Chapter 7: Concrete Mix Design

7.1 Definitions

Mix design is the process of determining required and specified characteristics of a concrete mixture. Characteristics can include: (1) fresh concrete properties; (2) required mechanical properties of hardened concrete such as **strength** and **durability** requirements; and (3) the inclusion, exclusion, or limits on specific ingredients.

Mixture proportioning refers to the process of determining the quantities of concrete ingredients, using local materials, to achieve the specified characteristics of the concrete. A properly proportioned concrete mix should possess these qualities:

1. Acceptable workability of the freshly mixed concrete
2. Durability, strength, and uniform appearance of the hardened concrete
3. Economy

Mixture proportioning is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete having certain minimum workability, strength and durability as economically as possible.

Mixture proportioning is to determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.

7.2 Factors to be Considered Mix Proportioning:

- Required workability (Cohesiveness, slump) based on placement conditions.
- Strength and durability.
- Appearance.
- Economy.
- Minimize the amount of cement, Minimize w/c ratio.
- Minimum amount of water, to reduce cement content.
- do not sacrifice the quality**.**

Advantages of low water/cement ratio:

- Increased strength.
- Lower permeability.
- Increased resistance to weathering.
- Better bond between concrete and reinforcement.
- Reduced drying shrinkage and cracking.
- Less volume change from wetting and drying.

7.3 Basic data required for mix proportioning.

The following basic data is required for concrete mix proportioning:

(i) **Grade designation**: It gives characteristic compressive strength of concrete. The target mean strength of concrete is fixed by adding a suitable margin to the characteristic strength depending upon the quality control to be envisaged.

(ii) **Type of cement**: The type and grade of cement mainly influences the rate of development of compressive strength of concrete.

(iii) **Maximum nominal size of aggregate**: The maximum nominal size of the aggregate to be used in concrete is governed by the size of the section to be concreted and spacing of the reinforcement.

(iv) **Maximum water-cement ratio**: The maximum water cement ratio to be used for a particular work is governed by the desired strength and limited by the durability requirements.

(v) **Minimum cement content**: The minimum cement content to be used is governed by the respective environmental exposure conditions.

(vi) **Workability**: The desired workability for a particular job depends upon the shape and size of section to be concreted, denseness of reinforcement, and method of transportation, placing and compaction of concrete.

(vii) **Exposure conditions**: The anticipated environmental exposure conditions in which the structure is intended to serve during its service span defines the durability requirements.

(viii) **Type and properties of aggregate**: It influences the workability and strength of concrete. The relative proportions of coarse and fine aggregate are determined from the characteristics of the aggregates such as grading, shape, size and surface texture.

(ix) **Method of transporting and placing**: It influences workability of the mix.

(x) **Use of admixtures**: admixtures are used to enhance and modify one or more properties of concrete in fresh as well as hardened state.

7.4 Compressive Strength Grading and Classes

Grade of concrete is the classification of concrete according to its compressive strength.

7.4.1 Indian Standards:

There are different grades of concrete are given as M10, M15, M20, M25, M30, M35 and M40.

The letter **"M"** denotes mix design with proportion of materials like cement: fine Aggregate: coarse Aggregate.

The numbers represent the predetermined cube strength of 15cm cube after curing of 28 days in N/mm^2.

M10 = $10N/mm^2$ compressive strength after 28days.
M15 = $15N/mm^2$ compressive strength after 28days.
M20 = $20N/mm^2$ compressive strength after 28days.

Nominal Grades

Grade of Concrete	Mix Ratio	Compressive Strength in N/mm2 or MPa	Compressive Strength in Psi
M5	1 : 5 : 10	5 MPa	725 psi
M7.5	1 : 4 : 8	7.5 MPa	1087 psi
M10	1 : 3 : 6	10 MPa	1450 psi
M15	1 : 2 : 4	15 MPa	2175 psi
M20	1 : 1.5 : 3	20 MPa	2900 psi

2. Standard Grades

M25	1 : 1 : 2	25 MPa	3625 psi
M30	Design Mix	30 MPa	4350 psi
M35	Design Mix	35 MPa	5075 psi
M40	Design Mix	40 MPa	5800 psi
M45	Design Mix	45 MPa	6525 psi

3. High Strength Grades

M50	Design Mix	50 MPa	7250 psi
M55	Design Mix	55 MPa	7975 psi
M60	Design Mix	60 MPa	8700 psi
M65	Design Mix	65 MPa	9425 psi
M70	Design Mix	70 MPa	10150 psi
M80	Design Mix	80 MPa	11600 psi
M90	Design Mix	90 MPa	13050 psi
M100	Design Mix	100 MPa	14500 psi
M150	Design Mix	150 MPa	21750 psi
M200	Design Mix	200 MPa	29000 psi

7.4.2 European Standard EN206-1 Part 1: Specification, performance, production and conformity

Concrete in EN206-1 is classified with respect to its compressive strength. The characteristic compressive strength at 28 days of 150 mm diameter by 300 mm cylinders or the characteristic compressive strength at 28 days of 150 mm cubes may be used for classification.

