 285 mm high. The concrete block contains holes of dia 50 mm at 1000 mm c/c. One of the legs of ISA angle of size (100 mm × 100 mm × 8 mm) is attached to the bottom SFCC wall panels by using 6 nos. of 16 mm dia HTS bolts (Figure 6.20a). The individually cast panels are transported to the experimental floor and then placed exactly to match the holes in the reaction floor (Figure 6.20b). SFCC floor panel is lifted and placed on the bottom angles (Figure 6.20c) and then the top angles are placed above SFCC floor panel. SFCC floor panel is connected to one of the legs of top angle and
bottom angle by means of 6 nos. of 16 mm dia HTS bolts (Figure 6.20d). The other leg of the top angles are connected to the top SFCC wall panel by using 6 nos. of 16 mm dia HTS bolts. A loading plate of size \(700 \text{ mm} \times 330 \text{ mm}\) and 32 mm thick is placed on the top of both the top SFCC wall panels (Figure 6.20e) so as to apply axial compression loading. A tie rod of length 2 m is inserted into the concrete block and reaction floor and is fully tightened (Figure 6.20f). The loading plate is connected to SFCC wall panel by using angle and bolt arrangement. On top of the loading plate, two guide channels are placed on either sides of the actuator and are connected to the columns of the reacting frame by using bolts (Figure 6.20f). The guide channels are also connected to the loading plate by using bolts to arrest the lateral movement of the walls during loading. To apply axial compression loading, a bottle neck jack with load cell arrangement on the top is placed at the centre of the loading plate (Figure 6.20g). A box beam with holes at 1000 mm c/c is inserted from the top of the tie rod and is placed just touching the load cell (Figure 6.20h). The bottle neck jack is adjusted so as to apply constant axial compression load of 2 tons, which is monitored from the load cell readings. A stiffened I-beam of width 150 mm and 600 mm high is placed at the middle of the floor panel (Figure 6.20i) and concentrated load is applied at top of the beam. The cement mortar is filled in the hollow spaces in the profiled steel sheet below the I-beam for uniform distribution of load along the width of SFCC floor panel. The specimen is instrumented with strain gauges, LVDT and dial gauges and the assembled experimental set-up with instrumentation is shown in Figure 6.20j. Strain gauges are pasted in SFCC floor panel to measure the bending strains. Out of six gauges, three gauges \((S1, S2, S3)\) are pasted on the compression side (Figure 6.21) of SFCC floor panel and other three gauges \((S4, S5, S6)\) on the tension side (Figure 6.22) of the SFCC floor panel. Six strain gauges \((A1, A2, A3, A4, A5, A6)\) are pasted on the top angle (Figure 6.23) and 6 strain gauges \((A7, A8, A9, A10, A11, A12)\) are pasted on the bottom angle (Figure 6.24). Two strain gauges are pasted in SFCC wall panel \((W1, W2, W3)\) close to SFCC connecting panel (Figures 6.23 & 6.24)
to measure the axial strain. Four dial gauges (D1, D2, D3, D4) are placed in the SFCC connecting panel of both SFCC wall panels to study the lateral deflection of the connection and their locations are shown in Figures 6.25 and 6.26. To measure the deflection of SFCC floor panel, one LVDT (L3) is placed below the middle of the SFCC floor panel. Two LVDT’s (L1, L3) are placed below the left and right bottom angles to measure the angle deflection. The location of LVDT’s is shown in Figure 6.27. The data from all the instrumentation are acquired through a computer aided data acquisition system. A constant axial load of 2 ton is applied on the top of SFCC wall panel through the bottle neck and tie rod assembly. With the constant axial load, a concentrated load is applied in the middle of SFCC floor panel through a hydraulic actuator at a rate of 0.5 mm/min in displacement controlled manner.

