Concrete Mix Design

It is defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain minimum properties notably workability, strength and durability

Factors to be considered

1. Strength
2. Workability
3. Durability
4. Cost

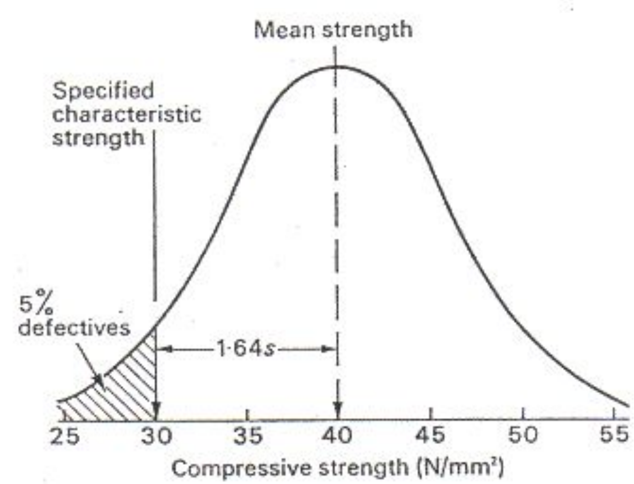
Strength of concrete

Strength is a variable quantity , it is required to aim at a mean strength which is higher than the minimum required by the designer, so that we expect every part of the structure to be made of concrete of adequate strength.

- **Minimum strength (f_{min}):** Termed as

In UK , it is called the specified characteristic strength

In USA , called the specified design strength , this is the minimum strength required by the designer for the concrete of structure.



The required average strength is determined from the following equations:

- For the probability 5 % of the specimens have strength less than the minimum strength

$$f_m = f_c + 1.64 \ * S$$

- For the probability 1 % of the specimens have strength less than the minimum strength

$$f_m = f_c + 2.33 \ * S$$

where:

f_c = the specified compressive strength

f_m = the required average compressive strength

s = the standard deviation , it should be increased by the following factors

Number of tests	Factor to increase the standard deviation
15	1.16
20	1.08
25	1.03
30 or more	1.0

$f_m = f_c + 1.64 * S$

when data of test results is not available then the increase in strength for the specified compressive strength can be taken from the following table ,

Specified compressive strength	Required increase in strength
Less than 21 MPa	7
21 To 35 MPa	8.5
35 or More	10

Workability :

The properties of fresh concrete such are governed by the type of construction and by the technique of placing and transporting.

Workability of fresh concrete affected greatly by the water content of the mix (kg/m^3)

Durability :

Durability affected by the water/cement ratio , because w/c ratio related to the porosity and permeability of concrete so w/c selected on the basis of strength should be satisfactory also for the durability requirements, it should be established prior to the commencement of the structural design.

American concrete institute method (ACI 211.1-91)

This method of proportioning updated in 1991. , the data should be collected includes:

- Fineness modulus of fine aggregate that is used for making the concrete
- Unit weight of dry rodded coarse aggregate
- S.G of fine and coarse aggregate in SSD condition
- Absorption characteristics of both fine and coarse aggregate
- Specific gravity of cement

The following is the procedure of mix design

1. **Choice the value of slump**

Decide the workability based on slump for fresh concrete for this type of Job,

2. **Choice of maximum size of aggregate**. Decide maximum size of aggregate to be used for the mix , generally for RCC is 20 mm and for prestressed is 10 mm.

3. **Water content.** Based on slump and maximum size of aggregate, determine the water content kg/m^3 required for the mix using table (1) , the table gives also the approximate amount of entrapped air in non-air entrained concrete

Table(1) Approximate requirements for mixing water and air content for different workabilities and nominal maximum size of aggregate according to ACI 211.1

Workability Or Air content	Water content Kg/m^3 of concrete for indicated maximum size of aggregate (mm)							
	Non-Air entrained concrete							
slump	10	12.5	20	25	40	50	70	150
30 -50	205	200	185	180	160	155	145	125
80 – 100	225	215	200	195	175	170	160	140
150 – 180	240	230	210	205	185	180	170	-
Approximate entrapped air content (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
Slump								
30 -50	180	175	165	160	145	140	135	120
80 -100	200	190	180	175	160	155	150	135
150 – 180	215	205	190	185	170	165	160	-
Recommended average total air content (%)								
Mild exposure	4.5	4	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

1. From the minimum strength specified estimate the average design strength using standard deviation table (2-A) when there is no tests record to determine standard deviation used , use Table (2-B) for the required increase of minimum strength
2. Find w/c ratio required for the average design strength using table (3-A) and use Table (3-B) to find w/c ratio required for the minimum specified strength.
3. find w/c ratio required for the durability using table (4) , Adopt lower value

Table (2-A) Classification of standard of control of concretes with strengths up to 35 Mpa According to ACI 214- 89

Standard of control	Overall standard deviation MPa	
	In the Field	Laboratory trial mixes
Excellent	Less than 3	Less than 1.5
Very Good	3 – 3.5	1.5
Good	3.5 – 4	1.5 – 2
Fair	4 – 5	2 – 2.5
Poor	Greater than 5	Greater than 2.5