Table 7 – Compressive strength classes for normal-weight and heavy-weight concrete

Compressive strength class	Minimum characteristic cylinder strength $f_{ck,cyl}$ N/mm^2	Minimum characteristic cube strength $f_{ck,cube}$ N/mm^2
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60
C55/67	55	67
C60/75	60	75
C70/85	70	85
C80/95	80	95
C90/105	90	105
C100/115	100	115

7.5 Characteristic Strength and Target Mean Strength

The strength of concrete produced in sites is varied between mixes and even in in the same mix. The overall variation in the measured strength of concrete that is obtained during a job can be considered to be made up of three component sources which are:

1. Variations in testing methods.
2. Variations in the properties or proportions of the constituent materials in the concrete mixture, variations in the production, delivery or handling procedures, and variations in climatic conditions.

Variation in concrete strengths follows the normal distribution such as that shown below

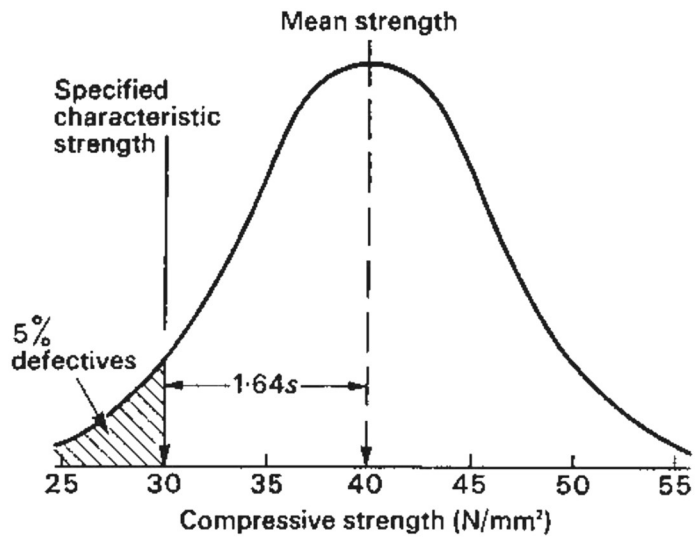

Figure: Normal distribution of concrete strengths

This normal distribution curve is symmetrical about its mean, has a precise mathematical equation and is completely specified by two parameters, its mean "m" and its standard deviation "s". Concrete cube strengths follow the normal distribution. There is therefore always the probability that a result will be obtained less than the specified strength.

The proportion of results less than some specified value is represented by the area beneath the curve to the left-hand side of a vertical line drawn through the specified value.

<u>Standard deviation</u>: The standard deviation is a measure of the variability calculated from the equation:

$$s = \sqrt{\frac{(x - \bar{x})^2}{n - 1}}$$

x = individual test result.
$\bar{x}$ = average strength results.
n = number of results.

Standard deviation increases as the specified characteristic strength increases up to a particular level. This type of relationship is shown below, the standard deviation being independent of the specified characteristic strength above 20 N/mm2.

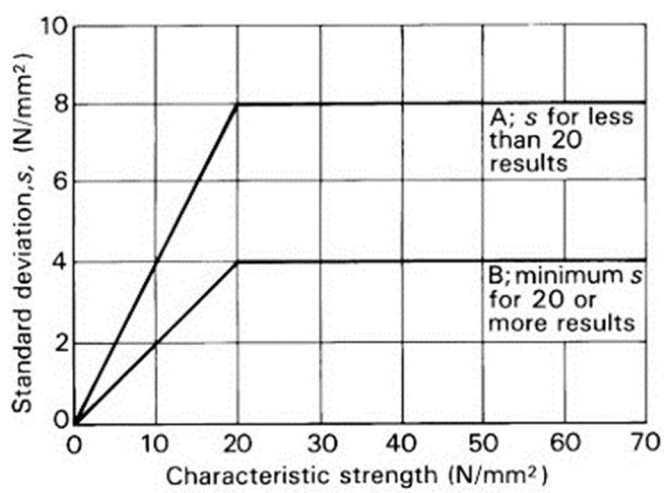

Figure A. Relationship between standard deviation and characteristic strength.

d) Coefficient of variation: It is an alternative method of expressing the variation of results. It is a non-dimensional measure of variation obtained by dividing the standard deviation by the arithmetic mean and is expressed as:

$$V\,\% = \frac{s}{\bar{x}} * 100$$

Characteristic Strength

The quality of concrete is specified '**characteristic strength**' below which a specified proportion of the test results, often called 'defectives', may be expected to fall. The characteristic strength could be the minimum design value which applied in the design of various structural elements and specified in the project specifications.

