Concrete Mix Design

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Introduction

- Concrete is a heterogeneous material.
- Composed of cement, water, coarse and fine aggregate.
- Can include other Cementitious materials (mineral admixtures)
- Can include chemical admixtures.
- Can include other materials.
Established by Duff Abrams in 1919.

Strength of fully compacted concrete is inversely proportional to the ratio of water to cement.
As the w/c increases the strength decreases as the w/c decreases the strength increases.
Important properties of fresh concrete

- Workability
- Cohesiveness
- Mobility
- Bleeding
- Finish ability
- Setting time
Workability

- Water content (no more than needed for placement and consolidation)
- Aggregate grading (certain amount of each size)
Cohesiveness

- Ability to stick together
- Tested by tapping slump specimen
- Dependent on amount of fines in mixture
- Dependent on amount of water
- Dependent on ratio of coarse to fine aggregate
Mobility

- Ability to flow (viscosity)
- Response to vibration
Bleeding

- Surface water gain
- Settlement of heavy particles
- Some bleeding beneficial
- Dependent of amount of fine particles in mixture
Finish Ability

- Dependent on type of finish
- Amount of fine aggregate
- Grading of fine aggregate
- Amount of Cementitious material
Setting Time

- Amount and type of Cementitious material
- Amount of water
- Concrete temperature
- Presence of chemical admixtures
What is Mix Design?

- Mix design is defined as process of selecting suitable Ingredients of concrete and determining their relative proportion with object of satisfying requirements in fresh as well as in hardened state as economically as possible.

Factors Affecting Mix Selection Process

- Durability
- Workability
- Maximum size of Aggregate
- Grading & Type of Aggregate
Durability

- IS 456-2000 (Table 4&5) lists the requirements of durable concrete in terms of all the mentioned factors for:
  - Specified conditions of exposure
  - Different Concentration of sulphates present in soil and ground water.
Concrete Mix Design

Workability

- Minimum size of section to be concreted and amount of reinforcement
- The method of placement to be used.
The grading of aggregate influences the mix proportion for desired workability and strength.

When cement content and w/c ratio are fixed a grading should be so chosen so as to give max workability.

Uniformity in grading of aggregate is important as any changes in it affects the workability and strengths.

Max. Size of Aggregate

- Choice of Max, size Depends upon
- Width of section
- Spacing of reinforcement
Cement Content

- Cement content is chosen from past experience and from charts and tables prepared from lab test.
- The cement content is also chosen from durability requirements of structure with respect to various durability conditions.
Mix Design Procedure - Outlines

1. Identify design stipulations
2. Check test data required
3. Calculation of Mean Target Strength
4. Selection of water/cement ratio
5. Estimation of water content
6. Calculation of cement content
7. Estimation of fine aggregate content
8. Estimation of Coarse aggregate content
9. First Trial mix/Adjustment to mix proportions
Identifying Design Stipulations

- Characteristic strength requirement at 28 days
- Maximum size of aggregate
- Degree of Workability
- Type of Exposure

Data required

- Specific Gravity
- Cement
- Coarse and fine aggregate
- Water Absorption
- Coarse aggregate
- Fine Aggregate
Data required

- Sieve Analysis
- Coarse aggregate
- Fine Aggregate
Target strength can be calculated by following relation

$$ft = fck + t \times s$$

Where

- $ft = \text{target mean compressive strength at 28 days}$
- $fck = \text{characteristic compressive strength at 28 days}$
- $S = \text{Standard Deviation (As per IS 456)}$
- $t = \text{a statistic, depending upon accepted proportions of low results and no of tests (Ref table 2 of IS10262-1982)}$

Taking value of $t=1.65$ (as per IS 456-2000)

$$ft = fck + 1.65 \times s$$
Selection of water cement ratio

- w/c ratio corresponding to target strength may be selected from:

- Actually established relationship between compressive strength and water cement ratio for material preferably to be used

- Preliminary w/c ratio from relationship between w/c ratio and 28-day compressive strength of cement intended to be used from fig 2 of IS 10262.

