2.7 CEMENT CONCRETE MIX DESIGN

2.7.1 Introduction

2.7.2 Required Properties of Concrete

2.7.3 Procedures for Determining Mix Proportions

2.7.4 Sample Computations

2.7.1 Introduction

- Concrete mix design describes methods for selecting proportions for hydraulic cement concrete.
- Concrete is composed principally of aggregates, Portland cement and water and may 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 an 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.
- Since strength and other important concrete qualities such as durability, shrinkage and cracking are related to the total water content and the w/c ratio, water-reducing admixtures are often used to improve concrete quality.

- Since less cement can be used with reduced water content to achieve the same w/c ratio or strength, water reducing admixtures are used widely for reasons of economy.

- Concrete proportions must be selected to provide necessary placeability, density, strength and durability.

- The procedures for concrete mix design presented here are taken from “Standard Practice for Selecting Proportions for Normal, Heavy weight and Mass Concrete (ACI 211.1-91)” published by the American Concrete Institute.

2.7.2 Required Properties of Concrete

Placeability

- Placeability mainly denotes workability, which is considered to be that property of concrete that determines its capacity to be placed and consolidated properly and to be finished without harmful segregation.
- It describes cohesiveness and compactability. Workability is affected by the grading, particle shape and proportions of aggregate.

Consistency

- Consistency is the relative mobility of the concrete mixture. It is measured in terms of slump, the higher the slump the more mobile the mixture.
- It affects the ease with which the concrete will flow during placement. Mixing water requirements usually are reduced significantly by certain chemical water-reducing admixtures.

2.7.2.3 Strength

- Strength at the age of 28 days is frequently used as a parameter for the structural design, concrete proportioning and evaluation of concrete.

2.7.2.4 Water Cement Ratio

- Concrete strength is determined by the net quantity of water used per unit quantity of cement. The net water content excludes water absorbed by the aggregates.

2.7.2.5 Durability

- Concrete must be able to endure exposures that may deprive it of its serviceability (freezing and thawing, wetting and drying, heating and cooling, chemicals etc.)

2.4.3 Procedures for Determining Mix Proportions
Background Data

- Sieve analysis of coarse and fine aggregates
- Bulk specific gravities and absorptions of aggregates
- Natural moisture content of aggregates
- Fineness modulus of fine aggregates
- Specific gravity of Portland cement

- Based on the above data the concrete mix is prepared in the laboratory. The concrete mix design gives the proportions by weight of the concrete ingredients **per meter cube of concrete** for the specified type of concrete. The mix design data contains the following:

  - Water/Cement ratio used
  - Average slump value achieved
  - Weight of cement per one meter cube of concrete
  - Weight of coarse aggregate per one meter cube of concrete

- Weight of sand (fine aggregate) per one meter cube of concrete
- Amount of free mixing water per one meter cube of concrete
- Amount of additive (if required) per one meter cube of concrete

- The job specification may indicate some or all of the following:

  - Maximum water-cement ratio
  - Minimum cement content
  - Air content
  - Slump
  - Maximum size of aggregate
  - Strength

Establishment of Batch Weights
A) Step 1: Choice of Slump

- If slump is not specified, a value appropriate for the work can be selected from Table 2.7.1.

Table 2.7.1: Recommended Slumps for Various Types of Construction*

Types of construction	Slump, mm	
	Maximum**	**Minimum**
Reinforced foundation walls and footings	75	25
Plain footings, caissons and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

*Slump may be increased when chemical admixture are used, provided that the admixture-treated concrete has the same or lower water-cement ratio and does not exhibit segregation potential or excessive bleeding.
**May be increased 25 mm for methods of consolidation other than vibration

Step 2: Choice of Maximum Size of Aggregate

- Large nominal maximum sizes of well graded aggregates have less voids than smaller sizes.
- Concrete with the larger-sized aggregates require less mortar per unit volume of concrete.
- In no event should the nominal maximum size exceed one-fifth of the narrowest dimension between sides of forms, one-third the depth of slabs, nor three-fourths of the minimum clear spacing between individual reinforcing bars.

Step 3: Estimation of Mixing Water and Air Content

❑ The quantity of water per unit volume of concrete required to produce a given slump is dependent on:

- The nominal maximum size
- Particle shape
- Grading of the aggregates
- Concrete temperature
- Amount of entrained air
- Use of chemical admixtures

❑ Slump is not greatly affected by the quantity of cement. Table 5.2 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment.

❑ Depending on aggregate texture and shape, mixing water requirements may be somewhat above or below the tabulated values, but they are sufficiently accurate for the first estimate.