Based on EN 206-1: the value of strength below which 5 % of the population (number of test results) of all possible strength determinations of the volume of concrete under consideration, are expected to fall.

Target Mean Strength

The producer of concrete should design the concrete mix using a higher strength than that of the characteristic strength by a certain **Margin** (risk factor), in order to ensure satisfying the quality criteria set by the client. This higher strength is called **Target Mean Strength**.

Target mean strength = specified characteristic strength + Margin

Target mean strength = $\boldsymbol{f_m}$
Specified characteristic strength = $\boldsymbol{f_c}$
Margin = $\boldsymbol{k.s}$

$$\boldsymbol{f_m = f_c + k.s}$$

The constant **k** is derived from the mathematics of the normal distribution and increases as the proportion of defectives is decreased, thus:

k for 10% defectives = 1.28
k for 5% defectives = 1.65
k for 2.5% defectives = 1.96
k for 1% defectives = 2.33

7.6 Methods of Concrete Mix design

Most of available methods of concrete mix design are based on empirical relationships, charts, graphs developed from intensive experimental programs. Basically, they follow the same principles and only minor changes exist in different mix design methods in selecting the mix proportions.

The requirements of the concrete mix is usually identified by the general experience with regard to the structural design conditions, durability and conditions of placing. Some of the commonly used mix design methods for medium strength concrete are the following:

- **Trial and adjustment method of mix design.**
- **British DoE mix design method.**
- **ACI mix design method.**
- **Indian standard Recommended method IS 10262-82**

7.7 British Method of Concrete Mix Design (DoE Method)

The DOE method was first published in 1975 and then revised in 1988. While Road Note No 4 or Grading Curve Method was specifically developed for concrete pavements, the DOE method is applicable to concrete for most purposes, including roads. The method can be used for concrete containing fly ash or GGBFS. The following are the steps involved in DOE method:

Step 1: Find Target Mean Strength

Find the **target mean strength** as explained before.

Step 2: Calculation of Water/Cement Ratio

This is done in a rather round about method, using Table 1 and Figure. 1.

Table 1: Approximate compressive strengths (MPa) of concrete mixes made with a free-water/cement ratio of 0.5

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm^2) Age (days) 3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Throughout this publication concrete strength is expressed in the units N/mm^2.
$1\ N/mm^2 = 1\ MN/m^2 = 1\ MPa$. (N = newton; Pa = pascal.)