- The free water cement ratio selected is checked against limiting value as per durability aspects and lower of the two values is selected
Concrete Mix Design

**Induction – Overview of ACC Concrete**

**Concrete Mix Design**

![Graph showing the relationship between water-cement ratio and 28-day concrete strength.](image)

**Graph 2: Relation between Free Water-Cement Ratio and Concrete Strength for Different Cement Strengths**

- **A**: 31.5-36.0 N/mm² (325-375 kg/cm²)
- **B**: 36.0-41.7 N/mm² (375-425 kg/cm²)
- **C**: 41.7-46.5 N/mm² (425-475 kg/cm²)
- **D**: 46.5-51.5 N/mm² (475-525 kg/cm²)
- **E**: 51.5-56.5 N/mm² (525-575 kg/cm²)
- **F**: 56.5-61.3 N/mm² (575-625 kg/cm²)
Estimation of Water Content

- The Quantity of mixing water per unit volume of concrete for various nominal max. size of aggregates can be obtained from reference tables as given by ACI 211.1-91.
**Concrete Mix Design**

**ACI COMMITTEE REPORT**

**TABLE A1.533 — APPROXIMATE MIXING WATER AND AIR CONTENT REQUIREMENTS FOR DIFFERENT SLUMPS AND NOMINAL MAXIMUM SIZES OF AGGREGATES (SI)**

<table>
<thead>
<tr>
<th>Slump, mm</th>
<th>9.5°</th>
<th>12.5°</th>
<th>19°</th>
<th>25°</th>
<th>37.5°</th>
<th>50†‡</th>
<th>75†‡</th>
<th>150†‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 to 50</td>
<td>207</td>
<td>199</td>
<td>190</td>
<td>179</td>
<td>166</td>
<td>154</td>
<td>130</td>
<td>113</td>
</tr>
<tr>
<td>75 to 100</td>
<td>228</td>
<td>216</td>
<td>205</td>
<td>193</td>
<td>181</td>
<td>169</td>
<td>145</td>
<td>124</td>
</tr>
<tr>
<td>150 to 175</td>
<td>243</td>
<td>228</td>
<td>216</td>
<td>202</td>
<td>190</td>
<td>178</td>
<td>160</td>
<td>—</td>
</tr>
</tbody>
</table>

**Approximate amount of entrapped air in non-air-entrained concrete, percent**

<table>
<thead>
<tr>
<th>Slump, mm</th>
<th>3</th>
<th>2.5</th>
<th>2</th>
<th>1.5</th>
<th>1</th>
<th>0.5</th>
<th>0.3</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 to 50</td>
<td>3</td>
<td>2.5</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>75 to 100</td>
<td>3</td>
<td>2.5</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>150 to 175</td>
<td>3</td>
<td>2.5</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Air-entrained concrete**

<table>
<thead>
<tr>
<th>Slump, mm</th>
<th>111</th>
<th>175</th>
<th>168</th>
<th>160</th>
<th>150</th>
<th>142</th>
<th>122</th>
<th>107</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 to 50</td>
<td>111</td>
<td>175</td>
<td>168</td>
<td>160</td>
<td>150</td>
<td>142</td>
<td>122</td>
<td>107</td>
</tr>
<tr>
<td>75 to 100</td>
<td>202</td>
<td>193</td>
<td>184</td>
<td>175</td>
<td>165</td>
<td>157</td>
<td>133</td>
<td>119</td>
</tr>
<tr>
<td>150 to 175</td>
<td>216</td>
<td>205</td>
<td>197</td>
<td>184</td>
<td>174</td>
<td>166</td>
<td>154</td>
<td>—</td>
</tr>
</tbody>
</table>

**Recommended average total air content, percent for level of exposure**

<table>
<thead>
<tr>
<th>Exposure</th>
<th>4.5</th>
<th>4.0</th>
<th>3.5</th>
<th>3.0</th>
<th>2.5</th>
<th>2.0</th>
<th>1.5+++</th>
<th>1.0+++</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild exposure</td>
<td>6.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.5</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5+++</td>
<td>3.0+++</td>
</tr>
<tr>
<td>Moderate exposure</td>
<td>7.5</td>
<td>7.0</td>
<td>6.0</td>
<td>6.0</td>
<td>5.5</td>
<td>5.0</td>
<td>4.5+++</td>
<td>4.0+++</td>
</tr>
</tbody>
</table>
Induction – Overview of ACC Concrete

Estimation of Water content – No Slump

- The Quantity of mixing water per unit volume of concrete for various nominal max. size of aggregates can be obtained from reference tables as given by ACI 211.1-91.
# Concrete Mix Design

