CHAPTER II

EXPERIMENTAL PROGRAMME

11.1. Object of tests:

The object of the tests in part II is to study the behaviour of R.C. columns with confined concrete under axial and eccentric loading (uniaxial and biaxial).

The behaviour of R.C. columns is studied with reference to the following:

a) Ultimate loads and curvatures

b) Ultimate strains in concrete

c) Yield curvatures in columns failing in tension.

11.2. Outline of experimental programme:

The outline of experimental programme presented in part II is given in Table 11.1.

Table 11.1

<table>
<thead>
<tr>
<th>No.</th>
<th>Shape</th>
<th>Size, cm.</th>
<th>Height, cm.</th>
<th>Type of loading</th>
<th>No. of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rectangular</td>
<td>12x18</td>
<td>120</td>
<td>Uniaxial eccentric loading</td>
<td>73</td>
</tr>
<tr>
<td>2</td>
<td>Square</td>
<td>15x15</td>
<td>150</td>
<td>Biaxial eccentric loading</td>
<td>24</td>
</tr>
</tbody>
</table>

The details of test specimens are given in Table 11.2.
11.3. Design of test specimens:

The sizes of the columns are fixed after taking into account the following points:

(1) The weight of a column specimen should be limited so that it can be handled manually as there is no overhead crane in the laboratory.

(2) The Tinius Olson Testing Machine which has been used for testing all the column specimens can accommodate only a maximum height of 180 cm.

(3) The slenderness ratio proposed is 10.

11.4. Details of Test Specimens:

(A) Rectangular columns under uniaxial eccentric loading:

Tests were conducted on 73 rectangular columns of 12 cm x 13 cm x 120 cm under uniaxial eccentricity consisting of 13 series from A to L as detailed in Table 11.2. Mild steel was used for longitudinal reinforcement and for binders in all the specimens. In the series "I, J, K, L", rectangular helicals and in the remaining series rectangular ties were used. The concrete cover over the binders was varied from 5 mm to 10 mm. The typical cross section and details of reinforcement are shown in Fig. 11.1.

(B) Square columns under biaxially eccentric loading:

Tests were conducted on 24 columns of 15 x 15 x 150 cm
under biaxially eccentric loading, the details of which are given in Table 11.3. Mild steel was used for longitudinal reinforcement and for binders. Only square ties were used as binders in all the specimens. The eccentric loading was applied along one of the diagonals of the square cross-section. The typical cross-section and the details of the reinforcement in a column are shown in Fig. 11.2.

11.5. Material used:

(a) Cement, aggregate and water: These materials were the same as described in the Chapter-3.

(b) Steel: The mechanical properties of steel used as longitudinal reinforcement and binders in the column specimens are given in Table 11.4. The typical stress strain curve for steel and binders are shown in Fig. 11.3 and Fig. 11.4.
FIG 11-1  RECTANGULAR SECTION WITH REINFORCEMENT DETAILS.
$f_y = 2040 \text{ kg/cm}^2$

$\epsilon_y = 0.001$

**Figure 3** Typical Stress-Strain Curve for 10mm ø M.S. Bar (Longitudinal Reinforcement)
Fig: 8 - Typical Stress-Strain Curve for 6 mm MS Bar.

$\sigma_y = 4750 \text{ kg/cm}^2$

$\varepsilon_y = 0.0022$
TABLE 11.3

Details of square columns tested under biaxially eccentric loading.

Size: 15 x 15 x 150 cm.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Designation</th>
<th>No. of Specimen</th>
<th>Form of Columns</th>
<th>Percenterage of the Cover Binder</th>
<th>Pitch of the Binder</th>
<th>Dia. of Thicker Steel</th>
<th>Cms. of Cover Binder</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>BE1, BE2</td>
<td>2</td>
<td>Square Ties</td>
<td>2.79</td>
<td>4</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>2.</td>
<td>BE3, BE4</td>
<td>2</td>
<td></td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>3.</td>
<td>BE5, BE6, BE7, BE8</td>
<td>4</td>
<td></td>
<td>4</td>
<td>7</td>
<td>25</td>
<td>3, 4, 5</td>
</tr>
<tr>
<td>4.</td>
<td>BE9, BE10, BE11, BE12</td>
<td>4</td>
<td></td>
<td>4</td>
<td>7</td>
<td>15</td>
<td>4.5, 8, 12</td>
</tr>
<tr>
<td>5.</td>
<td>BE13, BE14, BE15, LE16</td>
<td>4</td>
<td></td>
<td>2.84</td>
<td>4</td>
<td>7</td>
<td>7.5</td>
</tr>
<tr>
<td>6.</td>
<td>BE17, BE18, BE19, BE20</td>
<td>4</td>
<td></td>
<td>2.84</td>
<td>5</td>
<td>10.1</td>
<td>4.5</td>
</tr>
<tr>
<td>7.</td>
<td>BE21, BE22, BE23, BE24</td>
<td>4</td>
<td></td>
<td>2.90</td>
<td>4</td>
<td>8.15</td>
<td>4.3</td>
</tr>
</tbody>
</table>

