CHAPTER 3

MATERIAL PROPERTIES AND MIX DESIGN

Concrete is a composite material comprising of cement, fine aggregate, coarse aggregate and water. Nowadays, concrete is made with several types of cement that contains pozzolana, fly ash, blast furnace slag, sulphur, admixtures, polymers, fibers, etc. These concretes can be heated, steam-cured, autoclaved, vacuum-treated, hydraulically pressured, shock-vibrated, and sprayed.

To make a concrete of desired strength, it is necessary to analyse the basic properties of cement and aggregates. In such case of reinforced cement concrete, the study of the chemical composition and mechanical properties of steel reinforcements is an important aspect. Since these data are useful while designing a structure and give an idea about the corrosion resistance behaviour.

3.1 MATERIAL PROPERTIES

Coarse aggregate is comprised of 20mm downgraded aggregate procured from local sources and sieved through 20mm sieve. Natural river sand is obtained from local sources sieved through 4.75mm sieve forms the fine aggregate. Ordinary Portland Cement (OPC) of 53 grade (brand name: Ultratech) confirms to BIS-4031-5:1988 and is obtained from a single source. Reinforcing steel consists of 8mm, 12mm, and 16mm diameter with high yield strength Cold Twisted Deformed (CTD) rebars. Fe 415 grade, branded BIS grade CTD rebars are procured locally from the same batch to maintain...
uniformity. The following tests were conducted to study the properties of concrete constituent materials and reinforcement bar are mentioned below:

2. Initial and final setting time of cement.
3. Specific gravity of fine and coarse aggregate.
4. Water absorption of fine and coarse aggregate.
5. Fineness modulus of aggregate.
6. Dry rodded density of coarse aggregate.
8. Mechanical properties of steel.

3.2 STANDARD CONSISTENCY OF CEMENT

The consistency test was conducted as per BIS-4031-4:1988. Table 3.1 shows the observation of the consistency test. The consistency of the cement was found to be 28%.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Water content (%)</th>
<th>Final reading (mm) (from mould bottom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>7</td>
</tr>
</tbody>
</table>

3.3 SETTING TIME OF CEMENT

The initial setting time of cement was determined as per BIS-4031-5:1988.
Sample cement: Ultratech OPC 53 grade cement.
Initial setting time of cement: 45 min.
Final setting time of cement: 6 h 30 min.

3.4 SPECIFIC GRAVITY AND WATER ABSORPTION

The specific gravity of fine and coarse aggregate was determined per BIS-2386-3:1963. Table 3.2 and 3.3 show the specific gravity and water absorption test observation for fine aggregate and coarse aggregate.

Weight of saturated and surface dry sample = A
Weight of pycnometer with sample and water = B
Weight of pycnometer with the water = C
Weight of cool sample = D
Specific gravity = D / (A - (B-C))
Water absorption (%) = 100 (A-D) / D

<table>
<thead>
<tr>
<th>Description</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of saturated surface dry sample (kg)</td>
<td>0.50</td>
</tr>
<tr>
<td>Weight of pycnometer +sample+ water (kg)</td>
<td>1.75</td>
</tr>
<tr>
<td>Weight of pycnometer +Water (kg)</td>
<td>1.45</td>
</tr>
<tr>
<td>Weight of dry sample (kg)</td>
<td>0.49</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.84</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Table 3.3  Specific gravity and water absorption test observation for coarse aggregate

<table>
<thead>
<tr>
<th>Description</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of saturated surface dry sample (kg)</td>
<td>0.50</td>
</tr>
<tr>
<td>Weight of pycnometer +sample+ water (kg)</td>
<td>1.77</td>
</tr>
<tr>
<td>Weight of pycnometer +Water (kg)</td>
<td>1.45</td>
</tr>
<tr>
<td>Weight of dry sample (kg)</td>
<td>0.49</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.98</td>
</tr>
<tr>
<td>Water absorption</td>
<td>0.40</td>
</tr>
</tbody>
</table>

The final results of the above test as below:

Specific gravity of fine aggregate : 2.84
Specific gravity of coarse aggregate : 2.98
Water absorption of fine aggregate : 0.90
Water absorption of coarse aggregate : 0.40

