
Ready Mixed Concrete Plant to follow up the Good Concrete Mix Design

11

CHAPTER

Concrete Mix Design

General

One of the ultimate aims of studying the various properties of the materials of concrete, plastic concrete and hardened concrete, is to enable a concrete technologist to design a concrete mix for a particular strength and durability. The design of concrete mix is not a simple task on account of the widely varying properties of the constituent materials, the conditions that prevail at the site of work, in particular the exposure condition, and the conditions that are demanded for a particular work for which the mix is designed. 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.

With better understanding of the properties, the concrete is becoming more and more an exact material than in the past. The structural designer stipulates certain minimum strength; and 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. He also makes cubes or cylinders sufficient in numbers and test them to confirm the achievements with respect to the minimum specified strength. Mix designer, earlier, may have made trial cubes with representative materials to arrive at the value of standard deviation or coefficient of variation to be used in the mix design.

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 purpose of designing as can be seen from the above definitions is two-fold. The first object is to achieve the stipulated minimum strength and durability. The second object is to make the concrete in the most economical manner. Cost wise all concretes depend primarily on two factors; namely cost of material and cost of labour. Labour cost, by way of formworks, batching, mixing, transporting, and curing is nearly same for good concrete and bad concrete. Therefore attention is mainly directed to the cost of materials. 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.

Concept of Mix Design

It will be worthwhile to recall at this stage the relationships between aggregate and paste which are the two essential ingredients of concrete. Workability of the mass is provided by the lubricating effect of the paste and is influenced by the amount and dilution of paste. The strength of concrete is limited by the strength of paste, since mineral aggregates with rare exceptions, are far stronger than the paste compound. Essentially the permeability of concrete is governed by the quality and continuity of the paste, since little water flows through aggregate either under pressure or by capillarity. Further, the predominant contribution to drying shrinkage of concretes is that of paste.

Since the properties of concrete are governed to a considerable extent by the quality of paste, it is helpful to consider more closely the structure of the paste. The fresh paste is a suspension, not a solution of cement in water.

The more dilute the paste, the greater 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. Since the quantity of water required also depends upon the amount of paste, it is important that as little paste as possible should be used and hence the importance of grading.

Variables in Proportioning

With the given materials, the four variable factors to be considered in connection with specifying a concrete mix are:

(*a*) Water-Cement ratio

(*b*) Cement content or cement-aggregate ratio

(*c*) Gradation of the aggregates

(*d*) Consistency.

In general all four of these inter-related variables cannot be chosen or manipulated arbitrarily. Usually two or three factors are specified, and the others are adjusted to give minimum workability and economy. Water/cement ratio expresses the dilution of the paste-cement content varies directly with the amount of paste. Gradation of aggregate is controlled by varying the amount of given fine and coarse aggregate. Consistency is established by practical requirements of placing. In brief, the effort in proportioning is to use a minimum amount of paste (and therefore cement) that will lubricate the mass while fresh and after hardening will bind the aggregate particles together and fill the space between them. Any excess of paste involves greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering action. This is achieved by minimising the voids by good gradation.

Various Methods of Proportioning

(*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

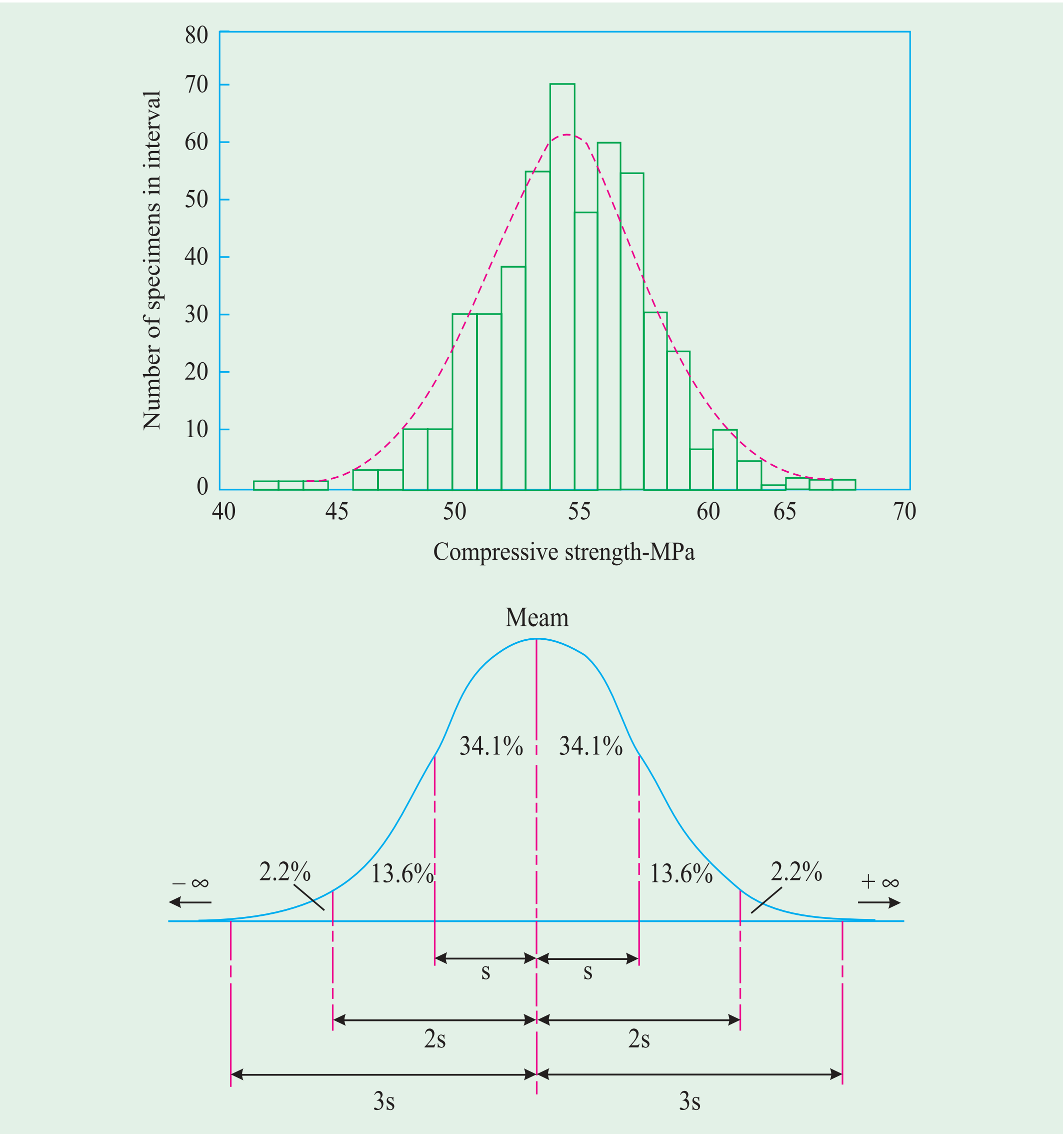
Out of the above methods, some of them are not very widely used these days because of some defficulties or drawbacks in the procedures for arriving at the satisfactory proportions. The ACI Committee 211 method, the DOE method and Indian standard recommended methods are commonly used. Since concrete is very commonly placed by pumping these days method of mix design of pumpable concrete has become important. Therefore, only the more popular and currently used methods are described.

Before we deal with some of the important methods of concrete mix design, it is necessary to get acquainted with statistical quality control methods, which are common to all the methods of mix design.

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.*

The aim of quality control is to limit the variability as much as practicable. 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. By devising a proper sampling plan it is possible to ensure a certain quality at a specified risk. Thus the method provides a scientific basis of acceptance which is not only realistic but also restrictive as required by the design requirements for the concrete construction.



The quality of concrete will be of immense value for large contracts where the specifications insist on certain minimum requirements. The efforts put in will be more than repaid by the resulting savings in the overall concreting operations.

The compressive strength test cubes from random sampling of a mix, exhibit variations, which are inherent in the various operations involved in the making and testing of concrete. If a number of cube test results are plotted on histogram, the results are found so follow a bell shaped curve known as "Normal Distribution Curve". The results are said to follow a normal distribution curve if they are equally spaced about the mean value and if the largest number of the cubes have a strength closer to the mean value, and very few number of results with much greater or less value than the mean value. However, some divergence from the smooth curve can be expected, particularly if the number of results available is relatively small. Fig 11.1 and Fig 11.2 show the histogram and the normal distribution curve respectively.

The arithmetic mean or the average value of the number of test result gives no indication of the extent of variation of strength. However, this can be ascertained by relating the individual strength to the mean strength and determining the variation from the mean with the help of the properties of the normal distribution curve.

Common Terminologies

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 $\bar{x}$ = *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*

$\bar{x}$ = *arithmetic mean.*

Standard deviation increases with increasing variability. The characteristics of the normal distribution curve are fixed by the average value and the standard deviation. The spread of the curve along the horizontal scale is governed by the standard deviation, while the position of the curve along the vertical scale is fixed by the mean value.

(d) Coefficient of variation: It is an alternative method of expressing the variation of results. It is a non-dimensional measure of variation obtained by dividing the standard deviation by the arithmetic mean and is expressed as:

$$v = \frac{\Sigma}{\bar{x}} \times 100$$

where v = coefficient of variation.

Calculation of Standard Deviation and Coefficient of Variation

Table 11.1 gives the typical method of calculating the standard deviation and coefficient of variation for a set of cubes cast and tested. Table 11.2 gives the value of typical standard deviation for different conditions.

Relationship between Average Design Strength and Specified Minimum Strength

In the design of concrete mixes, the average design strength to be aimed at should be appreciably higher than the minimum strength stipulated by the structural designer. The value of average design strength to be aimed at will depend upon the quality control exercised at the time of making concrete.

Table 11.1. Example of Calculation of Standard Deviation

Sample Number	Crushing Strength (x) MPa	Average strength $\bar{x} = \frac{\Sigma x}{n}$	Deviation $(x - \bar{x})$	Square of Deviation $(x - \bar{x})^2$
1	43		+ 2.8	7.84
2	48		+ 7.8	60.84
3	40		– 0.2	0.04
4	38		– 2.2	4.84
5	36		– 4.2	16.64
6	39		– 1.2	1.44
7	42		+ 1.8	3.24
8	45		+ 4.8	23.04
9	37		– 3.2	10.24
10	35	40.2	– 5.2	27.04
11	39		– 1.2	1.44
12	41		+ 0.8	0.64
13	49		+ 8.8	77.44
14	46		+ 5.8	33.64
15	36		– 4.2	16.64
16	38		– 2.2	4.84
17	32		– 8.2	67.24
18	39		– 1.2	1.44
19	41		+ 0.8	0.64
20	40		– 0.2	0.04
	Total 804			Total 359.20

Average strength $= \frac{804}{20} = 40.2$

Standard deviation $= \sqrt{\frac{359.20}{N-1}}$

$= \frac{359.2}{19} = 4.34$ MPa

Coefficient of Variation $= \frac{\text{Standard deviation}}{\text{Average strength}} \times 100$

$= \frac{4.34}{40.20} \times 100 = 10.80\%$

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

Refer table 11.3. If 1% result is allowed to fall below the minimum, the value of K is taken as 2.33). If 5% of result is allowed to fall below the minimum, the value of K is taken as 1.64 but it is generally taken as 1.65.

If coefficient of variation is used,

$$S_{av} = \frac{S_{min}}{1-\frac{Kv}{100}}$$

where v = Coefficient of variation and other notations have the same significance.

The use of either the standard deviation or the coefficient of variation is based on the following argument. If control was perfect, so that the materials and all operations involved in making concrete including sampling and testing were uniform, then every result would be the same and would correspond to the mean value. It is impossible for each operation to be perfect. The more uniform the operations the closer will be the result to the mean value and hence the lower will be the value of the standard deviation.

