1. CONCRETE MIX PROPORTIONING

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Introduction

Concrete mix proportioning or Mix Design is a process that consists of two interrelated steps: (1) selection of the suitable ingredients and (2) determination of their relative quantities to produce, as economically as possible, concrete of the appropriate workability, strength and durability. These proportions will depend on the characteristics of ingredients used. With concrete-making materials of given characteristics, the choice of variables are cement paste-aggregate ratio in the mixture, water-cement ratio in the cement paste, sand-coarse aggregate ratio in the aggregate and the use of construction chemicals. The overall objective of mix design is the selection of the suitable ingredients among the available materials and determining the most economical combination that will produce concrete with certain minimum performance characteristics.

Factors to be consider for Mix Design

- ***Water-cement ratio* (w/c)**

For given materials, mainly strength depends on one factor – the ratio of water to cement. The strength is inversely proportional to the water-cement ratio. Water-cement ratio determines the porosity in the cement paste. The water-cement ratio required to produce a given mean compressive strength is best determined from previously established relationships for mixes made from similar ingredients or by carrying out tests using trial mixes made with the actual ingredients to be used in the construction. For normal exposure condition of the structure, the water-cement ratio selected on the basis of strength is satisfactory also for the durability requirements. When strength or durability considerations require a low water-cement ratio, it is generally achieved not by increasing the cement content, but by lowering the water demand at given cement content. This is not only economical, but it also reduces the chance of cracking due to high heat of hydration or drying shrinkage.

- ***Water Content***

The most important factor governing the workability of concrete is the water content. Increasing the amount of water will increase the ease with which concrete flows and can be compacted. However, apart from reducing the strength, increased water may lead to segregation and to bleeding. In general, any collection of particles requires a certain amount of water to achieve plasticity so that it can be 'worked'. First there must be enough water to adsorb on the particle surfaces. Then, water must fill the spaces between the particles; additional water "lubricates' the particles by separating them with a film. From this it follows that finer particles, which have a higher specific area, require more water. Thus water content of the mix can be decided with particle size distribution and maximum size of aggregates.

- ***Cement Content***

Four major constituents of cements are Tricalcium silicate (C_3S), Dicalcium silicate (C_2S) Tricalcium aluminate (C_3A) and Tetra calcium alumino ferrite (C_4AF). When water is added to the cement, C_3S hydrates rapidly so strength is also developed rapidly. 7 days strength will be higher for the cement which has more C_3S content. But C_2S hydrates slowly, so strength development also occurs slowly. But in these two cases, ultimate strength will be high and equal. The quality of inner product of C_2S is better than that of C_3S. In designing a mix, it is essential to aim at economical cement content because cement is more expensive than aggregates. Moderate cement content confers a technical advantage of a lower cracking potential in the case of mass concreting and in the case of structural concrete where shrinkage is a problem. The cement content is governed by the mixing water requirement and the water-cement ratio. However the cement content has to be at least equal to that laid down by specifications from durability considerations.

- ***Aggregate Content***

Aggregate is an inert and inexpensive material dispersed throughout the cement paste to give stability and strength to the concrete. Aggregate occupies roughly three-fourths of the volume of concrete. The use of aggregate in concrete greatly reduces the needed amount of cement which is important both from technical and economical stand point. The paste is a weak link in a mass of concrete, the lesser the quantity of such weak material, the better will be the concrete. This object can be achieved by having well graded aggregates. The aggregate surface texture, shape and allied properties influence strongly the aggregate-cement ratio for a desired workability and a given water-cement ratio. The choice of aggregate-cement ratio is made either on the basis of personal experience of the mix designer or alternatively from charts and tables prepared from comprehensive laboratory tests. The dry bulk volume of coarse aggregate per unit volume of concrete is taken to depend on the fineness modulus of the fine aggregate and on the maximum size of aggregate.

Method of Mix Design

Number of procedures for computing concrete mix proportions are prevalent in the world. All are based on the relation between strength and water-cement ratio as well as on the relationships between workability, water-cement ratio and aggregate-cement ratio. The *absolute volume method* is considered more exact when compared to *weight method.* The following data should be collected before starting the mix design:

- Bulk specific gravity of cement, fine and coarse aggregates
- Dry-rodded unit weight of coarse aggregate
- Particle size distribution and fineness modulus of fine and coarse aggregate
- Absorption capacity or free moisture in fine and coarse aggregate.
- Relationships between strength and water-cement ratio for available combination of cement and aggregate.

