CONCRETE MIX PROPORTIONING

Purpose:

1. To ensure workability in green state.
2. To ensure required strength, durability and surface finish in the hardened state.

Approaches: (Two)

1. Nominal mix: (For grades M 20 and lower as per IS 456 - 2000 with the permission of engineer in-charge).
2. Design mix.

Note: Approaches differ from code to code.

Information required (Based on IS 456 -2000)

1. Type of mix, that is, design mix concrete or nominal mix concrete.
2. Grade designation.
3. Type of cement.
4. Maximum nominal size of aggregates.
5. Minimum cement content (for design mix concrete).
6. Maximum water/cement ratio.
7. Workability.
8. Mix proportion (for nominal mix concrete).
9. Exposure conditions (As per Tables 4 and 5 of IS 456 - 2000).
10. Maximum temperature of concrete at the time of placing.
11. Method of placing.
12. Degree of supervision

In appropriate circumstances, the following additional information may be specified

1. Type of aggregate.
13. Maximum cement content.
14. Whether an admixture shall or shall not be used, the type of admixture and the condition of use.

Standard deviation (IS 456 - 2000)

- Standard Deviation for each grade of concrete shall be calculated separately.

Standard deviation (σ) based on test strength of samples

a) No of test results of sample (n) for the calculation of standard deviation = 30. Attempt should be made to obtain the 30 samples, as early as possible, when a mix is used for the first time.
b) In case of significant changes in concrete, σ shall be separately calculated for each batch.
c) σ shall be updated after every change of mix design.

Assumed standard deviation (assumed σ)

Where sufficient test results for a particular concrete are not available, σ may be assumed for the first instance. As soon as the results of the samples are available, actual σ should be used.

Table 1 Assumed standard deviation (Based on IS 456 - 2000)

Grade of concrete	Assumed standard deviation, N/mm^2
M 10, M 15	3.5
M 20, M 25	4.0
M 30, M 35, M 40, M 45, M 50	5.0

Note: These values correspond to the site control conditions as mentioned in the code, otherwise the values shall be increased by $1 N/mm^2$.

Nominal mix (Based on IS 456-2000)

Table 2 Proportions for Nominal mix concrete

Grade	Total quantity of dry aggregate per 50 kg of cement, kg	Proportion of fine to coarse aggregate	Water per 50 kg of cement, max, kg
1	2	3	4
M 5	800	Generally 1:2 subject to an upper limit of 1: 1.5 and lower limit of 1:2.5.*	60
M 7.5	625		45
M10	480		34
M 15	330		32
M 20	250		30

* For an average grading of fine aggregate (Zone II, IS 383), the proportion of fine to coarse aggregate shall be 1:1.5, 1:2 and 1:2.5 for max size of aggregates 10, 20 and 40 mm respectively.

British mix design method

- The Building Research Establishment Laboratory (BRE), of the Department of Environment (DOE), U.K. has developed a method of concrete mix design (revised in 1988).
- Replaces the traditional method of Road Research Laboratory, Road Note No 4.
- The DOE method outlines a procedure for design of normal concrete mixes having 28-day cube compressive strength as high as 75 MPa for non-air-entrained concrete.
- It does not consider the use of combined aggregate grading curves, aggregate cement ratio and type of aggregate (rounded, angular or irregular) as was the case with the RRL method.
- The degree of workability 'very low', 'low', 'medium' and 'high' have also been replaced in terms of specific values of slump and Vee - Bee time.
- The proportion of fine aggregate is determined depending on the maximum size of aggregate, degree of workability, grading of fine aggregate and the water/cement ratio. The mix proportions are presented in terms of quantities of materials per unit volume of concrete.

The step-by-step procedure in the design of concrete mix by the DOE method is as follows:

Step 1: Determine the min. w/c based on the target lab. design strength and durability consideration using compressive strength versus w/c ratio curve Fig. 1 and (from similar tables say Table 4 from IS 456 - 2000 and Table 4 below again from IS 456 - 2000) (Note: A specified standard deviation should be adopted to obtain the target strength based on the supervision quality.)

Table 3 Workability of Concrete (as per IS 456 -2000)

Placing conditions	Degree of workability	Slump, (mm)
1	2	3
Blinding concrete Shallow sections; Pavements using pavers;	Very low	See Note1
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footing	Low	25 - 75
Heavily reinforced sections in slabs, beams, walls, columns;	Medium	50 - 100 75-100
Slipform work; Pumped concrete	Medium	50 - 100
Trench fill; In-situ piling;	High	100 - 150
Tremie concrete	Very high	See Note 2

Note 1: In the very low "category of workability" where strict control is necessary compacting factor will be more appropriate (C. F. = 0.75 to 0.80 is suggested).

Note: 2 For very high category of workability determination of flow (IS 9103) will be appropriate.

Table 4 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

(Clause 6.1.2, 8.2.4.1 and 9.1.2 IS 456 - 2000)

SN	Exposure	Plain Concrete (PCC)			Reinforced Concrete (RCC)		
		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

Step 2: Fix the workability (say from Table 3) and determine the free water content (Kg/m^3) from Table 5, depending upon the maximum size and type of aggregate to get a concrete of the specified slump or Vee – Bee time.

