CONCRETE
Civil Engineering is about community service, development and improvement. It involves the conception, planning, design construction and operation of facilities essential to modern life, ranging from transit systems to offshore structures to space satellites.

Civil Engineers are problem solvers, meeting the challenge of pollution, traffic, congestion, drinking water, energy needs, urban redevelopment and community planning.

As the oldest branch of engineering, civil engineering has been the foundation of all civilizations throughout history, providing higher standards of life. The Pyramids, the Coliseum, the Great wall of China are some of the structures where civil engineering principles where mainly used.

Nowadays, Civil Engineering is closely connected to all of our daily activities; the buildings we live in and work in, the transportation networks we use, the water we drink and the drainage and sewage systems we rely on are all results of civil engineering.

In the future, concerns will be rotating about four main axes: space, energy, environment and economy; and Civil Engineers will always be needed to link these themes so that the quality of life is improved.

The role Civil Engineers play in society and the responsibilities they hold, continuously increase with the incredible technological revolution, population growth and environmental concerns.
What is Concrete?

- Concrete is one of the most commonly used building materials.
- Concrete is a **composite material** made from several readily available constituents (aggregates, sand, cement, water).
- Concrete is a versatile material that can **easily be mixed** to meet a variety of special needs and formed to virtually **any shape**.
Advantages

- Ability to be cast
- Economical
- Durable
- Fire resistant
- Energy efficient
- On-site fabrication
Disadvantages

- Low tensile strength
- Low ductility
- Volume instability
- Low strength to weight ratio
Constituents

Cement
Water
Fine Agg.
Coarse Agg.
Admixtures
PROPERTIES OF FRESH CONCRETE

- Workability
- Consistency
- Segregation
- Bleeding
- Setting Time
- Unit Weight
- Uniformity
It is desirable that freshly mixed concrete be relatively easy to transport, place, compact and finish without harmful segregation.

A concrete mix satisfying these conditions is said to be **workable**.
Factors Affecting Workability

- Method and duration of transportation
- Quantity and characteristics of cementing materials
- Aggregate grading, shape and surface texture
- Quantity and characteristics of chemical admixtures
- Amount of water
- Amount of entrained air
- Concrete & ambient air temperature
WORKABILITY

- Workability is the most important property of freshly mixed concrete.
- There is no single test method that can simultaneously measure all the properties involved in workability.
- It is determined to a large extent by measuring the "consistency" of the mix.
CONSISTENCY

- Consistency is the fluidity or degree of wetness of concrete.
- It is generally dependent on the shear resistance of the mass.
- It is a major factor in indicating the workability of freshly mixed concrete.
CONSISTENCY

Test methods for measuring consistency are:

- **Flow test** → measures the amount of flow
- **Kelly-Ball test** → measures the amount of penetration
- **Slump test** (Most widely used test!)
Slump Test is related with the ease with which concrete flows during placement (TS 2871, ASTM C 143)
The slump cone is filled in 3 layers. Every layer is evenly rodded 25 times.

Measure the **slump** by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen.
True Slump  
Shear Slump  
Collapse slump

s = slump  
h = measured height
Segregation refers to a separation of the components of fresh concrete, resulting in a non-uniform mix.

The primary causes of segregation are differences in specific gravity and size of constituents of concrete. Moreover, improper mixing, improper placing and improper consolidation also lead to segregation.

<table>
<thead>
<tr>
<th></th>
<th>Sp.Gr.</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cement</strong></td>
<td>3-3.15</td>
<td>5-80 µm</td>
</tr>
<tr>
<td><strong>C.Ag.</strong></td>
<td>2.4-2.8</td>
<td>5-40 mm</td>
</tr>
<tr>
<td><strong>F.Ag.</strong></td>
<td>2.4-2.8</td>
<td>&lt; 5 mm</td>
</tr>
</tbody>
</table>
Some of the factors affecting segregation:

- Larger maximum particle size (25mm) and proportion of the larger particles.
- High specific gravity of coarse aggregate.
- Decrease in the amount of fine particles.
- Particle shape and texture.
- Water/cement ratio.
BLEEDING

- Bleeding is the tendency of water to rise to the surface of freshly placed concrete.
- It is caused by the inability of solid constituents of the mix to hold all of the mixing water as they settle down.
- A special case of segregation.
Undesirable effects of bleeding are:

- With the movement of water towards the top, the top portion becomes weak & porous (high w/c). Thus the resistance of concrete to freezing-thawing decreases.

