

CEMENT CONCRETE MIX DESIGN

DEFINITION

 The process of selecting suitable ingredients of concrete and determining their relative quantities with the objective of producing a concrete of the required strength, durability, and workability as economically as possible, is termed the concrete mix design

Types of Mixes

1. Nominal Mixes

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength

Nominal mix concrete

 Traditional way of mix proportion specified in terms of fixed ratios of Cement : Sand : coarse aggregate (In general by volume)

- Useful for small works
- Useful for routine concrete construction
- Limited up to M20 grade
- Requires high cement content

Standard mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm². The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

• The proportions generally adopted are as given below

Grade of Concrete	Nominal Mix proportions (Cement: FA : CA)
M 5	1:5:10
M7.5	1:4:8
M10	1:3:6
M15	1:2:4
M20	1:1.5:3

DESIGNED MIXES

 In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics.

DESIGN MIX CONCRETE

 Several methods of mix design evolved over the years in different countries

Ex: ACI practice, British practice, Indian Standard recommendations. etc.

RECOMMENDATIONS FOR CONCRETE MIX DESIGN ARE GIVEN IN

- I.S.10262-1982 & I.S.10262-2009
- > S.P.-23-1982
- Designed mix should meet the design requirements in the fresh and hardened states

FACTORS AFFECTING THE CHOICE OF MIX PROPORTIONS • The various factors affecting the mix design are:

o 1. Compressive strength

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

o 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.

o 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 aggregatecement 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.

MIX PROPORTION DESIGNATIONS

 The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass

FACTORS TO BE CONSIDERED FOR MIX DESIGN

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

IS CODE METHOD OF MIX DESIGN

PROCEDURE

- 1. Target strength for mean strength The target mean compressive strength at 28 days $(f_t) = f_{ck} + K.S$
 - K = a statistical value , usually taken as 1.65
 S = standard deviation for each grade of concrete (table 8 of I.S. 456 -2000)

Values of K

Accepted proportion of low results		K
1 in 5,	20%	0.84
1 in 10,	10%	1.28
1 in 15,	6.7%	1.50
1 in 20,	5%	1.65
1 in 40,	2.5%	1.86
1 in 100,	1%	2.33

TABLE-8, IS CODE

Grade of concrete	Assumed Standard , Deviations (N/mm ²)
M 10 ,M 15	3.5
M 20, M25	4.0
M 30, M 35, M 40, M 45 & M 50	5.0

2.Selection of water cement ratio :

 A) The free water cement ratio corresponding to the target strength is to be determined from the graph shown in fig.



Modified graph for Selection of water cement ratio :



 B) The water cement ratio, as selected above should be checked against the limiting water cement ratio for the durability requirements as given in table

Exposure	Plain Concrete		Reinforced Concrete		ete	
	Min.	Max	Min	Min.	Max	Min
	Cement	w/c	grade	Cement	w/c	grade
Mild	220 kg/m³	0.60		300 kg/m³	0.55	M 20
Moderate	240 kg/m³	0.60	M 15	300 kg/m₃	0.50	M 25
Severe	250 kg/m³	0.50	M 20	320 kg/m³	0.45	M 30
V. Severe	260 kg/m³	0.45	M 20	340 kg/m₃	0.45	M 35
Extreme	280	0.40	M 25	360	0.40	M 40

Durability Criteria as per IS 456-2000

Adjustments to minimum cement content for aggregates other than 20 mm nominal max. size aggregates as per IS 456: 2000.

