1. Introduction

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking.

The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

2. Requirements of concrete mix design

The requirements which form the basis of selection and proportioning of mix ingredients are:

a) The minimum compressive strength required from structural consideration
b) The adequate workability necessary for full compaction with the compacting equipment available.
c) Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
d) Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

2.1 Types of Mixes

i. Nominal Mixes
In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

ii. Standard mixes
The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.
IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm². The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

iii. Designed Mixes
In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.
For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm². No control testing is necessary reliance being placed on the masses of the ingredients.

3. Factors affecting the choice of mix proportions
The various factors affecting the mix design are:
3.1. **Compressive strength**
It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham’s law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

3.2. **Workability**
The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

3.3. **Durability**
The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

3.4. **Maximum nominal size of aggregate**
In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate. IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

3.5. **Grading and type of aggregate**
The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive. The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

3.6. **Quality Control**
The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

4 Mix Proportion designations
The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass

4.1 Factors to be considered for mix design
- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

5. Examples of concrete mix proportioning

5.1 Problems

1 - M40 pumpable concrete

A-1 Design stipulations for proportioning
a) Grade designation : M40
b) Type of cement : OPC 43 grade confirming to IS 8112
c) Maximum nominal size of aggregates : 20 mm
d) Minimum cement content : 320 kg/m³
e) Maximum water cement ratio : 0.45
f) Workability : 100 mm (slump)
g) Exposure condition : Severe (for reinforced concrete)
h) Method of concrete placing : Pumping 

i) Degree of supervision : Good 

j) Type of aggregate : Crushed angular aggregate 

k) Maximum cement content : $450 \text{ kg/m}^3$ 

l) Chemical admixture type : Superplasticiser 

A-2 TEST DATA FOR MATERIALS 

a) Cement used : OPC 43 grade confirming to IS 8112 

b) Specific gravity of cement : 3.15 

c) Chemical admixture : Superplasticiser conforming to IS 9103 

d) Specific gravity of 
   Coarse aggregate : 2.74 
   Fine aggregate : 2.74 

e) Water absorption 
   Coarse aggregate : 0.5 percent 
   Fine aggregate : 1.0 percent 

f) Free (surface) moisture 
   Coarse aggregate : Nil (absorbed moisture also nil) 
   Fine aggregate : Nil 

g) Sieve analysis 
   Coarse aggregate : Conforming to Table 2 of IS: 383 
   Fine aggregate : Conforming to Zone I of IS: 383 

A-3 TARGET STRENGTH FOR MIX PROPORTIONING 

$$f'_ck = f_{ck} + 1.65 \, s$$ 

Where

$f'_ck$ = Target average compressive strength at 28 days, 

$f_{ck}$ = Characteristic compressive strength at 28 days, 

$s$ = Standard deviation 

From Table 1 standard deviation, $s = 5 \, \text{N/mm}^2$ 

Therefore target strength $= 40 + 1.65 \times 5 = 48.25 \, \text{N/mm}^2$ 

A-4 SELECTION OF WATER CEMENT RATIO 

From Table 5 of IS:456-2000, maximum water cement ratio $= 0.45$ 

Based on experience adopt water cement ratio as 0.40 

0.4 < 0.45, hence ok
A-5 SELECTION OF WATER CONTENT

From Table-2, maximum water content = 186 liters (for 25mm – 50mm slump range and for 20 mm aggregates)

Estimated water content for 100 mm slump = 186 + 6/100 x 186 = 197 liters

As superplasticiser is used, the water content can be reduced up to 20 percent and above

Based on trials with SP water content reduction of 29 percent has been achieved.

Hence the water content arrived = 19 x 0.71 = 140 liters

A-6 CALCULATION OF CEMENT CONTENT

Water : cement ratio = 0.40
Cement content = 140/0.40 = 350 kg/m$^3$

From Table 5 of IS: 456, minimum cement content for severe exposure condition = 320 kg/m$^3$
350 kg/m$^3$ > 320 kg/m$^3$, hence OK

A-7 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 = 0.60

In the present case w/c = 0.40. The volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As w/c ratio is lower by 0.10, increase the coarse aggregate volume by 0.02 (at the rate of +/- 0.01 for every +/- 0.05 change in water cement ratio).

Therefore corrected volume of coarse aggregate for w/c of 0.40 = 0.62

Note: In case the coarse aggregate is not angular, then also the volume of CA may be required to be increased suitably based on experience

For pumpable concrete these values should be reduced by 10 percent

Therefore volume of coarse aggregate = 0.62 x 0.9 = 0.56
Volume of fine aggregate content = 1 - 0.56 = 0.44

A-8 MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows

a) Volume of concrete = 1 m$^3$
b) Volume of cement

\[
\text{Volume of cement} = \frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000}
\]

\[
= \frac{350}{3.15} \times \frac{1}{1000} = 0.111 \text{ m}^3
\]

c) Volume of water

\[
= \frac{140}{1} \times \frac{1}{1000} = 0.140 \text{ m}^3
\]

d) Volume of chemical admixture

( SP 2% by mass of cement)

\[
= \frac{7}{1.145} \times \frac{1}{1000} = 0.006 \text{ m}^3
\]

e) Volume of all in aggregates (e)

\[
e = a - (b + c + d)
\]

\[
= 1 - (0.111 + 0.140 + 0.006) = 0.743 \text{ m}^3
\]

f) Volume of coarse aggregates

\[
= e \times \text{Volume of CA} \times \text{specific gravity of CA}
\]

\[
= 0.743 \times 0.56 \times 2.74 \times 1000 = 11140 \text{ kg}
\]

g) Volume of fine aggregates

\[
= e \times \text{Volume of FA} \times \text{specific gravity of FA}
\]

\[
= 0.743 \times 0.44 \times 2.74 \times 1000 = 896 \text{ kg}
\]

