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DUROCRETE MIX DESIGN MANUAL

1.0 Introduction

Concrete is the basic engineering material used in most of the civil engineering structures. Its popularity as basic building material in construction is because of, its economy of use, good durability and ease with which it can be manufactured at site. The ability to mould it into any shape and size, because of its plasticity in green stage and its subsequent hardening to achieve strength, is particularly useful. Concrete like other engineering materials needs to be designed for properties like strength, durability, workability and cohesion. **Concrete mix design is the science of deciding relative proportions of ingredients of concrete, to achieve the desired properties in the most economical way.** With advent of high-rise buildings and pre-stressed concrete, use of higher grades of concrete is becoming more common. Even the revised IS 456-2000 advocates use of higher grade of concrete for more severe conditions of exposure, for durability considerations.
With advent of new generation admixtures, it is possible to achieve higher grades of concrete with high workability levels economically. Use of mineral admixtures like fly ash, slag, Met kaolin and silica fume have revolutionised the concrete technology by increasing strength and durability of concrete by many folds. Mix design of concrete is becoming more relevant in the above-mentioned scenario. **However, it should be borne in mind that mix design when adopted at site should be implemented with proper understanding and with necessary precautions**.

Durocrete mix design manual is an attempt to increase the awareness among the users, about concrete mix design. It is made with intention of serving as ready reckoner for personnel implementing the mix design at site.

1.1 Advantages of Concrete Mix design

Concrete Mix design aims to achieve good quality concrete at site economically.

I. Quality concrete means
- Better strength
- Better imperviousness and durability
- Dense and homogeneous concrete

II. Economy
a) Economy in cement consumption

It is possible to save up to 15% of cement for M20 grade of concrete with the help of concrete mix design. In fact higher the grade of concrete more are the savings. Lower cement content also results in lower heat of hydration and hence reduces shrinkage cracks.

b) Best use of available materials:

Site conditions often restrict the quality and quantity of ingredient materials. Concrete mix design offers a lot of flexibility on type of aggregates to be used in mix design. Mix design can give an economical solution based on the **available materials** if they meet the basic IS requirements. This can lead to saving in transportation costs from longer distances.

c) Other properties:

Mix design can help us to achieve form finishes, high early strengths for early deshuttering, concrete with better flexural strengths, concrete with pumpability and concrete with lower densities.

1.2 What is mix design?

Concrete is an extremely versatile building material because, it can be designed for strength ranging from M10 (10Mpa) to M100 (100 Mpa) and workability ranging from 0 mm slump to 150 mm slump. **In all these cases the basic ingredients of concrete are the same**, **but it is their relative proportioning that makes the difference.**

Basic Ingredients of Concrete: -

1. Cement – It is the basic binding material in concrete.
2. Water – It hydrates cement and also makes concrete workable.
3. Coarse Aggregate – It is the basic building component of concrete.
4. Fine Aggregate – Along with cement paste it forms mortar grout and fills the voids in the coarse aggregates.
5. Admixtures - They enhance certain properties of concrete e.g. gain of strength, workability, setting properties, imperviousness etc

Concrete needs to be designed for certain properties in the plastic stage as well as in the hardened stage.

Properties desired from concrete in plastic stage: -

- Workability
- Cohesiveness
- Initial set retardation

Properties desired from concrete in hardened stage: -

- Strength
- Imperviousness
- Durability

Concrete mix design is the method of correct proportioning of ingredients of concrete, in order to optimise the above properties of concrete as per site requirements. In other words; we determine the relative proportions of ingredients of concrete to achieve desired strength & workability in a most economical way.

1.3 Information required for concrete mix design

The site engineer should give following information while giving material for mix design to the mix design laboratory: -

a) Grade of concrete (the characteristic strength)
b) Type of cement,
c) Maximum size of aggregates,
d) Minimum/maximum cement content (specified If any)
e) Max. water cement ratio,
f) Workability requirement in terms of slump.
g) Maximum temperature of concrete permissible at the time of placing,
h) Method of transportation/ Placing of concrete.
i) Type and use of admixture.
j) Other properties (**if required)**: -
   i. Retardation of initial set (to avoid cold joints in case of longer leads or for ready mix concrete)
   ii. Slump retention (in case of ready mix concrete)
   iii. Pumpability (In case of ready mix concrete)
   iv. Acceleration of strength (for precast members or where early deshuttering is desired)
   v. Flexural strength (normally required for concrete pavements)

k) Ascertain whether condition of exposure to concrete is mild, moderate severe or very severe. Proper investigation of soil should be done to ascertain presence of sulphates & chlorides, in case of doubt.

l) What is the degree of control at site? Following factors indicate degree of control at site: -

   i. Batching – weigh batching / volume batching.

   ii. Type of aggregates – whether mixed graded aggregate will be used or 20mm, 10mm aggregates will be used separately.

   iii. Testing of concrete – whether casting & testing of concrete cubes will be done regularly at site.

   iv. Source of aggregate – whether sources of sand and aggregate will be standardised or likely to change frequently.

   v. Supervision – whether qualified staff will be present to supervise concreting work and make necessary corrections e.g. correction for moisture in sand and changes in material properties.

   vi. Site laboratory – whether the site will have necessary laboratory equipment like sieves, weighing balance etc. to check material properties.