3.5  FINENESS MODULUS

Fineness modulus of fine aggregates and coarse aggregates was determined by conducting the sieve analysis as per BIS-2386-1:1963. Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates as per BIS-2386-1:1963. By sieving the aggregates we use different sieves as standardized by the BIS code and then pass aggregates through them and thus collect different sized particles left over different sieves. The following test procedure below was given to determine the particle size distribution of aggregates.
i) The test sample is dried to a constant weight at a temperature of 110 + 5°C and weighed. Sieve the aggregate using the appropriate sieves (4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron & 150 micron). Record the weight of aggregate retained on each sieve.

ii) Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight. Calculate the cumulative weight of aggregate retained on each sieve. And Calculate the cumulative percentage of aggregate retained.

iii) Fineness modulus is obtained by adding the cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

Table 3.4 shows the observation of sieve analysis test for fine aggregate and Table 3.5 shows the sieve analysis test observation for coarse aggregate. Fineness modulus was obtained by adding the cumulative percentages of aggregate retained on each sieve divided by an arbitrary number 100. The fineness modulus of fine aggregate was calculated as 2.80. According to BIS-383:1970, the aggregates conform to Grade zone 3. The fineness modulus of coarse aggregate was calculated as 6.90.

### 3.5.1 Fineness Modulus of Fine Aggregate

Quantity of fine aggregate: 1000 gm

**Table 3.4 Observation on sieve analysis of fine aggregate**

<table>
<thead>
<tr>
<th>IS sieve no.</th>
<th>Weight retained (gm)</th>
<th>Weight retained (%)</th>
<th>Cumulative weight retained (%)</th>
<th>Cumulative passing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75 mm</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>190</td>
<td>19</td>
<td>24</td>
<td>76</td>
</tr>
<tr>
<td>600 µm</td>
<td>330</td>
<td>33</td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>300 µm</td>
<td>370</td>
<td>37</td>
<td>94</td>
<td>6</td>
</tr>
<tr>
<td>150 µm</td>
<td>50</td>
<td>5</td>
<td>99</td>
<td>1</td>
</tr>
</tbody>
</table>

Fineness modulus of fine aggregate = 279/100 = 2.79
3.5.2 Fineness Modulus of Coarse Aggregate

Quantity of Coarse Aggregate: 2000 gm

**Table 3.5 Observation on sieve analysis of coarse aggregate**

<table>
<thead>
<tr>
<th>IS sieve no.</th>
<th>Weight retained (gm)</th>
<th>Weight retained (%)</th>
<th>Cumulative weight retained (%)</th>
<th>Cumulative passing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mm</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>10 mm</td>
<td>4550</td>
<td>91</td>
<td>91</td>
<td>9</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>425</td>
<td>8.5</td>
<td>99.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>600 µm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>300 µm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>150 µm</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

Fineness modulus of coarse aggregate = 690.50/100 = 6.905

3.6 DRY RODDED DENSITY

Bulk density indicates the density of coarse aggregate when it was filled in a standard manner. The dry rodded density of coarse aggregate was determined as per BIS-383:1970. Table 3.6 shows the observation of the dry rodded density test. The dry rodded density of coarse aggregate was found to be 1630 kg/m³.

**Table 3.6 Dry rodded density test observation**

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Weight of mould (kg)</th>
<th>Weight of mould + aggregate (kg)</th>
<th>Weight of mould + water (kg)</th>
<th>Dry rodded Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>37.0</td>
<td>27.7</td>
<td>1632.6</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>36.8</td>
<td>27.7</td>
<td>1619.0</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>37.1</td>
<td>22.2</td>
<td>1639.5</td>
</tr>
</tbody>
</table>
3.7 STEEL COMPOSITION

The quantitative determination of chemical composition of Cold Twisted Deformed (CTD) rebars was analyzed by Optical Emission Spectroscopy (OES). The principle involves the production of light radiation characteristics of different constituents present in the sample and measurement of the spectral intensity. The intensity is proportional to the concentration of the element. The rebar samples were polished using 60 grit ‘Aloxide’ abrasive paper in an ‘UNIMAT’ polishing machine prior to testing. The test was carried out in an optical emission spectrometer. Table 3.7 shows the details of the chemical composition of rebars used in experiments.