A-9 MIX PROPORTIONS FOR TRIAL NUMBER 1

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>350 kg/m³</td>
</tr>
<tr>
<td>Water</td>
<td>140 kg/m³</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>896 kg/m³</td>
</tr>
<tr>
<td>Coarse aggregates</td>
<td>1140 kg/m³</td>
</tr>
<tr>
<td>Chemical admixture</td>
<td>7 kg/m³</td>
</tr>
<tr>
<td>Water cement ratio</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Aggregates are assumed to be in SSD. Otherwise corrections are to be applied while calculating the water content. Necessary corrections are also required to be made in mass of aggregates.

A-10 The slump shall be measured and the water content and dosages of admixture shall be adjusted for achieving the required slump based on trials, if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

A-11 Two more trials having variation of ± 10 percent of water cement ratio in A-10 shall be carried out keeping water content constant, and a graph between three water cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, durability requirements shall be met.
2. Problem 2
Illustrative examples on concrete mix proportioning [M40 pumpable concrete with fly ash]

A-1 Design stipulations for proportioning

- Grade designation: M40
- Type of cement: OPC 43 grade confirming to IS 8112
- Type of mineral admixture: Fly ash confirming to IS 3812 (Part-1)
- Maximum nominal size of aggregates: 20 mm
- Minimum cement content: 320 kg/m³
- Maximum water cement ratio: 0.45
- Workability: 100 mm (slump)
- Exposure condition: Severe (for reinforced concrete)
- Method of concrete placing: Pumping
- Degree of supervision: Good
- Type of aggregate: Crushed angular aggregate
- Maximum cement content: 450 kg/m³
- Chemical admixture type: Superplasticiser

A-2 TEST DATA FOR MATERIALS

- Cement used: OPC 43 grade confirming to IS 8112
- Specific gravity of cement: 3.15
- Fly ash used: Fly ash confirming to IS 3812 (Part-1)
- Specific gravity of fly ash: 2.2
- Chemical admixture: Superplasticiser conforming to IS 9103
- Specific gravity of
  - Coarse aggregate: 2.74
  - Fine aggregate: 2.74
- Water absorption
  - Coarse aggregate: 0.5 percent
  - Fine aggregate: 1.0 percent
- Free (surface) moisture
  - Coarse aggregate: Nil (absorbed moisture also nil)
  - Fine aggregate: Nil
- Sieve analysis
  - Coarse aggregate: Conforming to Table 2 of IS: 383
  - Fine aggregate: Conforming to Zone I of IS: 383

A-3 TARGET STRENGTH FOR MIX PROPORTIONING

\[ f'_{ck} = f_{ck} + 1.65 \sigma \]
Where
\( f'_{ck} \) = Target average compressive strength at 28 days,
\( f_{ck} \) = Characteristic compressive strength at 28 days,
s = Standard deviation

From Table 1 standard deviation, \( s = 5 \text{ N/mm}^2 \)
Therefore target strength = \( 40 + 1.65 \times 5 = 48.25 \text{ N/mm}^2 \)

**A-4 SELECTION OF WATER CEMENT RATIO**

From Table 5 of IS:456-2000, maximum water cement ratio = 0.45
Based on experience adopt water cement ratio as 0.40
0.4 < 0.45, hence ok

**A-5 SELECTION OF WATER CONTENT**

From Table-2, maximum water content = 186 liters (for 25mm – 50mm slump range and for 20 mm aggregates)
Estimated water content for 100 mm slump = \( 186 + \frac{6}{100} \times 186 = 197 \) liters
As superplasticiser is used, the water content can be reduced up to 20 percent and above
Based on trials with SP water content reduction of 29 percent has been achieved.
 Hence the water content arrived = \( 19 \times 0.71 = 140 \) liters

**A-6 CALCULATION OF CEMENT CONTENT**

Water cement ratio = 0.40
Cement content = \( \frac{140}{0.40} = 350 \text{ kg/m}^3 \)

From Table 5 of IS: 456, minimum cement content for severe exposure condition = \( 320 \text{ kg/m}^3 \)
350 kg/m\(^3\) > 320 kg/m\(^3\), hence OK

*For proportioning fly ash concrete, the suggested steps are;*

*Decide the percentage of fly ash to be used based on [project requirement and quality of materials]*

*In certain situations increase in cementitious material content may be warranted. The decision on increase in cementitious material content and its percentage may be based on experience and trial.*

*The example is with increase of 10% of cementitious material content*

Cementitious material content \( 1.1 \times 350 = 385 \text{ kg/m}^3 \)
Water content = \( 140 \text{ kg/m}^3 \)
Water cement ratio = $\frac{140}{385} = 0.364 \approx 0.40$

Let us use fly ash at 30 percent of cementitious material content in addition to cement

Fly ash = $385 \times 0.3 = 115 \text{ kg/m}^3$
Cement = $385 - 115 = 270 \text{ kg/m}^3$

(Saving of cement compared to previous design = $350 - 279 = 80 \text{ kg/m}^3$ and fly ash utilization = $115 \text{ kg/m}^3$)

A-7 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 = 0.60
In the present case w/c = 0.40. The volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As w/c ratio is lower by 0.10, increase the coarse aggregate volume by 0.02 (at the rate of +/- 0.01 for every +/- 0.05 change in water cement ratio).
Therefore, corrected volume of coarse aggregate for w/c of 0.40 = 0.62.