Table 5 Approximate water content (kg/m^3) required to provide various levels of workability

Maximum size of aggregate, mm	Slump,mm →	0-10	10-30	30-60	60-180
	Vee-Bee (s) →	>12	6–12	3–6	0-3
	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Step 3: Calculate the cement content from the w/c ratio and water content of the mix obtained in the previous step. Compare the resulting value with any minimum or maximum value of cement content specified for durability or other considerations, and modify the data, if necessary.

Step 4: Determine the wet density of concrete (γ_o) depending upon the free water content and relative density of the combined aggregate based on saturated and surface dry (SSD). Fig.2.

Calculate the total aggregate content as follows:

Total aggregate content (saturated and surface dry) = $\gamma_o - W_c - W_w$,

γ_o = Wet density of concrete, Kg/m^3,
W_c = Cement content, Kg/m^3,
W_w = Free water content, Kg/m^3,

Step 5: Determine the proportion of fine aggregate depending upon the w/c ratio, maximum size of aggregate, grading zone of fine aggregate and workability level from Fig. 3.

Note: The grading zones 1, 2, 3 and 4 in Fig. 3 are the zones, which lie in between 15% to 40%, 40% to 60%, 60% to 80%, and 80% to 100% of fine aggregates passing 600 μ m sieve. Grading zones 1, 2, 3 and 4 are very similar to IS grading Zones I, II, III and IV for sand grading.

Fine aggregate content (Kg/m^3) = total aggregate content x proportion of fine aggregate.
Coarse aggregate content (Kg/m^3) = total aggregate content - fine aggregate content.

The coarse aggregate may be sub-divided among 10 mm, 20 mm and 40 mm sizes. If 10 mm and 20 mm size aggregates are used, they may be taken in a ratio of 1:1 or 1:2. If 10 mm, 20 mm and 40 mm size aggregates are to be used, they may be taken in a ratio of 1:2:3.

Example 1 (DOE method)

Design a concrete mix from the following data for a RCC structure:

Characteristic strength = 30 MPa (exposure condition = severe); Type of cement = OPC; Slump required = 30-60 mm; Nominal max size of aggregate = 20 mm (crushed); Sand = 25 % passing in 600 micron (i.e. IS Zone I); Specific gravities of coarse and fine aggregates = 2.70 and 2.65 respectively.

Solution:

Steps 1, 2, 3:

$f_{mean} = 30 + 1.65*5 = 38.25$ MPa; From Fig. 1, w/c ≈ 0.48; From Table 5 w ≈ 210 liters.

Cement content: w/c = 0.48 → c = 437 Kg.

Check for durability (Based on Table 4 above). Maximum w/c = 0.45; Minimum cement = 320 Kg

Cement (recalculation) : w/c = 0.45 → C = 467 Kg. > 320 Kg. O.K.

Step 4:

Let relative density of combined aggregates = 2.68,
From Fig. 2 wet density of concrete ≈ 2400 Kg/m^3.
Total aggregate content = 2400 - cement - water = 2400 - 467 - 210 = 1723 Kg.

Step 5:

Proportion of fine aggregate:
For grading zone 1 (i.e. 25% passing in 600 micron) from Fig. 3 sand ≈ 43 % of 1723 ≈ 741 Kg.

The mix proportion is 1 : 1.58 : 2.10 : 0.45.

Note:

If aggregates (fine and / or coarse) will have surface moisture, that moisture content in weight should be considered as extra water in w/c. The same weight should be added in the form of coarse and fine aggregates accordingly as per their moisture contents.

ACI mix design method

- The method is suggested by the ACI committee 211.
- The ACI methods take into consideration the requirements for workability, consistency, strength and durability.
- One method is based on the estimated weight of the concrete per unit volume whereas the other is based on calculation of the absolute volume occupied by concrete ingredients.

The step by step operation involved is as follows: (for both methods)

Step 1: Determine (adopt) the slump depending on the degree of workability and placing conditions. A concrete of lowest slump that can be placed is preferred. Values given in Table 3 may be used for reference.

Step 2: Determine (adopt) the maximum size of coarse aggregate that is economically available and consistent with dimensions of the structure.

Step 3: Determine the amount of mixing water for the given slump and maximum size of coarse aggregate from Table 6. This table also indicates approximate amount of entrapped air.

Step 4: Determine the minimum w/c ratio either from the curve: strength –water/cement ratio (Fig.1) or from from durability consideration (similar to IS:456-2000, Table 4 above or Table 4, IS 456 -2000).

Step 5: Determine the amount of cement per unit volume of concrete from step 3 and 4. This cement content should not be less than the cement content required based on durability or some other criterion.

Step 6: Determine the amount of coarse aggregate required for a unit volume of concrete from Table 7. The value thus obtained is multiplied by the dry - rodded unit weight of the aggregate to get the required dry weight.