All dimensions are in mm

**Figure 6.19** Schematic diagram of experimental set-up for studies on connection assembly
a. Fixing of ISA angles at the joint by using HTS bolts in bottom SFCC wall panel

b. Placing of panels with holes in the concrete block over the matching holes in reaction floor

Figure 6.20 Step by step assembling of experimental set-up for studies on connection assembly (contd…)
c. Placing of SFCC floor panel over the ISA angle

d. Placing of HTS bolts to connect angle to SFCC floor panel

Figure 6.20 Step by step assembling of experimental set-up for studies on connection assembly (contd…)
e. Placing of loading plate on top of SFCC wall panel and connection by means of angle and bolts

f. Fixing of guide channels on top of the loading plate to prevent lateral movement and insertion of tie rods of length 3 m in the concrete block

Figure 6.20 Step by step assembling of experimental set-up for studies on connection assembly (contd…)
g. Placing of bottle neck jack and load cell on top of the loading plate

h. Insertion of box beam inside the tie rod to touch the load cell

i. Placing of stiffened I beam at the centre of floor for load application

Figure 6.20  Step by step assembling of experimental set-up for studies on connection assembly (contd…)
j. Assembled specimen with instrumentation

Figure 6.20  Step by step assembling of experimental set-up for studies on connection assembly
Figure 6.21 Location of strain gauges in compression face of SFCC floor panel

Figure 6.22 Location of strain gauges in tension face of SFCC floor panel
Figure 6.23  Location of strain gauges on top angle (A1-A6) and SFCC wall panel (W1, W2)

Figure 6.24 Location of strain gauges (A7-A12) on bottom angle

Figure 6.25  Location of dial gauges (D1, D2) and strain gauge W3 on left SFCC wall panel
Figure 6.26 Location of dial gauges (D3, D4) on right SFCC wall panel

Figure 6.27 Location of LVDTs in floor panel
6.5 RESULTS AND DISCUSSION ON CONNECTION ASSEMBLY

The test specimen resembles the beam-column joint in a steel framed building. The deformation of test specimen at the failure stage is shown in Figures 6.28 to 6.32. From the recorded data, the load-deflection behaviour of SFCC floor panel and the connection assembly are plotted. The load versus mid-span deflection of SFCC floor panel is plotted in Figure 6.33. The test results exhibited nonlinear behaviour of connection assembly. Initially, the load is carried by the FC in the SFCC floor panel. The load-deflection response is linear up to 4.96 kN load and due to release of bond, a slight slip is observed. Then again the behaviour is linear up to 18.63 kN load and a slight slip is observed due to the formation of first tensile crack in the exposed portions of FC in SFCC floor panel. This is followed by number of hair line cracks occurred at the loads of 17 kN, 22 kN (Figure 6.29) in the exposed portions of FC. The first tensile crack is noticed below the point of loading followed by subsequent cracks in the SFCC floor panel. The cracks in the edge portion of SFCC floor panel along with sheet debonding below loading point is observed at 34 kN. The punching of steel sheet near the loading point is observed at 40 kN load followed by a flexure crack in the middle of SFCC floor panel inclined at 45 degrees. The crack develops and reaches the top compression face at 76 kN. On further loading, the angle leg started yielding at 80 kN and transferred the load to SFCC connecting panel. Due to this, a crack has initiated at 104 kN in the exposed FC portion of SFCC wall panel on one of the sides followed by few cracks on both the sides (Figure 6.30). After this, the loading rate is increased to 3 mm/min. Due to the use of higher thickness of angle and larger dia of bolts in the connection assembly, the failure is by excessive deflection of SFCC floor panel (Figure 6.31) at the load of 107 kN. The reduction in load-deflection response is observed beyond the failure load and the experiment is terminated due to the
excessive deflection (90 mm) of SFCC floor panel. No visible lateral deflection of the sheet or buckling is observed in the SFCC connecting panel (Figure 6.32).