- Water rising to the surface carry fine particles of cement which weaken the top portion and form laitance. This portion is not resistant to abrasion.

- Water may accumulate under the coarse agg. and reinforcement. These large voids under the particles may lead to weak zones and reduce the bond between paste and agg. or paste and reinforcement.
The tendency of concrete to bleeding depends largely on properties of cement. It is decreased by:

- Increasing the fineness of cement
- Increasing the rate of hydration (C₃S, C₃A and alkalies)
- Adding pozzolans
- Reducing water content
The aim of mixing is to blend all of the ingredients of the concrete to form a uniform mass and to coat the surface of aggregates with cement paste.
MIXING OF CONCRETE

- Ready-Mix concrete: In this type ingredients are introduced into a mixer truck and mixed during transportation to the site.
  - Wet – Water added before transportation
  - Dry – Water added at site
- Mixing at the site
  - Hand mixed
  - Mixer mixed
Ready Mix Concrete
Mixing at Site
Mixing time should be sufficient to produce a uniform concrete. The time of mixing depends on the type of mixer and also to some properties of fresh concrete.

- Undermixing → non-homogeneity
- Overmixing → danger of water loss, breakage of aggregate particles
CONSOLIDATING CONCRETE

Inadequate consolidation can result in:

- Honeycomb
- Excessive amount of entrapped air voids (bugholes)
- Sand streaks
- Placement lines (Cold joints)
The process of compacting concrete consists essentially of the elimination of entrapped air. This can be achieved by:

- Tamping or rodding the concrete
- Use of vibrators
VIBRATORS

- **Internal vibrator**: The poker is immersed into concrete to compact it. The poker is easily removed from point to point.

- **External vibrators**: External vibrators clamp directly to the formwork requiring strong, rigid forms.
Internal Vibration

Radius of Action

$R$

$1\frac{1}{2} R$

$\frac{1}{2} R$

d
## Internal Vibrators

*Adapted from ACI 309*

<table>
<thead>
<tr>
<th>Diameter of head, (mm)</th>
<th>Recommended frequency, (vib./min.)</th>
<th>Approximate radius of action, (mm)</th>
<th>Rate of placement, (m³/h)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-40</td>
<td>9000-15,000</td>
<td>80-150</td>
<td>0.8-4</td>
<td>Plastic and flowing concrete in thin members. Also used for lab test specimens.</td>
</tr>
<tr>
<td>30-60</td>
<td>8500-12,500</td>
<td>130-250</td>
<td>2.3-8</td>
<td>Plastic concrete in thin walls, columns, beams, precast piles, thin slabs, and along construction joints.</td>
</tr>
<tr>
<td>50-90</td>
<td>8000-12,000</td>
<td>180-360</td>
<td>4.6-15</td>
<td>Stiff plastic concrete (less than 80-mm slump) in general construction.</td>
</tr>
</tbody>
</table>
Systematic Vibration

**CORRECT**

Vertical penetration a few inches into previous lift (which should not yet be rigid) of systematic regular intervals will give adequate consolidation

**INCORRECT**

Haphazard random penetration of the vibrator at all angles and spacings without sufficient depth will not assure intimate combination of the two layers
Internal Vibrators

- To aid in the removal of trapped air the vibrator head should be rapidly plunged into the mix and slowly moved up and down.

- The actual completion of vibration is judged by the appearance of the concrete surface which must be neither rough nor contain excess cement paste.
External Vibrators

- Form vibrators
- Vibrating tables (Lab)
- Surface vibrators
  - Vibratory screeds
  - Plate vibrators
  - Vibratory roller screeds
  - Vibratory hand floats or trowels
External Vibrators

- External vibrators are rigidly clamped to the formwork so that both the form & concrete are subjected to vibration.
- A considerable amount of work is needed to vibrate forms.
- Forms must be strong and tied enough to prevent distortion and leakage of the grout.
External Vibrators

- Vibrating Table: used for small amounts of concrete (laboratory and some precast elements)
CURING OF CONCRETE

Paras:

1. Properties of concrete can improve with age as long as conditions are favorable for the continued hydration of cement. These improvements are rapid at early ages and continues slowly for an indefinite period of time.