Step 1: ***Required Slump***

The slump value appropriate for the work can be selected from the Tables available in the country's code.

Step 2: ***Operating water and entrapped air***

The quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum size, shape and grading of aggregates. Operating water and entrapped air can be taken from the country's code for the given maximum size of aggregate.

Step 3: ***Water – cement ratio***

Water-cement ratio can be selected with reference to the required strength and durability criteria from the country's code.

Step 4: ***Cement content***

With quantity of water and water-cement ratio, cement content can be calculated.

$$\text{Cement content} = \frac{\text{Quantity of water}}{\text{Water-cement ratio}}$$

Step 5: ***Coarse aggregate content***

The volume of coarse aggregate content required per unit volume of concrete is estimated with reference to the maximum size of aggregate and the fineness modulus of fine aggregate.

Step 6: ***Fine aggregate content***

Knowing the amount of cement, water, coarse aggregate and entrapped air, the quantity of fine aggregate required is calculated by absolute volume method.

Conclusion

The calculated mix proportion should be checked by making trial mixes. Only a sufficient amount of water to produce the required workability should be used, regardless of the amount calculated. The trial mixes should be tested for workability, cohesiveness, finishing properties and air content as well as for yield and density. If any one of the properties, except the last two, is unsatisfactory, adjustments to the mix proportion are necessary. Although there are sound technical principles that govern mix proportioning, for several valid reasons the process is not entirely in the realm of science. Since mix proportion have great influence on the cost and properties of concrete, it is important that engineers who are often called on to develop or approve mix proportion be familiar with the underlying principles and the commonly used procedure.

Relevant IS codes

1. IS 12269 – 1987, 'Specification for 53 Grade Ordinary Portland Cement'
2. IS 2386 (Part I to VIII) – 1963, 'Method of test for aggregates for Concrete'
3. IS 383 – 1970, 'Specification for Coarse and Fine aggregate from natural sources'
4. IS 10262 – 2009, 'Concrete Mix Proportioning – Guidelines' (First Revision)
5. IS 516 – 1959, 'Method of test for Strength of Concrete'
6. IS SP 23 – 1982, 'Hand Book of Concrete Mixes'
7. IS 456 – 2000, 'Code of Practice for Plain and Reinforced Concrete'

References

1. de LARRARD F (1999), Concrete Mix Proportioning – A Scientific Approach, E & FN SPON, London.

2. Mehta P.K. and Monteiro P.J.M. (1999), Concrete Micro Structure Properties and Materials, Indian Concrete Institute, Chennai, India.

3. Mindess S and Francis Young J. (1981), Concrete, Prentice-Hall, Inc., Englewood Cliffs, New jersey.

4. Neville A.M. (1981), Properties of Concrete, Pitman Publishing Limited, London.

5. Newman J and Choo B.S. (2003) Advanced Concrete Technology, Vol. I to IV, Elsevier, London.

CONCRETE MIX DESIGN - BY USING IS 10262 : 2009

1. Data for Proportioning

a) Grade designation

b) Type of cement

c) Maximum size of aggregate

d) Minimum cement content

e) Maximum water-cement ratio

f) Workability

g) Exposure conditions as per Table 4 and Table 5 of IS 456 - 2000

h) Maximum temperature of concrete at the time of placing

j) Method of transporting and placing

k) Early age strength requirement, if required

l) Type of aggregate

m) Maximum cement content and

n) Whether an admixture shall or shall not be used and the type of admixture and condition of use.

2. Target strength for Mix Proportioning

The target means strength for specified characteristic cube strength @ 28 days,

$$f'_{ck} = f_{ck} + 1.65\, s$$

where

f'_{ck} is target average compressive strength at 28

f_{ck} is characteristics compressive strength @ 28 days, and

s is Standard Deviation values (suggested values available in **Table 1**, Page No. 2 of IS 10262 – 2009)

3. Selection of Mix Proportions

a) Selection of Water-Cement Ratio

Refer Table 5 of IS 456: 2000 for respective environmental exposure conditions. This value may be used as starting point.

The supplementary cementitious materials that are mineral admixtures shall be considered in water-cement ratio calculations.

The free water-cement ratio selected should be checked against the limiting water-cement ratio for the requirements of durability and the lower of the two values adopted.

b) Selection of Water Content

Refer Table 2 of page No. 3 of IS 10262: 2009

These values are for angular coarse aggregate and for a slump of 25mm to 50mm range.

