Concrete Mix Design

Lecture No. 18

Concrete Mix Design

- One of the ultimate aims of studying the various properties of the materials of concrete, plastic concrete and hardened concrete, is to enable a concrete technologist to design a concrete mix for a particular strength and durability.
- The conditions that prevail at the site of work, in particular the exposure condition, and the conditions that are demanded for a particular work for which the mix is designed.
- Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible.

Concept of Mix Design

- The relationships between aggregate and paste which are the two essential ingredients of concrete.
- Workability of the mass is provided by the lubricating effect of the paste and is influenced by the amount and dilution of paste.
- The strength of concrete is limited by the strength of paste, since mineral aggregates with rare exceptions, are far stronger than the paste compound.
- Essentially the permeability of concrete is governed by the quality and continuity of the paste, since little water flows through aggregate either under pressure or by capillarity.

Concept of Mix Design

- Since the properties of concrete are governed to a considerable extent by the quality of paste, it is helpful to consider more closely the structure of the paste.
- With the given materials, the four variable factors to be considered in connection with specifying a concrete mix are
  - (a) Water-Cement ratio
  - (b) Cement content or cement-aggregate ratio
  - (c) Gradation of the aggregates
  - (d) Consistency.

Various Methods of Proportioning

- Arbitrary proportion
- Indian Road Congress, IRC 44 method
- High strength concrete mix design
- Mix design based on flexural strength
- Road note No. 4 (Grading Curve method)
- ACI Committee 211 method
- DOE method
- Mix design for pumpable concrete
- Indian standard Recommended method IS 10262-82

Common Terminologies

- Mean strength:
- This is the average strength obtained by dividing the sum of strength of all the cubes by the number of cubes.

$$\bar{x} = \frac{\sum x}{n}$$

where x = mean strength

Σx = sum of the strength of cubes

n = number of cubes.

Common Terminologies

- Variance: This is the measure of variability or difference between any single observed data from the mean strength.
- Standard deviation: This is the root mean square deviation of all the results. This is denoted by s or σ.

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

where σ = Standard deviation,

n = number of observations

x = particular value of observations

x = arithmetic mean.

Common Terminologies

Table 11.1. Example of Calculation of Standard Deviation

Sample Number	Crushing Strength (x) MPa	Average strength $\bar{x} = \frac{\Sigma x}{n}$	Deviation $(x - \bar{x})$	Square of Deviation $(x - \bar{x})^2$
1	43		+ 2.8	7.84
2	48		+ 7.8	60.84
3	40		– 0.2	0.04
4	38		– 2.2	4.84
5	36		– 4.2	16.64
6	39		– 1.2	1.44
7	42		+ 1.8	3.24
8	45		+ 4.8	23.04
9	37		– 3.2	10.24
10	35	40.2	– 5.2	27.04
11	39		– 1.2	1.44
12	41		+ 0.8	0.64
13	49		+ 8.8	77.44
14	46		+ 5.8	33.64
15	36		– 4.2	16.64
16	38		– 2.2	4.84
17	32		– 8.2	67.24
18	39		– 1.2	1.44
19	41		+ 0.8	0.64
20	40		– 0.2	0.04
	Total 804			Total 359.20

$$\bar{x} = \frac{\sum x}{n} = \frac{804}{20}$$

$$\bar{x} = 40.2 \quad Mpa$$

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

$$\sigma = \sqrt{\frac{359.20}{20 - 1}}$$

$$\sigma = 4.34 \quad Mpa$$

American Concrete Institute Method of Mix Design (ACI–211.1)

- 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 mix design became the responsibility of ACI committee 211.
- ACI committee 211 have further updated the method of 1991.
- Almost all of the major multipurpose concrete dams in India built during 1950 have been designed by using then prevalent ACI Committee method of mix design.

Step 01: Data to be collected

- Fineness modulus of selected F.A.
- Unit weight of dry rodded coarse aggregate.
- Sp. gravity of coarse and fine aggregates in SSD condition
- Absorption characteristics of both coarse and fine aggregates.
- Specific gravity of cement.

Example:

Step 01: Data to be collected

- Design a concrete mix for construction of an elevated water tank.
- The specified design strength of concrete is 30 MPa at 28 days measured on standard cylinders.
- The specific gravity of FA and C.A. are 2.65 and 2.7 respectively.
- The dry rodded bulk density of C.A. is 1600 kg/m3, and fineness modulus of FA is 2.80.
- Ordinary Portland cement (Type I) will be used.
- C.A. is found to be absorptive to the extent of 1% and free surface moisture in sand is found to be 2 per cent.

