Course Code: CE2102 **Course name: Concrete Technology**

Course content:

UNIT I: Concrete Big Picture **(Contact Hours:8)**

History and significance of concrete as a construction material.Advantages and Disadvantages of concrete. Role of concrete in "Sustainable Infrastructure Development"

UNIT II: Concrete Constituent Materials **(Contact Hours:8)**

Cement- Manufacturing –Basic Cement Chemistry – Hydration – Classification – Tests – Relevant IS Codes

Aggregate – Classification – Characteristics – Properties of aggregates – Tests on aggregates and their significance – Grading – Fineness Modulus - Relevant IS Codes

Water – Mixing water, Curing Water – Tests of water - Relevant IS Codes

Admixtures – Functions – Classifications – Types - Relevant IS Codes.

UNIT III: Fresh Concrete **(Contact Hours:6)**

Workability – definition, tests and interpretation, Rheology of fresh concrete, Effect of constituent materials on workability, Relevant IS Standards.

UNIT IV: Hardened Concrete **(Contact Hours:8)**

Strength criterion, Stress-strain characteristics of concrete , fracture mechanics approach, tensile strength considerations, behavior under compressive strength.

Factors affecting strength of hardened concrete: porosity, gel-space ratio, total voids in concrete, w/c ratio, degree of compaction, age etc.

Dimensional Stability- Elasticity, Shrinkage and creep

Permeability & Durability: Permeability, Sulphate attack, attack by sea water, Acid attack, Alkali- aggregate reaction, corrosion of reinforcement.

UNIT V: Production of concrete and quality control **(Contact Hours:8)**

Batching of materials, Mixing of concrete materials, transpiration, RMC, placing, compaction, finishing and curing, form work.

Factors causing variations in concrete quality, field control, advantages of quality control, statistical quality control.

UNIT VI: Proportioning of concrete mixes **(Contact Hours:7)**

Basic considerations, factors influencing choice of mix design proportions, methods of concrete mix designing – IS method, ACI method, British DoE method

Unit VI: Proportioning of concrete mixes

Basic considerations:

One of the ultimate aims of studying the various properties of the materials of concrete (either plastic concrete or hardened concrete) is to enable a concrete technologist to design a concrete mix for a particular strength and durability.

Design of concrete mix requires complete knowledge of the various properties of these constituent materials, the implications in case of change on these conditions at the site, the impact of the properties of plastic concrete on the hardened concrete and the complicated inter-relationship between the variables. All these make the task of mix design more complex and difficult. Design of concrete mix needs not only the knowledge of material properties and properties of concrete in plastic condition, it also needs wider knowledge and experience of concreting. Even then, the proportion of the materials of concrete found out at the laboratory requires modification and readjustments to suit the field conditions.

The concrete technologist designs the concrete mix with the knowledge of the materials, site exposure conditions and standard of supervision available at the site of work to achieve this minimum strength and durability.

Further, the site engineer is required to make the concrete at site, closely following the parameters suggested by the mix designer to achieve the minimum strength specified by the structural engineer. In some cases the site engineer may be required to slightly modify the mix proportions given by the mix designer.

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.

The first objective of mix design is to achieve the stipulated minimum strength and durability. The second objective is to make the concrete in the most economical manner.

Since the cost of cement is many times more than the cost of other ingredients, attention is mainly directed to the use of as little cement as possible consistent with strength and durability.

The more dilute the paste, the greater is the spacing between cement particles, and thus the weaker will be the ultimate paste structure. The other conditions being equal, for workable mixes, the strength of concrete varies as an inverse function of the water/cement ratio.

Factors influencing choice of mix design proportions:

Following are the various factors affecting mix design:

1. Compressive strength

It is one of the most important properties of concrete and influences many other desirable 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.

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. 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.

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.

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.

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.