Table 11.3. Value for the Factor K Himsworth Constants[11.1]

Percentage of results allowed to fall below the minimum			Value K
0.1	...	...	3.09
0.6	...	...	2.50
1.0	...	...	2.33
2.5	...	...	1.96
6.6	...	...	1.50
16.00	...	...	1.00

It follows that if the same degree of control is exercised on the concrete with the mean strength of 15 MPa, the standard deviation will be same as for concrete with mean strength 45 MPa. Therefore, the concrete quality can be changed by standard deviation. In fact, site experience shows that it is more difficult to achieve consistent results with high strength concrete and the standard deviation is greater for high strength concrete than for concretes of medium or low strength.

It has been suggested that the standard deviation is proportional to the value of mean strength. In other words,

$$\frac{\text{Standard deviation}}{\text{Mean strength}} = \text{a constant}$$

This, of course, is the coefficient of variation. With a constant coefficient of variation the standard deviation increases with strength and is larger for higher strength.

There are some arguments as to whether the standard deviation or the coefficient of variation is correct parameter to apply. Murdock and Erntroy have shown that the coefficient of variation more nearly represents a particular standard of control at relatively low strengths, while the standard deviation more nearly represents the standard at high strength.[11.2] Indian standard method and most of the mix design methods adopt standard deviation parameter.

American Concrete Institute Method of Mix Design[11.3]

This method of proportioning was first published in 1944 by ACI committee 613. In 1954 the method was revised to include, among other modifications, the use of entrained air. In 1970, the method of mix design became the responsibility of ACI committee 211. ACI committee 211 have further updated the method (ACI–211.1) of 1991. Almost all of the major multipurpose concrete dams in India built during 1950 have been designed by using then prevalent ACI Committee method of mix design.

We shall now deal with the latest ACI Committee 211.1 of 1991 method. It has the advantages of simplicity in that it applies equally well, and with more or less identical procedure to rounded or angular aggregate, to regular or light weight aggregates and to air-entrained or non-air-entrained concretes. The ACI Committee mix design method assume certain basic facts which have been substantiated by field experiments or large works. They are:

(a) The method makes use of the established fact, that over a considerable range of practical proportions, fresh concrete of given slump and containing a reasonably well graded aggregate of given maximum size will have practically a constant total water content regardless of variations in water/cement ratio and cement content, which are necessarily interrelated.

(b) It makes use of the relation that the optimum dry rodded volume of coarse aggregate per unit volume of concrete depends on its maximum size and the fineness modulus of the fine aggregate as indicated in Table 11.4 regardless of shape of particles. The effect of angularity is reflected in the void content, thus angular coarse aggregates require more mortar than rounded coarse aggregate.

(c) Irrespective of the methods of compaction, even after complete compaction is done, a definite percentage of air remains which is inversely proportional to the maximum size of the aggregate.

The following is the procedure of mix design in this method:

(a) Data to be collected :

(i) Fineness modulus of selected F.A.

(ii) Unit weight of dry rodded coarse aggregate.

(iii) Sp. gravity of coarse and fine aggregates in SSD condition

(iv) Absorption characteristics of both coarse and fine aggregates.

(v) Specific gravity of cement.

Table 11.4. Dry Bulk Volume of Coarse Aggregate per Unit Volume of Concrete as given by ACI 211.1—91

Maximum Size of Aggregate	Bulk volume of dry rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of			
F.M.	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Note: The values given will produce a mix that is suitable for reinforced concrete construction. For less workable concrete the values may be increased by about 10 percent. For more workable concrete such as pumpable concrete the values may be reduced by up to 10 per cent.

(*b*) From the minimum strength specified, estimate the average design strength either by using standard deviation or by using coefficient of variation.

(*c*) Find the water/cement ratio from the strength point of view from Table 11.5. Find also the water/cement ratio from durability point of view from Table 11.6. Adopt lower value out of strength consideration and durability consideration.

Table 11.5. Relation between water/cement ratio and average compressive strength of concrete, according to ACI 211.1–91

Average compressive strength at 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

Note: Measured on standard cylinders. The values given are for a maximum size of aggregate of 20 o 25 mm and for ordinary portland cement and for recommended percent of air entrainment shown in Table 11.8.

Table 11.6. Requirements of ACI 318-89 for W/C ratio and Strength for Special Exposure Conditions

	Exposure Condition	Maximum W/C ratio, normal density aggregate concrete	Minimum design strength, low density aggregate concrete MPa
I.	Concrete Intended to be Watertight		
	(a) Exposed to fresh water	0.5	25
	(b) exposed to brackish or sea water	0.45	30
II	Concrete exposed to freezing and thawing in a moist condition:		
	(a) kerbs, gutters, gaurd rails or thin sections	0.45	30
	(b) other elements	0.50	25
	(c) in presense of de-icing chemicals	0.45	30
III.	For corrosion protection of reinforced concrete exposed to de-icing salts, brackish water, sea water or spray from these sources	0.40	33

(*d*) *Decide maximum size of aggregate to be used. Generally for RCC work 20 mm and prestressed concrete 10 mm size are used.*

(*e*) *Decide workability in terms of slump for the type of job in hand. General guidance can be taken from table 11.7.*

Table 11.7. Recommended Values of Slump for Various Types of Construction as given by ACI 211.1-91

Type of Construction	Range of Slump mm
Reinforced foundation walls and footings	20–80
Plain footings, caissons and substructure walls	20–80
Beams and reinforced walls	20–100
Building columns	20–100
Pavements and slabs	20–80
Mass Concrete	20–80

Note: The upper limit of slump may be increased by 20 mm for compaction by hand.

Table 11.8. Approximate requirements for mixing water and air content for different workabilities and nominal maximum size of Aggregates according to ACI 211.1-91

Workability or Air content	Water Content, Kg/m^3 of concrete for indicated maximum aggregate size							
	10 mm	12.5 mm	20mm	25 mm	40 mm	50 mm	70 mm	150 mm
Non-air-entrained concrete								
Slump								
30–50 mm	205	200	185	180	160	155	145	125
80–100 mm	225	215	200	195	175	170	160	140
150–180 mm	240	230	210	205	185	180	170	–
Approximate entrapped air content per cent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained Concrete								
Slump								
30–50 mm	180	175	165	160	145	140	135	120
80–100 mm	200	190	180	175	160	155	150	135
150–180 mm	215	205	190	185	170	165	160	–
Recommended average total air content percent								
Mild exposure	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 11.9. First estimate of density (unit weight) of fresh concrete as given by ACI 211.1-91

Maximum size of aggregate mm	First estimate of density (unit weight) of fresh concrete	
	Non-air-entrained kg/m³	Air-entrained kg/m³
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

(*f*) The total water in kg/m³ of concrete is read from table 11.8 entering the table with the selected slump and selected maximum size of aggregate. Table 11.8 also gives the approximate amount of accidentally entrapped air in non-air-entrained concrete.

(*g*) Cement content is computed by dividing the total water content by the water/cement ratio.

(*h*) From table 11.4 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.

(*j*) The weight of C.A. per cubic meter of concrete is calculated by multiplying the bulk volume with bulk density.

(*k*) The solid volume of coarse aggregate in one cubic meter of concrete is calculated by knowing the specific gravity of C.A.

(*l*) Similarly the solid volume of cement, water and volume of air is calculated in one cubic meter of concrete.

(*m*) The solid volume of sand is computed by subtracting from the total volume of concrete the solid volume of cement, coarse aggregate, water and entrapped air.

(*n*) Wight of fine aggregate is calculated by multiplying the solid volume of fine aggregate by specific gravity of F.A.

Table 11.10. Required increase in strength (mean strength) for specified design strength (specified characteristic strength) when no tests records are available, according to ACI 318–89

Specified design Strength MPa	Required increase in strength MPa
less than 21	7
21 to 35	8.5
35 or more	10.0

Example: ACI Committee 211.1-91 method

Design a concrete mix for construction of an elevated water tank. The specified design strength of concrete (characteristic strength) is 30 MPa at 28 days measured on standard cylinders. Standard deviation can be taken as 4 MPa. The specific gravity of FA and C.A. are 2.65 and 2.7 respectively. The dry rodded bulk density of C.A. is 1600 kg/m3, and fineness modulus of FA is 2.80. Ordinary Portland cement (Type I) will be used. A slump of 50 mm is necessary. C.A. is found to be absorptive to the extent of 1% and free surface moisture in sand is found to be 2 per cent. Assume any other essential data.

(*a*) Assuming 5 per cent of results are allowed to fall below specified design strength,

The mean strength, $f_m = f_{min} + ks$

$= 30 + 1.64 \times 4$

$= 36.56$

say 36.5 MPa

(*b*) Since OPC is used, from table 11.5, the estimated w/c ratio is 0.47.

This w/c ratio from strength point of view is to be checked against maximum w/c ratio given for special exposure condition given in Table 11.6 and minimum of the two is to be adopted.

From exposure condition Table11.6, the maximum w/c ratio is 0.50

Therefore, adopt w/c ratio of 0.47

(*c*) From Table 11.8, for a slump of 50 mm, 20 mm maximum size of aggregate, for non-air-entrained concrete,

the mixing water content is 185 kg/m^3 of concrete. Also the approximate entrapped air content is 2 per cent.

The required cement content $= \dfrac{185}{0.47}$

$= 394$ kg/m^3

(*d*) From Table 11.4, for 20 mm coarse aggregate, for fineness modulus of 2.80, the dry rodded bulk volume of C.A. is 0.62 per unit volume of concrete.

(*e*) Therefore the weight of C.A. $= 0.62 \times 1600$

$= 992$ kg/m^3

(*f*) From Table 11.9, the first estimate of density of fresh concrete for 20 mm maximum size of aggregate and for non-air-entrained concrete = 2355 kg/m^3

(*g*) The weight of all the known ingredient of concrete

weight of water = 185 kg/m^3

weight of cement = 394 kg.m^3

weight of C.A. = 992 kg/m^3

weight of F.A. = 2355 – (185 + 394 + 992)

= 784 kg/m^3

(*h*) Alternatively the weight of F.A. can also be found out by absolute volume method which is more accurate, as follows.

Tabulate the absolute volume of all the known ingredients

Item number	Ingredients	Weight kg/m^3	Absolute volume cm^3
1.	Cement	394	$\frac{394}{3.15} \times 10^3 = 125 \times 10^3$
2.	Water	185	$\frac{185}{1} \times 10^3 = 185 \times 10^3$
3.	Coarse Aggregate	992	$\frac{992}{2.7} \times 10^3 = 367 \times 10^3$
4.	Air		$\frac{2}{100} \times 10^6 = 20 \times 10^3$

Total absolute volume $= 697 \times 10^3$ cm^3

Therefore absolute volume of F.A.

$= (1000 - 697) \times 10^3$

$= 303 \times 10^3$

Weight of FA $= 303 \times 2.65$

$= 803$ kg/m^3

Adopt F.A. $= 803$ kg/m^3.

(*i*) Estimated quantities of materials per cubic meter of concrete are

Cement = 394 kg

F.A = 803 kg

C.A = 992 kg

Water = 185 kg

Density of fresh concrete 2374 kg/m^3 as against 2355 read from Table 11.9

(*j*) Proportions

C	:	F.A	:	C.A	:	water
394	:	803	:	992	:	185
1	:	2.04	:	2.52	:	0.47

Weight of materials for one bag mix in kg = 50 : 102 : 126 : 23.5

The above quantities is on the basis that both F.A and C.A are in saturated and surface dry condition (SSD conditions).

(*k*) The proportions are required to be adjusted for the field conditions. FA has surface moisture of 2 per cent

∴ Total free surface moisture in FA $= \frac{2}{100} \times 803 = 16.06$ kg/m^3

Weight of F.A in field condition $= 803 + 16.06 = 819.06$ kg/m^3

say 819 kg/m^3

C.A absorbs 1% water

∴ *Quantity of water absorbed by C.A.* $= \frac{1}{100} \times 992 = 9.92 \text{ kg/m}^3$

∴ *Weight of C.A in field condition* $= 992 - 9.92$

$= 982.08 \text{ kg/m}^3$

say 982.0 kg/m^3

With regard to water, 16.06 kg of water is contributed by F.A and 9.92 kg of water is absorbed by C.A.