Reduce the water content according to the type of coarse aggregate.

Increase 3% water for every additional 25mm slump.

For appropriate dosages of water reducing admixture, decrease water content by 5 to 10 percent
.

For appropriate dosages of superplasticizing admixture, decrease water content by 20 percent and above.

c) Calculation of Cementitious Material Content

The cement content per unit volume of concrete may be calculated from the water-cement ratio and the quantity of water per unit volume of concrete.

This cement content should be checked against the minimum content for the requirement of durability and greater of the two values adopted.

As per IS 456: 2000, the maximum cement content is 450 kg/m^3

d) Estimation of Coarse Aggregate Proportion

Refer Table 3 Page No. 3 of IS 10262: 2009

These values are for a water-cement ratio of 0.50, which may be suitably adjusted for other water-cent ratios.

For pumpable concrete, these values can be reduced up to 10%

e) combination of Different Coarse Aggregate Fractions

Coarse aggregate of different sizes may be combined in suitable proportions so as to result in an overall grading confirming to Table 2 of IS 383 for particular nominal maximum size of aggregate.

d) Estimation of Fine Aggregate Proportion

Total Aggregate volume = { 1 – (volume of cement + volume of water) }

Volume of fine aggregate = total aggregate volume – volume of coarse aggregate

e) Trial Batches

The calculated mix proportions shall be checked by means of trial batches

Check the mix for the following

Workability
Segregation
Bleeding
Finishability
Yield
Compressive strength

CONCRETE MIX DESIGN - M20 GRADE BY USING IS 10262 : 2009

1. Stipulations for Proportioning

a) Grade designation	:	M20
b) Type of cement	:	OPC. 43 Grade
c) Maximum size of aggregate	:	20 mm
d) Minimum cement content	:	320 kg/m^3
e) Maximum water-cement ratio	:	0.50
f) Workability	:	75 mm (slump)
g) Exposure condition	:	Mild
h) Method of concrete placing	:	Manual
j) Degree of supervision	:	Good
k) Type of aggregate	:	Crushed angular aggregate
m) Maximum cement content	:	450 kg/m^3
n) Chemical admixture type	:	Nil

2. Test Data for Materials

a) Cement used	:	OPC. 43 Grade
b) Specific gravity of cement	:	3.15
c) Chemical admixture	:	Nil
d) Specific gravity of		
1. Coarse aggregate	:	2.70
2. Fine aggregate	:	2.67
e) Water absorption		
1. Coarse Aggregate	:	0.5%
2. Fine Aggregate	:	1.0%

f) Free (surface) moisture

1. Coarse aggregate : 2.70
2. Fine aggregate : 2.67

g) Sieve Analysis:

1) Coarse Aggregate:

Sieve size mm	% Passing		Different fraction		Combined
	I	II	65% of I	35% of II	
20	93.67	100	60.88	35.00	95.88
10	-	77.75	-	27.21	27.21
4.75	-	2.07	-	0.72	0.72
2.36	-	-	-	-	-

2) Fine Aggregate:

Sieve size (mm)	% Passing	Confirming to Zone II of IS 383 - 1970
4.75	99.00	90 - 100
2.36	97.37	75 - 100
1.18	84.38	55 - 90
600 Micron	58.91	35 - 59
300 Micro	19.74	8 - 30
150 Micron	2.16	0 - 10

3. Target strength of concrete

The target means strength for specified characteristic cube strength @ 28 days,

$$f'_{ck} = f_{ck} + 1.65\, s$$

where

f'_{ck} is target average compressive strength at 28

f_{ck} is characteristics compressive strength @ 28 days, and

s is Standard Deviation values (suggested values available in Table 1, Page No. 2 of IS 10262 – 2009)

The value of '*s*' for M20 from **Table 1** is 4.0 N/mm^2

$$f'_{ck} = 20 + 1.65 \times 4.0$$
$$= 26.6 \ N/mm^2$$

4. Selection of water-cement ratio

From **Table 2,** for **Mild exposure** condition maximum water-cement ratio is 0.55

Based on experience adopt water-cement ratio 0.50

$0.50 < 0.55$, hence, o.k.

5. Selection of Water content

From **Table 3,** Maximum water content is 186 kg/m^3 (for a slump of 25 to 50mm)

Water content can be increased by 3% for every 25 mm increase of slump.