Note: In case the coarse aggregate is not angular, then also the volume of CA may be required to be increased suitably based on experience

For pumpable concrete these values should be reduced by 10 percent
Therefore volume of coarse aggregate = $0.62 \times 0.9 = 0.56$
Volume of fine aggregate content = $1 - 0.56 = 0.44$

A-8 MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows

h) Volume of concrete = $1 \text{ m}^3$

i) Volume of cement

\[
\text{Volume of cement} = \frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000}
\]

\[
= \left(\frac{270}{3.15}\right) \times \frac{1}{1000} = 0.086 \text{ m}^3
\]

j) Volume of fly ash

\[
= \left(\frac{115}{2.2}\right) \times \frac{1}{1000} = 0.052 \text{ m}^3
\]

k) Volume of water

\[
= \left(\frac{140}{1}\right) \times \frac{1}{1000} = 0.140 \text{ m}^3
\]
1) Volume of chemical admixture  = \left[\frac{7.7}{1.145}\right] \times \left[\frac{1}{1000}\right] = 0.007 \, m^3 \\
( SP 2\% \text{by mass of cementitious material})

m) Volume of all in aggregates (\( e \)) = \( a - (b + c + d) \) \\
= 1 - (0.086 + 0.052 + 0.140 + 0.007) = 0.715 \, m^3

n) Volume of coarse aggregates  = \( e \times \text{Volume of CA} \times \text{specific gravity of CA} \) \\
= 0.715 \times 0.56 \times 2.74 \times 1000 = 1097 \, kg

o) Volume of fine aggregates  = \( e \times \text{Volume of FA} \times \text{specific gravity of FA} \) \\
= 0.715 \times 0.44 \times 2.74 \times 1000 = 862 \, kg

A-9 MIX PROPORTIONS FOR TRIAL NUMBER 1

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>270 kg/m^3</td>
</tr>
<tr>
<td>Fly ash</td>
<td>115 kg/m^3</td>
</tr>
<tr>
<td>Water</td>
<td>140 kg/m^3</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>862 kg/m^3</td>
</tr>
<tr>
<td>Coarse aggregates</td>
<td>1097 kg/m^3</td>
</tr>
<tr>
<td>Chemical admixture</td>
<td>7.7 kg/m^3</td>
</tr>
<tr>
<td>Water cement ratio</td>
<td>0.364</td>
</tr>
</tbody>
</table>

Aggregates are assumed to be in SSD. Otherwise corrections are to be applied while calculating the water content. Necessary corrections are also required to be made in mass of aggregates.

A-10 The slump shall be measured and the water content and dosages of admixture shall be adjusted for achieving the required slump based on trials, if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

A-11 Two more trials having variation of ± 10 percent of water cement ratio in A-10 shall be carried out keeping water content constant, and a graph between three water cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, durability requirements shall be met.

3. Problem 3

Design of M20 concrete mix as per IS:10262-2009, Concrete mix proportioning-guidelines(First revision)
A-1 Design stipulations for proportioning

i. Grade designation : M20
ii. Type of cement : OPC 43 grade confirming to IS 8112
iii. Maximum nominal size of aggregates : 20 mm
iv. Minimum cement content : 320 kg/m³
v. Maximum water cement ratio : 0.55
vi. Workability : 75 mm (slump)
vn. Exposure condition : Mild
vii. Degree of supervision : Good
ix. Type of aggregate : Crushed angular aggregate
x. Maximum cement content : 450 kg/m³
xi. Chemical admixture : Not recommended

A-2 TEST DATA FOR MATERIALS

p) Cement used : OPC 43 grade confirming to IS 8112
q) Specific gravity of cement : 3.15
r) Specific gravity of
   Coarse aggregate : 2.68
   Fine aggregate : 2.65
s) Water absorption
   Coarse aggregate : 0.6 percent
   Fine aggregate : 1.0 percent
t) Free (surface) moisture
   Coarse aggregate : Nil (absorbed moisture full)
   Fine aggregate : Nil
u) Sieve analysis
   Coarse aggregate : Conforming to Table 2 of IS: 383
   Fine aggregate : Conforming to Zone I of IS: 383

A-3 TARGET STRENGTH FOR MIX PROPORTIONING

\[ f'_ck = f_{ck} + 1.65 \, s \]

Where
\( f'_ck \) = Target average compressive strength at 28 days,
\( f_{ck} \) = Characteristic compressive strength at 28 days,
\( s \) = Standard deviation

From Table 1 standard deviation, \( s = 4 \, \text{N/mm}^2 \)
Therefore target strength = \( 20 + 1.65 \times 4 = 26.60 \, \text{N/mm}^2 \)
A-4 SELECTION OF WATER CEMENT RATIO

From Table 5 of IS:456-2000, maximum water cement ratio = 0.55 (Mild exposure)
Based on experience adopt water cement ratio as 0.50
0.5 < 0.55, hence ok