Therefore 16.06 – 9.92 = 6.14 kg of extra water is contributed by aggregates. This quantity of water is deducted from Total water

i.e., $185.00 - 6.14 = 178.86 \text{ kg/m}^3$

say 179 kg/m^3

(*l*) *Quantities of materials to be used in field duly corrected for free surface moisture in F.A and absorption characteristic of C.A*

Cement $= 394 \text{ kg/m}^3$

F.A. $= 819 \text{ kg/m}^3$

C.A. $= 982 \text{ kg/m}^3$

Water $= 179 \text{ kg/m}^3$

Field density of fresh concrete $= 2374 \text{ kg/m}^3$

(*m*) *Field proportion as worked out above may not give the final answer. A trial mix is then made to study the properties of such a concrete in respect of workability, cohesiveness, finishing quality, yield and 28 days compressive strength. The mix may need grading improvement, by way of change in proportion between various fractions of C.A. or change in prportion between FA and CA. If feasible, change in the shape of C.A particularly 10 mm fraction would greatly improve the situation. If F.A and C.A are having different specific gravities, any change in their earlier calculated proportion, may affect the yield of concrete.*

If all the avenues do not improve the qualities of the concrete designed for the work in hand, then only, one must resort to increase in water content. If water content is increased, corresponding increase in cement content is also made so that W/C ratio remains same.

When both water and cement is increased, it will affect the yield of concrete. Therefore to keep the yield constant, both the quantities of F.A and C.A is required to be reduced correspondingly. All these needs a number of trials before one arrives at the final proportions. The mix designer must have sufficient experience, understanding and feel of concrete.

Road Note No. 4 Method

This method of designing concrete mix proportions is mainly based on the extensive laboratory and field experiments carried out by the Road Research Laboratory, U.K. It was first published in Road Note No 4 during 1950. They have established relationship between various properties of concrete and variable parameters. A series of standard grading curves have been established to give grading limits for all-in aggregates graded down from 20 mm and 40 mm. The grading curve as established and made use of in the mix design is shown in Fig. 3.4 and 3.5 in Chapter 3. The procedure of mix design by Road Note No 4 is also called Grading Curve Method.

This method of mix design was popular and was widely used up to 1970's all over the world. Most of our concrete roads and air field pavements where designed by this method.

The Building Research Establishment of Department of Environment (DOE) U.K. has evolved another method called DOE method to replace the earlier Road Note No 4 method.

DOE Method of Concrete Mix Design[11.4]

The DOE method was first published in 1975 and then revised in 1988. While Road Note No 4 or Grading Curve Method was specifically developed for concrete pavements, the DOE method is applicable to concrete for most purposes, including roads. The method can be used for concrete containing fly ash (in U.K. it is called pulverized fuel ash, PFA) or GGBFS.

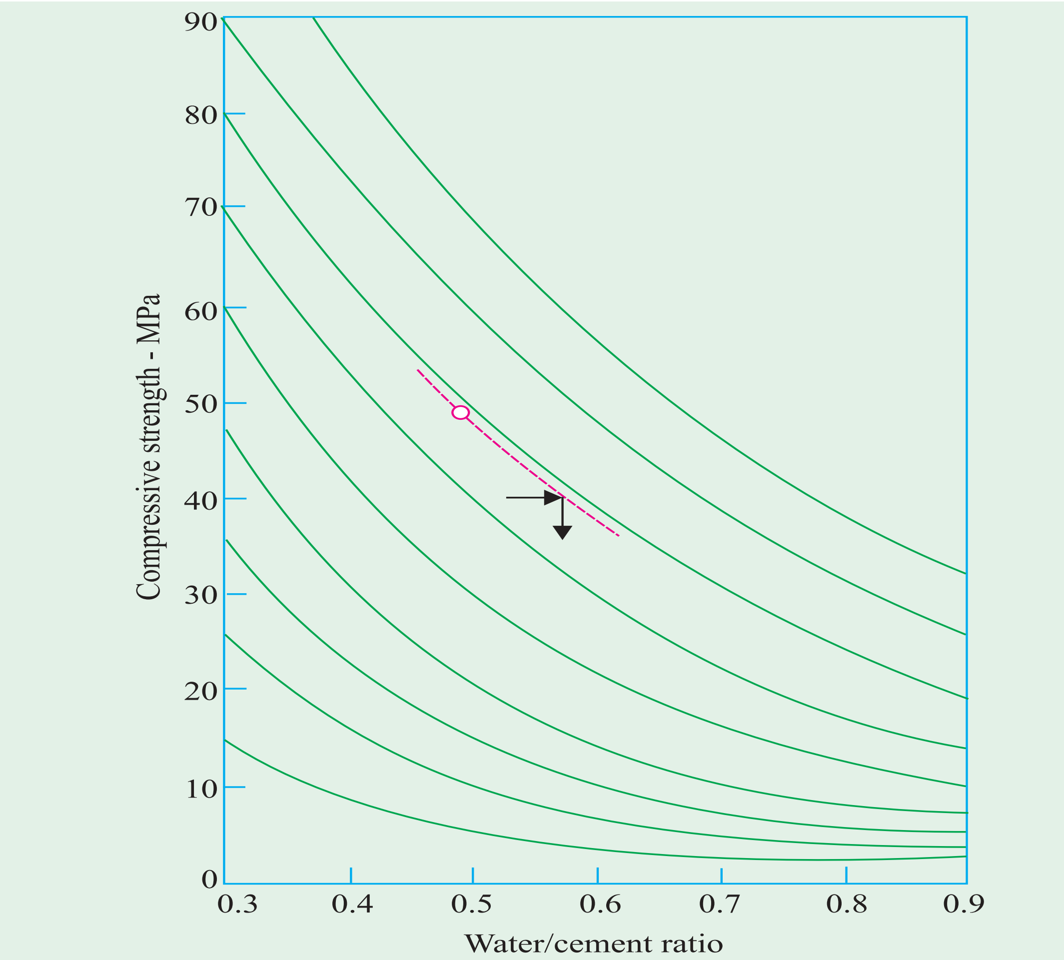
Since DOE method presently is the standard British method of concrete mix design, the procedure involved in this method is described instead of out dated Road Note No 4 method.

The following are the steps involved in DOE method.

Step 1: *Find the target mean strength from the specified characteristic strength*

Target mean strength = specified characteristic strength + Standard deviation x risk factor.

(risk factor is on the assumption that 5 percent of results are allowed to fall less than the specified characteristic strength).



Step 2: Calculate the water/cement ratio. This is done in a rather round about method, using

Table 11.11 and Fig. 11.3.

Table 11.11 gives the approximate compressive strength of concretes made with a free w/c ratio of 0.50.

Using this table find out the 28 days strength for the approximate type of cement and types of C.A.

Mark a point on the "Y" axis in Fig. 11.3 equal to the compressive strength read form Table 11.11

Table 11.11. Approximate Compressive Strength of Concrete Made with a free Water/Cement Ratio of 0.50. According to the 1988 British Method

Type of Cement	Type of C.A	Compressive Strength at the age (cube) of days MPa			
		3	7	28	91
Ordinary Portland cement (Type I)	uncrushed	22	30	42	49
Sulphate Resisting Cement (Type V)	Crushed	27	36	49	56
Rapid-Hardening Portland Cement (Type III)	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

which is at a W/C ratio of 0.50. Through this intersection point, draw a parallel dotted curve nearest to the intersection point. Using this new curve, we read off the W/C ratio as against target mean strength.

As an example, referring to Table 11.11 for sulphate resisting cement, crushed aggregate, approximate compressive strength, with a free W/C ratio of 0.5 at 28 days is 49 MPa. In Fig. 11.3 intersection point of 49 MPa and W/C ratio of 0.50 is marked. A parallel dotted curve is drawn to the neighboring curve. Water/Cement ratio is read off on this new dotted curve for any target mean strength. This Water/Cement ratio must be compared to the W/C requirement for durability (refer Table 9.20 or Table 9.21 given under chapter 9 on durability, depending upon whether it is RCC or plain concrete.

Step 3: Next decide water content for the required workability, expressed in terms of slump or Vebe time, taking into consideration the size of aggregate and its type from Table 11.12.

Table 11.12. Approximate Free Water Contents Required to Give Various Levels of Workability According to 1988 British method

Aggregate		Water Content kg/m³ for:			
Max-size mm	Type	Slump 0–10 Vebe > 12 seconds	10–30 6–12	30–60 3–6	60–180 0–3
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

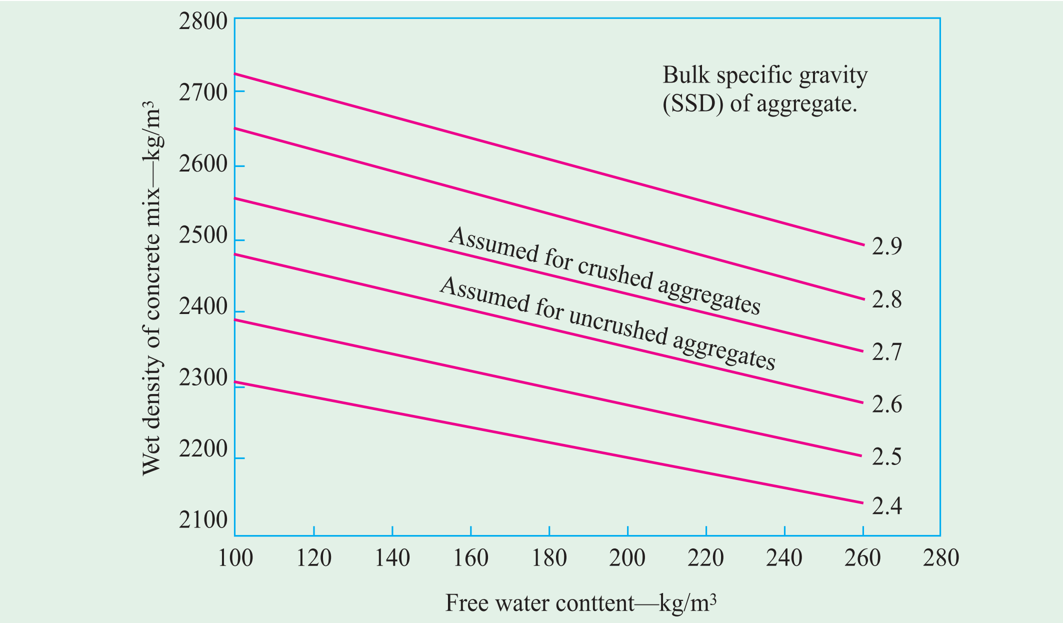
Table 11.13. Reduction in the free water contents of Table 11.12 when using fly ash

Percentage of Fly ash in Cementitious material	Slump mm Vebe seconds	Reduction in Water content kg/m³ 0–10 > 12	10–30 6–12	30–60 3–6	60–180 0–3
10		5	5	5	10
20		10	10	10	15
30		15	15	20	20
40		20	20	25	25
50		25	25	30	30

Step 4: Find the cement content knowing the water/cement ratio and water content. Cement content is calculated simply deviding the water content by W/C ratio. The cement content so calculated should be compared with the minimum cement content specified from the durability consideration as given in Table 9.20 or Table 9.21 and higher of the two should be adopted. Sometime maximum cement content is also specified. The calculated cement content must be less than the specified maximum cement content.

Step 5: Next find out the total aggregate content. This requires an estimate of the wet density of the fully compacted concrete. This can be found out from Fig. 11.4 for approximate water content and specific gravity of aggregate. If sp. gr. is unknown, the value of 2.6 for uncrushed aggregate and 2.7 for crushed aggregate can be assumed. The aggregate content is obtained by subtracting the weight of cement and water content from weight of fresh concrete.