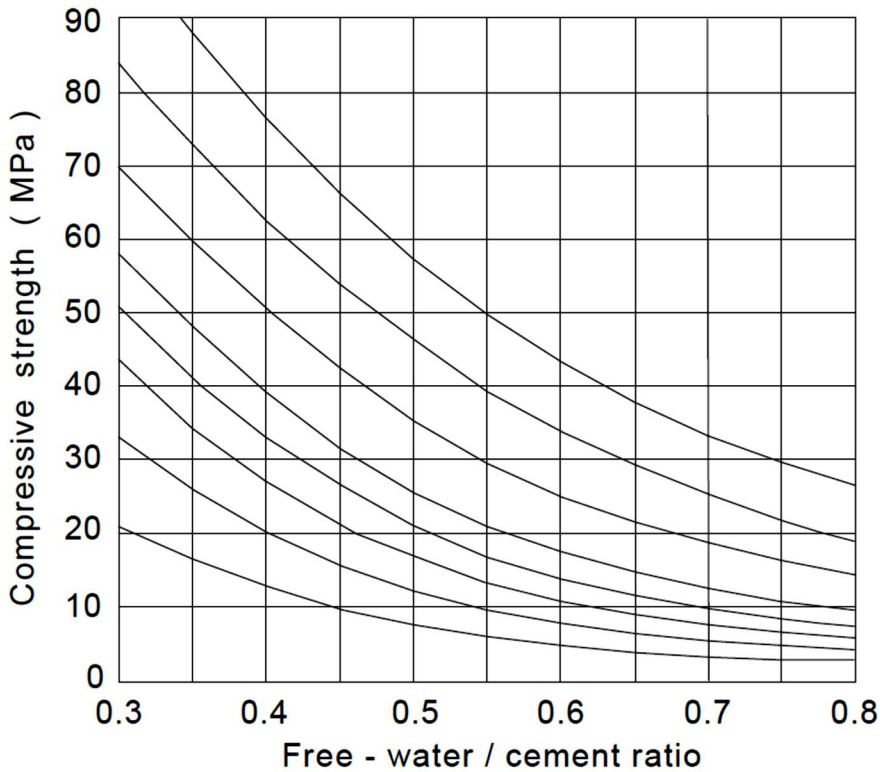

Figure 1 Relation between compressive strength and free-water/cement ratio

It is required to find the w/c for the 28 days compressive strength is 39 MPa. Referring to Table 1, for OPC, crushed aggregate, W/C ratio of 0.5, the 28 days compressive strength is 49 MPa. In Fig. 1 find an intersection point for 49 MPa and 0.5 W/C ratio. Draw a dotted line curve parallel to the neighboring curve. From this curve read off the W/C ratio for a target mean strength of 39 MPa. The Water/cement ratio is = 0.58.

<u>Check this W/C ratio from durability consideration from Table B. Adopt lower of the two ratios.</u>

Table B. requirements of BS 8110: Part I: 1985 to Ensure Durability Under Specified Exposure Conditions of Reinforced and Prestressed Concrete Made with Normal Weight Aggregate.

Condition of exposure	*Nominal Cover of Concrete in mm*				
Mild	25	20	20	20	20
Moderate	–	35	30	25	20
Severe	–	–	40	30	25
Very Severe	–	–	50	40	30
Extreme	–	–	–	60	50
Maximum Water/ Cementitious material ratio	0.65	0.60	0.55	0.50	0.45
Minimum content of cementitious Material in kg/m^3	275	300	325	350	400
Minimum grade MPa	30	35	40	45	50

Step 03: Calculation of free Water Content

Table 2 Approximate free-water contents (kg/m^3) required to give various levels of workability

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

For example: for uncrushed aggregate, MSA = 20 mm, slump from 30-60 mm, w/c ratio = 0.50, the Mixing water content is 180 kg/m^3 of concrete.

Step 04: Calculation of cement Content

$$w/c = \frac{w}{c} \quad \text{, cement content, } c = \frac{w}{w/c}$$

The calculated cement content should be compared with any given minimum cement content.

Step 05: Weight of Total Aggregate

This requires an estimate of the wet density of the fully compacted concrete. This can be found out from Figure below for approximate water content and specific gravity of aggregate. An approximation can be made by assuming an average value of specific gravity of **2.6 for uncrushed** aggregate and **2.7 for crushed aggregate**.

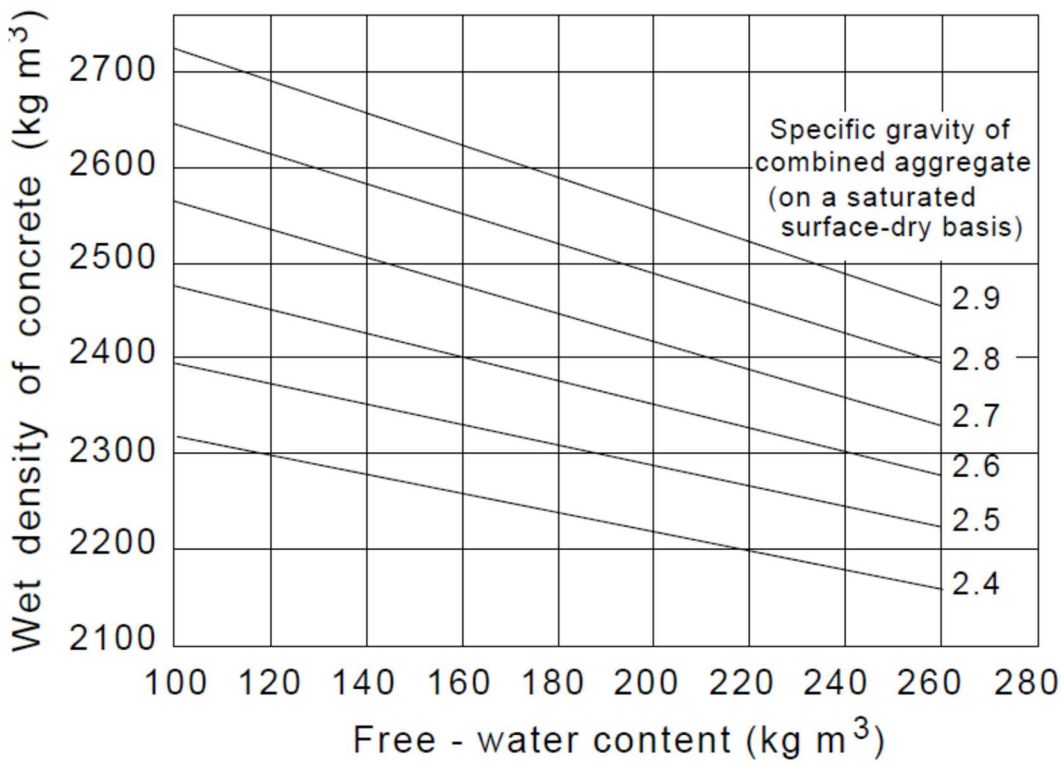

Figure 2 Wet density of fully compacted concrete

Estimated wet density of fully compacted concrete.