==----------------------------------------------------------------------------------------------
### Table 11.4

**Mechanical Properties of steel used in Eccentrically Loaded Columns**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Series</th>
<th>Longitudinal Reinforcement</th>
<th>Binder Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Diameter of bars (mm)</td>
<td>Yield stress (kg/cm²)</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>I</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>J</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>K</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>L</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>E</td>
<td>15.11</td>
<td>4075</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>15.44</td>
<td>3240</td>
</tr>
<tr>
<td>12</td>
<td>GM</td>
<td>15.16</td>
<td>4300</td>
</tr>
<tr>
<td>13</td>
<td>GO</td>
<td>15.40</td>
<td>3350</td>
</tr>
</tbody>
</table>
\[15 \times 15 \times 150 \text{ cm square columns. (Biaxial Eccentricity)}\]

| 14. | B31, B32 | 10 | 2000 | 0.0011 | 7 | 3600 | 0.0018 |
| 15. | B33, B34 | 10 | " | 7 | " | " | " |
| 16. | B5 to B8 | 10 | " | 7 | " | " | " |
| 17. | B6 to B12 | 10 | " | 7 | " | " | " |
| 18. | B13 to B16 | 10.1 | 2030 | 0.0010 | 7.0 | 3360 | 0.00175 |
| 19. | B17 to B20 | 10.1 | 2080 | 0.0010 | 10.1 | 2080 | 0.001 |
| 20. | B21 to B24 | 10.2 | 2000 | 0.0010 | 8.15 | 2000 | 0.001 |

\[\text{Table:}\]

**11.6. Fabrication of longitudinal reinforcement, helicals & Ties:**

The ties and rectangular helicals were prepared with a bonding tool. The longitudinal reinforcement was placed inside the ties or helicals and was tied to them with bonding wire before the reinforcement cage was placed in the moulds. As the column capitals have to transfer the eccentric load and the corresponding moment to the prismatic shaft of the column, suitable care was taken to connect the reinforcement in the bracket to the main reinforcement of
the column to avoid any premature failure of the bracket as shown in Fig. 11.1, 11.2, 11.5, 11.6.

11.7: Preparation of test specimens:

(a) Moulds: The moulds for all the columns were made of teak wood planks of 25 mm thickness as shown in Fig. 11.8.

The moulds for square columns tested under biaxially eccentric loading were of two types. For large eccentricities two brackets were provided at each end and for small eccentricities the two ends of the moulds were enlarged to have a single solid head on each end.

(b) Mix proportions: Two types of mixes 1:2:4 & 1:1½:3 by weight were used for rectangular column specimens and 1:2:4 mix by weight was used for square columns with a water cement ratio varying between 0.55 to 0.65 by weight. Six control cylinders were cast for each series of columns, the results of which are given in Table 11.5.

(c) Casting and curing:

Casting and curing of all the specimens were done as described in Chapter-3. The top ends of the control cylinders were capped with a neat cement paste and the surface was smoothened after 24 hours with a sharp steel blade.
11.8: Testing arrangement and procedure:

11.8.1. Rectangular columns under uniaxially eccentric loading:

All columns were tested in the Tinius Olsen Testing Machine which has two ranges of loading 60,000 lbs. and 400,000 lbs. with least counts of 100 and 1000 lbs., respectively. Both ranges were used in the present testing, depending on the expected ultimate load capacity of the specimen. A view of the machine during the tests is shown in Fig. 11.9.

The column to be tested was white-washed one day before the testing. The column was placed vertically on the machine and the ends of the columns were tied to the machine with manila ropes. The position of the column was adjusted to get the desired eccentricity of the load. Load was applied through rollers at top and bottom support of the column as shown in Fig. 11.10 and Fig. 11.11. The curvature-meters were then attached to the column in predetermined places. A dial gauge with a magnetic base was placed underneath the wing table of the machine to measure the rate at which the column specimen was strained. A deflection bridge on which dial gauges were fixed to measure the lateral deflections of the columns was attached to the wing-table.
### TABLE - 11.5