Step 6: Then, proportion of fine aggregate is determined in the total aggregate using Fig. 11.5. Fig. 11.5(a) is for 10 mm size, 11.5(b) is for 20 mm size and Fig. 11.5(c) is for 40 mm size coarse aggregate. The parameters involved in Fig. 11.5 are maximum size of coarse aggregate, the level of workability, the water/cement ratio, and the percentage of fines



passing 600 µ seive. Once the proportion of F.A. is obtained, multiplying by the weight of total aggregate gives the weight of fine aggregate. Then the weight of the C.A. can be found out. Course aggregate can be further devided into different fractions depending on the shape of aggregate. As a general guidance the figures given in Table 11.14 can be used.

Table 11.14. Proportion of Coarse Aggregate Fractions According to the 1988 British method

Total C.A	*5–10 mm*	*10–20 mm*	*20–40 mm*
100	*33*	*67*	*–*
100	*18*	*27*	*55*

The proportion so worked out should be tried in a trial mix and confirmed about its suitability for the given concrete structure.

Table 11.13 gives the reduction of free water contents from the figures given in Table 11.12 when fly ash is used in the mix.

Example—DOE Method

Design a concrete mix for a reinforced concrete work which will be exposed to the moderate condition. The concrete is to be designed for a mean compressive strength of 30 MPa at the age of 28 days. A requirement off 25 mm cover is prescribed. Maximum size of aggregate is 20 mm uncrushed aggregate will be used. Sieve analysis shows that 50% passes through 600 µ seive. The bulk specific gravity of aggregate is found to be 2.65

First step is to find out the target mean strength. In the above problem the target mean strength is directly given as 30 MPa at 28 days (cube strength)

Second step is to find out the water/cement ratio for 30 MPa concrete.

For this we have to refer to Table 11.11. Refering to Table 11.11, for OPC, uncrushed aggregate, for W/C ratio of 0.5, 28 days compressive strength is 42 MPa. In Fig. 11.3 find an

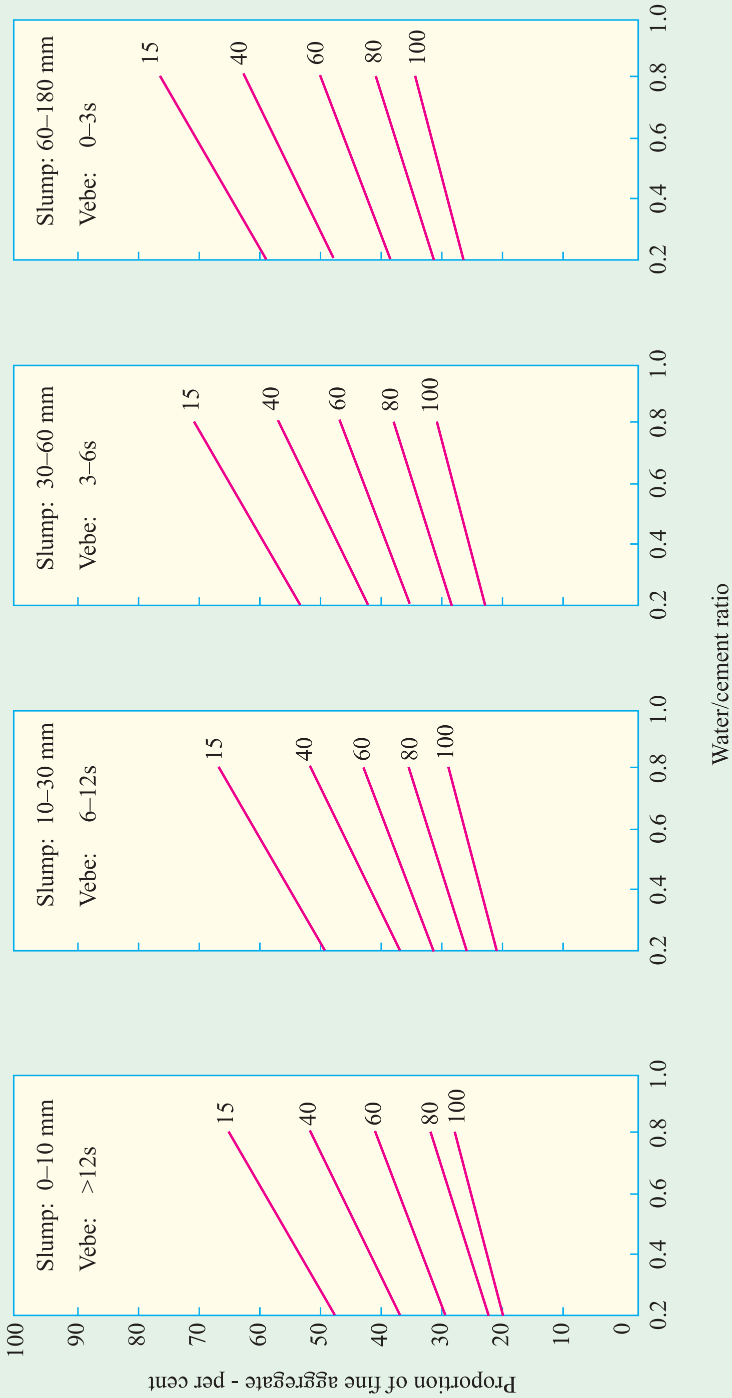
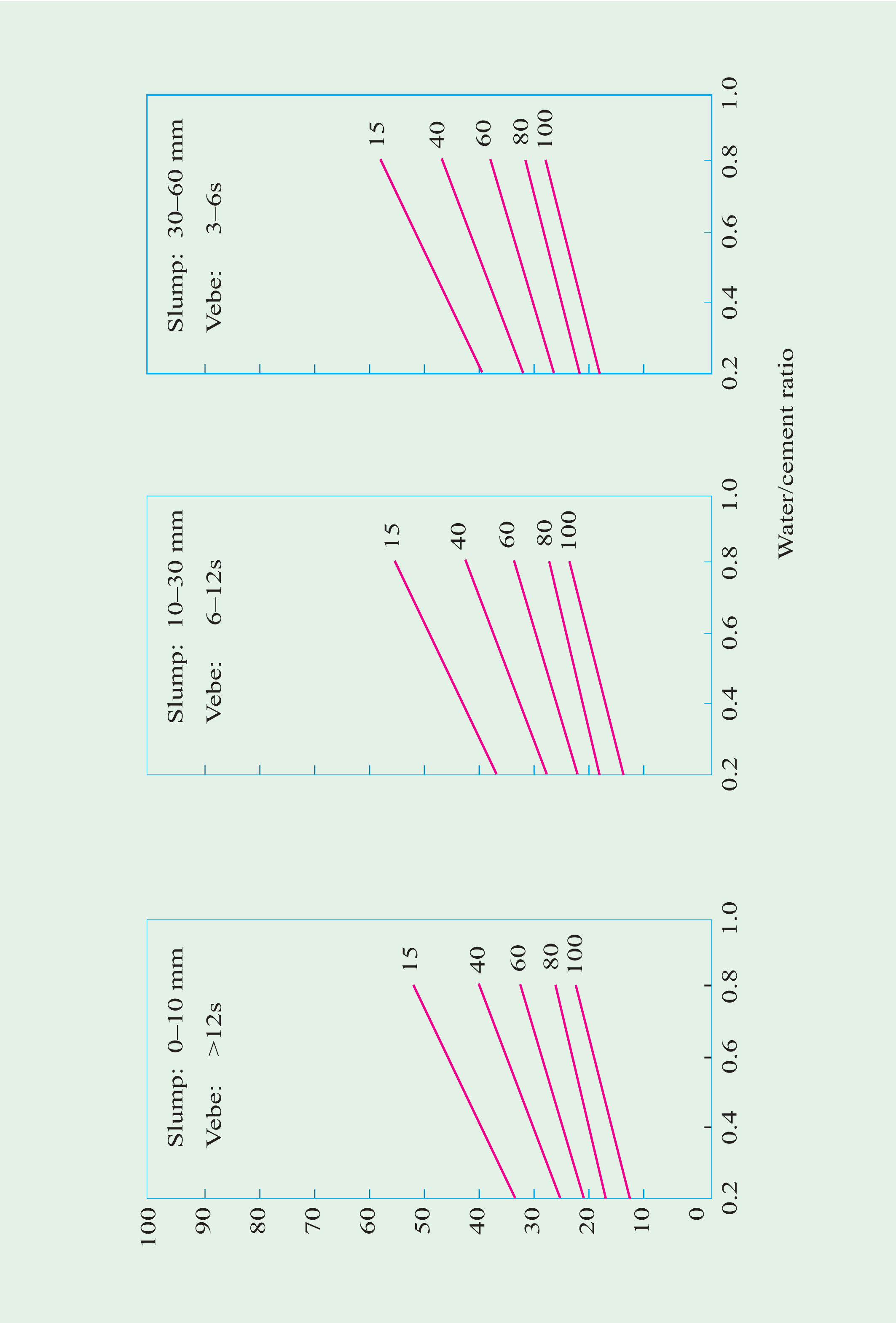
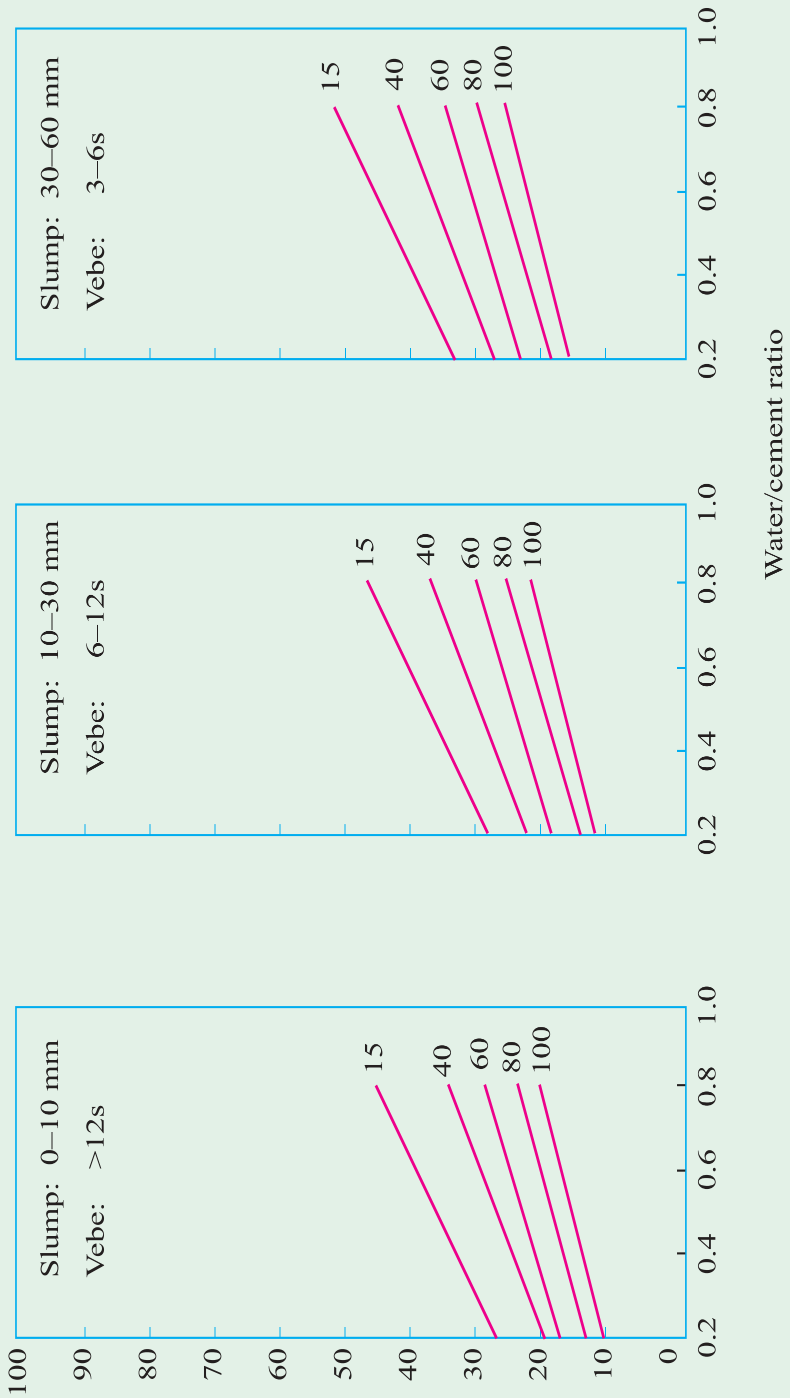