Table 6 Approximate water requirement for different slumps and maximum size of coarse aggregate

Slump, mm	Water, Kg/m^3 of concrete for maximum size of coarse aggregate							
	9.5 mm	12.5 mm	19 mm	25 mm	37.5 mm	50 mm	75 mm	150 mm
Non-air entrained concrete								
25-50	207	199	179	179	166	154	130	113
75-100	228	216	193	193	181	169	145	124
150-175	243	228	202	202	190	178	160	-
Amount of entrapped air, %	3	2.5	2	1.5	1	0.5	0.3	0.2
Air entrained concrete								
25-50	181	175	168	160	150	142	122	107
75-100	202	193	184	175	165	157	133	119
150-175	216	205	197	184	174	166	154	-
Total air content %, for:								
Improvement of workability:	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

Table 7 Bulk volume of coarse aggregate

Maximum size of coarse aggregate, mm	Bulk volume of dry-rodded coarse aggregate per unit volume of concrete			
	Fineness modulus of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Step 7: Determine the amount of fine aggregate. At completion of step 6, all ingredients except fine aggregates have been estimated. If the weight of concrete per unit volume is assumed, the weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of all other ingredients. An estimate of weight of fresh concrete can be made either by using (Eq. 1) or Table 8.

$$W_C = 10\,\rho_A\,(100 - A) + C\left(1 - \frac{\rho_A}{\rho_C}\right) - W\,(\rho_A - 1) \qquad \text{(Eq.1)}$$

where,

W_C = weight of fresh concrete, Kg/m^3

ρ_A = weighted average specific gravity of combined fine and coarse aggregate

ρ_C = specific gravity of cement (= 3.15)

C = cement requirement, Kg/m^3

W = mixing water requirement, Kg/m^3

A = air content, percent (From Table 6)

Table 8 First estimate of weight of fresh concrete

Maximum size of coarse aggregate	First estimate of concrete weight, Kg/m^3	
	Non-air entrained concrete	Air-entrained concrete
9.5	2285	2190
12.5	2315	2235
19	2355	2280
25	2375	2315
37.5	2420	2355
50	2445	2375
75	2465	2400

Note: In second method (i.e. absolute volume occupied by concrete ingredients, required volume of fine aggregate is obtained from the equation

Volume of fine aggregates = 1 - volume of all ingredients. (Eq. 2)

Step 8: Adjust the mixing water quantity based on the moisture content in the aggregate and obtain the final result.

Example 2 (ACI method)

Do the mix design for the concrete grade and conditions as mentioned in Example 1.

Solution

Steps 1, 2, 3, 4, 5:

Slump = 30 - 60 mm; Nominal size of aggregate = 20 mm; Water = 179 liters (from Table 6). $f_{mean} = 30 + 1.65*5 = 38.25$ MPa; From Fig. 1 $w/c \approx 0.48$, but from durability consideration take $w/c \approx 0.45$. Cement content = w/0.45 = 398 Kg. > minimum (say 320 Kg from Table 4).

Step 6

<u>Coarse aggregate</u>:

For fine aggregate of zone 1 adopt fineness modulus = 3.0

(For exact value calculate by sieving the material).

Volume of dry - rodded coarse aggregate = 0.60 x unit weight of dry rodded coarse aggregate (i.e. calculate from material the unit weight of dry rodded coarse aggregate i.e. for simplicity assume as 1600 Kg/m^3.)
Coarse aggregate = 960 Kg.

Step 7
From first method: (based on the estimated unit weight of the concrete per unit volume)
Unit weight of fresh concrete (from Table 8) = 2355 Kg.

Cement = 398 Kg; Water = 179 Kg; Coarse aggregate = 960 Kg;
Fine aggregate = 2355 - (398 + 179 + 960) = 818 Kg.

The ratio is 1 : 2.06 : 2.41 : 0.45.

From second method: (based on calculation of absolute volume occupied by concrete ingredients)

Volume of water = 179/1000	= 0.179 m^3.
Solid volume of cement, assuming usual specific gravity of 3.15 =398/(3.15x1000)	= 0.126 m^3.
Solid volume of coarse aggregate is 960/(2.70 x 1000)	= 0.356 m^3.
Volume of entrapped air, given in Table 6, is 2%	= 0.020 m^3.
Total volume of ingredients except fine aggregate	= 0.681 m^3.

The required volume of fine aggregate = 1 - 0.681 =	= 0.319 m^3.
Hence the weight of fine aggregate =0.319 x 2.65 x 1000	= 845 Kg.

Note:
If aggregates (fine and / or coarse) have moisture content, that moisture content in weight should be considered as extra water in w/c. The same weight should be added in the form of coarse and fine aggregates accordingly as per their moisture content.

Indian mix design method

- The National Council of Cement and Building Materials (NCCBM), New Delhi, India formerly Cement Research Institute of India (CRI) has developed a method of mix design based on extensive tests on Indian materials and cements.
- This method is applicable to design of normal concrete mixes (non-air-entrained) for different grades of cements based on their 28-day strength.

The procedure of the mix design is as follows.