Various methods of concrete mix design:

(a) Arbitrary proportion

(b) Fineness modulus method

(c) Maximum density method

(d) Surface area method

(e) Indian Road Congress, IRC 44 method

(f) High strength concrete mix design

(g) Mix design based on flexural strength

(h) Road note No. 4 (Grading Curve method)

(i) ACI Committee 211 method

(j) DOE method

(k) Mix design for pumpable concrete

(l) Indian standard Recommended method IS 10262-82

Out of the above methods, some of them are not very widely used these days because of some defficulties or drawbacks in the procedures for arriving at the satisfactory proportions.

The ACI (American Concrete Institute) Committee 211 method, the DoE (Department of Environment) method and Indian standard recommended methods are commonly used.

Statistical quality control of concrete:

Concrete like most other construction processes, have certain amount of variability both in materials as well as in constructional methods. This results in variation of strength from batch to batch and also within the batch. It becomes very difficult to assess the strength of the final product. It is not possible to have a large number of destructive tests for evaluating the strength of the end products and as such we have to resort to sample tests. It will be very costly to have very rigid criteria to reject the structure on the basis of a single or a few standard samples. The basis of acceptance of a sample is that a reasonable control of concrete work can be provided, by ensuring that the probability of test result falling below the design strength is not more than a specified tolerance level.

Statistical quality control method provides a scientific approach to the concrete designer to understand the realistic variability of the materials so as to lay down design specifications with proper tolerance to cater for unavoidable variations. The acceptance criteria are based on statistical evaluation of the test result of samples taken at random during execution.

Common terminology:

The common terminologies that are used in the statistical quality control of concrete are explained below.

(a) Mean strength:

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

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

where x = mean strength, Σx = sum of the strength of cubes, n = number of cubes.

(b)Variance:

This is the measure of variability or difference between any single observed data from the mean strength.

(c) Standard deviation:

This is the root mean square deviation of all the results. This is denoted by s or σ. Numerically, it can be explained as

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

where σ = Standard deviation, n = number of observations, x = particular value of observations, x = arithmetic mean.

Standard deviation increases with increasing variability.

Table 11.2. Typical values of the Standard Deviation for Different Conditions of Placing and Mixing Control

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

The value of standard deviation or coefficient of variation could be used to determine the average design strength of the mixes.

The following relationship can be used if standard deviation is made use of:

$$S_{av} = S_{min} + K\sigma$$

where S_{av} = Average design strength, S_{min} = Minimum strength, σ = Standard deviation

K = Himsworth constant

Indian Standard Recommended Method of Concrete Mix Design (IS 10262 – 1982)

The Bureau of Indian Standards recommended a set of procedure for design of concrete mix mainly based on the work done in national laboratories. The mix design procedures are covered in IS 10262–82. The methods given can be applied for both medium strength and high strength concrete.

The following short comings in this method are pointed out. Some of them have arisen in view of the revision of IS 456–2000. The procedures of concrete mix design needs revision and at this point of time (2000 AD) a committee has been formed to look into the matter of Mix Design.

(i) The strength of cement as available in the country today has greatly improved since 1982. The 28-day strength of A, B, C, D, E, F, category of cement is to be reviewed.

(ii) The graph connecting, different strength of cements and W/C is to be reestablished.

(iii) The graph connecting 28-day compressive strength of concrete and W/C ratio is to be extended up to 80 MPa, if this graph is to cater for high strength concrete.

(iv) As per the revision of IS 456–2000, the degree of workability is expressed in terms of slump instead of compacting factor. This results in change of values in estimating approximate sand and water contents for normal concrete up to 35 MPa and high strength concrete above 35 MPa. The Table giving adjustment of values in water content and sand percentage for other than standard conditions, requires appropriate changes and modifications.

(v) In view of the above and other changes made in the revision of IS 456–2000, the mix design procedure as recommended in IS 10262–82 is required to be modified to the extent considered necessary and examples of mix design is worked out However, in the absence of revision of Indian Standard on method of Mix Design, the existing method i.e., IS 10262 of 1982 is described below step by step. Wherever it is possible, the new information given in IS 456 of 2000 has been incorporated and the procedure is modified to that extent.

a) Target mean strength for mix design:

The target mean compressive (f_{ck}) strength at 28 days is given by

$$\bar{f}_{ck} = f_{ck} + tS$$

where f_{ck} = characteristic compressive strength at 28 days and S is the standard deviation. The value of standard deviation can be adopted from Table 11.22, to facilitate initial mix design.