Fig. 11.5. Recommended percentage of fine aggregate in total aggregate as a function of free water/cement ratio for various values of workability and maximum size of aggregate: (*a*) 10 mm, (*b*) 20 mm, and (*c*) 40 mm
Numbers on each graph are the percentage of fines passing a 600 μm sieve.
(Building Research Establishment, Crown copyright)


Slump: 0–10 mm
Vebe: >12s
Slump: 10–30 mm
Vebe: 6–12s
Slump: 30–60 mm
Vebe: 3–6s
15
40
60
80
100
0
10
20
30
40
50
60
70
80
90
100
0.2
0.4
0.6
0.8
1.0
Water/cement ratio



Slump: 0–10 mm
Vebe: >12s
Slump: 10–30 mm
Vebe: 6–12s
Slump: 30–60 mm
Vebe: 3–6s
15
40
60
80
100
100
90
80
70
60
50
40
30
20
10
0
0.2
0.4
0.6
0.8
1.0
Water/cement ratio

intersection point for 42 MPa and 0.5 W/C ratio. Draw a dotted line curve parallel to the neighbouring curve. From this curve read off the W/C ratio for a target mean strength of 30 MPa.

The Water/cement ratio is = 0.62

Check this W/C ratio from durability consideration from Table 9.20. The maximum W/C ratio permitted is 0.50. Adopt lower of the two

Therefore adopt W/C ratio of 0.50

Next decide the water content for slump of 75 mm (assumed) 20 mm uncrushed aggregate from Table 11.12.

The water content is 195 kg/m^3

With W/C of 0.5 and water content of 195 kg/m^3*, the cement content works out to*

$$\frac{195}{0.5} = 390 \text{ kg/m}^3$$

Check this cement content with that of durability requirements given in Table 9.20. Minimum cement content from durability point of view is 350 kg/m^3*. Adopt greater of the two.*

Therefore adopt cement content = 390 kg/m^3

Next, find out the density of fresh concrete from Fig. 11.4 for water content of 195 kg/m^3*,*

20 mm uncrushed aggregate of sp.gr. 2.65

The wet density = 2400 kg/m^3

Next, find the weight of total aggregate

2400 – (195 +390) = 1815 kg/m^3

Next, find the percentage of fine aggregate from Fig. 11.5(b)

For 20 mm aggregate size, W/C ratio of 0.50,

Slump of 75 mm, for 50% fines passing through 600 µ sieve, the percentage of

F.A. = 40 percent

$$\text{Weight of F A.} = 1815 \times \frac{40}{100} = 726 \text{ kg/m}^3$$

$$\therefore \quad \text{Weight of C.A.} = 1815 - 726 = 1089 \text{ kg/m}^3$$

Estimated quantities in kg/m^3

Cement	=	390
F.A.	=	726
C.A.	=	1089
Water	=	195
Wet density		2400

The above quantities are required to be adjusted for the field moisture content and absorption characteristics of aggregates

Lastly trial mixes are made to arrive at the correct quality of concrete.

Concrete Mix Design Procedure for Concrete with Fly Ash by DOE Method

Use of fly ash is gaining popularity in India as in other countries. Therefore one has to be acquainted with the procedure of concrete mix containing fly ash. The following example of Mix Design containing fly ash illustrates the procedures.

Example of Mix Design with Fly ash with DOE method

Design a concrete mix for a chracteristic strength of 25 MPa. (The target mean strength can be taken as 33 MPa). Crushed aggregates are used. The grading of F.A shows that 40% passes through 600 µ seive. Placing condition requires a slump range of 30–60 mm. The concrete is to be used in a moderate exposure condition. The cover to reinforcement adopted is 25 mm. The sp. gr. of F.A. is 2.6 and that of C.A is 2.7. It is proposed to use 30 percent fly ash.

In the case of mixes containing fly ash, DOE method gives the cement content as

$$C = \frac{(100-p)W}{(100-0.7p)\left\{\dfrac{W}{C+0.3F}\right\}}$$

fly ash content, $$F = \frac{pC}{100-p}$$

where $$p = \frac{100F}{C+F}$$

i.e., p *is the percentage of fly ash in the total cementitious material.*

W *is the free water content*

$\dfrac{W}{C+0.3F}$ *is the free water/cementitious ratio for design strength in Fig. 11.3. The free water/cementitious material ratio W/C + F should then be compared with the specified value.*

The free water/cement ratio to be used in Fig. 11.3 is $\dfrac{W}{C+0.3F}$

From Table 11.11, Compressive strength of ordinary cement with fly ash mix with a free $\dfrac{W}{C+0.3F}$ *ratio of 0.5 is 49 MPa. For target mean strength of 33 MPa, Fig. 11.3 gives a free* $\dfrac{W}{C+0.3F}$ *ratio of 0.65. (This value is not to be compared with the maximum permissible value of those given in table 9.20, but is used only for strength purposes)*

Referring to Table 11.12.

For slump of 60 mm, for maxim size aggregate of 20 mm, in case of crushed aggregate, the approximate water content is 210 kg/m^3

Since 30 per cent of fly ash is used, referring to Table 11.13, This water content is to be reduced by 20 kg/m^3

∴ *The water content = 210 – 20*

= 190 kg/m^3

Then cement content $= \dfrac{(100-30)190}{(100-0.7\times30)(0.65)}$

$= 259\ kg/m^3$

and the fly ash content F $= \dfrac{pC}{100-p}$

$= \dfrac{30\times259}{100-30} = 111.0\ kg/m^3$

Hence the total cementitious material content is 259 + 111.0 kg/m³ = 370 kg/m³

The free water/cementitious material ratio is $\dfrac{190}{370} = 0.51$

Referring to Table 9.20.

For moderate exposure condition, and concrete cover of 25 mm, the maximum free water/cementitious material ratio is 0.50 and minimum cement content is 350 kg/m³

Referring to Table 9.20 cement content satisfies the durability requirement. But water/cementitious material ratio does not satisfy the durability requirement. Therefore adopt Water/cementitious material ratio of 0.50, instead of 0.51.

Then water content $= 370 \times 0.5$

$= 185\ l/m^3$

From Fig. 11.4, for water content of 185 l/m³, average specific gravity of 2.65 of aggregates, the wet density of concrete comes to 2415 kg/m³

Hence the total weight of aggregates

$= 2415-(259 + 111 + 185)$

$= 1860\ kg/m^3$

From Fig. 11.5(b)

For free water/cementitious material ratio of 0.50, and for F.A, 40% passing through 600 µ seive, and for slump of 30–60 mm the proportion of F.A is = 38%

∴ *Weight of F.A* $= \dfrac{38}{100} \times 1860$

$= 707\ kg/m^3$

Weight of C.A $= 1860 - 707$

$= 1153\ kg/m^3$

Estimated quantities of materials in kg per m³ on the basis of SSD condition

Cement	=	259.00
Fly ash	=	111.00
Fine aggregate	=	707.00

Coarse aggregate = 1153.00

Water = 185.00

Total = 2415 kg/m³

The above weights of F.A, C.A are to be adjusted depending upon the free moisture content and absorption characteristics of aggregates. The corresponding correction is also to be made in the quantity of actual water added. and also consequent changes in the quantities of aggregates.

Then trial mixes are made to see that the concrete satisfies all the requirements in plastic conditions and strength at 28 days. If not, minor adjustment is made in the quantities of materials worked out.

Alternatively Superplasticizers in appropriate dose could be used for getting required workability.

Note: Referring to Table 9.20.The minimum grade of concrete is to be 45 MPa. This, aspect has not been satisfied. If this condition is to be satisfied, the whole problem is to be reviewed and reworked out.

Fig. 11.6. Degree of workability

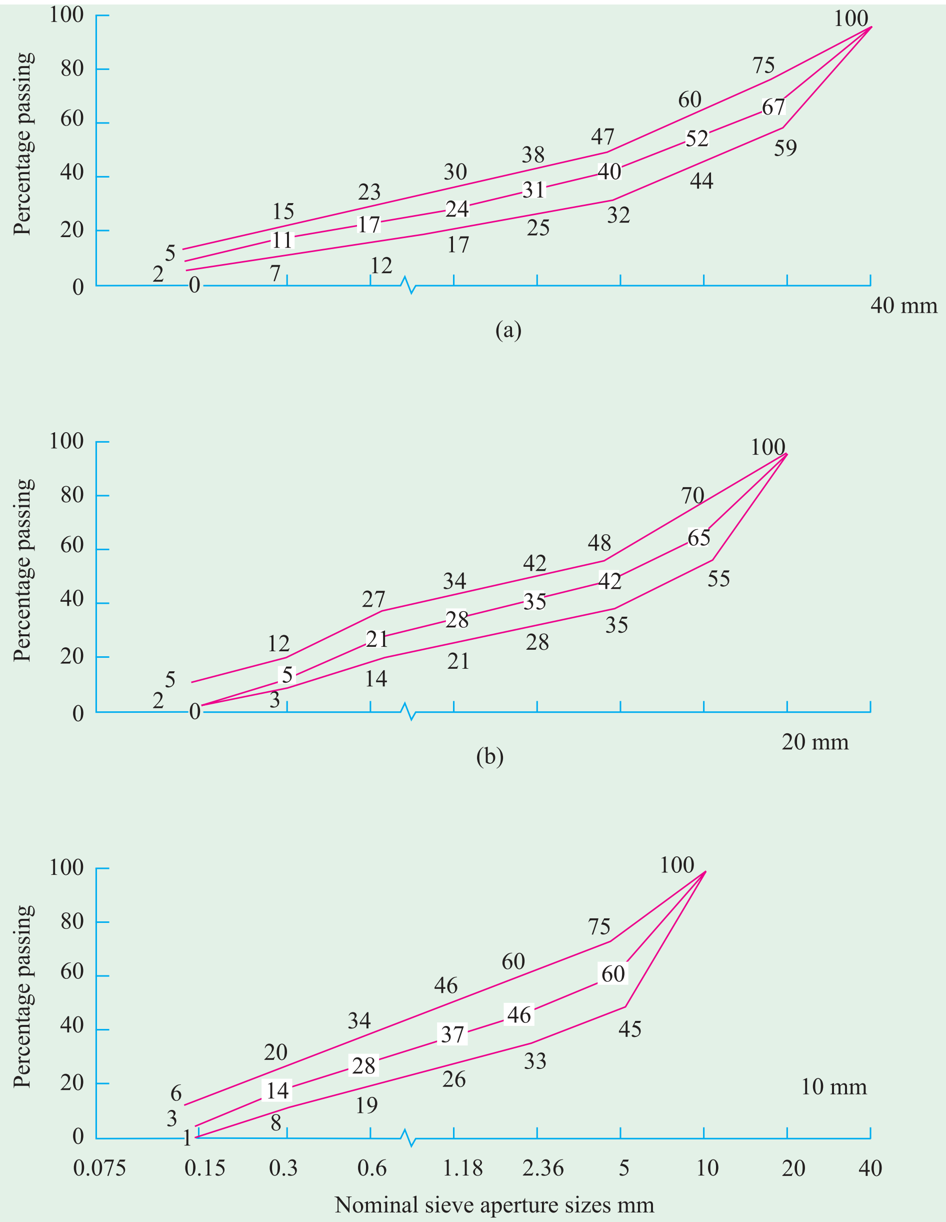
Mix Design for Pumpable Concrete[11.5]

A concrete which can be pushed through a pipe line is called a pumpable concrete. It is proportioned in such a manner that its friction at the inner wall of the pipeline does not become so high to prevent its movement at the pressure applied by the pump. A pumpable concrete is no special concrete. It is a standardised good concrete with certain content of fines to offer lubrication at the inner wall of pipe line.