A-5 SELECTION OF WATER CONTENT

From Table-2, maximum water content = 186 liters (for 25mm – 50mm slump range and for 20 mm aggregates)
Estimated water content for 75 mm slump = 186 + 3/100 x 186 = 191.6 liters

A-6 CALCULATION OF CEMENT CONTENT

Water cement ratio = 0.50
Cement content = 191.6/0.5 = 383 kg/m^3 > 320 kg/m^3 (given)
From Table 5 of IS: 456, minimum cement content for mild exposure condition = 300 kg/m^3
Hence OK

A-7 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 = 0.60

A-8 MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows

a) Volume of concrete = 1 m^3

b) Volume of cement

\[
\text{Volume of cement} = \frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000} = \frac{383.16}{3.15} \times \frac{1}{1000} = 0.122 \text{ m}^3
\]

c) Volume of water

\[
\text{Volume of water} = \frac{192}{1000} = 0.192 \text{ m}^3
\]

d) Volume of all in aggregates (e) = a – (b + c)
\[ = 1 - (0.122 + 0.192) = 0.686 \text{ m}^3 \]

e) Volume of coarse aggregates
\[ = e \times \text{Volume of CA} \times \text{specific gravity of CA} \]
\[ = 0.686 \times 0.6 \times 2.68 \times 1000 = 1103 \text{ kg} \]

f) Volume of fine aggregates
\[ = e \times \text{Volume of FA} \times \text{specific gravity of FA} \]
\[ = 0.686 \times 0.4 \times 2.65 \times 1000 = 727 \text{ kg} \]

**A-9 MIX PROPORTIONS FOR TRIAL NUMBER 1**

- Cement \( = 383 \text{ kg/m}^3 \)
- Water \( = 191.6 \text{ kg/m}^3 \)
- Fine aggregate \( = 727 \text{ kg/m}^3 \)
- Coarse aggregates \( = 1103 \text{ kg/m}^3 \)
- Water cement ratio \( = 0.50 \)
- Yield \( =2404.6 \text{ kg} \)

Aggregates are assumed to be in SSD. Otherwise corrections are to be applied while calculating the water content. Necessary corrections are also required to be made in mass of aggregates.

Trial mixes: Laboratory study

4. Problem 4

Design of M30 concrete mix as per IS:10262-2009, Concrete mix proportioning-guidelines(First revision)

**A-1 Design stipulations for proportioning**

- xii. Grade designation \( : \text{M30} \)
- xiii. Type of cement \( : \text{OPC 43 grade confirming to IS 8112} \)
- xiv. Maximum nominal size of aggregates \( : 20 \text{ mm} \)
- xv. Minimum cement content \( : 350 \text{ kg/m}^3 \)
- xvi. Maximum water cement ratio \( : 0.50 \)
- xvii. Workability \( : 25 - 50 \text{ mm (slump)} \)
- xviii. Exposure condition \( : \text{Moderate} \)
- xix. Degree of supervision \( : \text{Good} \)
- xx. Type of aggregate \( : \text{Crushed angular aggregate} \)
- xxi. Maximum cement content \( : 450 \text{ kg/m}^3 \)
- xxii. Chemical admixture \( : \text{Not recommended} \)
A-2 TEST DATA FOR MATERIALS

v) Cement used : OPC 43 grade confirming to IS 8112
w) Specific gravity of cement : 3.15
x) Specific gravity of
   Coarse aggregate : 2.68
   Fine aggregate : 2.65
y) Water absorption
   Coarse aggregate : 0.6 percent
   Fine aggregate : 1.0 percent
z) Free (surface) moisture
   Coarse aggregate : Nil (absorbed moisture full)
   Fine aggregate : Nil
aa) Sieve analysis
   Coarse aggregate : Conforming to Table 2 of IS: 383
   Fine aggregate : Conforming to Zone I of IS: 383

A-3 TARGET STRENGTH FOR MIX PROPORTIONING

\[ f'_{ck} = f_{ck} + 1.65 \times s \]

Where
\[ f'_{ck} \] = Target average compressive strength at 28 days,
\[ f_{ck} \] = Characteristic compressive strength at 28 days,
\[ s \] = Standard deviation

From Table 1 standard deviation, \( s = 5 \text{ N/mm}^2 \)
Therefore target strength = \( 30 + 1.65 \times 5 = 38.25 \text{ N/mm}^2 \)

A-4 SELECTION OF WATER CEMENT RATIO

From Table 5 of IS:456-2000, maximum water cement ratio = 0.50 (Moderate exposure)
Based on experience adopt water cement ratio as 0.45 as the cement is 53 grade
0.45 \( < \) or \( \leq 0.5 \), hence ok

A-5 SELECTION OF WATER CONTENT

From Table-2, maximum water content = 186 liters (for 25mm – 50mm slump range and for 20 mm aggregates)
Estimated water content for 25-50 mm slump = 186 liters
A-6 CALCULATION OF CEMENT CONTENT

Water cement ratio = 0.45
Cement content = 186/0.45 = 413 kg/m³

From Table 5 of IS: 456, minimum cement content for moderate exposure condition = 300 kg/m³
Hence OK

A-7 PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT

From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60. Modify this as w/c is 0.45. The new value is 0.61. Volume of fine aggregate is 0.39.