Step 1: Determine the target or design laboratory strength based on 28-day characteristic strength and standard deviation specified in code (IS : 456 - 2000).

Step 2: Determine the minimum w/c ratio for the design strength from Fg.4 (average curve for cements A, B and C and individual curve for cement D, E, F and G) and from durability consideration (Table 4 above and Table 4 from IS 456 -2000).

2.

The strengths of different cements are as follows:
A = 32.5 - 37.5 MPa; B = 37.5 - 42.5 MPa; C = 42.5 - 47.5 MPa; D = 47.5 - 52.5 MPa;
E = 52.5 - 57.5 MPa; F = 57.5 - 62.5 MPa; G* = 62.5 - 64.9 MPa.
(* Has been introduced in view of higher grade cement available in India).

Step 3: Determine the amount of entrapped air for the maximum size of aggregate from Table 9.

Table 9 Approximate entrapped air content (SP 23 - 1982)

Nominal maximum size of aggregate, mm	Entrapped air, as percent of volume of concrete
10	3.0
20	2.0
40	1.0

Step 4: The water content and percentage of sand in total aggregate are selected from Table 10 and Table 11. The tables are based on the following reference conditions:

i) Crushed coarse aggregate
ii) Fine aggregate conforming to grading zone II of IS : 383 – 1970 in saturated and surface dry conditions.
iii) Water/cement ratio of 0.60 and 0.35 for medium and high strength concretes, respectively.
iv) Workability corresponding to compaction factor of 0.80.

Step 5: Make adjustments in water content and percentage of fine aggregate for other conditions of workability, w/c ratio, grading of fine aggregate and uncrushed aggregate from Table 12

Step 6: Determine the cement content from w/c ratio and the final water content is obtained after adjustment. Compare the resulting value with the minimum or maximum cement content specified based on durability or any other considerations and modify, if necessary.

Table 10 Approximate sand and water contents per m^3 of concrete (SP 23 - 1982)
W/C = 0.60, Workability = 0.80 compaction factor
(Applicable for concrete up to grade M 35)

Maximum size of aggregate, mm	Water content per m^3 of concrete	Sand as % of total aggregate by absolute volume
10	208	40
20	186	35
40	165	30

Table 11 Approximate sand and water contents per m^3 of concrete (SP 23 - 1982)
W/C = 0.35, Workability = 0.80 compaction factor
(Applicable for concrete above grade M 35)

Maximum size of aggregate, mm	Water content per m^3 of concrete	Sand as % of total aggregate by absolute volume
10	200	28
20	190	25

Table 12 Adjustment of values in water content and sand percentage for other conditions (SP 23 - 1982)

Change in conditions	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 : 383-1970	0	+ 1.5 percent for Zone I
	0	- 1.5 percent for Zone III
	0	- 3.0 percent for Zone IV
Increase or decrease in the value of compaction factor by 0.1	± 3 percent	0
Each 0.05 increase or decrease in water/cement ratio	0	± 1 percent
For rounded aggregate	-15 Kg/m^3	-7 percent

> Note: Increasing cement content beyond a specified value may not increase the compressive strength. From these considerations as well as that of economy, the maximum cement content in prestressed concrete structures and liquid retaining structures is limited to 530 Kg/m^3. (Refer IS ;1343-1980, clause 8.1.1)

Step 7: Determine the quantities of coarse and fine aggregates from the following equations:

$$V = \left[W_W + \frac{W_C}{\rho_C} + \frac{1}{p} \cdot \frac{W_S}{\rho_S} \right] x \; \frac{1}{1000} \qquad \text{(Eq. 3)}$$

$$V = \left[W_W + \frac{W_C}{\rho_C} + \frac{1}{1-p} \cdot \frac{W_{CA}}{\rho_{CA}} \right] x \; \frac{1}{1000} \qquad \text{(Eq. 4)}$$

where

V = net volume of fresh concrete = 1 m^3 – volume of entrapped air
ρ_C = specific gravity of cement
ρ_S = specific gravity of sand (SSD)
ρ_{CA} = specific gravity of coarse aggregate (SSD)
W_W = mass of water per m^3 of concrete
W_C = mass of cement per m^3 of concrete
W_S = mass of sand per m^3 of concrete
W_{CA} = mass of coarse aggregate per m^3 of concrete
p = ratio of fine aggregate to total aggregate by absolute volume

Step 8: Obtain actual amount of water to be added after making corrections for moisture in aggregates. Similarly, get actual quantities of fine aggregate and coarse aggregate required.

Step 9: Check the calculated mix proportions by means of trial batches and make suitable modification, if requires.

Example 3 (Indian mix design method)

Do the concrete mix design of example 1 by using Indian mix design method. Adopt compaction factor = 0.~~85~~90; free moisture: fine aggregate = 2 %, coarse aggregate = 1.5 %. Assume necessary data appropriately if required and but not possible to obtain them in the lab.

Solution

Step 1, 2, 3, 4:

$f_{mean} = 30 + 1.65*5 = 38.25$ MPa; From Fig. 4 (Cement E i.e. Udayapur cement has been adopted), $w/c \approx 0.43$; Amount of entrapped air for 20 mm size of aggregate = 2 %; Water = 186 liters (from Table 10); sand = 35 % of the total aggregate.