2. Curing is the procedures used for promoting the hydration of cement and consists of a control of temperature and the moisture movement from and into the concrete.
The primary objective of curing is to keep concrete saturated or as nearly saturated as possible.

Hydration reactions can take place in only saturated water filled capillaries.
Curing Methods

1. Methods which supply additional water to the surface of concrete during early hardening stages.
   - Using wet covers
   - Sprinkling
   - Ponding
2. Methods that prevent loss of moisture from concrete by sealing the surface.

- Water proof plastics
- Use liquid membrane-forming compounds
- Forms left in place
3. Methods that accelerate strength gain by supplying heat & moisture to the concrete.
   - By using live steam (steam curing)
   - Heating coils.
Hot Weather Concrete

- Rapid hydration → early setting → rapid loss of workability
- Extra problems due to
  - Low humidity
  - Wind, excessive evaporation
  - Direct sunlight

Solutions
- Windbreaks
- Cooled Concrete Ingredients
- Water ponding (cooling due to evaporation)
- Reflective coatings/coverings
Cold Weather Concrete

- Keep concrete temperature above 5 °C to minimize danger of freezing

**Solutions**

- Heated enclosures, insulation
- Rely on heat of hydration for larger sections
- Heated ingredients --- concrete hot when placed
- High early strength cement
Concrete uniformity is checked by conducting tests on fresh and hardened concretes.

- Slump, unit weight, air content tests
- Strength tests
Due to heterogeneous nature of concrete, there will always be some variations. These variations are grouped as:
- Within-Batch Variations: inadequate mixing, non-homogeneous nature
- Batch-to-Batch Variations: type of materials used, changes in gradation of aggregates, changes in moisture content of aggregates
The principal properties of hardened concrete which are of practical importance can be listed as:
1. Strength
2. Permeability & durability
3. Shrinkage & creep deformations
4. Response to temperature variations

Of these compressive strength is the most important property of concrete. Because;
PROPERTIES OF HARDENED CONCRETE

Of the abovementioned hardened properties compressive strength is one of the most important property that is often required, simply because:

1. Concrete is used for compressive loads
2. Compressive strength is easily obtained
3. It is a good measure of all the other properties.
What Affects Concrete Strength

What Doesn’t?
Factors Affecting Strength

- Effect of materials and mix proportions
- Production methods
- Testing parameters
The strength of a concrete specimen prepared, cured and tested under specified conditions at a given age depends on:

1. w/c ratio
2. Degree of compaction
Compressive Strength is determined by loading properly prepared and cured cubic, cylindrical or prismatic specimens under compression.
COMPRESSIVE STRENGTH

- **Cubic: 15x15x15 cm**
  Cubic specimens are crushed after rotating them 90° to decrease the amount of friction caused by the rough finishing.

- **Cylinder: h/D=2 with h=15**
  To decrease the amount of friction, capping of the rough casting surface is performed.
COMPRESSIVE STRENGTH

Cubic specimens without capping

Cylindrical specimens with capping
COMPRESSIVE STRENGTH

Bonded sulphur capping

Unbonded neoprene pads
The compressive strength value depends on the shape and size of the specimen.

<table>
<thead>
<tr>
<th>Basınç dayanımı sınıfı</th>
<th>En düşük karakteristik silindir dayanımı $f_{ck,sil}$ N/mm²</th>
<th>En düşük karakteristik küp dayanımı $f_{ck,küp}$ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 8/10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>C 12/15</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>C 16/20</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>C 20/25</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>C 25/30</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>C 30/37</td>
<td>30</td>
<td>37</td>
</tr>
<tr>
<td>C 35/45</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>C 40/50</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>C 45/55</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>C 50/60</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>C 55/67</td>
<td>55</td>
<td>67</td>
</tr>
<tr>
<td>C 60/75</td>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>C 70/85</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>C 80/95</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>C 90/105</td>
<td>90</td>
<td>105</td>
</tr>
<tr>
<td>C 100/115</td>
<td>100</td>
<td>115</td>
</tr>
</tbody>
</table>
TENSILE STRENGTH

- Tensile Strength can be obtained either by direct methods or indirect methods.
  Direct methods suffer from a number of difficulties related to holding the specimen properly in the testing machine without introducing stress concentration and to the application of load without eccentricity.
DIRECT TENSILE STRENGTH
Due to applied compression load a fairly uniform tensile stress is induced over nearly 2/3 of the diameter of the cylinder perpendicular to the direction of load application.
The advantage of the splitting test over the direct tensile test is that the same molds are used for compressive & tensile strength determination.