Table 3.7 Details of chemical composition for steel rebars

<table>
<thead>
<tr>
<th>Type of rebar</th>
<th>Diameter (mm)</th>
<th>Chemical composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fe</td>
</tr>
<tr>
<td>CTD</td>
<td>12</td>
<td>99.010</td>
</tr>
<tr>
<td>CTD</td>
<td>16</td>
<td>98.019</td>
</tr>
</tbody>
</table>

3.8 MECHANICAL PROPERTIES OF STEEL

Mechanical properties of mild steel rebars were determined by conducting direct tension test as per BIS-1512:1972. FIE automatic load-rate control, electronic Universal Testing Machine (UTM) of 1000 kN capacity was used to conduct tension test. Table 3.8 shows the mechanical properties of CTD rebars.
Table 3.8 Mechanical properties of steel rebars

<table>
<thead>
<tr>
<th>SI. No.</th>
<th>Mechanical properties</th>
<th>Steel rebar Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12 mm</td>
</tr>
<tr>
<td>1</td>
<td>Yield stress (N/mm²)</td>
<td>505</td>
</tr>
<tr>
<td>2</td>
<td>Ultimate stress (N/mm²)</td>
<td>626</td>
</tr>
<tr>
<td>3</td>
<td>Actual breaking stress (N/mm²)</td>
<td>826</td>
</tr>
<tr>
<td>4</td>
<td>Elongation (%)</td>
<td>15.80</td>
</tr>
</tbody>
</table>

3.9 MIX DESIGN

The mix design was carried out as per ACI Committee 211.1:1991 method. The material properties of fine aggregate and coarse aggregate given in Table 3.9.

Table 3.9 Material properties of aggregates

<table>
<thead>
<tr>
<th>Test conducted on coarse and fine aggregates</th>
<th>Coarse aggregates</th>
<th>Fine aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity test</td>
<td>2.98</td>
<td>2.84</td>
</tr>
<tr>
<td>Fineness Modulus</td>
<td>6.90</td>
<td>2.80</td>
</tr>
<tr>
<td>Water absorption</td>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Bulk density (kg/m³)</td>
<td>1600</td>
<td>1630</td>
</tr>
</tbody>
</table>

3.9.1 Design Stipulations (M30 OPC)

Characteristic compressive strength required in the field at 28 days (MPa) = 30

Maximum size of aggregate (mm) = 20 (angular)

Degree of workability = 0.90
Degree of quality control = Good
Type of exposure = Mild

Test data for materials

Compressive strength of cement at 28 days (N/mm²) = 30
Specific gravity of cement = 3.15
Specific gravity of fine aggregate = 2.84
Specific gravity of coarse aggregate = 2.98
Fineness modulus of fine aggregate = 2.79
Fineness modulus of coarse aggregate = 6.90
Dry rodded density of coarse aggregate (kg/m³) = 1600
Size of coarse aggregate (mm in downgraded) = 20
Shape of aggregate = Angular
Slump value (mm) = 50-75
Degree of control = Very Good
Water absorption (coarse aggregate) = 0.40
Water absorption (fine aggregate) = 0.90

Target strength of concrete for mix proportioning

Target mean strength, \( f_{ck} = f_{ck} + Ks \)

Assuming 5% of the results are allowed to fall below the specified, designed strength, \( K = 1.65 \), standard deviation (s) for the mixing and placing control = 5 N/mm².

Mean strength = 30 + 1.65 × 5 = 38.25 N/mm².
Target mean strength of concrete for M30 grade is calculated. Based on $f'_{ck}$, target mean strength was found to be 38.25 N/mm$^2$ for proper design.

**Selection of water cement ratio**

From Table 11.5 of ACI-211.1:1991, water–cement ratio for the compressive strength of 38.25 N/mm$^2$ is 0.45.

From Table 11.8 of ACI-211.1:1991, for a slump of 50 mm, 20 mm maximum size of aggregate, for air entrained concrete, the mixing water content for 20 mm aggregate per cubic metre of concrete is 186 kg/m$^3$ of concrete. The entrapped air content is 2%.

The required cement content is 186 / 0.45 = 413 kg/m$^3$.