Step 5:

Adjustments in Table 12

SN	Parameters	Adjustment required in	
		water content (%)	% of sand in total aggregate
1	Decrease in w/c from 0.6 to 0.43	nil	- 3.4 %
2	Increase in compacting factor from 0.80 to 0.90	+ 3 %	nil
3	For sand conforming to zone I of IS 383 - 1970	nil	+ 1.5 %
4	For crushed aggregate	nil	nil
Total adjustment		+ 3%	~~+~~ 1.9 %

So
Percentage of sand in total aggregate = 35 - 1.9 = 33.10 %;
Water required = 186 + 186 x 3 % ≈ 191.60 liters.

Step 6:

Cement content = 191.60/0.43 = 445.60 Kg. > 320 Kg. O. K.

Step 7:

Absolute volume of fresh concrete = 1 - 0.02 = 0.98 m^3.
(From Table 9 volume of entrapped air = 2 %).

<u>Sand</u>

$$0.98 = \left[191.6 + \frac{445.6}{3.15} + \frac{1}{0.331} \cdot \frac{W_S}{2.65}\right] x \frac{1}{1000};\qquad W_S = 567.50 \text{ Kg.}$$

Coarse aggregate

$$0.98 = \left[191.6 + \frac{445.6}{3.15} + \frac{1}{0.669} \cdot \frac{W_{CA}}{2.70}\right] \times \frac{1}{1000}, \qquad W_{CA} = 1168.60 \text{ Kg.}$$

Step 8:

Correction for moisture content

Water to be deducted from
a) Fine aggregate = 0.02 x 567.50 = 11.35 liters.
b) Coarse aggregate = 0.015 x 1168.60 = 17.53 liters.

Actual quantities
Water = 191.60 - 11.35 - 17.53 = 162.72 liters.
Sand = 567.50 + 11.35 = 578.85 Kg.
Coarse aggregate = 1168.60 + 17.53 = 1186.13 Kg.
Cement = 445.60 Kg.