The test is simple to perform and gives uniform results than other tension tests.

\[ \sigma_{st} = \frac{2P}{\pi DI} \]

- P: applied compressive load
- D: diameter of specimen
- I: length of specimen
The flexural tensile strength at failure or the modulus of rupture is determined by loading a prismatic concrete beam specimen.

The results obtained are useful because concrete is subjected to flexural loads more often than it is subjected to tensile loads.
\[
\sigma = \frac{Mc}{I} = \frac{(Pl/4)(d/2)}{bd^3/12} = \frac{3}{2} \frac{Pl}{bd^2}
\]

\[
\sigma = \frac{(Pl/6)(d/2)}{bd^3/12} = \frac{Pl}{bd^2}
\]
Factors Affecting the Strength of Concrete

1) Factors depended on the test type:
   - Size of specimen
   - Size of specimen in relation with size of agg.
   - Support condition of specimen
   - Moisture condition of specimen
   - Type of loading adopted
   - Rate of loading
   - Type of test machine

2) Factors independent of test type:
   - Type of cement
   - Type of agg.
   - Degree of compaction
   - Mix proportions
   - Type of curing
   - Type of stress situation
STRESS-STRAIN RELATIONS IN CONCRETE

\( \sigma - \varepsilon \) relationship for concrete is nonlinear. However, specially for cylindrical specimens with \( h/D=2 \), it can be assumed as linear upto 40-50% of \( \sigma_{\text{ult}} \).
MODULUS OF ELASTICITY OF CONCRETE

Due to the nonlinearity of the $\sigma$-$\varepsilon$ diagram, $E$ is defined by:

1. Initial Tangent Method
2. Tangent Method
3. Secant Method

ACI $\rightarrow$ $E = 15200 \, \sigma_{ult}^{\frac{1}{2}} \rightarrow 28$-D cylindrical comp. str. (kgf/cm$^2$)

TS $\rightarrow$ $E = 15500 \, W^{\frac{1}{2}} \rightarrow 28$-D cubic comp. str. (kgf/cm$^2$)
PERMEABILITY OF CONCRETE

Permeability is important because:

1. The penetration of some aggressive solution may result in leaching out of Ca(OH)$_2$ which adversely affects the durability of concrete.

2. In R/C ingress of moisture of air into concrete causes corrosion of reinforcement and results in the volume expansion of steel bars, consequently causing cracks & spalling of concrete cover.

3. The moisture penetration depends on permeability & if concrete becomes saturated it is more liable to frost-action.

4. In some structural members permeability itself is of importance, such as, dams, water retaining tanks.
The permeability of concrete is controlled by capillary pores. The permeability depends mostly on w/c, age, degree of hydration.

In general the higher the strength of cement paste, the higher is the durability & the lower is the permeability.
Non-air-entrained concrete
Specimens: 25 x 150 mm (1 x 6 in.) mortar disks
Pressure: 140 kPa (20 psi)

Leakage, kg/(m² • h), average for 48 hours

Leakage, psf per hour

Period of moist curing and age at test, days

w/c ratio: 0.80
w/c ratio: 0.64
w/c ratio: 0.50
A durable concrete is the one which will withstand in a satisfactory degree, the effects of service conditions to which it will be subjected.