**Concrete strength in the eccentrically loaded R.C. columns**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Series</th>
<th>No. of columns</th>
<th>Mix proportion</th>
<th>W/C</th>
<th>$f'_{c}$ kg/cm$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>7</td>
<td>1:2:3.33</td>
<td>0.55</td>
<td>280.00</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>8</td>
<td>1:2:3.33</td>
<td>0.55</td>
<td>280.00</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>5</td>
<td>1:1.6:3</td>
<td>0.60</td>
<td>371.00</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>5</td>
<td>1:1.6:3</td>
<td>0.60</td>
<td>320.00</td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>4</td>
<td>1:2:4</td>
<td>0.65</td>
<td>200.00</td>
</tr>
<tr>
<td>6</td>
<td>I</td>
<td>8</td>
<td>1:2:3.33</td>
<td>0.60</td>
<td>273.50</td>
</tr>
<tr>
<td>7</td>
<td>J</td>
<td>10</td>
<td>1:2:3.33</td>
<td>0.60</td>
<td>313.50</td>
</tr>
<tr>
<td>8</td>
<td>K</td>
<td>5</td>
<td>1:1.6:3</td>
<td>0.60</td>
<td>343.00</td>
</tr>
<tr>
<td>9</td>
<td>L</td>
<td>5</td>
<td>1:1.6:3</td>
<td>0.60</td>
<td>320.00</td>
</tr>
<tr>
<td>10</td>
<td>E</td>
<td>5</td>
<td>1:2:4</td>
<td>0.60</td>
<td>260.00</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>5</td>
<td>1:2:4</td>
<td>0.60</td>
<td>260.00</td>
</tr>
<tr>
<td>12</td>
<td>GM</td>
<td>2</td>
<td>1:2:4</td>
<td>0.65</td>
<td>200.00</td>
</tr>
<tr>
<td>13</td>
<td>GO</td>
<td>4</td>
<td>1:2:4</td>
<td>0.65</td>
<td>200.00</td>
</tr>
</tbody>
</table>

**R.C. columns under uniaxial eccentricity**
An initial load of about 1½ tonnes was applied on the column and all the gauges were adjusted for initial reading. The load was applied by strain rate control using a stop watch and noting the readings of the dial gauge below the wing-table. The inlet valve of the machine, was so operated to get the axial strain of 1/600 per minute, on the column indicated relatively
by the wing-table movement. As the load was gradually increased, the readings of all the dial gauges attached were recorded at intervals of half a minute. The initial tension crack on the tension face of the column, the start of crushing of concrete and the peeling of concrete on the compression face were carefully observed during the testing.

The testing of a column specimen was continued until the load dropped by about 15 percent of the maximum load. In the case of specimens with closer spacing of binders the load did not drop quickly and the loading was stopped after a sufficient number of readings beyond maximum load was taken. The time taken for testing of a column varied from 30 minutes to 60 minutes.

11.8.2: Measurement of curvatures and lateral deflections:

The curvatures of the columns were obtained from the measurements taken from the curvature metres and the lateral deflections from the measurements taken from the deflection dial gauges.

(a) Fabrication of curvature metre for measuring strains in concrete:

The DEMEC gauge points and the electrical resistance
strain gauges were not used to measure the strains in concrete as they got peeled off with concrete at ultimate stage. A curvature metre was fabricated to measure the rotations between the two cross-sections of a column. The set up of this curvature metre is similar to the curvature metres used in the axially loaded columns described in Chapter-3.

The curvature metre consists of four rectangular frames made out of a steel bar of 12 x 12 mm cross-section. They are fitted with suitable aluminium angles at top and bottom of which were attached deflection dial gauges as shown in Fig. 11.9 and Fig. 11.12. The frames were attached to the column by screws. Four dial gauges were arranged between any two frames. The column with the curvature metre attached was shown in Fig. 11.7 and Fig. 11.10. The dial gauges on compression face and tension face of the column measure the compressive and tensile deformations in concrete respectively. The three curvature metres were attached in the central portion of the column over a gauge length of 15 cms for each set. All the columns have failed only in one of the three gauge lengths. The dial gauges used were of 0.002 mm least count with a maximum travel of 13 mm.

(b) Lateral deflections: The lateral deflections were measured by attaching dial gauges to a bridge i.e., a steel
FIG. 11.10 - CURVATURE METERS AND DEFLECTION

FIG. 11 - LOADING ARRANGEMENT (UNIAXIAL ECC.)

FIG. 11.0 - MOULD FOR RECTANGULAR
FIG. 11.12 EXPERIMENTAL SETUP.
FIG: 11.14 - TEST ARRANGEMENT FOR COLUMNS
FIG:11.15 - EXPERIMENTAL SETUP IN SQUARE COLUMN WITH CAPITAL OR WITH SOLID HEAD (BIAXIAL ECCENTRICITY)
rod fitted to a magnetic base as shown in Fig. 11.12. The dial gauges have a least count of 0.01 mm and a maximum travel of 5 cms.

11.2.3: Square Columns under biaxial eccentric loading:

The columns were tested with two types of capitals. The columns tested under larger eccentricities were provided (er = 12 cms and above) with two brackets at each end in two perpendicular directions. The test arrangement is shown in Fig. 11.13 and Fig. 11.14.

A solid capital was used for columns tested under eccentricities not greater than 12 cms. The test arrangement for columns with solid capital is shown in Fig. 11.12 and Fig. 11.14. The same type of curvature meters and devices to measure lateral deflections used for columns under uniaxial eccentricity were used in these columns as shown in Fig. 11.7, Fig. 11.13, Fig. 11.14.

The details of loading arrangement at top and bottom of the two types of columns (i.e., with brackets and with solid capital) are shown in Fig. 11.15 to Fig. 11.18.