Table 11.22. Assumed standard Deviation as per IS 456 of 2000

Grade of Concrete	Assumed standard Deviation N/mm²
M 10 M 15	3.5
M 20 M 25	4.00
M 30 M 35 M 40 M 45 M 50	5.00

t = a statistical value depending on expected proportion of low results (risk factor).

According to IS: 456–2000 and IS: 1343–80, the characteristic strength is defined as that value below which not more than 5 per cent results are expected to fall, in which case the above equation reduces to

$$\bar{f}_{ck} = f_{ck} + 1.65\ S$$

(b) Selection of Water/Cement ratio:

W/C ratio is to be calculated as per Table 9.18

Table 9.18. Minimum Cement Content, Maximum W/C Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum size. IS 456 : 2000

Sl. No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum cement contents kg/m³	Maximum Free W/C ratio	Minimum Grade of concrete	Minimum Cement Content kg/m³	Maximum Free W/C ratio	Minimum Grade of Concrete
1.	Mild	220	0.60	–	300	0.55	M 20
2.	Moderate	240	0.60	M 15	300	0.50	M 25
3.	Severe	250	0.50	M 20	320	0.45	M 30
4.	Very Severe	260	0.45	M 20	340	0.45	M 35
5.	Extreme	280	0.40	M 25	360	0.40	M 40

(c) Estimation of Entrapped Air:

The air content is estimated from Table 11.23 for the normal maximum size of aggregate used.

Table 11.23. Approximate Entrapped Air Content

Maximum Size of Aggregate (mm)	Entrapped Air, as % of Volume of Concrete
10	3.0
20	2.0
40	1.0

(d) Selection of Water Content and Fine to Total Aggregate ratio:

The water content and percentage of sand in total aggregate by absolute volume are determined from Table 11.24 and 11.25 for medium (below grade M 35) and high strength (above grade M 35) concrete respectively.

Table 11.24. Approximate Sand and Water Contents Per Cubic Metre of Concrete W/C = 0.60, Workability = 0.80 C.F. (Slump 30 mm approximately) (Applicable for concrete upto grade M 35)

Maximum Size of Aggregate (mm)	Water Content including Surface Water, Per Cubic Metre of Concrete (kg)	Sand as per cent of Total Aggregate by Absolute volume
10	200	40
20	186	35
40	165	30

Table 11.25. Approximate Sand and Water Contents Per Cubic Metre of Concrete W/C = 0.35, Workability = 0.80 C.F. (Applicable for above grade M 35)

Maximum Size of Aggregate	Water Content including Surface Water Per Cubic Metre of Concrete (kg)	Sand as per cent of Total Aggregate by Absolute Volume
10	200	28
20	180	25

Table 11.26. Adjustment of Values in Water Content and Sand Percentage for Other Conditions

Change in Conditions Stipulated for Tables	Adjustment Required in Water Content	% Sand in Total Aggregate
For sand conforming to grading Zone I, Zone III or Zone IV of Table 4, IS: 383–1979	0	+ 1.5% for Zone I – 1.5 % for Zone III – 3% for Zone IV
Increase or decrease in the value of compacting factor by 0.1	± 3%	0
Each 0.05 increase or decrease in water-cement ratio	0	± 1%
For rounded aggregate	– 15 kg	– 7%

(e) Calculation of Cement Content:

The cement content per unit volume of concrete may be calculated from free water-cement ratio and the quantity of water per unit volume of concrete (cement by mass = Water content/Water cement ratio). The cement content so calculated shall be checked against the minimum cement content for the requirement of drurability Table 9.18 and the greater of the two values to be adopted.