Then, total weight of aggregate is find out:

$$Weight\ of\ Total\ Aggregate = wet\ density - [Weight\ of\ Cement + Weight\ of\ Free\ Water]$$

Step 06: Weight of Fine Aggregate

Then, proportion of fine aggregate is determined in the total aggregate using Figure above. Figure (a) is for 10 mm size, (b) is for 20 mm size and (c) is for 40 mm size coarse aggregate.

The parameters involved are

- maximum size of coarse aggregate,
- the level of workability,
- water/cement ratio, and
- Fineness Modulus (FM).

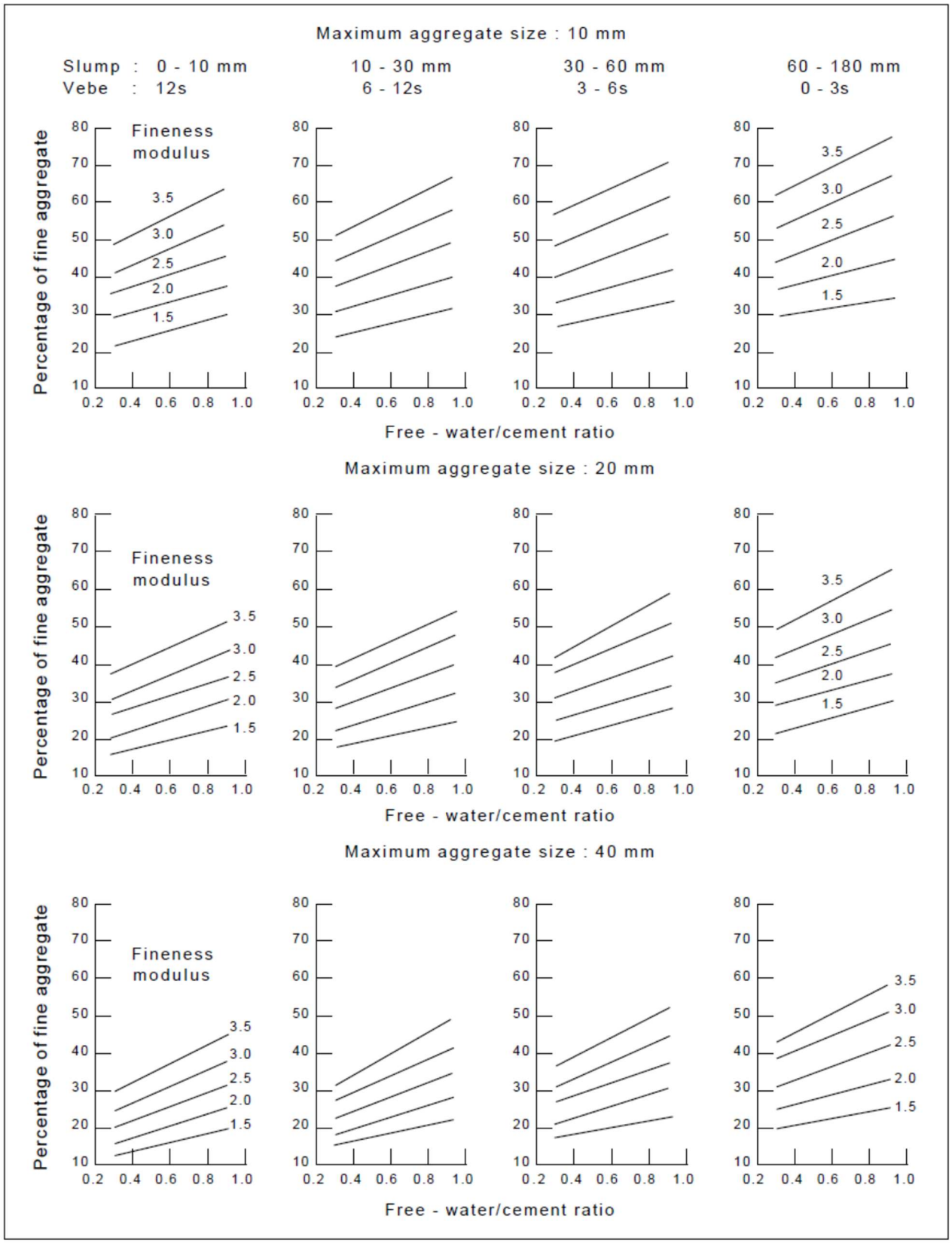

Figure 3 Proportions of fine aggregate determined from Fineness Modulus

For example: for 20 mm aggregate size, w/c ratio of 0.50, Slump of 75 mm, for FM=2.5, the % $Fine\ Aggregate$ =39 %

Then:

Fine aggregate content = total aggregate content × % wt of fine aggregates..