1.4 Material properties and how they affect mix design ?

A) Hydraulic Cement

Compressive Strength / Grade of cement:

Grade of cement e.g. 43 grades or 53 grades can influence the mix design. Grade of cement indicates minimum strength of cement in N/mm^2 tested as per standard conditions laid down by IS codes (OPC 43 grade – IS 8112-1989, OPC 53 grade – IS 12269 – 1987 e.g. a 43 grade cement should give minimum strength of 43 N/mm^2 at 28 days). Higher the strength of cement, higher is the strength of concrete for the same water/cement ratio. In other words a higher strength of cement permits use of higher water/cement ratio to achieve the same strength of concrete.

The IS10262-2009 for mix design says that different cements, supplementary cementitious materials, aggregates of different maximum sizes, grading, surface texture, shape and other characteristic may produce concrete of different compressive strengths for the same water cement ratio. Therefore, the relationship between free water cement ratio and compressive strengths be established for the materials to be used on site. In the absence of such data the preliminary water cement ratios corresponding to target mean strength may be selected from the established relationships, if available. Otherwise the water cement ratios given in IS 456-2000 table 5 for respective environment exposure conditions may be used as starting point.

Apart from strength of cement, the type of cement e.g. Ordinary Portland Cement, pozzolona cement (blended cement) etc, is also important factor affecting the gain of strength. Blended cements achieve strengths later than Ordinary Portland Cements and require extended curing period. However, use of these cements result in more durable concrete by offering greater resistance to sulphate and chloride attacks.

Initial & Final setting time of cement:

The initial setting time of cement indicates the time after which the cement paste looses its plasticity. Operations like mixing, placing and compaction should be completed well before the initial setting time of cement .The minimum initial setting time specified by IS 456 –2000 (Clause 5.4.1.3 page no 14 and IS 8112-1989 page 2) is 30 minute. Most of the cements produced today give an initial set of more than 60 minutes. Beginning of hardening of cement paste indicates the final setting of cement. The maximum limit for final setting permitted by IS 8112:1989 (Clause 6.3. page 2) is 600 minute. Most of the cements produced today give a final setting of between 3 to 5 hours. Curing can be started after final setting of cement. The initial setting and the final setting can be extended by use of retarders in order to avoid cold joints when lead-time for placing concrete is longer.

B. Fine Aggregates

Gradation of fine aggregates:

The gradation of sand is given by sieve analysis. The sieve analysis is done by passing sand through a set of standard sieves and finding out cumulative passing percentage through each sieve. The IS 383 – 1970 -Table 4, clause 4.3 (refer Annexure I page no 57 of Durocrete Mix Design Manual) classifies fine aggregates in 4 zones starting from zone I representing coarse sand, to zone IV representing the finest sand.

The limits of cumulative percentage passing for each sieve for above zones are given in table 4 of IS 383 (refer Annexure I Page 57 of Durocrete Mix Design Manual). The fineness of sand found by sieve analysis governs the proportion of sand in concrete .The overall fineness of sand is given by factor called fineness modulus. Fineness Modulus is given by division of the summation of cumulative retained fractions for standard sieves up to 150-micron sieve size by 100. The fineness modulus of sand varies from 2.0 to 4.0; higher the FM coarser is the sand.

Type of Sand	-	F M
Fine	-	2.0 to 2.8
Medium	-	2.8 to 3.2
Coarse	-	3.2 and above

Specific gravity of fine aggregates:

This is the ratio of solid density of sand particles to the density of water. Higher the specific gravity heavier is the sand particles and higher is the density of concrete. Conversely a lower specific gravity of sand will result in lower density of concrete. Specific gravity of sand is found with help of pycnometer bottles. The specific gravity of fine aggregates found in Pune region varies from 2.6 to 2.8.