Hence, for our required 75 mm slump

$$\text{water content} = 186 + \frac{3 \times 186}{100} = 191.58 \ kg/m^3 \approx 192 \ kg/m^3$$

6. Calculation of Cement content

Water-cement ratio = 0.50

Cement content $= \dfrac{192}{0.50} = 384$ kg

From **Table 2,** for Mild exposure condition, minimum cement content is 300 kg/m^3

$384 \ kg/m^3 > 300 \ kg/m^3$, hence, o.k.

7. Proportion of volume of coarse aggregate and fine aggregate content

From **Table 4**, volume of coarse aggregate corresponding to 20 mm size and fine aggregate Zone II is 0.62 (for water-cement ratio of 0.50)

In the present design, water-cement ratio is 0.50, hence it is not necessary to modify the above coarse aggregate volume.

Volume of fine aggregate = 1 - Volume of coarse aggregate

= 1 - 0.62
= 0.38

8. Mix calculations

a) Volume of concrete = 1 m^3

b) Volume of cement = $\frac{\text{Mass of cement}}{\text{Speci. grav. of cement}} \times \frac{1}{1000}$

= $\frac{384}{3.15} \times \frac{1}{1000}$

= 0.122 m^3

c) Volume of water = $\frac{\text{Mass of water}}{\text{Speci. grav.of water}} \times \frac{1}{1000}$

= $\frac{192}{1} \times \frac{1}{1000}$

= 0.192 m^3

d) Volume of admixture = Nil

e) Volume of all in aggregate = { a – (b + c + d) }

= { 1 – (0.122 + 0.192 + 0) }

= 0.686 m^3

f) Mass of coarse aggregate = (e) × Volume of coarse aggregate × Spec.gravi.of coarse aggregate × 1000

= 0.686 × 0.62 × 2.70 × 1000

= 1148 kg.

g)	Mass of fine aggregate	=	(e) × Volume of fine aggregate × Spec.gravi.of fine aggregate × 1000
		=	0.686 × 0.38 × 2.67 × 1000
		=	696 kg.

9. Mix Proportions for Trial No. 1

Cement	= 384 kg/m^3
Water	= 192 kg/m^3
Fine aggregate	= 696 kg/m^3
Coarse aggregate	= 1148 kg/m^3
Chemical admixture	= Nil
Water-cement ratio	= 0.50

Table 1

Assumed Standard Deviation

Sl.No.	**Grade of Concrete**	**Assumed Standard Deviation** N/mm^2
i) ii)	M 10 M 15	3.5
iii) iv)	M 20 M 25	4.0
v) vi) vii) viii) ix) x)	M 30 M 35 M 40 M 45 M 50 M 55	5.0

Note – The above values correspond to the site control having proper storage of cement; controlled addition of water; regular checking of all materials, aggregate grading and moisture content; and periodical checking of workability and strength. Where there is deviation from the above, values given in the above table shall be increased by 1 N/mm^2

Table 2

Extract of IS 456 - 2000

Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(*Clauses 6.1.2*, 8.2.4.1 and 9.1.2)

S.No	**Exposure**	**Plain concrete**			**Reinforced concrete**		
		Minimum cement content kg/m^3	Maximum Free water cement Ratio	Minimum Grade of concrete	Minimum cement content kg/m^3	Maximum Free water cement Ratio	Minimum Grade of concrete
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i	Mild	220	0.60	-	300	0.55	M 20
ii	Moderate	240	0 60	M 15	300	0.50	M 25
iii	Severe	250	0.50	M 20	320	0.45	M 30
iv	Very severe	260	0.45	M 20	340	0.45	M 35
v	Extreme	280	0.40	M 25	360	0.40	M 40

NOTES:

1. Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in 5.2. The addition such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water- cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolona and slag specified in IS 1489 (Part 1) and IS 455 respectively.
2. Minimum grade for plain concrete under mild exposure condition is not specified.

Note: As per IS: 456-2000, 8.2.4.2 Maximum cement content:
Cement content not including fly ash and ground granulated blast furnace slag in excess of 450 kg/m^3 should not be used unless special consideration has been given in design to increase risk of cracking due to drying shrinkage.