A-8 MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be as follows

g) Volume of concrete = 1 m³

h) Volume of cement

\[
\frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000} = \frac{413}{3.15} \times \frac{1}{1000} = 0.131 \text{ m}³
\]

i) Volume of water

\[
= \frac{186}{1} \times \frac{1}{1000} = 0.186 \text{ m}³
\]

j) Volume of all in aggregates (e) =a – (b + c)

\[
= 1 - (0.131 + 0.186) = 0.683 \text{ m}³
\]

k) Volume of coarse aggregates = e x Volume of CA x specific gravity of CA

\[
= 0.683 \times 0.61 \times 2.68 \times 1000 = 1117 \text{ kg}
\]

l) Volume of fine aggregates = e x Volume of FA x specific gravity of FA

\[
= 0.683 \times 0.39 \times 2.65 \times 1000 = 706 \text{ kg}
\]

A-9 MIX PROPORTIONS FOR TRIAL NUMBER 1

Cement = 413 kg/m³
Water = 186 kg/m³
Fine aggregate  = 706 kg/m$^3$
Coarse aggregates  = 1117 kg/m$^3$
Water cement ratio  = 0.45
Yield  =2422 kg

ACI AND BRITISH (DOE) METHOD OF CONCRETE MIX DESIGN

ACI METHOD OF CONCRETE MIX DESIGN

American Concrete Institute Method of Mix Design 11.3 (ACI Concrete Mix Design)
This method of proportioning was first published in 1944 by ACI committee 613. In 1954 the method was revised to include, among other modifications, the use of entrained air. In 1970, the method of ACI mix design became the responsibility of ACI committee 211. We shall now deal with the latest ACI Committee 211.1 method.
It has the advantages of simplicity in that it:
Applies equally well
With more or less identical procedure to rounded or angular aggregate
To regular or light weight aggregates
To air entrained or non-air-entrained concretes.

SCOPE
ACI 211.1-91, Reapproved 2002. This Standard Practice describes methods for selecting proportions for hydraulic cement concrete made with and without other cementitious materials and chemical admixtures. This concrete consists of normal and/or high density aggregates, with a workability suitable for usual cast-in-place construction.

INTRODUCTION
ACI 211.1-91, Reapproved 2002, states: "Concrete is composed principally of aggregates, Portland cement, and water, and many contain other cementitious materials and/or chemical admixtures. It will contain some amount of entrapped air and may also contain purposely entrained air obtained by use of admixture or air-entraining cement. Chemical admixtures are frequently used to accelerate, retard, improve workability, reduce mixing water requirements, increase strength, or alter other properties of the concrete. The selection of concrete proportions involves a balance between economy and requirements of placeability, strength, durability, density, and appearance."

BASIC RELATIONSHIP
ACI 211.1-91, Reapproved 2002, states: "Concrete proportions must be selected to provide workability, consistency, density, strength, and durability, for the particular application.

- **Workability**: The property of the concrete that determines its capacity to be placed and consolidated properly and be finished without harmful segregation.
- **Consistency**: It is the relative mobility of the concrete mixture, and measured in terms of the slump; the greater the slump value the more mobile the mixture.
- **Strength**: The capacity of the concrete to resist compression at the age of 28 days.
- **Water-cement (w/c) or water-cementitious (w/(c+p)) ratio**: Defined as the ratio of weight of water to the weight of cement, or the ratio of weight of water to the weight of cement plus added pozzolan. Either of these ratios is used in mix design and considerably controls concrete strength.
- **Durability**: Concrete must be able to endure severe weather conditions such as freezing and thawing, wetting and drying, heating and cooling, chemicals, deicing agents, and the like. An increase of concrete durability will enhance concrete resistance to severe weather conditions.
- **Density**: For certain applications concrete may be used primarily for its weight characteristics. Examples are counterweights, weights for sinking pipelines under water, shielding from radiation, and insulation from sound.
- **Generation of heat**: If the temperature rise of the concrete mass is not held to a minimum and the heat is allowed to dissipate at a reasonable rate, or if the concrete is subjected to severe differential or thermal gradient, cracking is likely to occur."

**EFFECTS OF CHEMICAL ADMIXTURES ON CONCRETE PROPORTIONS**

ACI 211.1-91, Reapproved 2002, states: "Chemical admixtures, pozzolanic, and other materials can be added to concrete mix to alter some properties or to produce desired characteristics. Additives are used to affect the workability, consistency, density, strength, and durability of the concrete."

**BACKGROUND DATA**

ACI 211.1-91, Reapproved 2002, states: "To the extent possible, selection of concrete proportions should be based on test data or experience with the materials actually to be used. The following information for available materials will be useful:

- Sieve analyses of fine and coarse aggregates.
- Unit weight of coarse aggregate.
- Bulk specific gravities and absorption of aggregates.
- Mixing-water requirements of concrete developed from experience with available aggregates.
- Relationship between strength and water-cement ratio or ratio of water-to-cement plus other cementitious materials.
- Specific gravity of Portland cement and other cementitious materials, if used."
• Optimum combination of coarse aggregates to meet the maximum density grading for mass concrete.
• Estimate of proportions of mix for preliminary design."

DESIGN PARAMETERS
ACI 211.1-91, Reapproved 2002, states: "The procedure for selection of mix proportions given below is applicable to normal weight concrete. Estimating the required batch weights for the concrete involves a sequence of logical straightforward steps. Some or all of the following specifications are required; maximum water-cement or water-cementitious material ratio, minimum cement content, air content, slump, maximum size of aggregate, strength, and admixtures."