The pumpable concrete has:

(a) a minimum content of FINES (cement + fine aggregate particle smaller than 0.25 mm size) of approximately 400 kg/m³ for maximum size of 32 mm C.A. In case of very angular, flaky aggregates this quantity is to be increased by approximately 10%.

(b) a minimum cement content of approximately 240 kg/m³ for maximum size of 32 mm



(c)

Fig. 11.7. Typical grading curves for pumpable mixes

C.A. It must be increased by 10% in case of maximum size aggregate of 16 mm.

(c) a water/cement ratio of 0.42 to 0.65

(d) a slump of 75 mm to 150 mm or a consistency determinable by means of the flow table spread in the range of k_2 and k_3 (refer Fig. 11.6)

(e) a grading of aggregate typically as shown in Fig. 11.7 is to be used.

A clear understanding of what happens to concrete when it is pumped through a pipeline is fundamental to any study of concrete pumping and when designing a pumpable concrete mix.

Under pressure from the pump, the mix must not segregate or bleed. The mix must be able to bind all the constituent materials together. The mix should also be able to deform while flowing through the pipeline at bends and tapered section. To achieve this, the proportion of "FINES" is of prime importance. The FINES content of 350 to 400 kg/m^3 are considered necessary for pumpable concrete. This much of FINES is also required for maintaining lubricating film around the concrete plug to reduce wear and tear of the whole system.

Assuming the pump is mechanically sound, there are two reasons why blockage occur. The plug of concrete will not move because either

(a) water is being forced out of the mix creating bleeding and blockages by jamming, or

(b) there is too much frictional resistance due to the nature of ingredients of the mix.

Fig. 6.19 of chapter six illustrates the relationship between cement content, aggregate void content and excessive friction on segregation and bleeding.

A good grading is very important to produce pumpable concrete. Elongated and flaky aggregate will make the concrete harsh for the given cement content and water/cement ratio. The typical grading curves are shown in Fig. 11.7 for pumpable mixes. The aggregates for the proposed mix should have a grading parallel to these curves, but not coarser than curve 2. Adjustments to bring the grading parallel to the curves can be made by altering the proportions between C.A and F.A.

It is recommended that 10–20% of the fine aggregate should pass through 300 µ sieve. Sometimes 3–4% extra sand is added to safeguard against undersanding. Table 11.15 shows the total FINES in kg per m^3 for various maximum size of C.A.

Table 11.15. FINES quantities and aggregate size

Maximum size of coarse aggregate mm	FINES per cubic meter of concrete kg
8	525
16	450
32	400
63	325

Table 11.16. Limits of FINES content (calculated on the absolute density of cement equal to 3100 kg/m^3.)

Free water content l/m^3	FINE solids kg/m^3 Minimum	Maximum
150	260	365
160	280	390
170	295	415
180	315	440
190	330	465
200	350	490
210	365	515
220	385	540
230	400	565
240	420	590

Table 11.17. Mix Proportions on SSD basis for 75–100 mm slump

Material	Quantity in kg
Fine Aggregate	880
Coarse Aggregate	930
OPC	310
Water	190
Total	2310

Table 11.18. Absolute density of materials

Material	Density kg/m^3
OPC	3100
F.A	2650
C.A	2550

Table 11.19. Aggregate Gradings (for mix proportions in Table 11.17)

Sieve Size	Percentage passing	
mm	Coarse Agg.	Fine Agg.
20	100	
14	60	
10	37	100
5	6	94
2.4	1	84
1.2		70
0.6		53
0.3		18
0.15		5

Table 11.20. Calculation of all-in aggregate grading, based on F.A content of 880 kg and C.A content of 930 kg/m^3 and as per grading given in Table 11.19.

Sieve Size	Percentage Passing		
mm	C.A	F.A	Combined grading
20	51.5	48.5	100
14	31.0	48.5	79.5
10	19.0	48.5	67.5
5	3.0	45.5	48.5
2.4	0.5	41.0	41.5
1.2	–	34.0	34.0
0.6		25.5	25.5
0.3		9.0	9.0
0.15		2.5	2.5

Example: Basic design calculations for a pumpable concrete mix

The following steps will illustrate the procedure.

(*a*) While Fig. 11.7 shows the typical grading limits, Fig. 11.8 shows the more acceptable grading limits for pumpable concrete using 20 mm maximum size aggregates. The grading pattern should fall within the curve envelope of Fig. 11.8. If necessary the proportions of fine and coarse aggregate can be readjusted.

(*b*) The limits of the FINES content should be as given in Table 11.16

(*c*) Mix proportions on SSD basis, for 75 to 100 mm slump, are given in Table 11.17.

(*d*) The mix proportions given in Table 11.17 is based on the gradings of aggregate as given in Table 11.19.

(*e*) The absolute density of material used is given in Table 11.18.

(*f*) The calculation of grading of combined aggregate on the basis of proportions given in Table 11.17 is given in Table 11.20. These combined grading figures should fall within the limits indicated in Fig. 11.8.

(*g*) The FINES content should then be worked out.

cement content = 310 kg (From Table 11.17)

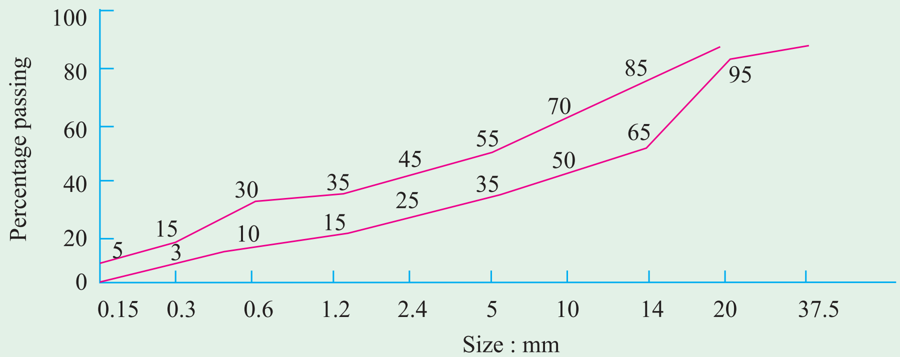


Fig. 11.8. Grading limits for Pumpable mix

Fine aggregate grading shows that 18% passing through 0.3 mm sieve and 5% passing through 0.15 mm by interpolation probable percentage passing through 0.25 mm sieve = 15%

$\therefore$ Fine particles in sand = $\frac{15}{100}$ x 880 = 132 kg/m^3

$\therefore$ Total FINES = 310 + 132

= 442 kg/m^3

Referring to Table 11.16 for 190 l/m^3 of water content, the range of FINES is 330 to 465 kg/m^3

$\therefore$ FINES of 442 kg/m^3 is considered suitable.

Note. Crushed aggregate can be obtained in wide range of single sized particles from which required gradings can be readily produced. These aggregates usually require higher sand contents to achieve the required void content. Crushed fine aggregates contain lot of dust that passing the 150 m sieve and care must be taken to avoid excess of dust which could cause high pipe line friction and blockages.

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.

Before we proceed with describing this method step by step, 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 have been incorporated and the procedure is modified to that extent.

(a) **Target mean strength for mix design:** The target mean compressive ($\bar{f}_{ck}$) strength at 28 days is given by

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

where f_{ck} = characteristic compressive strength at 28 days.

S is the standard deviation. The value of the standard deviation has to be worked out from the trials conducted in the laboratory or field. An example has been worked out in Table 11.1. In the absence of such trials, the value of standard deviation can be adopted from Table 11.22, to facilitate initial mix design. As soon as enough test results become available, standard deviation should be worked out and the mix design is modified accordingly.

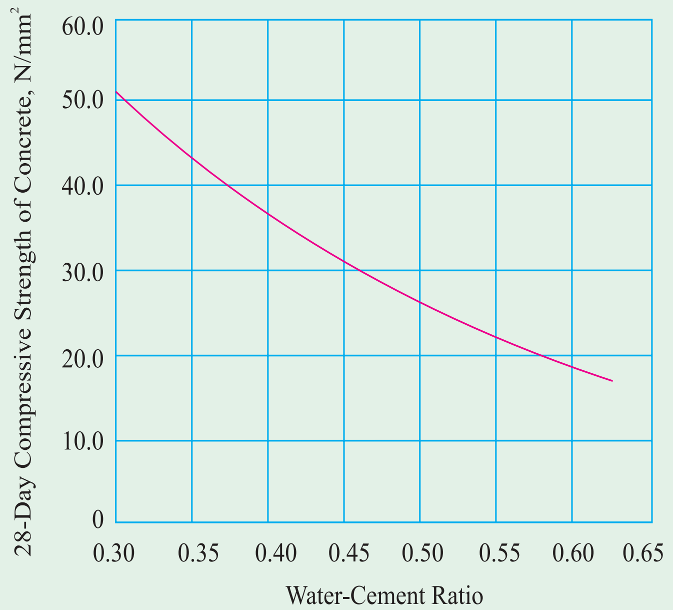
t = a statistical value depending on expected proportion of low results (risk factor). According to IS: 456–2000 and IS: 1343–'80, the characteristic strength is defined as that value below which not more than 5 per cent results are expected to fall, in which case the above equation reduces to—

$$\bar{f}_{ck} = f_{ck} + 1.65\ S \qquad \text{(Refer Table 11.21)}$$

Table 11.21. Values of Tolerance Factor (t) (Risk Factor)

Tolerance level. No of Samples	1 in 10	1 in 15	1 in 20	1 in 40	1 in 100
10	1.37	1.65	1.81	2.23	2.76
20	1.32	1.58	1.72	2.09	2.53
30	1.31	1.54	1.70	2.04	2.46
Infinite	1.28	1.50	1.64	1.96	2.33

Note: Under conditions of major concreting Job, where large number of samples are tested, it would be appropriate to adopt a tolerance factor corresponding to infinite number of samples.



(b) Selection of Water/Cement ratio

Various parameters like types of cement, aggregate, maximum size of aggregate, surface texture of aggregate etc. are influencing the strength of concrete, when water/cement ratio remain constant, hence it is desirable to establish a relation between concrete strength and free water cement ratio with materials and condition to be used actually at site. In absence of such relationship, the free water/cement ratio corresponding to the target strength may be determined from the relationship shown in Fig. 11.9.

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

Grade of Concrete	Assumed standard Deviation N/mm^2
M 10	
M 15	3.5

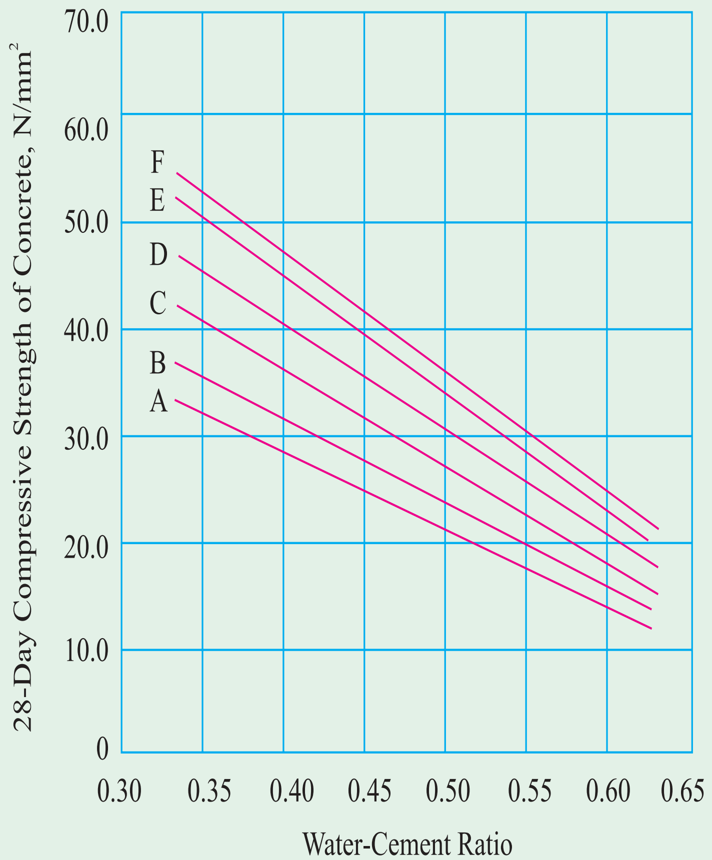
M 20	
M 25	*4.00*
M 30	
M 35	
M 40	*5.00*
M 45	
M 50	

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

One of the good features of IS 10262 of 1982 method of mix design is that it incorporates the strength of cement in the mix design procedure. By incorporating the strength of cement, it is possible to effect economy in concrete mix.