The ratio is
1 : 1.30 : 2.66 : 0.365

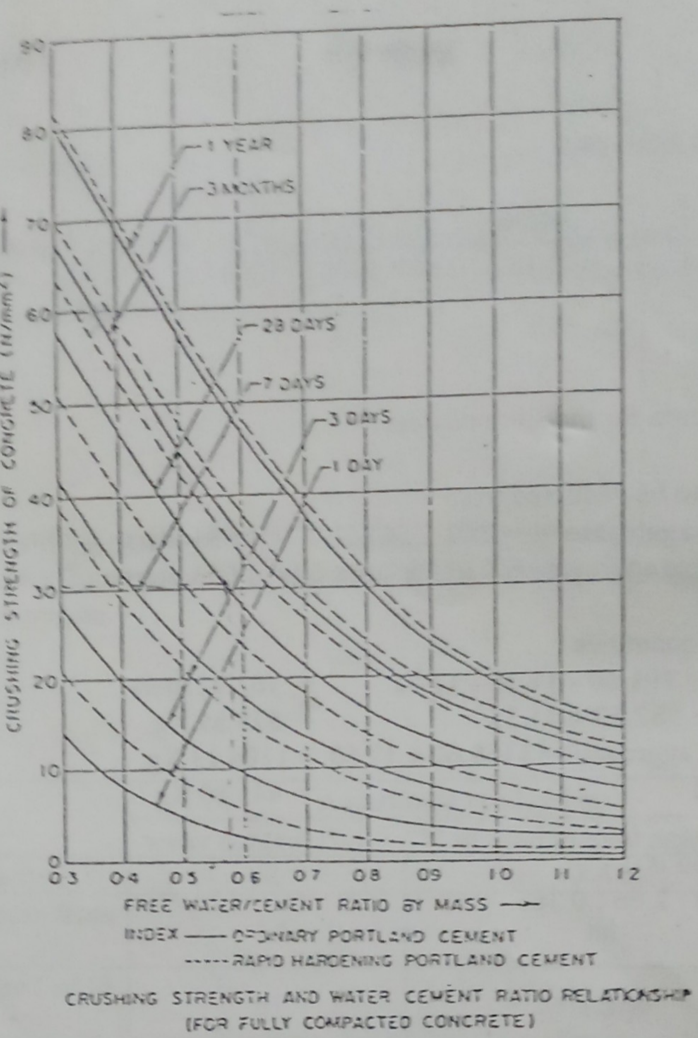


Fig. 1 Relationship between W/C and strength of concrete

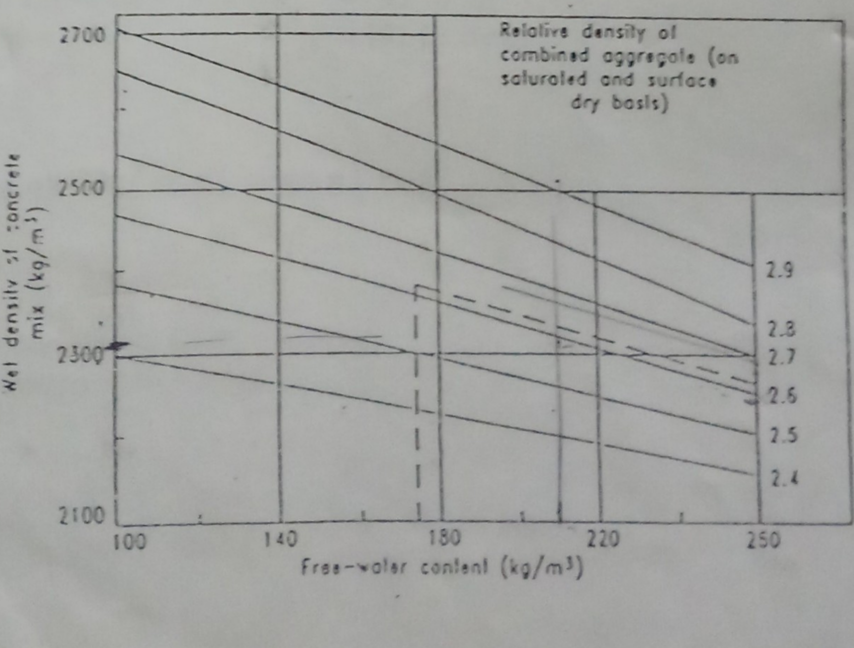


Fig. 2 Estimated wet density of fully compacted concrete

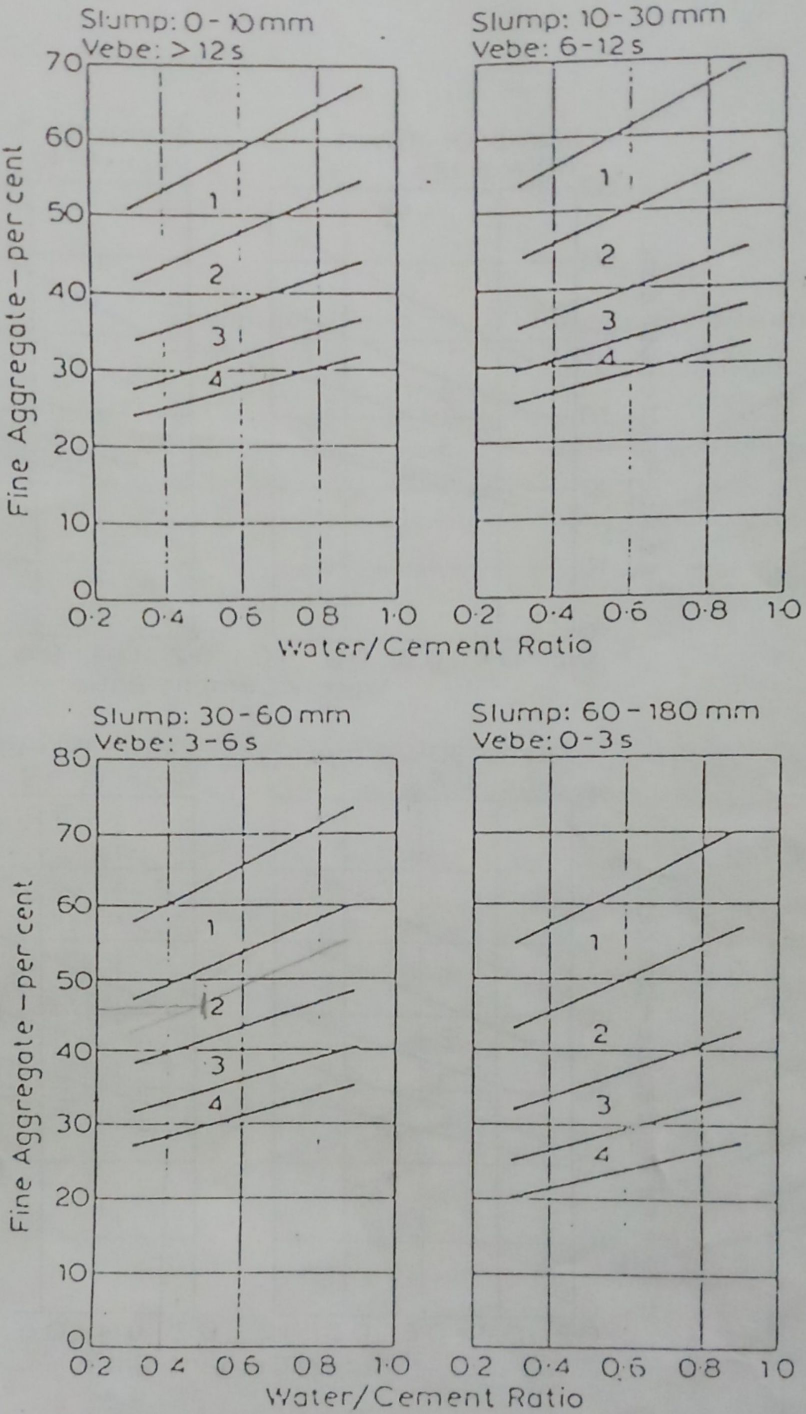


Fig 3 Recommended weight of fine aggregate (expressed as percentage of total aggregate) as a function of free water / cement ratio for various workabilities and maximum sizes of aggregates