(f) Calculation of aggregate content:

Aggregate content can be determined from the following equations:

$$V = \left[W + \frac{C}{S_e} + \frac{1}{P}\frac{f_a}{S_{fa}} \right] \frac{1}{1000}$$

$$C_a = \frac{1-P}{P} \times f_a \times \frac{S_{ca}}{S_{fa}}$$

where

V = absolute volume of fresh concrete, which is equal to gross volume (m3) minus the volume of entrapped air,

W = Mass of water (kg) per m3 of concrete

C = Mass of cement (kg) per m3 of concrete

S_c = Specific gravity of cement

P = Ratio of FA to total aggregate by absolute volume

f_a, C_a = Total masses of FA and CA (kg) per m3 of concrete respectively and

S_{fa}, S_{ca} = Specific gravities of saturated, surface dry fine aggregate and coarse aggregate respectively.

(g) Actual quantities required for mix:

It may be mentioned that above mix proportion has been arrived at on the assumption that aggregates are saturated and surface dry. For any deviation from this condition i.e., when aggregate are moist or air dry or bone dry, correction has to be applied on quantity of mixing water as well to the aggregate.

Gradation of coarse aggregates of different sizes (As per Table 2 of IS 383-1970)

TABLE 2 COARSE AGGREGATES

(*Clauses* 4.1 *and* 4.2)

IS Sieve Designation	Percentage Passing for Single-Sized Aggregate of Nominal Size						Percentage Passing for Graded Aggregate of Nominal Size			
	63 mm	40 mm	20 mm	16 mm	12·5 mm	10 mm	40 mm	20 mm	16 mm	12·5 mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
80 mm	100	—	—	—	—	—	100	—	—	—
63 mm	85 to 100	100	—	—	—	—	—	—	—	—
40 mm	0 to 30	85 to 100	100	—	—	—	95 to 100	100	—	—
20 mm	0 to 5	0 to 20	85 to 100	100	—	—	30 to 70	95 to 100	100	100
16 mm	—	—	—	85 to 100	100	—	—	—	90 to 100	—
12·5 mm	—	—	—	—	85 to 100	100	—	—	—	90 to 100
10 mm	0 to 5	0 to 5	0 to 20	0 to 30	0 to 45	85 to 100	10 to 35	25 to 55	30 to 70	40 to 85
4·75 mm	—	—	0 to 5	0 to 5	0 to 10	0 to 20	0 to 5	0 to 10	0 to 10	0 to 10
2·36 mm	—	—	—	—	—	0 to 5	—	—	—	—

Various zones of fine aggregate (as per table 4 of IS 383-1970)

TABLE 4 FINE AGGREGATES

(*Clause* 4.3)

IS Sieve Designation	Percentage Passing for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4·75 mm	90-100	90-100	90-100	95-100
2·36 mm	60-95	75-100	85-100	95-100
1·18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

Illustrative Example of Concrete Mix Design (Grade M 20):

a) Design requirements:

(i) Characteristic compressive strength required in the field at 28 days: 20 MPa

(ii) Maximum size of aggregate: 20 mm (angular)

(iii) Degree of workability: 0.90 compacting factor

(iv) Degree of quality control: Good

(v) Type of Exposure: Mild

b) Test results on the materials:

(i) Specific gravity of cement: 3.15

(ii) Compressive strength of cement at 7 days: Satisfies the requirement of IS: 269–1989

(iii) 1. Specific gravity of coarse aggregates: 2.60

2. Specific gravity of fine aggregates: 2.60

(iv) Water absorption:

1. Coarse aggregate: 0.50%

2. Fine aggregate: 1.0%

(v) Free (surface) moisture:

1. Coarse aggregate: Nil

2. Fine aggregate: 2.0%

(vi) Sieve analysis of aggregates:

1. Coarse aggregate

Sieve size (mm)	Analysis of Coarse aggregate fractions (% passing)		Percentage of different Fractions			Remark
	I	II	I 60%	II 40%	Combined 100%	
20	100	100	60	40	10	Conforming
10	0	71.20	0	28.5	28.5	to Table 2, IS: 383—
4.75		9.40	–	3.7	3.7	1970
2.36	–	–	–	–	–	

2. Fine aggregate

Sieve sizes	Fine aggregate (% passing)	Remarks
4.75 mm	100	
2.36 mm	100	Conforming to grading
1.18 mm	93	Zone III of Table 4
600 micron	60	IS: 385–1970
300 micron	12	
150 micron	2	