**Table A2.2.3.1(c):** Approximate mixing water requirements for different consistencies and maximum sizes of aggregates

<table>
<thead>
<tr>
<th>Consistency</th>
<th>slump, mm</th>
<th>V-fall, sec</th>
<th>Relative water content, percent</th>
<th>Water, kg/m³ of concrete for indicated maximum sizes of coarse aggregate in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Non-air-entrained concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extremely dry</td>
<td>—</td>
<td>—</td>
<td>7%</td>
<td>178</td>
</tr>
<tr>
<td>Very Stiff</td>
<td>0-25</td>
<td>10-5</td>
<td>8%</td>
<td>187</td>
</tr>
<tr>
<td>Stiff</td>
<td>25-75</td>
<td>5-3</td>
<td>9%</td>
<td>190</td>
</tr>
<tr>
<td>Stiff Plastic</td>
<td>75-125</td>
<td>3-0</td>
<td>10%</td>
<td>201</td>
</tr>
<tr>
<td>Plastic</td>
<td>125-100</td>
<td>—</td>
<td>10%</td>
<td>245</td>
</tr>
<tr>
<td>Very Plastic</td>
<td>—</td>
<td>—</td>
<td>10%</td>
<td>245</td>
</tr>
<tr>
<td>Approximate amount of entrapped air in non-air-entrained concrete, percent</td>
<td></td>
<td></td>
<td>3%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Air-entrained concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extremely dry</td>
<td>—</td>
<td>—</td>
<td>7%</td>
<td>157</td>
</tr>
<tr>
<td>Very Stiff</td>
<td>0-25</td>
<td>10-5</td>
<td>8%</td>
<td>160</td>
</tr>
<tr>
<td>Stiff</td>
<td>25-75</td>
<td>5-3</td>
<td>9%</td>
<td>178</td>
</tr>
<tr>
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<td>75-125</td>
<td>3-0</td>
<td>10%</td>
<td>202</td>
</tr>
<tr>
<td>Plastic</td>
<td>125-100</td>
<td>—</td>
<td>10%</td>
<td>241</td>
</tr>
<tr>
<td>Very Plastic</td>
<td>—</td>
<td>—</td>
<td>10%</td>
<td>241</td>
</tr>
<tr>
<td>Recommended average total air content, percent</td>
<td></td>
<td></td>
<td>8%</td>
<td>7%</td>
</tr>
</tbody>
</table>

*Note: Values are approximate and may vary depending on specific site conditions and materials used.*

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**Holcim**

Induction – Overview of ACC Concrete
Calculation of Cement content

- Cement content can be calculated from free water ratio and quantity of water per unit volume of concrete.
- The cement content so obtained shall be checked against the requirements of durability and greater of the two values shall be adopted.
Estimation of Fine aggregate Content

![Graph showing the relationship between the proportion of fine aggregate and the free-water/cement ratio for different slump and maximum aggregate size conditions.](image)

Fig 15 (Continued)
For Pump Concrete

The percentage of Fine of Aggregate obtained can be adjusted so as to meet the requirement of Combined aggregate gradation for Pump Concrete.
## Concrete Mix Design

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Limit</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L.</td>
<td>U.</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>61</td>
<td>72</td>
</tr>
<tr>
<td>4.75</td>
<td>40</td>
<td>58</td>
</tr>
<tr>
<td>2.36</td>
<td>28</td>
<td>47</td>
</tr>
<tr>
<td>1.18</td>
<td>18</td>
<td>35</td>
</tr>
<tr>
<td>0.6</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>0.3</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>0.15</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>
## Combination of Different Coarse Aggregate & fine aggregate fractions

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Individual Grading</th>
<th>Best Combined Grading</th>
<th>Pumped concrete limits ACI 304.2r - 91 MAS 20 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20mm</td>
<td>10mm</td>
<td>N.Sand</td>
</tr>
<tr>
<td>20</td>
<td>100.0</td>
<td>100.0</td>
<td>100.00</td>
</tr>
<tr>
<td>10</td>
<td>22.3</td>
<td>76.5</td>
<td>100.00</td>
</tr>
<tr>
<td>4.75</td>
<td>2.0</td>
<td>24.5</td>
<td>96.13</td>
</tr>
<tr>
<td>2.36</td>
<td>0.0</td>
<td>3.2</td>
<td>84.67</td>
</tr>
<tr>
<td>1.18</td>
<td>0.0</td>
<td>0.0</td>
<td>68.69</td>
</tr>
<tr>
<td>0.6</td>
<td>0.0</td>
<td>0.0</td>
<td>42.10</td>
</tr>
<tr>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>22.38</td>
</tr>
<tr>
<td>0.15</td>
<td>0.0</td>
<td>0.0</td>
<td>9.23</td>
</tr>
</tbody>
</table>
Combination of Different Coarse Aggregate & fine aggregate fractions
Estimation of Coarse aggregate Content