The various steps for ACI method is illustrated in the following steps.
1) SLUMP

<table>
<thead>
<tr>
<th>Types of construction</th>
<th>Maximum Slump (mm)</th>
<th>Minimum Slump (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced foundation walls and footings</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Plain footings, caissons, and substructure</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Beams and reinforced walls</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Building columns</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Pavements and slabs</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Mass concrete</td>
<td>75</td>
<td>25</td>
</tr>
</tbody>
</table>

2) MAXIMUM AGGREGATE SIZE
The nominal maximum size of coarse aggregate = 10mm or 20 mm or 40 mm

3) MIXING WATER & AIR CONTENT

| Approximate mixing water (kg/m³) for indicated nominal maximum sizes of aggregate |
|----------------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| Slump (mm)                            | 9.5 mm                      | 12.5 mm                     | 19 mm                       | 25 mm                       | 37.5 mm                     | 50 mm                       | 75 mm                       | 150 mm                      |
| 25 to 50                              | 207                          | 199                          | 190                          | 179                          | 166                          | 154                          | 130                          | 113                          |
| 75 to 100                              | 228                          | 216                          | 205                          | 193                          | 181                          | 169                          | 145                          | 124                          |
| 150 to 175                             | 243                          | 228                          | 216                          | 202                          | 190                          | 178                          | 160                          | -                           |
| More than 175                          | -                            | -                            | -                            | -                            | -                            | -                            | -                            | -                            |

Approximate amount of entrapped air in non-air-entrained concrete (%)
From Table above water weight for non-air-entrained concrete =

### 4) WATER-CEMENT RATIO

Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete

<table>
<thead>
<tr>
<th>Compressive strength at 28 days (MPa)</th>
<th>Water-cement ratio by weight (Non-air-entrained concrete)</th>
</tr>
</thead>
<tbody>
<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>

Check the maximum permissible water-cement ratio from the Table below and revise the water-cement ratio entered in the box above accordingly.

### Maximum permissible water-cement or water-cementitious materials ratios for concrete in severe exposure

<table>
<thead>
<tr>
<th>Type of Structure</th>
<th>Structure wet continuously and exposed to frequent freezing and thawing</th>
<th>Structure exposed to sea water or sulfates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin section (railings, curbs, sills, ledges, ornamental work) and sections with less than 25 mm cover over steel</td>
<td>0.45</td>
<td>0.40</td>
</tr>
<tr>
<td>All other structures</td>
<td>0.50</td>
<td>0.45</td>
</tr>
</tbody>
</table>

### 5) COARSE AGGREGATE

Volume of oven-dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate

<table>
<thead>
<tr>
<th>Nominal maximum size of aggregate (mm)</th>
<th>2.40</th>
<th>2.60</th>
<th>2.80</th>
<th>3.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>0.50</td>
<td>0.48</td>
<td>0.46</td>
<td>0.44</td>
</tr>
<tr>
<td>12.5</td>
<td>0.59</td>
<td>0.57</td>
<td>0.55</td>
<td>0.53</td>
</tr>
</tbody>
</table>
Nominal maximum size of aggregate =

### 6) FINE AGGREGATE

<table>
<thead>
<tr>
<th>Nominal maximum size of aggregate (mm)</th>
<th>Non-air-entrained concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>2280</td>
</tr>
<tr>
<td>12.5</td>
<td>2310</td>
</tr>
<tr>
<td>19</td>
<td>2345</td>
</tr>
<tr>
<td>25</td>
<td>2380</td>
</tr>
<tr>
<td>37.5</td>
<td>2410</td>
</tr>
<tr>
<td>50</td>
<td>2445</td>
</tr>
<tr>
<td>75</td>
<td>2490</td>
</tr>
<tr>
<td>150</td>
<td>2530</td>
</tr>
</tbody>
</table>

### 7) ADJUSTMENT FOR MOISTURE IN AGGREGATE

Design mix water
- total moisture content in coarse aggregate
- total moisture content in fine aggregate
- the degree of moisture absorption of coarse aggregate %
- the degree of moisture absorption of fine aggregate %

Net mix water =
- Wet weight of coarse aggregate
- Wet weight of fine aggregate
- Nominal maximum size of aggregate

### 8) SUMMARY OF MIX DESIGN

Batch percentage Compressive strength at 28 days
- Slump:
  - Maximum and minimum =
- Nominal maximum size of aggregate
- Water-cement (or water-cementitious materials) ratio
- Concrete type
Air content %
Unit weight of coarse aggregate =

**Ingredients of Concrete Mixture**

<table>
<thead>
<tr>
<th>Water $kg/m^3$</th>
<th>Cement $kg/m^3$</th>
<th>Coarse Aggregate $kg/m^3$</th>
<th>Fine Aggregate $kg/m^3$</th>
<th>Pozzolanic Materials $kg/m^3$</th>
<th>Water Reducer $kg/m^3$</th>
</tr>
</thead>
</table>

For design problems, refer standard text books given at the end.

**DOE METHOD OF CONCRETE MIX DESIGN**

The British method of concrete mix design, popularly referred to as the "DOE method", is used in the United Kingdom and other parts of the world and has a long established record. The method originates from the "Road Note No 4" which was published in Great Britain in 1950. In 1975 the note was replaced by the "Design of Normal Concrete Mixes", published by the British Department of the Environment (DOE). In 1988 the "Design of Normal Concrete Mixes" was issued in a revised and updated edition to allow for changes in various British Standards.