Coarse aggregate content = total aggregate content – fine aggregate content.

Coarse aggregate content can be subdivided if single sized 10, 20 and 40 mm aggregates are to be combined. The best proportions will depend on aggregate shape and concrete usage, but the following ratios are suggested as a guide:

1: 2 for combination of 10mm and 20mm aggregates.

1 :1.5 : 3 for combination of 10mm, 20mm and 40 mm aggregates.

Step 07: Trial Mixes

The design procedure outlined above is based on materials which may not be what is used for your design. It is unlikely that the first mix design would achieve the target results. It usually takes a few trials before a satisfactory design is achieved.

After each trial mix, the concrete mix design should be adjusted before the next trial. The following items may be given consideration:

Density: The density of the concrete measured during the trial mix should be checked against the assumed density during the mix design, and necessary adjustments should be made accordingly.

Slump: The slump can be adjusted by adjusting the water content and the fine aggregate/coarse aggregate ratio. Slump can be increased by increasing the water content and/or decreasing the fine aggregate/coarse aggregate ratio. A slump adjustment of 20 mm can be achieved by changing the water content by 5 kg and fine aggregate by 5 kg. The water/cement ratio should be maintained so that the strength is not altered.

Strength: The strength can be adjusted by adjusting the water/cement ratio according to the Figure 1. Use the results from the trial mix, the water/cement ratio and the strength, and plot a point in Figure 1. Draw the curve parallel to the other curves through the point, and use this curve to estimate the water/cement ratio required for the target strength.

Step 08. Adjustments for Aggregate Weights and Water Content.

1- The **effective absorption (EA)** represents the amount of water required to bring an aggregate from the AD state to the SSD, expressed as a fraction of the SSD weight:

$$\mathbf{EA = (W_{SSD} - W_{AD}) / W_{SSD} \times 100\%}$$

2- The surface moisture (SM) represents water in excess of the SSD state, also expressed as a fraction of the SSD weight:

$$\mathbf{SM = (W_{wet} - W_{SSD}) / W_{SSD} \times 100\%}$$

***Aggregate weights*.** Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

***Amount of mixing water*.** If the batched aggregate is anything but saturated surface dry it will absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

Example 1

Design a concrete mix to obtain a characteristic compressive strength (fc) = 30 N/mm^2 at 28 days, with a 2.5% defective rate (k = 1.96), assume that less than 20 previous results are available for calculating the standard deviation. The design requirements are as follows:

- Slump required = 10–30 mm.
- the Maximum aggregate size, MSA = 20 mm (uncrushed),
- Fine aggregate: Fineness modulus, FM =2.5.
- Portland cement class = 42.5.
- maximum free-w/c ratio = 0.55,
- minimum cement content = 290 kg/m^3,
- maximum cement content = not specified.

Absorption of fine aggregate = 2%; Absorption of coarse aggregate = 1.1%
Total Moisture content of coarse aggregate = 2.5%; Total Moisture content of fine aggregate = 1.5%.
What are the proportions to produce trial mix of 0.05 m^3 concrete?
What are the proportions to produce 25 m^3 concrete?

Step 1: Find Target Mean Strength

Find the **target mean strength**.

Target mean strength = $\boldsymbol{f_m}$
Specified characteristic strength = $\boldsymbol{f_c}$, Margin = $\boldsymbol{k.s}$

From Figure A. the standard deviation is 8 MPa

$$\boldsymbol{f_m = f_c + k.s}$$

$$\boldsymbol{f_m = 30 + 1.96 \times 8 = 45.7\ MPa}$$

Step 2: Calculation of Water/Cement Ratio

From Table 1 the compressive strength for w/c =0.50 is 42MPa. From Figure 1 the w/c for compressive strength of 45.7 MPA is **0.47**.

Step 03: Calculation of free Water Content

From Table 2, for 10-30mm level of workability, uncrushed aggregates and maximum aggregate size of 20mm the water content is **160kg/m^3** concrete.