\[ V = \left( \frac{\text{Cement}}{S_c} + \frac{\text{Water}}{S_w} + \frac{20 \text{ mm} \times 0.36X}{S_{20mm}} + \frac{10 \text{ mm} \times 0.24X}{S_{10mm}} + \frac{\text{Natural sand} \times 0.40X}{S_{F.A}} \right) \times \frac{1000}{1000} \]

Where,
\( V \) = Absolute volume of fresh concrete, which is equal to gross volume \( m^3 \) minus the volume of entrapped air.

\[ \begin{align*}
S_c & = \text{Specific gravity of cement} \\
S_w & = \text{Specific gravity of water} \\
S_{20mm} & = \text{Specific gravity of 20 mm aggregate} \\
S_{10mm} & = \text{Specific gravity of 10 mm aggregate} \\
S_{F.A} & = \text{Specific gravity of Fine aggregate}
\end{align*} \]
The Approximate amount of entrapped air content can be estimated as follow:

<table>
<thead>
<tr>
<th>N.M.S</th>
<th>Entrapped air ( % of Vol. Of Concrete)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm</td>
<td>3.0%</td>
</tr>
<tr>
<td>20mm</td>
<td>2.0%</td>
</tr>
<tr>
<td>40mm</td>
<td>1.0%</td>
</tr>
</tbody>
</table>
The mass of Total aggregate (X) can be calculated & the respective proportions of coarse & fine aggregate can be determined.
The first Trial mix now can be made with the quantities of various ingredients obtained as such further adjustments can be done for Workability and Strength Requirements.
Example

Design a mix of concrete Grade M30 having slump of 150 mm.

The max. size of aggregate to be used is 20 mm.

The concrete Shall be Non Air Entrained.
Concrete Mix Design

Step 1:- Identifying Design Stipulations

Characteristic Compressive strength :- 30 N/mm²
Max. size of aggregate :- 20 mm
Type of Exposure :- Mild

Step 2:- Test Data

Specific gravity of Cement :- 3.15
Specific Gravity of Coarse Aggregate :- 2.75
Specific Gravity of fine Aggregate :- 2.60
Concrete Mix Design

Water Absorption of aggregate

C.A 1 (10mm) :- 2.16%
C.A. 2 (20mm) :- 1.84%
F.A 1 (Natural sand) :- 2.80
F.A. 2 (Crushed sand) :- 2.90
Fineness Modules of N. Sand :- 1.61
Fineness Modules of C. Sand :- 2.89

Oven Dry rodded mass of aggregate :- 1650 kg/m³
Concrete Mix Design

Step 3:- Target Mean Strength (ft)

\[ \text{Target Mean Strength (ft)} = 30 + 1.65 \times 5.0 = 38.25 \]

Step 4:- Estimation of water cement ratio

From fig 2 of IS 10262-1984 The w/c ratio can be selected as 0.47

So

\[ \frac{W}{C} = 0.47 < 0.55 \text{ (As per IS-456:2000)} \]

Step 5:- Estimation of water Content :-

As per ACI211.3 the water requirement for Concrete with very Stiff Consistency is 169 kg/m³.
Step 6:- Estimation of Air Content :-

The air content for 20mm NMS max. size of aggregate is 2.0%

Step 7:- Calculation of cement content :-

Cement = $169/0.47= 359.57$ kg

say 360 kg > 300 kg as required from durability consideration.