Factors Affecting Durability:

- External → Environmental
- Internal → Permeability, Characteristics of ingredients, Air-Void System...
Structure of “un-damaged” Concrete

- **Macrostructure**
  - Aggregates (CA, FA)
  - Hydrated cement paste (hcp)
  - Entrapped air voids

- **Microstructure**
  - Hydrated cement paste (Hydration products: C-S-H, ettringite, monosulfate; porosity: gel, capillary pores entrained/entrapped air voids)
  - Transition zone (TZ)
Structure of “un-damaged” Concrete

Macrostructure

Microstructure
Structure of “damaged” Concrete

Macrostructure
Visible cracks in hcp and aggregates due to volume changes (to understand cause of cracks, microstructure should be examined)

Microstructure
- Alkali-silica reaction: Reaction product forms at TZ and expands
- Frost action: Water freezes in capillary pores and expands
- Sulfate attack: reaction products form in hcp and expand
Leaching & Efflorescence

- When water penetrates into concrete, it dissolves the non-hydraulic CH (and various salts, sulfates and carbonates of Na, K, Ca).

- Remember $\text{C-S-H}$ and $\text{CH}$ is produced upon hydration of $\text{C}_3\text{S}$ and $\text{C}_2\text{S}$.

- These salts are taken outside of concrete by water and leave a salt deposit.
Sulfate Attack

- Ground water in clayey soils containing alkali sulfates may affect concrete.
- These solutions attack CH to produce gypsum. Later, gypsum and calcium alumina sulfates together with water react to form “ettringite”.
- Formation of ettringite is hardened cement paste or concrete leads to volume expansion thus cracking.
- Moreover, Magnesium sulfate may lead to the decomposition of the C-S-H gel.
Sulfate Attack

Seawater contains some amount of Na and Mg Sulfates. However, these sulfates do not cause severe deleterious expansion/cracking because both gypsum and ettringite are soluble in solutions containing the Cl ion. However, problem with seawater is the frequent wetting/drying and corrosion of reinforcing steel in concrete.

To reduce the sulfate attack
1. Use low w/c ratio → reduced permeability & porosity
2. Use proper cement → reduced C₃A and C₃S
3. Use pozzolans → they use up some of the CH to produce C-S-H
Acid Attack

- Concrete is pretty resistant to acids. But in high concentrations:
  - Causes leaching of the CH
  - Causes disintegration of the C-S-H gel.
Carbonation

- $\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$

- Accompanied by shrinkage $\rightarrow$ carbonation shrinkage

- Makes the steel vulnerable to corrosion (due to reduced alkalinity)
Alkali-Agg. Reactions

- Alkalies of cement + Reactive Silica of Aggs → Alkali-Silica Gel
- Expansions in volume
- Slow process
- Don’t use aggs with reactive silica or use cements with less alkalies.
Corrosion

- Electrochemical reactions in the steel rebars of a R/C structure results in corrosion products which have larger volumes than original steel.

- Thus this volume expansion causes cracks in R/C. In fact, steel is protected by a thin film provided by concrete against corrosion. However, that shield is broken by CO$_2$ of air or the Cl$^-$ ions.
Freezing and Thawing

- Water when freezes expands in volume. This will cause internal hydraulic pressure and cracks the concrete.
- To prevent the concrete from this distress air-entraining admixtures are used to produce air-entrained concrete.
Abrasion

- Aggregates have to be hard & resistant to wear.
- Bleeding & finishing practices are also important.
There are two sets of requirements which enable the engineer to design a concrete mix.

1. The requirements of concrete in hardened state. These are specified by the structural engineer.

2. The requirements of fresh concrete such as workability, setting time. These are specified by the construction engineer (type of construction, placing methods, compacting techniques and transportation)
Mix design is the process of selecting suitable ingredients of concrete & determining their relative quantities with the objective of producing as economically as possible concrete of certain minimum properties such as workability, strength & durability.

So, basic considerations in a mix design is cost & min. properties.
Cost → Material + Labor

Water + Cement + Aggregate + Admixtures

Most expensive (optimize)

Using less cement causes a decrease in shrinkage and increase in volume stability.

Min. Properties → Strength has to be more than...

Durability → Permeability has to be...

Workability → Slump has to be...
In the past specifications for concrete mix design prescribed the proportions of cement, fine agg. & coarse agg.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of cement</td>
<td>Fine Agg.</td>
<td>Coarse Agg.</td>
<td></td>
</tr>
</tbody>
</table>

However, modern specifications do not use these fixed ratios.
Modern specifications specify min compressive strength, grading of agg, max w/c ratio, min/max cement content, min entrained air & etc.