Step 02: Target Mean Strength

- Target Mean Strength $f_m = f_{min} + ks$

Placing and Mixing condition	*Degree of control*	*Standard Deviation MPa*
Dried aggregates, completely accurate grading, exact water/cement ratio, controlled temperature curing.	Laboratory Precision	1.3
Weigh-batching of all materials, control of aggregate grading, 3 sizes of aggregate plus sand, control of water added to allow for moisture content of aggregates, allowance for weight of aggregate & sand displaced by water, continual supervision.	Excellent	2.8
Weigh-batching of all materials, strict control of aggregate grading, control of water added to allow for moisture content of aggregates, continual supervision.	High	3.5
Weigh-batching of all materials, control of aggregate grading, control of water added, frequent supervision.	Very good	4.2
Weighing of all materials, water content controlled by inspection of mix, periodic check of workability, use of two sizes of aggregate (fine & coarse) only, intermittent supervision.	Good	5.7
Volume batching of all aggregates allowing for bulking of sand, weigh batching of cement, water content controlled by inspection of mix, intermittent supervision.	Fair	6.5
Volume batching of all materials, use of all in aggregate, little or no supervision.	Poor Uncontrolled	7.0 8.5

$$f_m = f_{min} + ks$$

$$f_m = 30 + 1.65 \, x \, 4.2$$

$$f_m = 36.93 \, MPa$$

Step 03: Water/cement ratio

- Find the water/cement ratio from the strength point of view from Table 11.5.
- Find also the water/ cement ratio from durability point of view from Table 11.6.
- Adopt lower value out of strength consideration and durability consideration.
- Since OPC is used, from table 11.5, the estimated w/c ratio is 0.47.
- From exposure condition Table11.6, the maximum w/c ratio is 0.50
- Therefore, adopt w/c ratio of 0.47

Step 03: Water/cement ratio

Table 11.5. Relation between water/cement ratio and average compressive strength of concrete, according to ACI 211.1–91

Average compressive strength at 28 days	*Effective water/cement ratio (by mass)*	
MPa	*Non-air entrained concrete*	*Air-entrained concrete*
45	0.38	–
40	0.43	–
35	0.48	0.40
30	0.55	0.46
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

Step 03: Water/cement ratio

Table 11.6. Requirements of ACI 318-89 for W/C ratio and Strength for Special Exposure Conditions

	Exposure Condition	*Maximum W/C ratio, normal density aggregate concrete*	*Minimum design strength, low density aggregate concrete MPa*
I.	Concrete Intended to be Watertight		
	(a) Exposed to fresh water	0.5	25
	(b) exposed to brackish or sea water	0.45	30
II	Concrete exposed to freezing and thawing in a moist condition:		
	(a) kerbs, gutters, gaurd rails or thin sections	0.45	30
	(b) other elements	0.50	25
	(c) in presense of de-icing chemicals	0.45	30
III.	For corrosion protection of reinforced concrete exposed to de-icing salts, brackish water, sea water or spray from these sources	0.40	33

Step 04: Maximum Size of Aggregate & Workability

- Decide maximum size of aggregate to be used. Generally for RCC work 20 mm and prestressed concrete 10 mm size are used.
- Decide workability in terms of slump for the type of job in hand. General guidance can be taken from table 11.7.
- Maximum size of aggregate 20 mm.
- Slump of concrete 50 mm

Step 04: Maximum Size of Aggregate & Workability

Type of Construction	*Range of Slump mm*
Reinforced foundation walls and footings	20–80
Plain footings, caissons and substructure walls	20–80
Beams and reinforced walls	20–100
Building columns	20–100
Pavements and slabs	20–80
Mass Concrete	20–80

Step 05: Cement Content

- From Table 11.8, for a slump of 50 mm, 20 mm maximum size of aggregate, for non air- entrained concrete,
- the mixing water content is 185 kg/m^3 of concrete. Also the approximate entrapped air content is 2 per cent.

$$Cement\ Content = \frac{185}{0.47}$$

$$Cement\ Content = 394.0\ kg/m^3$$

Step 05: Cement Content

Table 11.8. Approximate requirements for mixing water and air content for different workabilities and nominal maximum size of Aggregates according to ACI 211.1-91

Workability or Air content	*Water Content, Kg/m³ of concrete for indicated maximum aggregate size*							
	10 mm	*12.5 mm*	*20mm*	*25 mm*	*40 mm*	*50 mm*	*70 mm*	*150 mm*
				Non-air-entrained concrete				
Slump								
30–50 mm	205	200	185	180	160	155	145	125
80–100 mm	225	215	200	195	175	170	160	140
150–180 mm	240	230	210	205	185	180	170	–
Approximate entrapped air content per cent	3	2.5	2	1.5	1	0.5	0.3	0.2
				Air-entrained Concrete				
Slump								
30–50 mm	180	175	165	160	145	140	135	120
80–100 mm	200	190	180	175	160	155	150	135
150–180 mm	215	205	190	185	170	165	160	–
Recommended average total 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
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 06: Weight of Coarse Aggregate