From Table 11.4 of ACI-211.1:1991, 20mm coarse aggregate, for fineness modulus 2.80, the dry rodded bulk volume of coarse aggregate is 0.62 per unit volume of concrete.

Weight of coarse aggregate = 0.62 × 1600 = 992 kg/m$^3$.

Finding fine aggregate content by the absolute volume method is as given in Table 3.10.
Table 3.10 Absolute volume of all the known ingredients

<table>
<thead>
<tr>
<th>S.No</th>
<th>Ingredients</th>
<th>Weight (kg/m³)</th>
<th>Specific gravity</th>
<th>Absolute volume (cm³) × 10³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cement</td>
<td>413</td>
<td>3.15</td>
<td>131</td>
</tr>
<tr>
<td>2</td>
<td>Water</td>
<td>186</td>
<td>1</td>
<td>186</td>
</tr>
<tr>
<td>3</td>
<td>Coarse Aggregate</td>
<td>992</td>
<td>2.98</td>
<td>333</td>
</tr>
<tr>
<td>4</td>
<td>Air Content (2%)</td>
<td>-</td>
<td>-</td>
<td>20</td>
</tr>
</tbody>
</table>

Total absolute volume = 670 × 10³ cm³.

Therefore, absolute volume of fine aggregate = (1000 – 670) × 10³
= 330 × 10³ cm³.

Weight of fine aggregate = 330 × 2.79 = 920 kg/m³.

From Table 11.9 of ACI-211.1:1991, the first estimate of density of fresh concrete 20mm maximum size of aggregate, and for non air entrained concrete is 2355 kg/m³.

Therefore the weight of all the known ingredient of concrete as:

Weight of water = 186 kg/m³.

Weight of cement = 413 kg/m³.

Weight of coarse aggregate = 992 kg/m³.

Weight of fine aggregate = 764 kg/m³.

The estimated quantities of materials per cubic metre of concrete are shown in Table 3.11. Table 3.12 gives the mix design details.
### Table 3.11 Mix proportions

<table>
<thead>
<tr>
<th>Water (litres)</th>
<th>Cement (kg)</th>
<th>Coarse Aggregate (kg)</th>
<th>Fine aggregate (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>186</td>
<td>413</td>
<td>992</td>
<td>764</td>
</tr>
<tr>
<td>0.45</td>
<td>1</td>
<td>2.40</td>
<td>1.85</td>
</tr>
</tbody>
</table>

### Table 3.12 Mix design details

<table>
<thead>
<tr>
<th>S.No</th>
<th>Material Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Characteristic compressive strength (N/mm$^2$)</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>Target Mean Strength (N/mm$^2$)</td>
<td>38.25</td>
</tr>
<tr>
<td>3</td>
<td>Degree of quality control</td>
<td>Very good</td>
</tr>
<tr>
<td>4</td>
<td>Type of Exposure Condition</td>
<td>Normal</td>
</tr>
<tr>
<td>5</td>
<td>Nominal Size of Aggregate (mm)</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>Shape of Aggregate</td>
<td>Angular</td>
</tr>
<tr>
<td>7</td>
<td>Specific Gravity of Cement</td>
<td>3.15</td>
</tr>
<tr>
<td>8</td>
<td>Specific Gravity of 20 mm Aggregate</td>
<td>2.84</td>
</tr>
<tr>
<td>9</td>
<td>Specific Gravity of 10 mm Aggregate</td>
<td>2.878</td>
</tr>
<tr>
<td>10</td>
<td>Specific Gravity of Fine Aggregate</td>
<td>2.78</td>
</tr>
<tr>
<td>11</td>
<td>Workability (Slump)</td>
<td>50-75 mm</td>
</tr>
<tr>
<td>12</td>
<td>Maximum Water Cement Ratio</td>
<td>0.45</td>
</tr>
<tr>
<td>13</td>
<td>Maximum Water content (L)</td>
<td>186</td>
</tr>
<tr>
<td>14</td>
<td>Cement content per cubic metre of concrete (kg)</td>
<td>413</td>
</tr>
<tr>
<td>15</td>
<td>Mix Proportion</td>
<td>1:1.85:2.40</td>
</tr>
</tbody>
</table>