**Concrete Mix Design**

Concrete mix design is the process of finding the proportions in which the concrete materials - cement, water, fine aggregate and coarse aggregate - should be combined in order to provide the required strength, workability, durability and other specified properties. Firstmix enables anyone who has a basic knowledge of concrete to design a concrete mix, that is to find the proportions in which cement, water, fine aggregate and coarse aggregate must be combined in order to produce concrete of the required workability, strength and durability.

**Specification of a Concrete Mix**

The object of concrete mix design is to find the proportions in which the concrete materials - cement, water, fine aggregate and coarse aggregate - should be combined in order to provide the specified strength, workability and durability and possibly meet other requirements, as listed in standards. The specification of a concrete mix must therefore define the materials and the strength, workability and durability to be attained. How Firstmix deals with these requirements, is discussed below:

Cement
In mix design the most important property of a type of cement is its influence on the strength of the concrete. Firstmix allows the properties of three standard cements to be used.

**Water**
In mix design water is assumed not to contain impurities that affect its suitability for concrete and its specification is therefore irrelevant to mix design.

**Fine Aggregate**
The type (crushed or uncrushed) and grading of the fine aggregate are important in mix design and should be specified. The density should be also be specified if known but Firstmix will use a typical value if it is not specified.

**Coarse Aggregate**
The type (crushed or uncrushed) and maximum size of the coarse aggregate are important in mix design and should be specified. The density should be also be specified if known but Firstmix will use a typical value if it is not specified.

**Strength**
The required concrete strength, the age at testing and the method of testing must be specified for a designed concrete mix. In mix design a target mean strength is aimed for. The target mean strength is generally derived from a characteristic strength or ‘grade of concrete’, to which a ‘margin’ is added to allow for statistical variation. In Firstmix a characteristic strength must be specified together with either a margin or statistical particulars from which a margin can be calculated.

**Workability**
The required workability and the method of testing must be specified for a designed concrete mix.

**Durability**
Tests for durability are not normally specified for concrete. Instead conditions are set for the mix, which are intended to provide the required durability. The conditions may include:

- A maximum free water/cement ratio;
- A minimum cement content;
- A given percentage of entrained air or a given total air content.

All these conditions can be set in Firstmix.

**Other Requirements**
- Sometimes a maximum cement content is specified to limit the heat of hydration and/or shrinkage.
- Sometimes limits are set for the concrete density.

**Importance of the method**

In this lecture, design of concrete mixes is discussed based on the approach proposed by the Department of Environment, Building Research Establishment of United Kingdom, which sometimes is referred to as DOE approach. Students are therefore recommended to refer Building Research Report, BR 106 "Design of Normal Concrete Mixes", for more details. Concrete mix design involves a wide range of knowledge concerning the properties and interactive influences of constituent materials, influence of ambient conditions and concrete technology. Students are recommended to read Neville's "Concrete Technology" when needed.

Concrete mix design is to select suitable constituent materials and determine proportions of the materials to meet specifications for that concrete. The specifications normally include requirement on strength, durability of hardened concrete and workability of fresh concrete.

Many factors affect the properties of concrete. It is not necessary, and indeed it is not possible, to include all of them in a mix design. The design method introduced in this lecture considers a few factors that possess relatively significant influences, namely water/cement ration, water content, types of cement, size, grading and density of aggregates. These factors are briefly discussed in the following sections. Relations of these factors are reflected in figures and tables available in books.

**Steps for DOE method**

**SPECIFIED STRENGTH AND TARGET STRENGTH FOR MIX DESIGN**

**a. Variation and probability of concrete strength**

Table 1 is a collection, or a sample, of testing records of concrete cube tests for a construction project. It is now generally accepted that the strength of concrete follows normal distribution. The standard deviation of the sample, s, may be calculated using equation (1).

| Table 1 Compressive strength of 60 cubes from a construction site |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                     | 24.1| 20.8| 21.1| 14.6| 20.6| 22.0| 28.1| 17.1| 22.1| 26.4 |
|                     | 19.6| 28.8| 23.5| 19.1| 28.9| 31.5| 24.4| 28.3| 32.6| 17.2 |
|                     | 26.7| 35.7| 21.6| 26.0| 31.6| 15.4| 26.9| 22.8| 27.0| 15.1 |
where \( x \) = an individual test result  
\( n \) = the number of results  
\( m \) = the mean of the \( n \) results.

m of the sample in Table a is 24.08 N/mm\(^2\), and \( s \) is 6.13 N/mm\(^2\).

Normal distribution is expressed as follows.

\[
p(m, s) = \frac{1}{s\sqrt{2\pi}} e^{\frac{(x-m)^2}{2s^2}}  \quad (2)
\]

Normal distribution curve with \( m \) and \( s \) obtained from data I Table a is plotted in Fig. a for comparison with the histogram.

b. Characteristic strength

Probability and statistics have been widely adopted in engineering to describe structure failure and material properties. In the old practice, concrete strength is specified using "minimum strength". From the probability theory adopted today, there is always a possibility, however remote, that the strength of concrete falls below a specified strength. Therefore concrete strength is specified in term of "Characteristic Strength". The characteristic strength is the strength below which a specified proportion of test results, often called "defectives", may be expected to fail. The characteristic strength may be defined to have any proportion of defectives, BS 5328 "Concrete" and BS8110 "Structure use of concrete" adopt 5% defectives level for the determination of characteristic strength.