- From table 11.4 the bulk volume of dry rodded coarse aggregate per unit volume of concrete is selected, for the particular maximum size of coarse aggregate and fineness modulus of fine aggregate.
- The weight of C.A. per cubic meter of concrete is calculated by multiplying the bulk volume with bulk density.
- From Table 11.4, for 20 mm coarse aggregate, for fineness modulus of 2.80, the dry rodded bulk volume of C.A. is 0.62 per unit volume of concrete.

$$\text{The weight of C. A.} = 0.62\ x\ 1600 = \ 992.0\ kg/m^3$$

Step 06: Weight of Coarse Aggregate

Table 11.4. Dry Bulk Volume of Coarse Aggregate per Unit Volume of Concrete as given by ACI 211.1—91

Maximum Size of Aggregate	*Bulk volume of dry rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of*			
F.M.	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Step 07: Weight of Fine Aggregate

- From Table 11.9, the first estimate of density of fresh concrete for 20 mm maximum size of aggregate and for non-air-entrained concrete = 2355 kg/m^3
- The weight of all the known ingredient of concrete
- Weight of water = 185 kg/m^3
- Weight of cement = 394 $kg.m^3$
- Weight of C.A. = 992 kg/m^3

Weight of F. A. = 2355 – (185 + 394 + 992)

$$= 784.0\, kg/m^3$$

Step 07: Weight of Fine Aggregate

Table 11.9. First estimate of density (unit weight) of fresh concrete as given by ACI 211.1-91

Maximum size of aggregate mm	*First estimate of density (unit weight) of fresh concrete*	
	Non-air-entrained kg/m^3	*Air-entrained kg/m^3*
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

Step 07: Weight of Fine Aggregate

- From Table 11.9, the first estimate of density of fresh concrete for 20 mm maximum size of aggregate and for non-air-entrained concrete = 2355 kg/m^3
- Alternatively the weight of F.A. can also be found out by absolute volume method which is more accurate, as follows.

Tabulate the absolute volume of all the known ingredients

Item number	*Ingredients*	*Weight kg/m^3*	*Absolute volume cm^3*
1.	Cement	394	$\frac{394}{3.15} \times 10^3 = 125 \times 10^3$
2.	Water	185	$\frac{185}{1} \times 10^3 = 185 \times 10^3$
3.	Coarse Aggregate	992	$\frac{992}{2.7} \times 10^3 = 367 \times 10^3$
4.	Air		$\frac{2}{100} \times 10^6 = 20 \times 10^3$

Step 07: Weight of Fine Aggregate

Item	Ingredients	Weight	Absolute volume
1	Cement	From Step 5	$\frac{\text{Weight of Cement}}{\text{Sp. gravity of Cement}} \times 10^3 = \quad \times 10^3$
2	Water	From Step 4	$\frac{\text{Weight of Water}}{\text{Sp. gravity of Water}} \times 10^3 = \quad \times 10^3$
3	Coarse Aggregate	From Step 6	$\frac{\text{Weight of C.A.}}{\text{Sp. gravity of C.A.}} \times 10^3 = \quad \times 10^3$
4	Air	---	$\frac{\text{\% of Air Voids}}{100} \times 10^6 = \quad \times 10^3$
	Total absolute volume		=

Step 07: Weight of Fine Aggregate

Total absolute volume = 697.0 x 103 cm^3

Therefore absolute volume of F.A.

$= (1000 – 697) \times 10^3$

$= 303.0 \times 10^3$

Weight of FA = 303 x 2.65

= 803.0 kg/m^3

Step 08: Proportions

Ingredients	Cement	Fine Aggregate	Coarse Aggregate	Water	Chemical
Quantity kg/m^3	394.0	803.0	992.0	185.0	NM
Ratio	**1.00**	**2.04**	**2.52**	**0.47**	NM
1 Bag Cement	50.0	102.0	126.0	23.5	NM

Step 09: Adjustment for Field Condition

- The proportions are required to be adjusted for the field conditions. Fine Aggregate has surface moisture of 2 %

$$\text{Weight of F. A.} = 803.0 + \frac{2}{100}803.0$$
$$= 819.06\ \mathrm{kg/m^3}$$

- Course Aggregate absorbs 1% water

$$\text{Weight of F. A.} = 992.0 - \frac{1}{100}992.0$$
$$= 982.0\ \mathrm{kg/m^3}$$

Step 10: Final Design Proportions

Ingredients	Cement	Fine Aggregate	Coarse Aggregate	Water	Chemical
Quantity kg/m^3	394.0	819.0	982.0	185.0	NM
Ratio	**1.00**	**2.08**	**2.49**	**0.47**	NM
1 Bag Cement	50.0	104.0	124.5	23.5	NM