Step 04: Calculation of cement Content

$$^{w}/_{c} = \frac{w}{c} \quad \text{, cement content, } c = \frac{160}{0.47} = 340\,\frac{kg}{m^3}\,concrete$$

Step 05: Weight of Total Aggregate

From Figure 2 for free water content of **160 kg/m^3**, Specific gravity of Uncrushed aggregates =2.6 (assumed), the wet density of concrete = **2400 kg/m^3**. Therefore, the total aggregate content is

Total aggregate content = Wet density of 1m^3 concrete – water content – cement content

= 2400 – 160 – 340 = **1900 kg/m^3**

Step 06: Weight of Fine Aggregate

From Figure 3. The workability level =10-30mm, FM=2.5, w/c=0.47, MSA=20mm the percentage of fine aggregates = 32%.

Fine aggregate content = 1900×0.32 = **608 kg/m^3 concrete**

Coarse aggregate content = 1900 – 608 = **1292 kg/m^3 concrete**

Step 08. Adjustments for Aggregate Weights and Water Content.

***Adjusted Fine Aggregate weight*.**

Total moisture of fine aggregates = 1.5%, and absorption = 2%,
So, the aggregates are in **Air dry condition**,

0.5% = W_w/W_{SSD} , W_w = weight of water to reach SSD = 0.5% * 608 = 3.04 kg.

Adjusted weight of fine aggregates = 608 – 3.04 = **605 kg**

The mixing water should be increased by an amount of 3.04 kg

Adjusted Coarse Aggregates weight

Total moisture content of coarse aggregate = 2.5 %, and absorption of coarse aggregate = 1.1%, so the coarse aggregates are in **Wet condition** and there is moisture on the aggregates surface.

Surface water, SM = (2.5% – 1.1%) = 1.4% = W_w / W_{SSD} = W_w / 1292,

SM = 1.4% * 1292/100 = 18.1 kg

Adjusted coarse aggregates, CA = 1292 + 18.1 = 1310.1 kg.

Also, amount of water from CA to be added to the mixing water = 18.1 kg

Adjusted Mixing Water

Adjusted mixing water = 160 + 3.04 – 18.1 = 145 kg.

Final Results

	Cement (kg)	Water (kg or litre)	Fine aggregate (kg)	Coarse Aggregates (kg)	
				10 mm	20 mm
Per 1m^3 (to nearest 5kg)	340	160	605	1310.1	
				436.7	873.4
	1	0.47	1.78	3.85	
				1.28	2.57
Per 0.05 m^3	17	8	30.3	21.8	43.7
Per 25 m^3	8500	4000	15125	10918	21835

Problem 1.

Calculate the quantities of cement, water, fine aggregate and coarse aggregate per trial mix of 0.08 m^3 for the following specifications:

- Characteristic compressive strength = 15 MPa at 28 days;
- Defective rate = 5%;
- Cement = Cement strength class 42.5;
- Slump required = 30-60 mm;
- Max. Aggregate size = 40 mm;
- Coarse aggregate (crushed) (10, 20 and 40 mm),
- fine aggregate (crushed), FM= 2.25
- Specific gravity of aggregates = 2.50;
- Maximum allowable free – water/cement ratio = 0.50;
- Minimum allowable cement content = 290 kg/m^3

Problem 2.

Calculate the quantities of cement, water, fine aggregate and coarse aggregate per trial mix of 0.08 m^3 for the following specifications.

- Characteristic compressive strength = 50 MPa at 28 days; Defective rate = 1%;
- Cement strength class 42.5; Slump required = 30-60 mm;
- Max. Aggregate size = 10 mm;
- Coarse aggregate (crushed) (10 mm),
- fine aggregate (crushed), FM= 2.5
- Maximum allowable free – water/cement ratio = 0.50; Maximum allowable cement content = 550 kg/m^3

7.8 ACI Mix Design Method

The ACI Standard 211.1 is a "*Recommended Practice for Selecting Proportions for Concrete*". The procedure is as follows:

Step 1. Choice of slump

Step 2. Choice of maximum size of aggregate

Step 3. Estimation of mixing water and air content

Step 4. Selection of water/cement ratio

Step 5. Calculation of cement content

Step 6. Estimation of coarse aggregate content

Step 7. Estimation of Fine Aggregate Content

Step 8. Adjustments for Aggregate Moisture

Step 9. Trial Batch Adjustments

Step 1. Choice of slump

If slump is not specified, a value appropriate for the work can be selected from the Table below, or from any other references.

Type of Construction	Slump	
	(mm)	(inches)
Reinforced foundation walls and footings	25 - 75	1 - 3
Plain footings, caissons and substructure walls	25 - 75	1 - 3
Beams and reinforced walls	25 - 100	1 - 4
Building columns	25 - 100	1 - 4
Pavements and slabs	25 - 75	1 - 3
Mass concrete	25 - 50	1 - 2

Step 2. Choice of maximum size of aggregate.