Table 2.7.2: Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregates

Slump, mm	Water, kg/m^3 of concrete for indicated nominal maximum sizes of aggregate							
	9.5	12.5	19	25	37.5	50	75	150
Non-air-entrained concrete								
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	-
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air- entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	-
Recommended average total air content, percent for level of exposure								
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
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 4: Selection of Water – Cement Ratio

- Selection of water-cement ratio w/c is determined not only by strength requirements but also by factors such as durability.

- With typical materials, the w/c ratios given on Table 2.7.3 produce the strength shown, based on 28-day tests of specimens cured under standard laboratory conditions. The **average strength** selected **must exceed the specified strength** by a sufficient margin to keep the number of low tests within specific limits.

- The required average strength, f_{cr}, can be obtained based on the specified strength, f'c as follows:

f'c	f_{cr}
< 20 MPa	f'c+7 MPa
20 – 35 MPa	f'c+ 8 MPa
>35 MPa	f'c+ 10 MPa

Table 2.7. 3: Relationships between Water-Cement Ratio and Compressive Strength of Concrete

Compressive strength at 28 days, MPa*	Water Cement ratio, by mass	
	Non-air-entrained concrete	Air-entrained concrete
40	0.42	-
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

*Values are estimated average strengths for concrete containing not more than 2 percent air for non-air-entrained concrete and 6% total air content for air entrained concrete.

For a constant water-cement ratio, the strength of concrete is reduced as the air content is increased.

Strength is based on 152 X 302 mm cylinders moist cured for 28 days.

The relationship in this table assumes a nominal maximum aggregate size of about 19 to 25 mm. For a given source of aggregate, strength produced at a given water-cement ratio will increase as nominal maximum size of aggregate decreases.

Step 5: Calculation of Cement Content

- The amount of cement per unit volume of concrete is fixed by the determinations made in steps 3 and 4 above.

- The required cement is equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio (Step 4).

- If, however, the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement.

Step 6: Estimation of Coarse Aggregate Content

- Aggregates of essentially the same nominal maximum size and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate, on an oven-dry-rodded basis, is used per unit volume of concrete.

- Appropriate values for this aggregate volume are given in Table 5.4. It can be seen that, for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maxim size and fineness modus of the fine aggregate.

❑ The quantity of coarse aggregate is estimated by taking the volume from Table 2.7.4 and multiplying it by the unit weight of the aggregate.

❑The **dry mass of coarse aggregate** required for a cubic meter of concrete is equal to the value from Table 2.7.4 multiplied by the dry-rodded unit mass of the aggregate in kilograms per cubic meter.

Table 2.7.4: Volume of Coarse Aggregate per unit of Volume of Concrete

Nominal Maximum Size of Aggregare, mm	Volume of Dry-Rodded Coarse Aggregate* per unit volume of concrete for different fineness modulii of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in **dry-rodded** conditions.
These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction.

Step 7: Estimation of Fine Aggregate Content

- At completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate.

- Its quantity is determined by difference. Either of two procedures may be employed: the weight method or the absolute volume method.

- If the weight of the concrete per unit volume is assumed, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients.

- Table 5.5 can be used to make a first estimate of the unit weight of concrete.

Table 2.7.5: First Estimate of Mass of Fresh Concrete

Nominal Maximum Size of Aggregate, mm	First Estimate of Concrete Unit Mass, kg/m^3*	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

- A **more exact procedure** for calculating the required amount of fine aggregate involves the **use of volumes** displaced by the ingredients.

- The total volume displaced by the known ingredients: water, air, cement, and coarse aggregate is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate.

- The volume occupied in concrete by any ingredient is equal to its weight divided by the density of that material (**the latter being the product of the unit weight of water and the specific gravity of the material**).

Step 8: Adjustment for Aggregate Moisture

- The aggregate quantities actually to be weighed out for the concrete must allow for moisture in the aggregates.

- Generally, the aggregates will be moist and their **dry weights** should be **increased** by the percentage of water they contain, both absorbed and surface.

- The **mixing water** added to the batch must be **reduced** by an amount equal to the free moisture contributed by the aggregate, i.e. total moisture minus absorption.

5.4 Sample Computations

- Required average strength: 25 MPa
- Required slump: 75 to 100mm.
- Coarse aggregate nominal maximum size: 37.5 mm
- Coarse aggregate dry-rodded unit mass: 1600 kg/m^3.
- Coarse aggregate bulk specific gravity: 2.68
- Coarse aggregate absorption 0.5 percent;
- Fine aggregate bulk specific gravity: 2.64
- Fine aggregate absorption 0.7 percent
- Fine aggregate fineness modulus 2.8.
- Cement specific gravity: 3.15
- Concrete will be non-air-entrained since the structure is not exposed to severe weathering.