Most of the time job specifications dictate the following data:

- Max w/c
- Min cement content
- Min air content
- Slump
- Strength
- Durability
- Type of cement
- Admixtures
- Max agg. size
PROCEDURE FOR MIX DESIGN

1. Choice of slump (Table 14.5)

<table>
<thead>
<tr>
<th>Type of Construction</th>
<th>Slump, mm</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced foundation walls</td>
<td>75</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Reinforced footings</td>
<td>75</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Plain footings</td>
<td>75</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Substructure walls</td>
<td>75</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Pavement and slabs</td>
<td>75</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Mass concrete</td>
<td>50</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Building columns</td>
<td>100</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Beams</td>
<td>100</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Reinforced walls</td>
<td>100</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>
PROCEDURE FOR MIX DESIGN

2. Choice of max agg. size
   - 1/5 of the narrowest dimension of the mold
   - 1/3 of the depth of the slab
   - ¾ of the clear spacing between reinforcement
   - $D_{\text{max}} < 40\text{mm}$
PROCEDURE FOR MIX DESIGN

3. Estimation of mixing water & air content (Table 14.6 and 14.7)

<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>
</tr>
</thead>
<tbody>
<tr>
<td>25-50</td>
<td>207</td>
<td>199</td>
<td>190</td>
<td>179</td>
<td>166</td>
<td>154</td>
<td>130</td>
</tr>
<tr>
<td>75-100</td>
<td>228</td>
<td>216</td>
<td>205</td>
<td>193</td>
<td>181</td>
<td>169</td>
<td>145</td>
</tr>
<tr>
<td>150-175</td>
<td>243</td>
<td>228</td>
<td>216</td>
<td>202</td>
<td>190</td>
<td>178</td>
<td>160</td>
</tr>
<tr>
<td>Entrapped Air(%)</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>
</tr>
</tbody>
</table>

Table 14.7: Approximate Mixing Water and Air Content Requirements for Air-Entrained Concrete

<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>
</tr>
</thead>
<tbody>
<tr>
<td>25-50</td>
<td>181</td>
<td>175</td>
<td>168</td>
<td>160</td>
<td>150</td>
<td>142</td>
<td>122</td>
</tr>
<tr>
<td>75-100</td>
<td>202</td>
<td>193</td>
<td>184</td>
<td>175</td>
<td>165</td>
<td>157</td>
<td>133</td>
</tr>
<tr>
<td>150-175</td>
<td>216</td>
<td>205</td>
<td>197</td>
<td>184</td>
<td>174</td>
<td>166</td>
<td>154</td>
</tr>
<tr>
<td>Entraped Air(%)</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5</td>
<td>3.0</td>
<td>2.5</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<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>
</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>
</tr>
</tbody>
</table>
PROCEDURE FOR MIX DESIGN

4. Selection of w/c ratio (Table 14.8 or 14.9)

<p>| Table 14.8 Relationship between the “Water/Cement” Ratio and Compressive Strength of Concrete |
|-----------------------------------------------|-----------------------------------------------|</p>
<table>
<thead>
<tr>
<th>Compressive Strength at 28 days, MPa</th>
<th>“Water/Cement” Ratio, by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-air-entrained concrete</td>
<td>Air-entrained concrete</td>
</tr>
<tr>
<td>40</td>
<td>0.42</td>
</tr>
<tr>
<td>35</td>
<td>0.47</td>
</tr>
<tr>
<td>30</td>
<td>0.54</td>
</tr>
<tr>
<td>25</td>
<td>0.61</td>
</tr>
<tr>
<td>20</td>
<td>0.69</td>
</tr>
<tr>
<td>15</td>
<td>0.79</td>
</tr>
</tbody>
</table>

| Table 14.9 Maximum Permissible “Water/Cement” Ratios for Concretes in Severe Exposure |
|-----------------------------------------------|-----------------------------------------------|
| Type of Structure | Structures that will be wet continuously and exposed to freezing and thawing | Structures exposed to seawater or sulfates |
| Thin sections and sections with less than 25 mm cover over steel | 0.45 | 0.40 |
| All other structures | 0.50 | 0.45 |
5. Calculation of cement content with selected water amount (step 3) and w/c (step 4)