(c) Target mean strength of concrete

The target mean strength for specified characteristic cube strength is

20 + 1.65 x 4 = 26.6 MPa

(d) Selection of water-cement ratio

Adopt a w/c ratio of 0.5 (trail 1). This is lower than the maximum value of 0.55 prescribed for 'Mild' exposure in table 9.18

(e) Selection of water and sand content

From Table 11.24, for 20 mm maximum size aggregate, sand conforming to grading Zone II, water content per cubic metre of concrete = 186 kg and sand content as percentage of total aggregate by absolute volume = 35 per cent.

For change in value in water-cement ratio, compacting factor, for sand belonging to Zone III, following adjustment is required.

Change in Condition (See Table 11.26)	Per cent adjustment required Water content	Sand in total aggregate
For decrease in water-cement ratio by (0.60–0.50) that is 0.10.	0	– 2.0
For increase in compacting factor (0.9–0.8), that is 0.10	+ 3	0
For sand conforming to Zone III of Table 4, IS: 383–1970	0	– 1.5
Total	+ 3	– 3.5

Therefore, required sand content as percentage of total aggregate by absolute volume = 35 – 3.5 = 31.5%

Required water content = 186 + 5.58 = 191.6 litres/m^3

(f) Determination of cement content

Water-cement ratio = 0.50

Water = 191.6 litre

∴ Cement = $\frac{191.6}{0.5}$ = 383 kg/m^3

This cement content is adequate for 'mild' exposure condition. (refer Table 9.18)

(g) Determination of coarse and fine aggregate contents:

From Table 11.23, for the specified maximum size of aggregate of 20 mm, the amount of entrapped air in the wet concrete is 2 per cent. Taking this into account and applying equations as below:

$$V = \left[W + \frac{C}{S_e} + \frac{1}{P}\frac{f_a}{S_{fa}}\right]\frac{1}{1000}$$

$$C_a = \frac{1-P}{P} \times f_a \times \frac{S_{ca}}{S_{fa}}$$

$$0.98 = \left[191.6 + \frac{383}{3.15} + \frac{1}{0.315} \times \frac{f_a}{2.60}\right]\frac{1}{1000}$$

f_a = 546 kg/m^3, and

$$C_a = \frac{1-0.315}{0.315} \times 546 \times \frac{2.6}{2.6} = 1188 \text{ kg/m}^3$$

f_a = 546 kg/m³, and

C_a = 1188 kg/m³.

The mix proportion then becomes:

Water		Cement		Fine aggregate		Coarse Aggregate
191.6		383 kg		546 kg		1188 kg
0.50	:	1	:	1.425	:	3.10

(h) Actual quantities required for the mix per bag of cement:

The mix is 0.50:1:1.425:3.10

For 50 kg of cement, the quantities of materials are worked out as below:

(i) Cement = 50 kg

(ii) Sand = 71.0 kg

(iii) Coarse aggregate = 155 kg $\left|\begin{array}{l}\text{Fraction I} = 60\% = 93 \text{ kg} \\ \text{Fraction II} = 40\% = 62 \text{ kg}\end{array}\right|$

(iv) Water

1. for w/c ratio of 0.50, quantity = 25 litres of water.

2. Extra quantity of water to be added for absorption in case of CA, at 0.5 per cent mass.

= 0.77 litres

3. Quantity of water to be deducted for moisture present in sand, at 2 per cent by mass.

= 1.42 litres

4. Actual quantity of water required to be added

= 25.0 + 0.77 – 1.42

= 24.35 litres.

(i) Actual quantity of sand required after = 71.0 + 1.42 allowing for mass of free moisture = 72.42 kgs.

(j) Actual quantity of CA required

1. Fraction I = 93 – 0.46 = 92.54 kg

2. Fraction II = 62 – 0.31 = 61.69 kg

Therefore, the actual quantities of different constituents required for one bag mix are

Water: 24.35 kg

Cement: 50.00 kg

Sand: 72.42 kg

CA Fraction I: 92.54 kg

Fraction II: 61.69 kg