Step 8:- Estimation of Fine Aggregate Content

From DoE Curves for 600µ passing of 42.1 % the approximate fine aggregate content is 43%
## Concrete Mix Design

### Step :- 9 Estimation of Coarse Aggregate Content

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Individual Grading</th>
<th>Best Combined Grading</th>
<th>Pumped concrete limits ACI 304.2r - 91 MAS 20 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20mm</td>
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</tr>
<tr>
<td>20</td>
<td>100.0</td>
<td>100.0</td>
<td>100.00</td>
</tr>
<tr>
<td>10</td>
<td>22.3</td>
<td>76.5</td>
<td>100.00</td>
</tr>
<tr>
<td>4.75</td>
<td>2.0</td>
<td>24.5</td>
<td>96.13</td>
</tr>
<tr>
<td>2.36</td>
<td>0.0</td>
<td>3.2</td>
<td>84.67</td>
</tr>
<tr>
<td>1.18</td>
<td>0.0</td>
<td>0.0</td>
<td>68.69</td>
</tr>
<tr>
<td>0.6</td>
<td>0.0</td>
<td>0.0</td>
<td>42.10</td>
</tr>
<tr>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>22.38</td>
</tr>
<tr>
<td>0.15</td>
<td>0.0</td>
<td>0.0</td>
<td>9.23</td>
</tr>
</tbody>
</table>
Step :- 9 Estimation of Coarse Aggregate Content
Step :- 9 Estimation of Total Aggregate

Total aggregate is calculated by the Absolute volume method

\[
0.98 = \frac{360}{3.15} + \frac{169}{1.0} + \frac{0.30X}{2.75} + \frac{0.27X}{2.75} + \frac{0.43X}{2.6}
\]


\[
\begin{array}{cccc}
0.98 &=& 1000 \\
X &=& 1870 \text{ kg}
\end{array}
\]
Concrete Mix Design

**Step :- 9 Estimation of Total Aggregate**

Total aggregate calculated by the Absolute volume method is

\[ X = 1870 \text{ kg} \]

Hence

\[ 20 \text{ mm} = 1870 \times 0.3 = 560 \text{ kg} \]
\[ 10 \text{ mm} = 1870 \times 0.27 = 505 \text{ kg} \]
\[ \text{Natural sand} = 1870 \times 0.43 = 805 \text{ kg} \]
Concrete Mix Design

Now various ingredients in kilogram per cubic meter of concrete are as follows:

Cement :- 360 kg
Water    :- 169 kg
Coarse Aggregate :-
20 mm = 560 kg
10 mm = 505 kg
Natural sand:- 805 kg
Now First Lab Trial Will Be Done with Following Ingredients

Cement : 360 kg
Water : 169 kg
Coarse Aggregate :-
20 mm : 560 kg
10mm : 505 kg
Natural Sand : 805 kg
Concrete Mix Design

Example to be solved in class:

Design a mix of concrete Grade M35 having slump of 100 mm. The max. size of aggregate to be used is 20 mm. The concrete Shall be Non Air Entrained.

The following data shall be used:-
## Concrete Mix Design

<table>
<thead>
<tr>
<th>Type of Exposure</th>
<th>:- Mild</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Data</strong></td>
<td></td>
</tr>
<tr>
<td>Specific gravity of Cement</td>
<td>:- 3.15</td>
</tr>
<tr>
<td>Specific Gravity of Coarse Aggregate</td>
<td></td>
</tr>
<tr>
<td>20 mm</td>
<td>:- 2.75</td>
</tr>
<tr>
<td>10 mm</td>
<td>:- 2.75</td>
</tr>
<tr>
<td>Specific Gravity of Fine Aggregate</td>
<td></td>
</tr>
<tr>
<td>Natural sand</td>
<td>:- 2.60</td>
</tr>
<tr>
<td>Crushed sand</td>
<td>:- 2.60</td>
</tr>
</tbody>
</table>
## Concrete Mix Design

### Water Absorption of aggregate

<table>
<thead>
<tr>
<th>Size</th>
<th>Absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20mm</td>
<td>1.84%</td>
</tr>
<tr>
<td>10mm</td>
<td>2.16%</td>
</tr>
<tr>
<td>Natural sand</td>
<td>2.80%</td>
</tr>
<tr>
<td>Crushed sand</td>
<td>2.90%</td>
</tr>
</tbody>
</table>

### Fineness Modules

- Fineness Modules of N. Sand: -1.61
- Fineness Modules of C. Sand: -2.89

### Oven Dry rodded mass of aggregate

- 1650 kg/m³
Concrete Mix Design

Take Combined gradation percentages as follows:

20 mm  :- 33%
10 mm  :- 24%
Natural sand  :- 43%