The deflection of bottom angles on both the sides of connection assembly are measured by using LVDT’s and the corresponding load-deflection behaviour is plotted in Figure 6.34. Maximum deflection of around 7.63 mm is observed in the angle at failure. The strain gauge readings (A1 to A12) observed in the tension and compression side angles versus load is plotted in Figure 6.35. The maximum tensile strain of 2500 microns is observed in the top angle and compression strain of 1200 microns is observed in the bottom angle. The strain values indicate that the angle has just yielded at the failure stage. The load versus lateral deflection of SFCC connecting panel plotted in Figure 6.36 shows the negligible lateral deflection of 2 mm enabling the connection to maximize the loading on SFCC floor panel. The moment-rotation behaviour of angle in the connection assembly and the floor panel plotted in Figure 6.37 shows nominal angle rotation of around 3.5 degrees as compared to the floor panel rotation of 13 degrees. The deflection, strain readings and rotation values confirm the rigid behaviour of connection assembly, which prevents the further yielding of angles. The load versus strain behaviour of the sheet in SFCC floor panel is plotted in Figure 6.38. The strain gauges S4, S5, S6 placed in the tension side of sheet recorded the maximum tensile strain of 24,500 microns, which shows the full plastic yielding of the sheet. SFCC floor panel behaves as a fixed slab with plastic hinge formation in the supports and mid-span. From the simply supported floor panel tests conducted and reported in Chapter 4, the failure load for fixed boundary condition at wall-floor panel interface can be computed as 100 kN, which matches well with the experimental value. The experimental failure load can be accurately assessed using the simplified model suggested
in Chapter 4 with the assumption of plastic hinge formation at ends and in the middle.

Figure 6.28 Deformed view of the specimen at failure stage

Figure 6.29 Crack initiation in SFCC floor panel
Figure 6.30 Crack formation in SFCC floor and wall panel

Figure 6.31 Deformed view of SFCC floor panel
Figure 6.32 Lateral deflection of SFCC wall panel

Figure 6.33 Load versus mid-span deflection of SFCC floor panel

![Graph](image-url)
Figure 6.34 Load versus deflection in angle

Figure 6.35 Load versus strain behaviour in angles
Figure 6.36 Load versus lateral deflection of SFCC wall panel

Figure 6.37 Moment-rotation behaviour of angle and floor panel
Figure 6.38 Load versus strain behaviour of SFCC floor panel

The proposed connection assembly resembles the top and seat angle connection used to join the beam with column and hence the connection deformation can be idealized as shown in Figure 6.39.

Figure 6.39 Idealized deformation of the connection assembly (Source: Akbar Pirmoz et al. 2009)
To calculate the plastic moment capacity of the connection $M_{pc}$, the top angle plastic axial force ($V_p$ in Figure. 6.39) is needed. The plastic axial force of the angle $V_p$ can be estimated using a simple plastic analysis as below:

$$V_p = \frac{2M_{p\text{-angle}}}{L_{hinge}}$$  \hspace{1cm} (6.1)$$

$M_{p\text{-angle}}$ in Equation (6.1) is the plastic moment capacity of the angle leg and can be calculated using Equation (6.2) and $L_{hinge}$ is the distance between two plastic hinges (Figure 6.39). The 2 in the numerator is due to the dual plastic hinges shown in Figure 6.39.

$$M_{p\text{-angle}} = \frac{f_{ya} b_a t^2}{4}$$  \hspace{1cm} (6.2)$$

where $f_{ya}$ is the yield strength of angle, $b_a$ is the width of angle, $t_a$ is the thickness of angle. Using Equation (6.1), the $V_p$ value is estimated as 176.5 kN and the moment capacity of the angle connection is estimated as 22.95 kNm. The moment capacity of SFCC floor panel obtained from Chapter 4 is 10.9 kNm. Since the moment capacity of angle connection is higher than the floor panel capacity, the failure has occurred in SFCC floor panel. From the experimental studies, the proposed connection assembly is found to have performed well. Optimization of the connection assembly can be investigated in terms of the size of angle, number and diameter of bolts.