10 mm	+ 40 kg/cum
20 mm	0
40 mm	- 30 kg/cum

	D		
Placing	Degree	Slump	Compaction
condition		(mm)	factor
	LOW	25 to 75	0.8 to 0.85
Mass concrete, lightly reinforced sections in beams, walls, columns and floors			
	MEDIUM	50 to 100	0.9 to 0.92
Heavily reinforced sections in slabs, beams, walls, columns and footings			
	HIGH	100 to 150	0.95 to 0.96
Slip formwork, pumped concrete,			
in- situ piling			

Approximate water content (Kg) per cubic metre of concrete (Table 32, SP:23-1982)

	Maximum Size of			
Slump	Aggregate			
(mm)				
	10	20	40	
30-50	205	185	160	
80-100	225	200	175	
150-180	240	210	185	

3.Estimation of entrapped air

Depends on nominal max size of aggregate as given in table

C502.6

Max. size of aggregate (mm)	Entrapped air as % of volume of concrete
10	3.0
20	2.0
40	1.0

4. Selection of water content and fine to total aggregate ratio

- The values are given in the tables, based on the following conditions
 - (a) Crushed (Angular) Coarse aggregate conforming to IS: 383
 - (b) Sand conforming to grading zone II of table 4 of IS 383
 - (c) Workability corresponds to C.F. of 0.8

5.a. Approximate sand and water contents per cu.m of concreteW/C = 0.6, Workability = 0.8 C.F. (For medium strength concrete up to M35)

Maximum size of aggregate (mm)	Water content including surface water per m ³ of concrete (kg)	Sand as % of total aggregate by absolute volume
10	200	40
20	186	35
40	165	30

C502.6

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Step 5 - Estimation of Coarse Aggregate Proportion

■ For W/C ratio of 0.5 use following Table

Table 3 Volume of Coarse Aggregate per Unit		
Volume of Total Aggregate for Different		
Zones of Fine Aggregate		
(Clauses 4.4, A-7 and B-7)		

SI Nominal No. Maximum Size of Aggregate		Volume of Coarse Aggregate ¹⁾ per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
(1)	mm	Zone IV	Zone III	Zone II	Zone I
	(2)	(3)	(4)	(5)	(6)
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

¹⁾ Volumes are based on aggregates in saturated surface dry condition.

Correction in Coarse Aggregate values The table specified for W/C ratio of 0.5

For Every +0.05 change in W/C ratio: -0.01
 For Every -0.05 change in W/C ratio: +0.01
 For Pumpable Mix : -10 %

5.c. Adjustments of values in Water Content and sand % for other conditions

Change in conditions stipulated	Adjustment required in			
for tables	Water contents	% sand in total		
		aggregate		
For sand conforming to zone I	0	+1.5% for zone I		
,zone III or zone Iv of I.S 383-		-1.5% for zone III		
1979		-3.0 % 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	±1.0 %		
For rounded aggregates	-15kg/m³	-7 %		

For Other Conditions as per IS:10262,2009

Condition	Correction
Sub-Angular Aggregates	- 10 Kg
Gravel + Crushed Particles	- 20 Kg
Rounded Gravel	- 25 Kg
For every slump increase of 25 mm	+ 3 %
Use of Water Reducing Admixture	- 5 to 10 %
Use of Superplasticzing Admixtures	- 20 %

6.Determination of cement content

- a) From free W/C ratio and
- b) quantity water per unit volume of concrete for workability (as derived in 5.c)
 Cement by mass = (Water content) / (w.c.r.)
- This cement content should not be less than minimum content from the aspect of durability (given in 2.b)

7.Calculation of aggregate content (fa and Ca)

$$V = \left[W + \frac{C}{Sc} + \frac{1}{P} \frac{fa}{Sfa} \right] \frac{1}{1000}$$

$$V = \left[W + \frac{C}{Sc} + \frac{1}{1-P} \frac{Ca}{Sca} \right] \frac{1}{1000}$$

- where V = absolute volume of concrete
- \circ = gross volume (1m³) minus the volume of entrapped air
- S_c = specific gravity of cement
- W = Mass of water per cubic metre of concrete, kg
- C = mass of cement per cubic metre of concrete, kg
- p = ratio of fine aggregate to total aggregate by absolute volume
- f_a, C_a = total masses of fine and coarse aggregates, per cubic metre of concrete, respectively, kg, and
- S_{fa}, S_{ca} = specific gravities of saturated surface dry fine and coarse aggregates, respectively