Silt Content by weight:

This is found by wet-sieving of sand and material passing 75 micron sieve is classified as silt. This silt affects the workability of concrete, results in higher water/cement ratio and lower strength. The upper limit for 75-micron sieve in case of sand is 3% by weight. This limit has however been extended to 15% in case of crushed sand in IS 383 – 1970 Table 1. (Refer Annexure I page 59 of Durocrete Mix Design Manual)

C) Coarse Aggregate

Maximum size of coarse aggregate:

Maximum size of aggregate is the standard sieve size (40mm, 25mm, 20mm, 12.5mm, 10mm) through which at least 90% of coarse aggregate will pass. Maximum size of aggregate affects the workability and strength of concrete. It also influences the water demand for getting a certain workability and fine aggregate content required for achieving a cohesive mix. For a given weight, higher the maximum size of aggregate, lower is the surface area of coarse aggregates and vice versa. As maximum size of coarse aggregate reduces surface area of coarse aggregate increases. Higher the surface area, greater is the water demand to coat the particles and generate workability. Smaller maximum size of coarse aggregate will require greater fine aggregate content to coat particles and maintain cohesiveness of concrete mix. Hence 40 mm down coarse aggregate will require much less water than 20 mm down aggregate. In other words for the same workability, 40mm down aggregate will have lower water/cement ratio, thus higher strength when compared to 20mm down aggregate. Because of its lower water demand, advantage of higher maximum size of coarse aggregate can be taken to lower the cement consumption. Maximum size of aggregate is often restricted by clear cover and minimum distance between the reinforcement bars. Maximum size of coarse aggregate should be 5 mm less than clear cover or minimum distance between the reinforcement bars, so that the aggregates can pass through the reinforcement in congested areas, to produce dense and homogenous concrete.

It is advantageous to use greater maximum size of coarse aggregate for concrete grades up to M 35 where mortar failure is predominant. Lower water/cement ratio will mean higher strength of mortar (which is the weakest link) and will result in higher strength of concrete. However, for concrete grades above M40, bond failure becomes predominant. Higher maximum size of aggregate, which will have lower area of contact with cement mortar paste, will fail earlier because of bond failure. Hence for higher grades of concrete (M40 and higher) it is advantageous to use lower maximum size of aggregate to prevent bond failure.

Grading of coarse aggregate:

The coarse aggregate grading limits are given in IS 383 – 1970 - table 2, Clause 4.1 and 4.2 (Refer Annexure I page 57 of Durocrete Mix Design Manual) for single size aggregate as well as graded aggregate. The grading of coarse aggregate is important to get cohesive & dense concrete. The voids left by larger coarse aggregate particles are filled by smaller coarse aggregate particles and so on. This way, the volume of mortar (cement-sand-water paste) required to fill the final voids is minimum. However, in some cases gap graded aggregate can be used where some intermediate size is not used. Use of gap-graded aggregate may not have adverse effect on strength. By proper grading of coarse aggregate, the possibility of segregation is minimised, especially for higher workability. Proper grading of coarse aggregates also improves the compactability of concrete.

Shape of coarse aggregate:

Coarse aggregates can have round, angular, or irregular shape. Rounded aggregates because of lower surface area will have lowest water demand and also have lowest mortar paste requirement. Hence they will result in most economical mixes for concrete grades up to M35. However, for concrete grades of M40 and above (as in case of max size of aggregate) the possibility of bond failure will tilt the balance in favour of angular aggregate with more surface area. Flaky and elongated coarse aggregate particles not only increase the water demand but also increase the tendency of segregation. Flakiness and elongation also reduce the flexural strength of concrete. Specifications by Ministry of Surface Transport restrict the combined flakiness and elongation to 30% by weight of coarse aggregates.

Strength of coarse aggregate:

Material strength of coarse aggregate is indicated by crushing strength of rock, aggregate crushing value, aggregate impact value, aggregate abrasion value. In Maharashtra the coarse aggregates are made of basalt rock, which has strengths in excess of 100 N/mm^2. Hence aggregates rarely fail in strength. The IS limits for above tests are given below:

- Aggregate Crushing value
- Aggregate Impact value
- Aggregate abrasion value

Aggregate Absorption:

Aggregate can absorb water up to 2 % by weight when in bone dry state, however, in some cases the aggregate absorption can be as high as 5%. Aggregate absorption is used for applying a correction factor for aggregates in dry condition and determining water demand of concrete in saturated surface dry condition.

1.5 Decision Variables in Mix Design

A. Water/cement ratio
B. Cement content
C. Relative proportion of fine & coarse aggregates
D. Use of admixtures

A. Water/cement ratio

Water to cement ratio (W/C ratio) is the single most important factor governing the strength and durability of concrete. Strength of concrete depends upon W/C ratio rather than the cement content. Abram's law states that higher the water/cement ratio, lower is the strength of concrete. As a thumb rule every 1% increase in quantity of water added, reduces the strength of concrete by 5%. A water/cement ratio of only 0.38 is required for complete hydration of cement. (Although this is the theoretical limit, water cement ratio lower than 0.38 will also increase the strength, since all the cement that is added, does not hydrate) Water added for workability over and above this water/cement ratio of 0.38, evaporates leaving cavities in the concrete. These cavities are in the form of thin capillaries. They reduce the strength and durability of concrete. Hence, it is very important to control the water/cement ratio on site. **Every extra lit of water will approx. reduce the strength of concrete by 2 to 3 N/mm^2 and increase the workability by 25 mm.** As stated earlier, the water/cement ratio strongly influences the permeability of concrete and durability of concrete. Revised IS 456-2000 has restricted the maximum water/cement ratios for durability considerations by clause 8.2.4.1, table 5 (Refer Annexure VI page 78 of Durocrete Mix Design Manual)