6.6 FEA OF CONNECTION ASSEMBLY FOR SFCC PANELS

FE model consists of five parts such as top SFCC wall panel, bottom SFCC wall panel, SFCC connecting panel, SFCC floor panel and angles. The problem is symmetric and hence only half symmetric model is considered as shown in Figure 6.40. The steel sheet of SFCC connecting panel is not modeled separately, instead the bottom 200 mm portion of the top
SFCC wall panel and top 200 mm portion of the bottom SFCC wall is assigned double the thickness of sheet (i.e. 1.6 mm). The mesh comprises 8-node brick element (C3D8R) for FC core, angles and 4-node shell elements (S4R) for the steel sheet. FE model is incorporated with contact surface to simulate the interfaces between 1. profiled steel sheets and concrete core in top, bottom SFCC wall panel, floor panel and connecting panel 2. angle and profiled sheet sheet 3. bottom SFCC wall FC and connecting panel FC 4. top SFCC wall FC and connecting panel FC. The penalty friction contact option for tangential contact behaviour with appropriate friction values for various mating surfaces and hard contact for normal behaviour is utilized. HSFG bolts and mild steel studs are not modeled and the two nodes are tied together at the locations of bolts/studs by using node tie constraints to simulate the effect of bolts/studs. At the locations of bolts/studs, node tie constraint is used to simulate the connectivity between sheet and FC. The profiled steel sheets are tied to FC at 72 nodes (at the location of 36 nos. of 8 mm dia studs) and 64 nodes (at the location of 32 nos. of 16 mm dia HTS bolts) as shown in Figure 6.40a. Each angle in the connection assembly is connected to the SFCC wall panel by using 6 nos. of 16 mm bolts and node tie constraints are used to simulate the effect of bolts (Figure 6.40b) in both the angles. In order to take into account of the concrete confinement due to 36 studs/32 bolts, 136 node restraints are utilized to restrain the nodes against out-of-plane displacement. The out-of-plane displacement of the top surface of top SFCC wall panel is restrained to avoid the lateral movement of SFCC wall panel. The half symmetric boundary condition is assigned at the mid-span of SFCC floor panel. In experiment, the base of bottom SFCC wall panel is embedded inside the concrete block of 285 mm depth to provide fixed base and is simulated in FE model by restraining all the three displacement and rotation degrees of freedom (DOF) at the base as shown in Figure 6.41. The loading is achieved in two steps. In the first step, the constant axial loading of 2 tons is applied on both the steel and FC. In the second step, the loading is achieved by assigning
a prescribed displacement at the mid-span of SFCC floor panel (along the half symmetry). The material models used for steel sheet and FC core explained in Section 3.6.2 of Chapter 3 are adopted. The geometric/material parameters of FC, profiled steel sheet and angle are used in FE model to simulate the behaviour of test specimen. The material properties of steel sheet (Table 5.3 of Chapter 5) and FC core presented in Table 6.1 obtained from the experiments are utilized in the respective material model.

Figure 6.40 Half symmetric FE model for studies on connection assembly
Figure 6.41 Node tie constraints between 1 a. sheet and FC b. angle to sheet

Figure 6.42 Loading and boundary conditions of FE model for studies on connection assembly
The stress-strain relation of ISA angle steel is represented by a tri-linear constitutive model as shown in Figure 6.43. Final arrangement of FE mesh is decided based upon the computer time, convergence of solution and by comparison with the experiment results. The sizes of meshes are controlled between the components of connection to enable surface-to-surface contacts and easy convergence. Nonlinearity that arises from large displacement effects, material and from boundary such as contact and friction are also considered in the present study.

6.6.1 Comparison of Results for Studies on Connection Assembly

The comparison of FEA results with that of experimental results is made on the following three aspects.