6. Estimation of coarse agg. content (Table 14.10)

<table>
<thead>
<tr>
<th>Maximum size of aggregate, mm</th>
<th>Volume of dry-rod dense coarse aggregate per unit volume of concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fineness Moduli of Fine Aggregate</td>
</tr>
<tr>
<td></td>
<td>2.40</td>
</tr>
<tr>
<td>9.5</td>
<td>0.50</td>
</tr>
<tr>
<td>12.5</td>
<td>0.59</td>
</tr>
<tr>
<td>19.0</td>
<td>0.66</td>
</tr>
<tr>
<td>25.0</td>
<td>0.71</td>
</tr>
<tr>
<td>37.5</td>
<td>0.75</td>
</tr>
<tr>
<td>50.0</td>
<td>0.78</td>
</tr>
<tr>
<td>75.0</td>
<td>0.82</td>
</tr>
</tbody>
</table>
PROCEDURE FOR MIX DESIGN

7. Calculation of fine aggregate content with known volumes of coarse aggregate, water, cement and air

8. Adjustions for aggregate field moisture
PROCEDURE FOR MIX DESIGN

9. Trial batch adjustments

- The properties of the mixes in trial batches are checked and necessary adjustments are made to end up with the minimum required properties of concrete.

- Moreover, a lab trial batch may not always provide the final answer. Only the mix made and used in the job can guarantee that all properties of concrete are satisfactory in every detail for the particular job at hand. That’s why we get samples from the field mixes for testing the properties.
Example:
- Slump $\rightarrow$ 75-100 mm
- $D_{\text{max}} \rightarrow$ 25 mm
- $f'_{c,28} = 25$ MPa
- Specific Gravity of cement = 3.15
- Non-air entrained concrete

<table>
<thead>
<tr>
<th></th>
<th>Coarse Agg.</th>
<th>Fine Agg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD Bulk Sp.Gravity</td>
<td>2.68</td>
<td>2.62</td>
</tr>
<tr>
<td>Absorption</td>
<td>0.5%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Total Moist.Content</td>
<td>2.0%</td>
<td>5.0%</td>
</tr>
<tr>
<td>Dry rodded Unit Weight</td>
<td>1600 kg/m$^3$</td>
<td>$-$</td>
</tr>
<tr>
<td>Fineness Modulus</td>
<td>$-$</td>
<td>2.6</td>
</tr>
</tbody>
</table>
1. Slump is given as 75-100 mm
2. $D_{\text{max}}$ is given as 25 mm
3. Estimate the water and air content (Table 14.6)

Table 14.6 Approximate Amounts of Mixing Water and Air Content Requirements for Non-Air Entrained Concrete

<table>
<thead>
<tr>
<th>Slump, mm</th>
<th>Water Content kg/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5</td>
<td>1.25</td>
</tr>
<tr>
<td>25-50</td>
<td>2.07</td>
</tr>
<tr>
<td>75-100</td>
<td>2.18</td>
</tr>
<tr>
<td>150-175</td>
<td>2.43</td>
</tr>
<tr>
<td>Entrapped Air(%)</td>
<td>3</td>
</tr>
</tbody>
</table>

Slump and $D_{\text{max}} \rightarrow W=193$ kg/m$^3$
Entrapped Air $\rightarrow 1.5\%$
4. Estimate w/c ratio (Table 14.8)

Table 14.8 Relationship between the “Water/Cement” Ratio and Compressive Strength of Concrete

<table>
<thead>
<tr>
<th>Compressive Strength at 28 days, MPa</th>
<th>“Water/Cement” Ratio, by weight</th>
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<tr>
<td>30</td>
<td>0.54</td>
</tr>
<tr>
<td>25</td>
<td>0.61</td>
</tr>
<tr>
<td>20</td>
<td>0.69</td>
</tr>
<tr>
<td>15</td>
<td>0.79</td>
</tr>
</tbody>
</table>