Table(2-B) Required increase in strength (mean strength) for specified design strength

Specified design strength (MPa)	Required increase in strength (MPa)
Less than 21	7
21 – 35	8.5
35 or more	10

Table(3-A) Relation between w/c ratio and average compressive strength of concrete ACI 211.1

Average compressive strength at age of 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

Table(3-B) Relation between w/c ratio and specified compressive strength of concrete (ACI 318)

Minimum compressive strength at age of 28 days		Effective water /cement ratio by Mass	
(MPa)	psi	Non-air entrained concrete	Air-entrained concrete
--	4500	0.38	-
30	--	0.40	-
--	4000	0.44	0.35
25	--	0.50	0.39
--	3500	0.51	0.40
--	3000	0.58	0.46
20	--	0.60	0.49
17	--	0.66	0.54
--	2500	0.67	0.54

Table (4) Requirements of ACI 318 -89 for w/c ratio and strength for special exposure condition

Exposure condition	Maximum w/c ratio normal density aggregate concrete	Minimum design strength
Concrete intended to be watertight		
a. Exposed to fresh water	0.5	25
a. Exposed to brackish or sea water	0.45	30
Concrete exposed to freezing and thawing in a moist condition		
a. Kerbs , gutters, Guard rails,or thin sections	0.45	30
a. Other elements	0.5	25
a. In presence of de-icing salts	0.45	30
For corrosion protection of reinforced concrete exposed to de-icing salts, brackish water, Sea water or spray from these sources	0.40	33

6. Compute cement content by dividing the total water content by the water to cement ratio.

$$\textbf{Cement Content} = \frac{\textbf{Water Content}}{\boldsymbol{w/c}}$$

7. 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 using table (5)

Table -5 Dry roodede Volume of Coarse Aggregate per Unit Volume of Concrete

Maximum Size of Aggregate, mm (inches)	Volume of Rodded Coarse Aggregates per Unit Volume of Concrete for Different Fineness Moduli of Fine Aggregates as per ASTM Designation: C 29a			
	2.40	2.60	2.80	3.0
9.5 mm (⅜ in.)	0.5	0.48	0.46	0.44
12.5 mm (. in.)	0.59	0.57	0.55	0.53
19 mm (. in.)	0.66	0.64	0.62	0.60
25 mm (1 in.)	0.71	0.69	0.67	0.65
37.5 mm (1.5 in.)	0.75	0.73	0.71	0.69
50 mm (2 in.)	0.78	0.76	0.74	0.72
76 mm (3 in.)	0.82	0.80	0.78	0.76

***Important Notice:**

Volumes are based on aggregates in oven-dry-rodded condition as described in ASTM C 29. These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete, such as required for concrete pavement construction, they may be increased about 10 percent. For more workable concrete such as concrete placed by pump decrease the above values by about 10 percent.

8. The weight of coarse aggregate per cubic meter of concrete is calculated by multiplying the bulk volume with dry rodded unit weight (Dry bulk density)

$$\boldsymbol{Weight\ of\ coarse\ aggregate = Bulk\ volume\ (Table5) X\ Dry\ Bulk\ density}$$

9. The solid volume of coarse aggregate per cubic meter of concrete is calculated , knowing the specific gravity of coarse aggregate

10 . Similarly the solid volume of cement , water and volume of air is calculated in one cubic meter of concrete.

$$Volume\ of\ coarse\ aggregate\ Vca = Ac/\gamma_a$$

$$Volume\ of\ cement\ Vc = C/\gamma$$

$$Volume\ of\ water\ Vw = \frac{W}{\gamma_w} = W$$

11. The solid volume of fine aggregate is calculated by subtracting the volume of the above constituents including volume of air from 1 m^3 of concrete

12. Calculate the weight of fine aggregate by multiplying the solid volume of fine aggregate by specific gravity of fine aggregate.

$$A_f = \gamma_f \left(1000 - \left(W + \frac{C}{\gamma} + \frac{A_c}{\gamma_a} + 10 * A\right)\right)$$

Or -

13 Calculate the weight of fine aggregatae by mass method , firstly determine wet density then use this equation to find fine aggregate

$$A_f = \text{Wet Density} - (\text{Cement} + \text{Water} + \text{Coarse aggregate})$$

Where;

$\gamma = \text{Specific gravity of cement}, = 3.15$ $\gamma_w = \text{Specific gravity of water} = 1$

$\gamma_a = \text{Specific gravity of coarse aggregate } (2.6 - 2.7)$ for natural gravel and Specific gravity of fine aggregate $(2.6 - 2.7)$ for natural sand

A=Air content %

C: Weight of cement or cement content kg/m^3

A: Coarse aggregate content kg/m^3 , Af: Fine aggregate content, W: Water c content

Table(6) First estimate of density (unit weight) of fresh concrete given by ACI 211.1

Maximum size of	First estimate of density (unit weight) of fresh concrete	
Aggregate (mm)	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