If the 28 days strength of cement is known, use of Fig. 11.10 may be made for more accurate estimation of water cement ratio. However, this will need at least 28 days for testing the strength of cement, thereby delaying the whole process by 28 days. Accelerated strength test may be adopted to cut down the delay.

In view of the improvements in the quality and strength of Indian cement since 1982 the graph given in Fig. 11.11 will give a more realistic picture of water-cement ratio.



The graph given in Fig. 11.11 is not a part of IS recommended method of mix design. But the author recommends the use of Fig. 11.11 for better results. This graph is taken from practice in Germany.

The free water-cement ratio thus selected as mentioned above, should be checked against the limiting water-cement ratio for the durability requirement (Table 9.18 and the lower of the two values should be adopted.

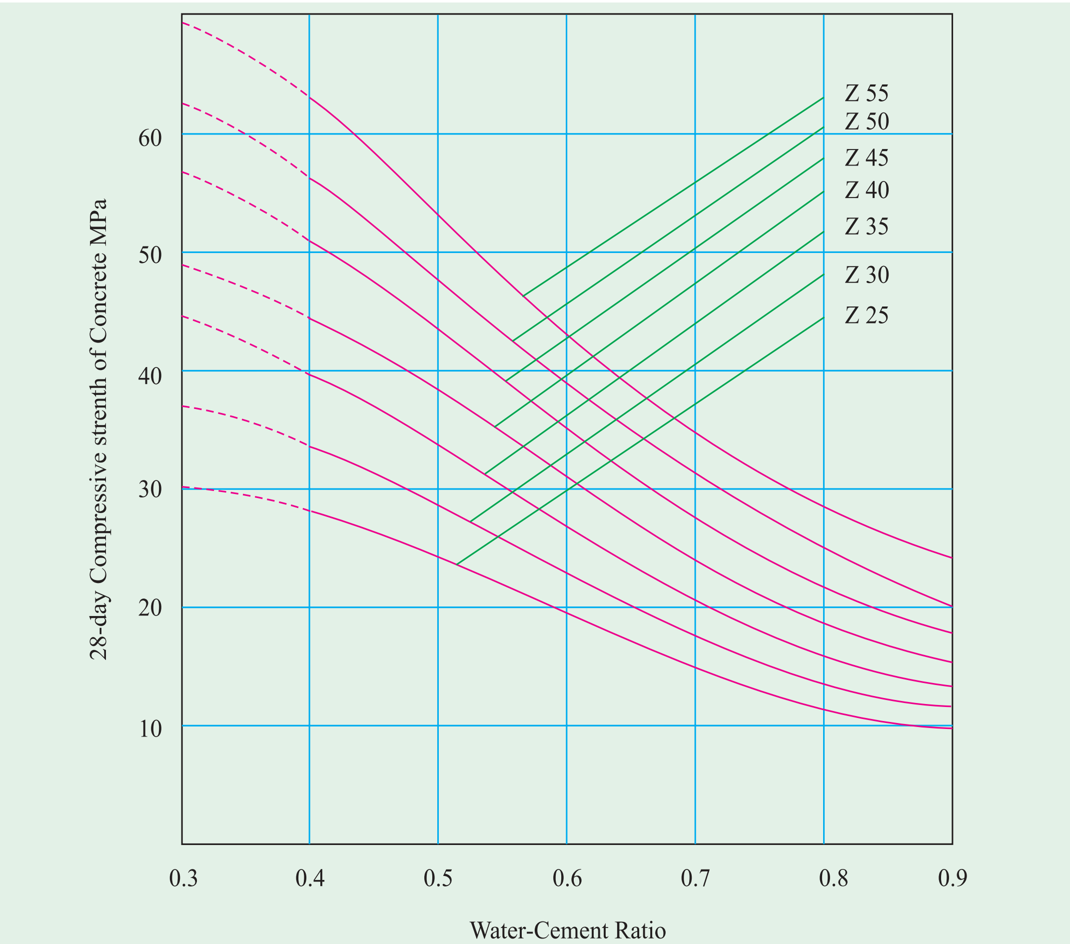
(c) Estimation of Entrapped Air. *The air content is estimated from Table 11.23 for the normal maximum size of aggregate used.*

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. Both Table 11.24 and Table 11.25 are based on the following conditions.

(a) Crushed (Angular) coarse aggregate, conforming to IS: 383—'70.

(b) Fine aggregate consisting of natural sand conforming to grading zone II of Table of IS: 383—'70.

(c) Workability corresponds to compacting factor of 0.80 (Slump 30 mm approximately)

Water cement ratio in case of Table 11.24 is 0.6 0 (by mass) whereas the same for Table 11.25 is 0.35 (by mass). For any departure from above mentioned conditions, corrections have to be applied as per Table 11.26, for water content and percent sand in total aggregate by absolute volume, determined from table 11.24 or table 11.25.

Note: Refer Table 6.1 for relation between compacting factor and slump.

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	Adjustment Required in % 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:

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

$$C_a = \frac{1-P}{P} \times f_a \times \frac{S_{ca}}{S_{fa}} \qquad \text{... (2)}$$

where

V = absolute volume of fresh concrete, which is equal to gross volume (m^3) minus the volume of entrapped air,

W = Mass of water (kg) per m^3 of concrete

C = Mass of cement (kg) per m^3 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 m^3 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.

(h) The calculated mix proportions shall be checked by means of trial batches. Quantities of material for each trial shall be enough for at least three 150 mm size cubes and concrete required to carry out workability test according to IS: 1199–'59.

Trial mix number 1 should be checked for workability and freedom from segregation and bleeding and its finishing property.

If the measured workability is different from that assumed in the calculation, a change in the water content has to done from table 11.26 and the whole mix design has to be recalculated keeping W/C ratio constant. A minor adjustment in the aggregate quantity may be made to improve the finishing quality or freedom from segregation and bleeding. This will comprise trial mix number 2. Now water/cement ratio is changed by ± 10 per cent of pre-selected value and mix proportions are recalculated. These will form trial mix numbers 3 and 4. Testing for trial mix numbers 2, 3, 4 are done simultaneously. These tests normally provide sufficient information, including the relationship between compressive strength and water cement ratio, from which the mix proportions for field trials may be arrived at.

Illustrative Example of Concrete Mix Design (Grade M 20)

(a) Design stipulations

(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 data for 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 is shown below:	

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 to Table 2, IS: 383—1970
10	0	71.20	0	28.5	28.5	
4.75		9.40	–	3.7	3.7	
2.36	–	–	–	–	–	

2. Fine aggregate

Sieve sizes	Fine aggregate (% passing)	Remarks
4.75 mm	100	
2.36 mm	100	Conforming to grading Zone III of Table 4 IS: 385–1970
1.18 mm	93	
600 micron	60	
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 (refer Table 11.21 and Table 11.22 for values of t and s)

(*d*) Selection of water-cement ratio

From Fig. 11.10 the water-cement ratio required for the target mean strength of 26.6 MPa is 0.50. This is lower than the maximum value of 0.55 prescribed for 'Mild' exposure. (refer Table 9.18) adopt W/C ratio of 0.50.

(*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 $= 186 + 5.58 = 191.6 \text{ 1/m}^3$

(*f*) Determination of cement content

Water-cement ratio $= 0.50$

water $= 191.6$ *litre*

$\therefore$ *cement* $= \dfrac{191.6}{0.50} = 383 \text{ kg/m}^3$

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. 1 and 2 given on page 494.

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

$f_a = 546 \text{ kg/m}^3$, *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/m^3, and

C_a = 1188 kg/m^3.

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 quantity 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

I Trial mix

A typical trial mix test programme is given in Table 11.27.

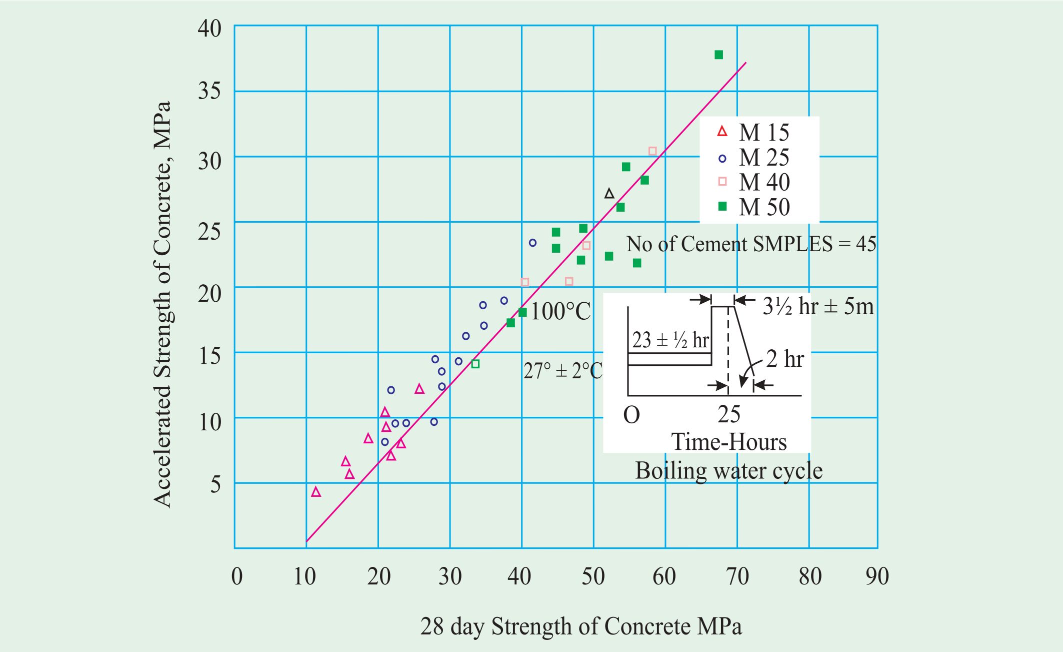
Table 11.27. Typical Test Results of Trial Mix

Mix. No.	Quantities of material per cubic metre of concrete: Cement	Water	Sand	C Type I	A Type II	Concrete characteristic: Workability (CF)	Visual observation	28 days compressive strength
1	2	3	4	5	6	7	8	9
	kg	(l)	(kg)	(kg)	(kg)			N/mm^2
1.	383	191.6 w/c = 0.5	546 (31.5%)	712	475	0.80	Under sanded	–
2.	394.6	197.3 w/c = 0.5	564 (33%)	687	458	0.91	Cohesive	28.8
3.	358.7	197.3 w/c = 0.55	591 (34%)	688	459	0.90	Cohesive	26.0
4.	438.4	197.3 w/c = 0.45	535 (32%)	682	455	0.89	Cohesive	31.2

Rapid Method

However, the approach outlined above will need at least 28 days for the trial mix of concrete, and 56 days if cement is to be tested to use Fig. 11.10. This brings out a major difficulty in adoption of design mix concrete in our country. In view of shortage of cement with interrupted supplies, once cement is received at the construction sites, there is a tendency to straightaway use it without waiting for trial mixes. Unless one is in a position to procure adequate quantities of cement and aggregates well in advance, protect and store them at the site, it will be difficult to expect the site-engineer to wait for completing the trial mixes, before using cement in constructions. Variability of materials, on the other hand, will not enable one mix design worked out earlier with one set of material to be applicable in all cases. In other words, another prime requirement for adoption of design mix concrete is to cut down the time required for trial mixes.