Table 3

Maximum Water Contents per Cubic Metre of Concrete for Nominal Maximum Size of Aggregate

Nominal max. size of aggregate mm	Water content per cubic meter of concrete kg
10	208
20	186
40	165

Table 4

Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate

Sl.No.	Nominal Maximum Size of Aggregate mm	Volume of Coarse Aggregate# per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
		Zone IV	Zone III	Zone II	Zone I
i)	10	0.50	0.48	0.46	0.44
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.75	0.73	0.71	0.69

Volumes are based on aggregate in saturated surface dry condition

Table 5

Grading limits of Fine aggregates IS: 383 – 1970

IS Sieve	Percentage of passing by weight for				
	Grading Zone - I	Grading Zone - II	Grading Zone - III	Grading Zone - IV	Our sample
10 mm	100	100	100	100	100
4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100	97
2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100	93.3
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100	79.3
600 micron	15 – 34	35 – 59	60 – 79	80 – 100	46.3
300 micron	5 – 20	8 – 30	12 – 40	15 – 50	15
150 micron	0 – 10	0 – 10	0 – 10	0 – 15	1.3

Grading Limits for Coarse Aggregate IS 383 : 1970

IS Sieve Designation	Percentage Passing for single sized Aggregate of Nominal Size						Percentage Passing for Graded Aggregate of Nominal Size			
	63mm	40mm	20mm	16mm	12.5mm	10mm	40mm	20mm	16mm	12.5mm
80mm	100	-	-	-	-	-	100	-	-	-
63mm	85to100	100	-	-	-	-	-	-	-	-
40mm	0 to 30	85 to100	100	-	-	-	95 to100	100	-	-
20mm	0 to 5	0 to 20	85 to100	100	-	-	30 to 70	95 to 100	100	100
16mm	-	-	-	85 to100	100	-	-	-	90 to 100	-
12.5mm	-	-	-	-	85 to100	100	-	-	-	90 to 100
10mm	-	0 to 5	0 to 20	0 to 30	0 to 45	85 to100	10 to 35	25 to 55	30 to 70	40 to 85
4.75mm	-	-	0 to 5	0 to 5	0 to10	0 to 20	0 to 5	0 to 10	0 to 10	0 to 10
2.36mm	-	-	-	-	-	0 to 5	-	-	-	-

Changes in IS10262 : 2000

Sl.No.	IS 10262 : 1982	IS 10262 : 2009
1	Table 1 Suggested value of Standard Deviation *s*	Modified to Table 1 Assumed standard Deviation *s*
2	$\overline{f}_{ck} = f_{ck} + t \times s$	$f'_{ck} = f_{ck} + 1.65\ s$
3	Fig. 1 Generalized Relation Between Free Water-Cement Ratio and Compressive strength of concrete.	This Fig. is removed. Wate-cement ratio can be arrived from IS 456 :2000 with different exposure condition This can be adjusted with personnel experience. .
4	Fig. 2 Relation between free water-cement ratio and concrete strength for different cement strength.	This Fig. is removed.
5	Table 3 Approximate air content	This Table is removed. Air content is not included in the mix design.
6	Table 4 Approximate sand and water contents per cubic metre of concrete for grades up to M 35	This Table is modified into two Tables. Table 2 Maximum water content per cubic metre for nominal maximum size of aggregate and Table 3 Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate.
7	Table 5 Approximate sand and water contents per cubic metre of concrete for grades above M 35	This Table is removed.
8	Table 6 Adjustments of values in water content and sand percentage for other conditions.	This Table is removed. The water content from Table 2 is for 50 mm slump. Further, 3% water can be increased for every increase of 25 mm slump

ANNAMALAI UNIVERSITY

DEPARTMENT OF CIVIL & STRUCTURAL ENGINEERING

CONCRETE MIX DATA SHEET

(The client should fill the data sheet)

With reference to our concrete mix design, we are furnishing the following data:

1.	**Characteristic Compressive strength required**	:	**MPa.**
2.	**Maximum size of aggregate**	:	**mm**
3.	**If more than one size of aggregate is used, Ratio of mixing**	:	
4.	**Required Degree of Workability – Slump**	:	**mm**
5.	**Degree of Quality control maintained in the site**	:	
6.	**Type of Exposure of the structure**	:	
7.	**Type and Brand name of cement to be used in the site**	:	
8.	**Chemical Admixture to be used**	:	
	Type and brand name	:	
	Maximum and Minimum dosages	:	
	(Literature about the Admixture should be furnished)		
9.	**Minimum cement content to be used**	:	**kg/m^3**
10.	**Permitted maximum free w/c ratio**	:	