Example: Based on the test results in Table a, the characteristic strength of that concrete is 24.08 - 1.64 \times 6.08 = 14.1 N/mm\(^2\).

c. Target strength for mix design
As a result of variability of concrete it is necessary to design the mix to have a mean strength greater than the specified characteristic strength by an amount termed the margin. Thus the target strength, \( f_{\text{m}} \), is

\[
f_{\text{m}} = f_c + ks
\]

where

- \( f_c \) = specified characteristic strength
- \( s \) = standard deviation
- \( k \) = constant depending on the defective level associated with the specified strength.
- \( ks \) is termed the margin.

For example, for a specified characteristic strength of 40 N/mm\(^2\) in a design comply to BS8110 (5% defective level), and standard deviation is 7 N/mm\(^2\), the target mean strength is

\[
f_{\text{m}} = f_c + ks = 40 + 1.64 \times 7 = 51.5 \text{ N/mm}^2,
\]

Standard deviation should be based on previous record of the concrete produced by the concerned concrete plant or supplier.

**DURABILITY REQUIREMENT**

Durability requirement specified by, for example, minimum cement content and maximum water/cement ratio, etc. The durability requirement specified in BS8110 for structural concrete is exacted as an example.

### Durability requirement for concrete cover (extracted from BS8110)

<table>
<thead>
<tr>
<th>Conditions of exposure</th>
<th>Nominal cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
</tr>
<tr>
<td>Mild</td>
<td>25</td>
</tr>
<tr>
<td>Moderate</td>
<td>-</td>
</tr>
<tr>
<td>Severe</td>
<td>-</td>
</tr>
<tr>
<td>Very severe</td>
<td>-</td>
</tr>
<tr>
<td>Extreme</td>
<td>-</td>
</tr>
<tr>
<td>Max Free water/cement ratio</td>
<td>0.65</td>
</tr>
<tr>
<td>Min cement content (kg/m(^3))</td>
<td>275</td>
</tr>
<tr>
<td>Lowest grade of concrete</td>
<td>C30</td>
</tr>
</tbody>
</table>
PROCEDURES OF MIX DESIGN

DOE mix design generally involves the following stages.

- Determine the target strength
- Determine the water/cement (W/C) ratio according to the target strength, types of cement and aggregate.
- Determine the water content, W, from required workability, size and type of aggregate.
- Determine cement content, C, from W/C ratio and water content.
- Estimate the density of wet fresh concrete, D, based on relative density of combined aggregate and water content.
- Determine the total aggregate content from D, C, and W.
- Determine the proportion of fine aggregate according to the fineness of fine aggregate, maximum aggregate size, slump/Vebe time and W/C.

Refer standard text books for the design problems

QUESTIONS

1. Discuss the influence the following factors on the workability of a normal concrete mix.
   - Shape of aggregate
   - Maximum size of aggregate
   - Grading of course aggregate
   - Grading of fine aggregate

2. The following is results from a sieve analysis test,
   (a) calculate the per cent passing 600µm sieve, and
   (b) draw grading chart (size distribution chart) of the aggregate.

<table>
<thead>
<tr>
<th>Sieve Size (mm or μm)</th>
<th>5 mm</th>
<th>2.36 mm</th>
<th>1.18 mm</th>
<th>600 μm</th>
<th>300 μm</th>
<th>150 μm</th>
<th>75 μm</th>
<th>Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Retained (g)</td>
<td>11</td>
<td>110</td>
<td>230</td>
<td>273</td>
<td>286</td>
<td>69</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

3. The following is a set of result from cube compressive strength tests on a construction site. Determine the mean, standard deviation and characteristic strength of the concrete at 2.5% defective level.

   Results cube compressive strength on 150×150 mm cubes (N/mm²)
4. Based on the record in Question 3, if a specified characteristic cube strength is $40\text{N/mm}^2$, what should be the target mean strength when design a concrete mix.


6. Define the term Saturated and surface-dry condition.

7. Define the term "aggregate absorption".

8. Define the term "Free water" in the context of concrete mix proportions. Why use free water instead of total water when design a concrete mix?

9. What is "relative density" of an aggregate? What is "bulk density of an aggregate? What is "percentage void of an aggregate?"

10. Proportions of a concrete mix is shown in the following Table.

<table>
<thead>
<tr>
<th>Proportions of a concrete mix (for 1 cubic meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
</tr>
<tr>
<td>400kg</td>
</tr>
</tbody>
</table>

Estimate the density of fresh concrete.

References
3. Teychene D C et al "Design of Normal Concrete Mixes" Department of Environment, Building Research Establishment, 1992
5. IS 10262-1982, Indian Standard, Recommended guidelines for concrete mix design, Bureau of India Standard., New Delhi, India.
6. IS: 10262-2009, Indian standard Concrete mix proportioning - guidelines (First revision Bureau of India Standard, New Delhi, India
7. SP: 23-1988, Handbook on concrete mixes (based on Indian Standards), Bureau of Indian Standards, New Delhi, India
11. Nataraja, M. C., Dhang, N and Gupta, A. P., ‘Computerised Concrete Mixture Proportioning Based on BIS Method-A Critical Review, Fifth International Conference on Concrete Technology for Developing Countries, NCCBM, New Delhi, 17-19 Nov. 99