Concretes with the larger-sized aggregates require less mortar per unit volume of concrete, and of coarse it is the mortar which contains the most expensive ingredient, cement. Thus the ACI method is based on the principle that the **maximum size of aggregate should be the largest available so long it is consistent with the dimensions of the structure.**

Step 3. Estimation of mixing water and air content.

The ACI Method uses past experience to give a first estimate for the quantity of water per unit volume of concrete required to produce a given slump. The approximate amount of water required for average aggregates is given in Table 1.

Table 1. Approximate Mixing Water and Air Content Requirements for Different Slumps and Maximum Aggregate Sizes.

	Mixing Water Quantity in kg/m³ (lb/yd³) for the listed Nominal Maximum Aggregate Size							
Slump	9.5 mm (0.375 in.)	12.5 mm (0.5 in.)	19 mm (0.75 in.)	25 mm (1 in.)	37.5 mm (1.5 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)
Non-Air-Entrained								
25 - 50 (1 - 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 - 100 (3 - 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 - 175 (6 - 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	-
Typical entrapped air (percent)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained								
25 - 50 (1 - 2)	181 (305)	175 (295)	168 (280)	160 (270)	148 (250)	142 (240)	122 (205)	107 (180)
75 - 100 (3 - 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 - 175 (6 - 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	-
Recommended Air Content (percent)								
Mild Exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate Exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 4. Selection of water/cement ratio.

The required water/cement ratio is determined by strength, durability and finishability. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table 2 and/or Table 3.

Table 2: Water-Cement Ratio and Compressive Strength Relationship

28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	0.41	-
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

Table 3. Maximum permissible water/cement ratios for concrete in severe exposures

Type of Structure	Structure wet continuously or fequently exposed to freezing & thawing*	Structure exposed to seawater
Thin sections (railings, curbs, sills, ledges, ornamental work) & sections with less than 1-inch cover over steel	0.45	0.40
All other structures	0.50	0.45

* Concrete should also be air-entrained.

Step 5. Calculation of cement content.

The amount of cement is fixed by the determinations made in Steps 3 and 4 above.

$$\text{weight of cement} = \frac{\text{weight of water}}{w/c}$$

Step 6. Estimation of coarse aggregate content.

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Table 4: Volume of Coarse Aggregate per Unit Volume for Different Fine aggregate Fineness Moduli

Nominal Maximum Aggregate Size	Fine Aggregate Fineness Modulus			
	2.40	**2.60**	**2.80**	**3.00**
9.5 mm (0.375 inches)	0.50	0.48	0.46	0.44
12.5 mm (0.5 inches)	0.59	0.57	0.55	0.53
19 mm (0.75 inches)	0.66	0.64	0.62	0.60
25 mm (1 inches)	0.71	0.69	0.67	0.65
37.5 mm (1.5 inches)	0.75	0.73	0.71	0.69
50 mm (2 inches)	0.78	0.76	0.74	0.72

Notes:

1. These values can be increased by up to about 10 percent for pavement applications.
2. Coarse aggregate volumes are based on oven-dry-rodded weights obtained in accordance with ASTM C 29.

Step 7. Estimation of Fine Aggregate Content.

At the completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate. Then, once the volumes are known the weights of each ingredient can be calculated from the specific gravities.

Step 8. Adjustments for Aggregate Moisture.

As explained previously

Step 9. Trial Batch Adjustments.

The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finishability, unit weight, air content and strength.

Problem (1)

The 28-day compressive strength should be 34 MPa, The slump should be between 75 mm and 100 mm and the maximum aggregate size should not exceed 19 mm The properties of the materials are as follows:

- Cement : Type I, specific gravity = 3.15
- Coarse Aggregate: Bulk specific gravity (SSD) = 2.65; absorption capacity = 0.5%; dry-rodded unit weight = 1605 kg/m^3; surface moisture = 1%
- Fine Aggregate: Bulk specific gravity (SSD) = 2.60; absorption capacity = 1.1%; fineness modulus = 2.70; surface moisture = 3%.

Problem (2)

Repeat problem 1 if the concrete is to be subjected to severe exposure to seawater. Compare the material cost.

Problem (3)

Repeat problem 1 for max. aggregate size of 37.5 mm. Compare the material cost.

Problem (4)

Repeat problem 2 for compressive strength of 41 MPa. Compare the material cost

Problem (5)

Repeat problem 1 for slump value of 40mm. Compare the material cost.

Problem (5)

Repeat problem 1 for fineness modulus of the fine aggregates 3.00. Compare the material cost.