a) Maximum aggregate size – 10 mm

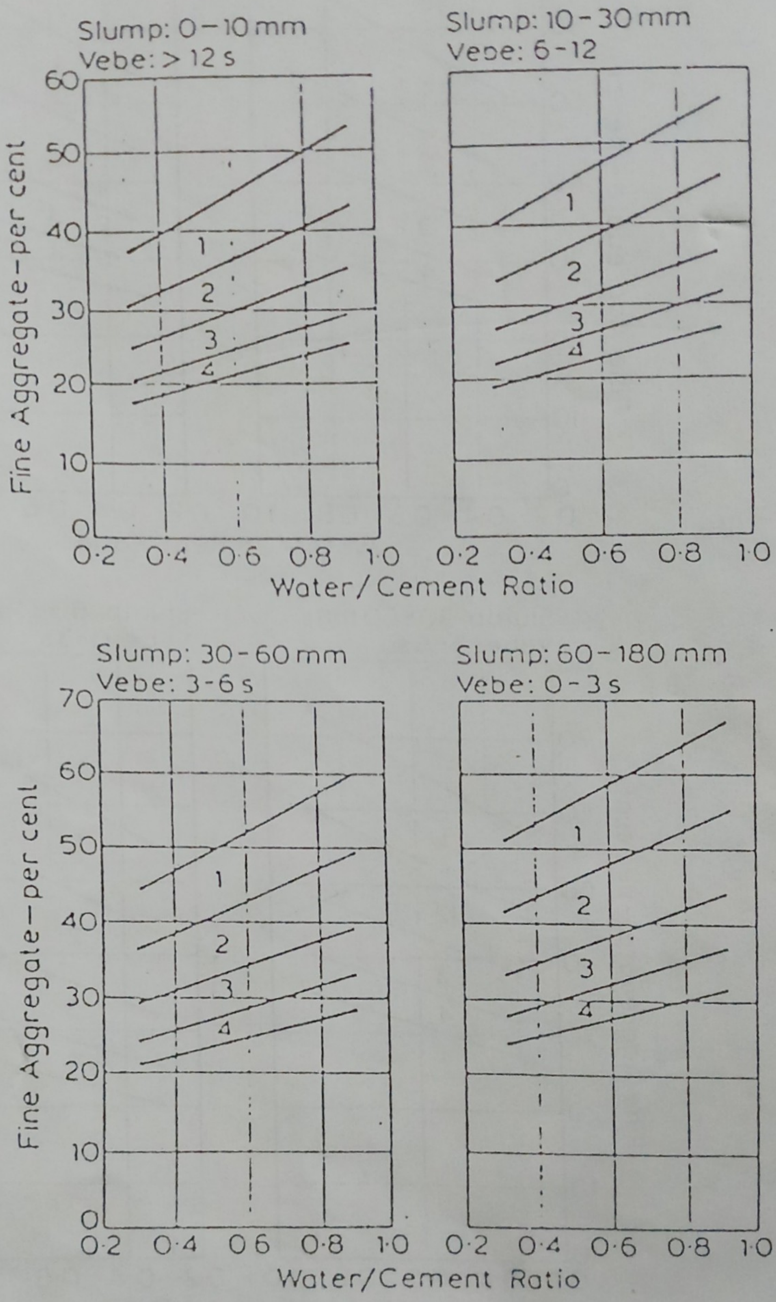


Fig. 3 contd..