In a method developed by erstwhile CRI; now NCBM, where use of accelerated curing method of testing compressive strength of concrete have brought down the time required for mix proportioning to 3 days only. Such methods of accelerated curing of concrete for strength tests are now standardised and covered in IS: 9013–1978. In so far as concrete is concerned, there exists a statistically significant correlation between its 28 days strength and accelerated strength, so much so that the trial of mixes can be related to target 'accelerated strength' rather than the target 28 days strength, with the help of correlation between the two. A typical correlationis shown in Fig. 11.12 which is based on cements from all plants in the country and different grades of concrete, using boiling water method of accelerated curing. The correlation is found to be not affected by the type or characteristics of cement, presumably because they affect both the accelerated and 28 days strength of concrete in a proportionate manner, so that the influence is nullified, when their ratios are compared. Moreover, for individual



applications such correlations can be easily established for the type of materials and mix proportions in hand.

In so far as the compressive strength of cements is concerned, accelerated tests on standard cement mortars (as per IS: 4032–1968) have not given equally reliable results. This problem has been overcome by testing cements also in a 'reference' concrete mix and determining its accelerated strength. The 'reference' concrete mix has w/C = 0.35 and workability = 0.80 (compacting factor). The nominal maximum size of natural crushed aggregate should be 10 mm and fine aggregate conforming to zone II of Table 4 of IS: 383–1970 are used. Typical composition of such a reference concrete mix, per m^3 of concrete is

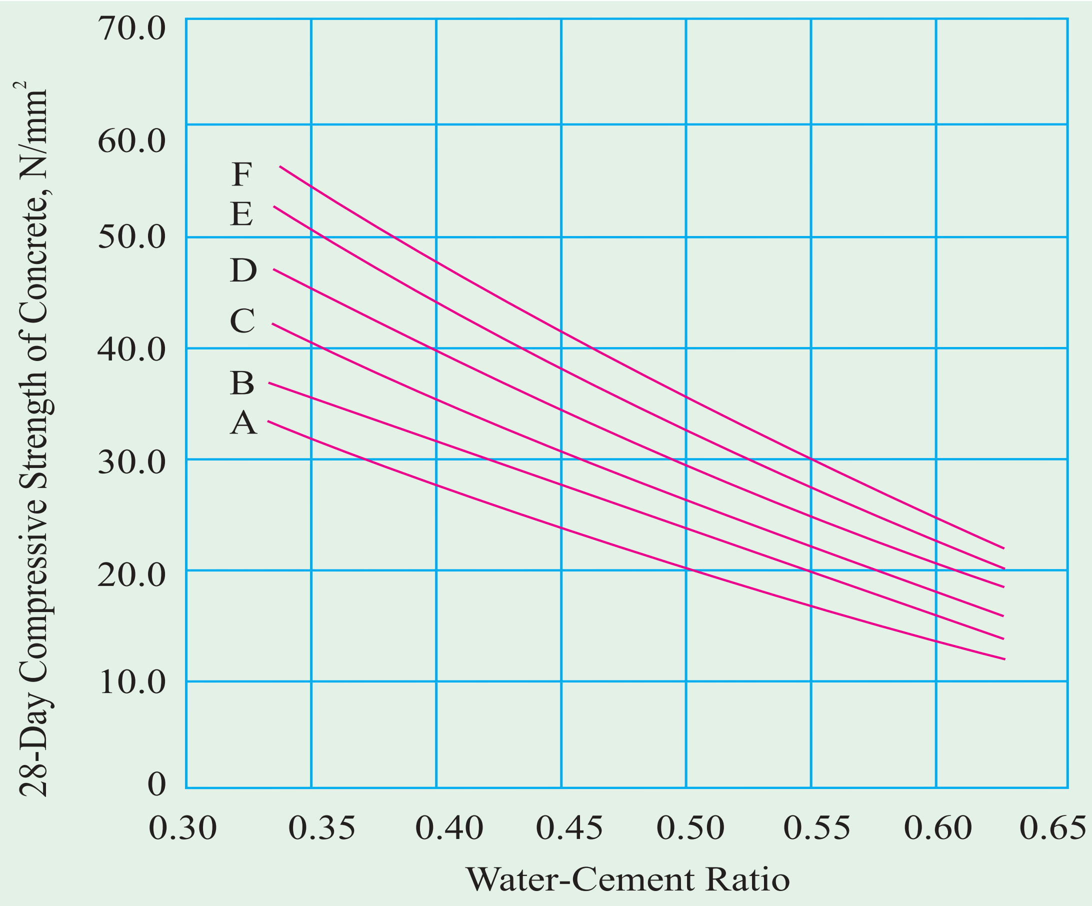
Cement – 570 kg		
Water – 200 kg		
Fine aggregate – 400 kg	]	
Coarse aggregate– 1178 kg	]	On saturated-surface dry basis

150 mm size cube specimens of such reference concrete mix are made with the cement at hand. From the accelerated strength (boiling water method), the 28 days compressive strength of concrete is obtained and using correlation between cement and concrete strengths of such mix proportions, established by exhaustive tests at CRI, the 28 days cement strength can be estimated. However, for use in field, the relationships given in Fig. 11.10 are recalled in terms of the accelerated strength of the reference concrete mix which is shown in Fig. 11.13.

Steps of Mix Design based on rapid method

(i) Determine the accelerated strength (boiling water method) of 150 mm cube specimens of a standard concrete mix, using the cement at hand as per IS: 9013–1978.

(ii) Corresponding to the accelerated strength in step (i) determine the water cement ratio for the required target strength of concrete mix from Fig. 11.13.



Example. *Suppose the target 28 days strength of concrete mix to be designed is 30 N/mm², and accelerated strength of standard concrete mix is 18 N/mm². Then from Fig. 11.13 (curve B), the required water-cement ratio is 0.423.*

(iii) *Work out the remaining mix proportions as per the example worked out in preceding pages or by any other accepted method of mix design and check the workability of fresh concrete, against the desired value.*

(iv) *Determine the accelerated compressive strength of the trial mix.*

(v) *Estimate the 28 day compressive strength from the accelerated strength in step (iv), using correlations of the type of Fig. 11.12 and check against the target strength.*

Sampling and Acceptance Criteria

A random sampling procedure should be adopted to ensure that each concrete batch will have reasonable chance of being tested. It means that sampling and cube casting should be spread over the entire period of concreting. In case of more than one mixing units or batching plants are used for a concrete construction, the sampling should cover all the mixing units.

Frequency of Sampling: *The minimum frequency of sampling of concrete of each grade will be as shown in Table 11.28.*

Table 11.28. Frequency of Sampling

Quantity of concrete in the work, m^3	*Number of Samples*
1–5	*1*
6–15	*2*
16–30	*3*
31–50	*4*
51 and above	*4 plus one additional sample for each additional 50 m^3 or part thereof*

Note: At least one sample must be taken from each shift.

Test Specimen: Three test specimens should be made for each sample for testing at 28 days. Additional samples may be required for 7 days strength or for finding out the strength for striking the formwork etc.

Test Results: The test result of sample is the overage of the strength of three specimen. The individual variation should not be more than ± 15 per cent of the overage. If more, the test result of the sample is rejected.

In a major construction site a register is maintained showing the test results of the samples of concrete taken. Possibly samples should denote the time and part of the structure to which the concrete represented by this samples has been used, so that the strength of test specimen and the part of the structure can be matched, if need be. The test register is an important legal document and should be kept in safe custody. When the number of samples tested becomes more than 30 or at a pre determined interval of time, standard deviation is worked out to see that the mix design adopted is neither very conservative nor too liberal. If so, using the standard deviation actually worked out from the kind of quality control exercised at site, a fresh mix design is worked out and the proportions of materials are recast. In other words mix design is not a one time job. It should be reviewed continuously to make the whole concreting operation safe and economical.

Earlier it was said that 5 per cent of test results are allowed to fall below the characteristic strength. But it was not mentioned that this 5 per cent is how much below the characteristic strength. IS 456 of 2000 has simplified the earlier version of acceptance criteria of concrete used in a major work site. The compliance requirement is given in Table 11.29.

Table 11.29. Characteristic Compressive Strength Compliance Requirements as per IS 456–2000

Specified Grade	*Mean of the Group of 4 Non-overlapping Consecutive Test Results in N/mm^2*	*Individual Test Results in N/mm^2*
(1)	(2)	(3)
M 15	$\geq f_{ck}$ + 0.825 x established standard deviation (rounded off to the nearest 0.5 N/mm^2) or f_{ck} + 3 N/mm^2 whichever is greater	$\geq f_{ck}$ – 3 N/mm^2

M 20 or above	$\geq f_{ck}$ + 0.825 x established standard deviation (rounded off to the nearest 0.5 N/mm^2) or f_{ck} + 4 N/mm^2 whichever is greater	$\geq f_{ck} - 4$ N/mm^2

Note: In the absence of established value of standard deviation, the values given in Table 11.22 may be used. And attempt should be made to obtain results of 30 samples as early as possible to establish the value of standard deviation.

Acceptance Criteria

Compressive strength

The concrete is deemed to comply with the compressive strength requirements when both the following conditions are met,

(a) *The mean strength determined from any group of four consecutive test results complies with the appropriate limits in column 2 of Table 11.29.*

(b) *Any individual test result complies with the appropriate limits in column 3 of Table 11.29*

Flexural strength

When both the following conditions are met, the concrete complies with the specified flexural strength.

(a) *The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 0.3 N/mm^2*

(b) *The strength determined from any test result is not less than the specified characteristic strength less 0.3 N/mm^2*

Inspection and Testing of Structures

Concrete is a very faithful construction material. If care is taken with respect to various constituent materials and workmanship, it, generally, does not fail to give the required results. In case the test results show unacceptable values, the compressive strength can be established from core test and load test.

Core Test

The points from which the cores to be taken can be established from cube testing register. If not possible it can be at the descretion of inspecting authority. The number of test cores will be not less than three which should represent the whole of the doubtful concrete.

The core strength should be converted to equivalent cube strength. If the equivalent cube strength gives at least 85 per cent of characteristic strength of the grade of concrete, and no individual core has a strength less than 75 per cent, the strength of the concrete can be considered adequate.

In case the core test results do not satisfy the requirements or where such core tests have not been done, load test may be resorted to.

Load Tests for Flexural Member

The structure should be subjected to a load equal to full load plus 1.25 times the live load for a period of 24 hours and then the imposed load is removed.

The deflection due to imposed load only is recorded. If within 24 hours of removal of the imposed load, the structure does not recover at least 75 per cent of the deflection under super imposed load, the test may be repeated after a lapse of 72 hours. If the recovery is less than 80 percent, the structure is deemed to be unacceptable.

If the maximum deflection in mm, shown during 24 hour under load is less than $\frac{40l^2}{D}$, *where l is the effective span in metre and D, is the overall depth of the section in mm, it is not necessary for the recovery to be measured and the recovery provision mentioned above does not apply.*

Non-destructive Tests

Non-destructive tests used for estimation of strength of concrete has been discussed in chapter number 10. Non-destructive tests provide alternatives to core tests for estimating the strength of concrete in a structure, or can supplement the data obtained from a limited number of cores.

Any of the non-destructive methods may be adopted, in which case the acceptance criteria shall be agreed upon prior to the testing.

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

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