- 9. Determine the concrete mix proportions for the first trial mix.
- 10. Prepare the concrete using the calculated proportions and cast three cubes of 150 mm size and test them wet after 28-days moist curing and check for the strength.
- 11. Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

So the mix proportion works out to be

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W : C : fa : ca
= 185 : 411 : 635 : 1150
= 0.45 : 1 : 1.55 : 2.80
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This mix will be considered as Trial Mix No.2

 Step VII:- Make slump trials to find out the actual weight of water to get required slump. Make corrections to the water content & %FA, if required.

Step VIII:- Compute 2 more trial mixes with W/C ratios as 0.40 & 0.50, taking %FA as 34% and 38% respectively.

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Trial Mix No. 1:-
Cement = 185 / 0.4 = 462.5 Kg.
Substituting the values in Eq(1), we get
1000 = 185 + 462.5/3.0 + (1/0.34) * \text{fa} / 2.6)
     = 584 Kg.
fa
Substituting the values in Eq(2), we get
1000 = 185 + 462.5/3.0 + (1/0.66) * ca /2.65)
      = 1156 Kg.
ca
So the mix proportion works out to be
W : C : fa : ca
= 185 : 462.5 : 584 : 1156
= 0.4 : 1 : 1.26 : 2.50
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Trial Mix No. 3:-
Cement = 185 / 0.5 = 370 Kg.
Substituting the values in Eq(1), we get
1000 = 185 + 370/3.0 + (1/0.38) * fa /2.6)
     = 683 Kg.
fa
Substituting the values in Eq(2), we get
1000 = 185 + 370/3.0 + (1/0.62) * ca /2.65)
      = 1136 Kg.
ca
So the mix proportion works out to be
W : C : fa : ca
= 185 : 370 : 683 : 1136
= 0.5 : 1 : 1.85 : 3.07
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- ✓ Step IX:- Cast atleast 3 cubes for each trial mix.
- ✓ Step X:- Test the cubes for compressive strength at 28 days.

28 Days Compressive Strengths of Trial Mixes

W/C Ratio	C/W Ratio	Compressive Strength (Kg/Cm ²)		
0.40	2.50	457		
0.45	2.22	420		
0.50	2.00	360		

✓ Step XI:- Draw a graph between compressive strength Vs C/W Ratio.

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Step XII:- From the graph, find the W/C ratio for the required target mean compressive strength.

 Step XIII:- Calculate the mix proportions corresponding to the W/C ratio, obtained from the graph.

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Final Mix:-
From the graph, for a target strength of 390 Kg/Cm<sup>2</sup>, W/C ratio = 0.47
Cement = 185 / 0.47 = 394 Kg.
Substituting the values in Eq(1), we get
1000 = 185 + 394/3.0 + (1/0.38) * fa /2.6)
     = 675 Kg.
fa
Substituting the values in Eq(2), we get
1000 = 185 + 394/3.0 + (1/0.62) * ca /2.65)
      = 1123 Kg.
ca
So the mix proportion works out to be
W:C:fa:ca
= 185 : 394 : 675 : 1123
= 0.47 : 1 : 1.71 : 2.85
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✓ Step XIV:- Check the cement content & W/C ratio against the limiting values given in Table-5 of I.S: 456-2000 for given type of exposure & type of Concrete.

Table-5 Minimum Cement content Maximum Water-Cement ratio and Minimum Grade of Concrete for different exposures with normal weight of aggregate of 20mm nominal maximum size.

		Р	lain Concret	е	Reinforced Concrete			
SI. No.	Exposure	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	
i)	Mild	220	0.60	-	300	0.55	M20	
ii)	Moderate	240	0.60	M15	300	0.50	M25	
iii)	Severe	250	0.50	M20	320	0.45	M30	
iv)	Very Severe	260	0.45	M20	340	0.45	M35	
v)	Extreme	280	0.40	M25	360	0.40	M40	

From the table 5 of IS: 456–2000, the minimum Cement content & W/C ratio, For moderate, for RCC are 300Kgs. & 0.5

The Cement content = 394Kgs. > 300Kgs. Hence Ok

The W/C Ratio = 0.47 < 0.5 Hence Ok

TEST REPORT

Concrete Mix RCC M30 with 20.0mm M.S.A.