b) Maximum aggregate size – 20 mm

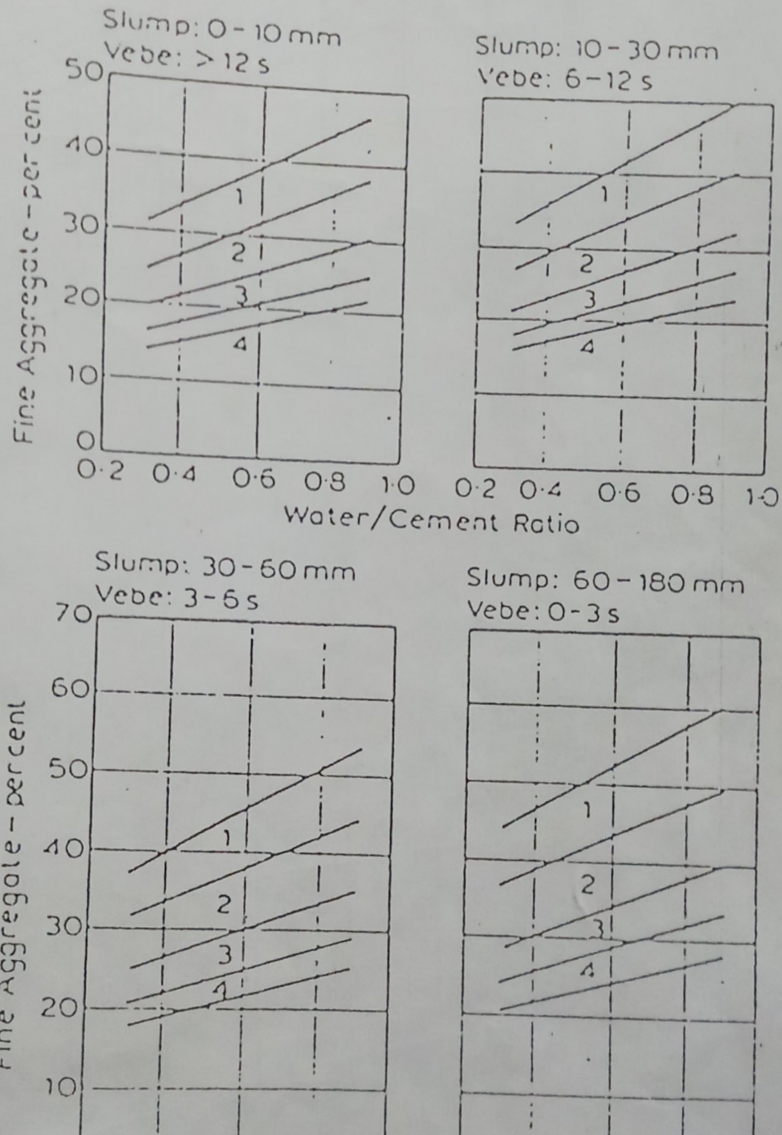
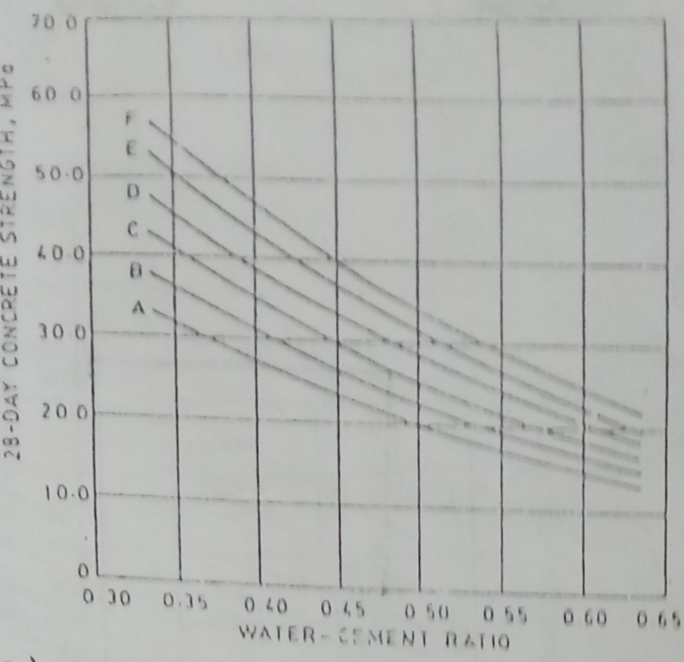


Fig 3 contd.

c) Maximum aggregate size – 40 mm



a)

2.58
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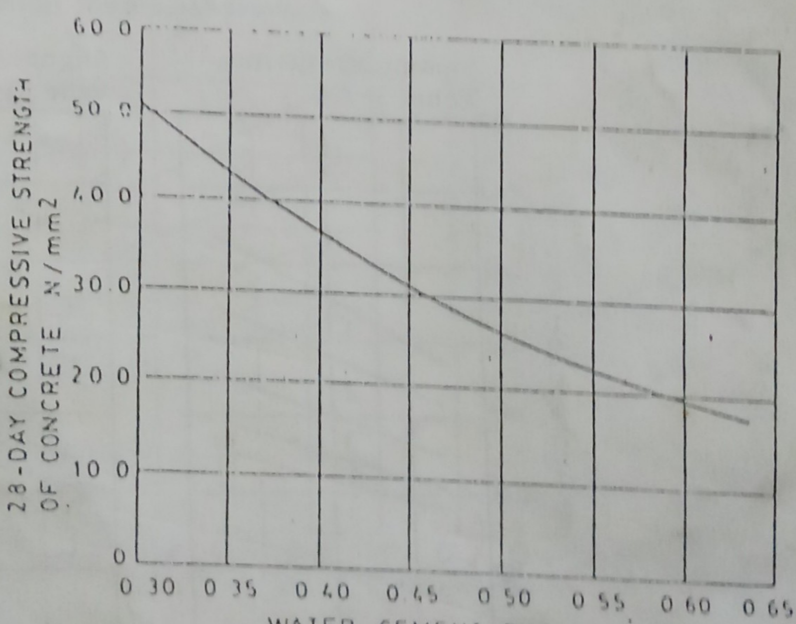

b)

Fig 4 Compressive strength of concrete for different free water / cement ratios and strength of concrete: a) Various grades of cement, b) Generalized relation