$f'_c$ & non-air entrained $\rightarrow$ w/c=0.61 (by wt)
5. Calculation of cement content

\[ W = 193 \text{ kg/m}^3 \quad \text{and} \quad w/c=0.61 \]

\[ C = \frac{193}{0.61} = 316 \text{ kg/m}^3 \]
6. Coarse Agg. from Table 14.10

$D_{\text{max}}$ and F.M. $\rightarrow V_{\text{C.A}} = 0.69 \text{ m}^3$

<table>
<thead>
<tr>
<th>Maximum size of aggregate, mm</th>
<th>Volume of dry-roddeed coarse aggregate per unit volume of concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fineness Moduli of Fine Aggregate</td>
</tr>
<tr>
<td></td>
<td>2.40</td>
</tr>
<tr>
<td>9.5</td>
<td>0.50</td>
</tr>
<tr>
<td>12.5</td>
<td>0.59</td>
</tr>
<tr>
<td>16.0</td>
<td>0.66</td>
</tr>
<tr>
<td>25.0</td>
<td>0.71</td>
</tr>
<tr>
<td>31.5</td>
<td>0.75</td>
</tr>
<tr>
<td>50.0</td>
<td>0.78</td>
</tr>
<tr>
<td>75.0</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Dry $W_{\text{C.A.}} = 1600 \times 0.69 = 1104 \text{ kg/m}^3$

SSD $W_{\text{C.A.}} = 1104 \times (1 + 0.005) = 1110 \text{ kg/m}^3$
7. To calculate the F.Agg. content the volumes of other ingredients have to be determined.

\[ V_{\text{water}} = \frac{193}{1.0 \times 1000} = 0.193 \, \text{m}^3 \]

\[ V_{\text{cement}} = \frac{316}{3.15 \times 1000} = 0.100 \, \text{m}^3 \]

\[ V_{C.Agg.} = \frac{1110}{2.68 \times 1000} = 0.414 \, \text{m}^3 \]

\[ V_{\text{air}} = 0.015 \, \text{m}^3 \, (1.5\% \times 1) \]

\[ \Sigma V = 0.722 \, \text{m}^3 \rightarrow V_{F.Agg} = 1 - 0.722 = 0.278 \, \text{m}^3 \]

\[ W_{F.Agg} = 0.278 \times 2.62 \times 1000 = 728 \, \text{kg/m}^3 \]
Summary of Mix Design

- Based on SSD weight of aggregates

<table>
<thead>
<tr>
<th></th>
<th>Sp. Gr.</th>
<th>Weight (kg/m³)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3.15</td>
<td>316</td>
<td>0.100</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>193</td>
<td>0.193</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>2.68</td>
<td>1110</td>
<td>0.414</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>2.62</td>
<td>728</td>
<td>0.278</td>
</tr>
<tr>
<td>Air</td>
<td>-</td>
<td>-</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>2347</td>
<td>1.000</td>
</tr>
</tbody>
</table>
8. Adjustment for Field Moisture of Aggregates

\[ W_{SSD} = W_{Dry} \times (1+a) \]
\[ W_{Field} = W_{Dry} \times (1+m) \]

<table>
<thead>
<tr>
<th>Aggregates</th>
<th>Absorption</th>
<th>Moisture</th>
<th>Weight (kg/m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SSD Dry Field</td>
</tr>
<tr>
<td>Coarse</td>
<td>0.005</td>
<td>0.02</td>
<td>1110 1104 1127</td>
</tr>
<tr>
<td>Fine</td>
<td>0.01</td>
<td>0.05</td>
<td>728   721 759</td>
</tr>
</tbody>
</table>

Correction for water:
From coarse aggregate: \( 1127 - 1110 = 17 \) kg
From fine aggregate: \( 759 - 728 = 31 \) extra

Corrected water amount: \( 193 - 48 = 145 \) kg
Summary of Mix Design

- Based on field weight of aggregates

<table>
<thead>
<tr>
<th>Ingredient amount</th>
<th>Weight (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SSD</td>
</tr>
<tr>
<td>Cement</td>
<td>316</td>
</tr>
<tr>
<td>Water</td>
<td>193</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>1110</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>728</td>
</tr>
<tr>
<td>Total</td>
<td>2347</td>
</tr>
</tbody>
</table>
9. **Trial Batch**

Usually a 0.02 m³ of concrete is sufficient to verify the slump and air content of the mix. If the slump and air content are different readjustments of the proportions should be made.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Field Weight (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>6.3</td>
</tr>
<tr>
<td>Water</td>
<td>2.9</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>22.5</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>15.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>46.9</strong></td>
</tr>
</tbody>
</table>