- **From Table 5.2**, the estimated mixing water for a slump of 75 to 100 mm in non-air-entrained concrete made with 37.5 mm aggregate is found to be 181 kg/m^3.

- The water-cement ratio for non-air-entrained concrete with a strength of 25 MPa is found from **Table 5.3** to be 0.62.

- Based on the estimated mixing water and water cement ratio, the required cement content is found to be 181/0.62 = 292 kg of Cement/m^{3} of concrete.

- The quantity of coarse aggregate is estimated from **Table 5.4**. For a fine aggregate having a fineness modulus of 2.8 and a 37.5 mm nominal maximum size of coarse aggregate, the table indicates that 0.71 m^3 of coarse aggregate, on a dry-rodded basis, may be used in each cubic meter of concrete. The required dry mass is, therefore, 0.71 x 1600 = 1136 kg.

- With the quantities of water, cement and coarse aggregate established, the remaining material comprising the cubic meter of concrete must consist of fine aggregate and whatever air will be entrapped.

- The required fine aggregate may be determined on the basis of either **mass** or **absolute volume** as shown below:

2.7.4.1 Mass Basis

- From **Table 2.7.5**, the mass of a cubic meter of non-air-entrained concrete made with aggregate having a nominal maximum size of 37.5 mm is estimated to be 2410 kg.

- Masses already known are:

  - Water (net mixing) 181 kg
  - Cement 292 kg
  - Coarse aggregate 1136 kg
  - Total 1609 kg

- The mass of fine aggregate, therefore, is estimated to be

  2410 – 1609 = 801 kg

5.4.2 Absolute Volume Basis

- With the quantities of cement, water, and coarse aggregate established, and the approximate entrapped air content of 1 percent determined from Table 5.2, the sand content can be calculated as follows:

  - Volume of Water = 181 kg/1000 kg/m^3 = 0.181m^3
  - **Solid volume** of Cement = 292 kg/ [3.15X1000 kg/m^3] = 0.093 m^3
  - Solid volume of coarse aggregate = 1136/[2.68X1000] = 0.424 m^3
  - Volume of entrapped air: [0.01 x 1.000] = 0.010 m^3
  - Total solid volume of ingredients except fine aggregate = 0.708 m^3
  - Solid volume of fine aggregate required:[1.000 – 0.708]= 0.292 m^3

- Required weight of **dry** fine aggregate = 0.292 m^3 x 2.64 x 1000 kg/m^3 = 771 kg

Batch masses per cubic meter of concrete calculated on the two bases are compared below:

	Based on estimated concrete mass, kg	**Based on absolute volume of ingredients, kg**
water (net mixing)	181	181
cement	292	292
coarse aggregate (dry)	1136	1136
Sand (dry)	801	771

2.7.4.3 Adjustment for Moisture Content

- Tests indicate total moisture of 2 percent in the coarse aggregate and 6 percent in the fine aggregate. If the trial batch proportions based on assumed **concrete mass** are used, the adjusted aggregate masses become
  - Coarse aggregate (wet) = 1136(1.02) = 1159 kg
  - Fine aggregates (wet) = 801(1.06) = 849 kg
- Absorbed water does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 2 – 0.5 = 1.5 percent; by the fine aggregate 6 – 0.7 = 5.3 percent. The estimated requirement for added water, therefore, becomes
  - 181 – 1136 (0.015) – 801 (0.053) = 122 kg
- The estimated batch masses for cubic meter of concrete are:

Water (to be added)	122 kg
Cement	292 kg
Coarse aggregate (wet)	1159 kg
Fine aggregate (wet)	849 kg
Total	**2422 kg**

- For the laboratory trial batch, it is found convenient to scale the masses down to produce 0.02 m^3 of concrete.

- Although the calculated quantity of water to be added was 2.44 kg, the amount actually used in an effort to obtain the desired 75 to 100 mm slump is 2.70 kg.

- The batch as mixed, therefore, consists of

  - Water (added) 2.70 kg
  - Cement 5.84 kg [0.02X292]
  - Coarse aggregate (wet) 23.18 kg [0.02X1159]
  - Fine aggregate (wet) 16.98 kg [0.02X849]
  - **Total** **48.70 kg**

Continued on Slide No. 2.3

(Asphalt Concrete Mix Design)