- Failure of the connection
- Deformation and stress distribution in the connection
- Load-deflection behaviour

The deformed shape of test specimen from FEA at the ultimate stage is shown in Figure 6.43. Load is applied at the top of SFCC floor panel in the mid-span.
which causes compression at the top sheet and tension at the bottom sheet. The failure modes are compared with the experimental observation of failures to validate FE model (Figure 6.44). As explained previously (Section 6.5) due to the rigidity of the connecting angle and larger diameter bolts used in the experiment, the ultimate specimen failure resulted from the plastic deformation of SFCC floor panel and nominal connection rotation is observed. The local buckling of SFCC floor panel compression side steel sheet close to the connecting angle is observed at the ultimate stage similar to the experiment. The failure mode of FE model specimen is due to the cracking of FC in SFCC floor panel followed by the excessive mid-span deflection of SFCC floor panel similar to those observed in experiments. The failure mode and the deformation of the specimen predicted by FE model is found to be agreeing well with the experimental observations. The von Mises stress distribution superposed on deformation suffered by the various components of the specimen is shown in Figure 6.45. From the von Mises stress pattern, it is observed that the maximum stress of 358 MPa is observed in the floor panel sheet (Figure 6.45a) at the location of load application, which shows the plastic yielding of steel sheet. The stress values in the ISA angle shows that the tension angle has just yielded with the maximum stress value of 278 MPa (Figure 6.45c). Also the stress values observed in the steel sheet at the connection between bottom wall to top wall panel (Figures 6.45d,e) indicate the stress values of 270 MPa, which is just above the yield value. Higher stress is observed in the bottom SFCC wall panel FC compared to the top SFCC wall panel FC (Figures 6.45f,g). Nominal stress values are observed in the SFCC connecting panel FC (Figure 6.45h) due to the confinement by steel sheet thickness of 1.6 mm. The comparison of load versus mid-span floor deflection is shown in Figure 6.46. To a large extent, FE model is capable of predicting the experimental responses. The initial stiffness portion of the curve has a good match with the experiment results. The kinks representing drop in load in the experimental load–deflection
response are possibly due to the formation of major cracks in the FC core, which could not be captured by FE model. The maximum load capacity of the connection assembly predicted by FE model is 127 kN compared to 109 kN from the experiment, which is 17% higher. The connection deflection is measured by using LVDT in the experiment and is compared with the deflection in angle obtained from FEA (Figure 6.47).
The comparison shows that the maximum deflection obtained in the connection assembly by FEA is 9.9 mm which is 5.5% more than the experimental value of 6.4 mm. This overestimation could be due to the utilization of node to node tie constraints to simulate the behaviour of bolts in the connection region rather than the detailed modeling of the holes, bolts and nuts and the non-incorporation of damage parameters in the material model.
However, due to this simplifications in FE modeling, the failure load and connection deflection is higher than those obtained from the experiment.

Figure 6.46 Von Mises stress pattern superposed on deformation of various parts of the specimen (contd…)
Figure 6.46 Von Mises stress pattern superposed on deformation on various parts of the specimen (contd...)
f. Bottom SFCC wall panel FC

g. Top SFCC wall panel FC

Figure 6.46 Von Mises stress pattern showing the deformation on various parts of the specimen (Contd…)
h. SFCC Connecting panel FC

Figure 6.47 Von Mises stress pattern showing the deformation on various parts of the specimen

Figure 6.48 Comparison of load-mid span SFCC floor panel deflection response
In this chapter, the details of proposed connection assembly to connect SFCC wall-to-wall panels and SFCC wall-to-floor panels are presented. Experimental and numerical investigations have been conducted to assess the behaviour of proposed connection assembly under combined axial and bending loads. The plastic moment capacity of the connection assembly is higher than the floor panel capacity and hence the specimen failed due to excessive plastic deformation of SFCC floor panel. Based on the experiment results, the proposed connection assembly is found to have effectively transferred the forces. The simplified FE model could simulate the experimental behaviour in terms of load-deflection response and the failure modes with reasonable accuracy.