SI. No.	Particulars	Result
1	Characteristic Compressive strength in N/Sq.mm	30
2	Maximum size of Aggregate in mm	20.0
3	Type of Exposure	Moderate
4	Type of Site control	Good
5	Target Average Compressive Strength in N/Sq.mm	38.2
6	Workability in terms of Slump in mm	25-75
7	Mode of Compaction	Vibration
8	Mix Partiuclars: a. Water-Cement Ratio b. Materials per cubic metre of concrete in Kg.	0.47
	i) Water ii) Cement (OPC 43 Grade) iii) Fine Aggregate iv) Coarse Aggregate c. Mix Portion by weight	185 394 675 1123 1:1-71:2-85

CONVERTING WEIGHT TO VOLUME

- Unit weight of Cement =1440 Kg/mt³
- Unit weight of F.A =1600 Kg/mt³
- Unit weight of C.A =2200 Kg/mt³
- 1 bag of cement =1.25 cft

Proportions for Nominal Mix Concrete

Grade of Concrete	Total qty of dry aggregate (CA + FA) per 50 kg cement	Proportion of FA to CA by volume	Water per 50 kg cement (max) lit
M 5	800	1: 2 (Zone II) subject to upper	60
M 7.5	625	limit of 1: 1.5	45
M 10	480	(Zone I) & lower limit of	34
M 15	330	1: 2.5 (Zone III)	32
M 20	250		30

Example for Nominal Mixes

- Grade of Concrete: M 20
- Total Aggregate (CA + FA) per 50 kg cement: 250 kg, FA of Zone II (say)
- Water content: 30 lit per 50 kg cement
- w/c ratio= 30/50= 0.60
- Considering FA: CA= 1: 2,
- Sand= (250 X 1)/ 3= 83 kg

Coarse Aggregate) = ((250)	X 2)/	3=	167	/ kg
		-					

Cement	FA	СА	Water
50 kg (35 Lit)	83 kg	167 kg	30 lit

Major Changes in : IS 10262

S,N		
	Old Edition 1982	Revised 2009 Edition
1	Title - " Recommanded guidelines for Concrete mix Design ¹¹	Title - "Concrete mix Proportioning - Guidelines ¹ '
2	Applicability was not specified for any specific Concrete Grades	Specified for Ordinary (M 10 - M 20} and Standard (M25 - M 55) Concrete Grades only.
3	Based on IS 456 : 1982	Modification in iine with IS 456 : 2000
4	W / C ratio was based on Concrete grade and 28 days compressive strength of Concrete and the durability criteria	W/C ratio is based on Durability criteria and the Experience and Practical trials
5	Water Content could be modified taking into account the compaction factor value (Laboratory based test for Workability) and the shape of aggregates.	Water content can be modified Based on Slump vale (Field test of Workability) and Shape of Aggreagtes, and use of Admixtu res.
6	Entrapped Air cotent considered according to Nominal Maximum size of Aggregates	No Entrapped Air content taken into account
7	Not much Consideration for Trial Mixes	Trial Mixes concept is mentioned
e	Concrete Mix Design with Fly ash is not mentioned	An illustrative example of Concrete Mix Prportioning using Fly ash has been added

Cement	FA	СА	Water
50 kg	83 kg	167 kg	30 lit
(by weight) 1	1.66	3.32	0.6
1.43 kg/ lit	1.52 kg/ lit	1.60 kg/ lit	
35 lit	54.6 lit	104.4 lit	30 lit
(by volume) 1	1.56	2.98	

M 20 Grade Concrete (by Volume) is 1: 1.5 % : 3