B. Cement content

Cement is the core material in concrete, which acts as a binding agent and imparts strength to the concrete. From durability considerations cement content should not be reduced below 300Kg/m^3 for RCC. IS 456 –2000 (Refer annexure VI page 78 of Durocrete Mix Design Manual) recommends higher cement contents for more severe conditions of exposure of weathering agents to the concrete. It is not necessary that higher cement content would result in higher strength. In fact latest findings show that for the same water/cement ratio, a leaner mix will give better strength. However, this does not mean that we can achieve higher grades of concrete by just lowering the water/cement ratio. This is because lower water/cement ratios will mean lower water contents and result in lower workability. In fact for achieving a given workability, a certain quantity of water will be required. If lower water/cement ratio is to be achieved without disturbing the workability, cement content will have to be increased. Higher cement content helps us in getting the desired workability at a lower water/cement ratio. In most of the mix design methods, the water contents to achieve different workability levels are given in form of empirical relations. Water/cement ratios required to achieve target mean strengths are interpolated from graphs given in IS 10262 Clause 3.1 and

3.2 fig 2 (Refer Annexure II page 61 of Durocrete Mix Design Manual. The cement content is found as follows: -

$$\text{Cement content (Kg/m}^3) = \frac{\text{Water required achieving required workability (Lit/m}^3)}{\text{Water/cement ratio}}$$

Thus, we see that higher the workability of concrete, greater is cement content required and vice versa. Also, greater the water/cement ratio, lower is the cement content required and vice versa.

C. Relative proportion of fine, coarse aggregates gradation of aggregates

Aggregates are of two types as below:

a. Coarse aggregate (Metal): These are particles retained on standard IS 4.75mm sieve.
b. Fine aggregate(Sand): These are particles passing standard IS 4.75mm sieve.

Proportion of fine aggregates to coarse aggregate depends on following:

i. **Fineness of sand:** Generally, when the sand is fine, smaller proportion of it is enough to get a cohesive mix; while coarser the sand, greater has to be its proportion with respect to coarse aggregate.

ii. **Size & shape of coarse aggregates:** Greater the size of coarse aggregate lesser is the surface area and lesser is the proportion of fine aggregate required and vice versa. Flaky aggregates have more surface area and require greater proportion of fine aggregates to get cohesive mix. Similarly, rounded aggregate have lesser surface area and require lesser proportion of fine aggregate to get a cohesive mix.

iii. **Cement content:** Leaner mixes require more proportion of fine aggregates than richer mixes. This is because cement particles also contribute to the fines in concrete.

D. Use of admixtures

Now days, admixtures are rightly considered as the fifth ingredient of concrete. The admixtures can change the properties of concrete.
Commonly used admixtures are as follows:

i. Plasticisers & superplasticisers
ii. Retarders
iii. Accelerators
iv. Air entraining agents
v. Shrinkage compensating admixtures
vi. Water proofing admixtures

i. Plasticizers & super plasticisers

Plasticizers help us in increasing the workability of concrete without addition of water. It means that we can achieve lower water/cement ratio without reducing the workability at the same cement content. Cement particles tend to form flocs trapping a part of mixing water in them. Hence not all the water added is useful for generating workability. Plasticisers work as dispersion agents (de flocculent) releasing the water trapped in the flocs resulting in workability. Use of plasticisers is economical as the cost incurred on them is less than the cost of cement saved; this is more so in concrete designed for higher workability. Compatibility of plasticisers with the cement brand should be checked before use. Also plasticiser should not be added in dry concrete mix**.** Plasticizers are used for moderate increase of workability whereas super plasticizers are used where very large increase in workability is required. Plasticizers are normally lignosulphonated formaldehydes and are normally added in small dosages. This is because large dosage can cause permanent retardation in concrete and adversely affect its strength. Super plasticizers are naphthalene or melamine based formaldehyde. They can be used in large dosages without any adverse effect on concrete. This is contrary to popular perception that term super plasticizers means more potent, hence lower dosage is required when compared to normal plasticizers. In practice super plasticizers are used in large dosages for generating higher workability and better slump retention. Compatibility of plasticizers with cement should be ascertained before use in concrete. Since action of plasticizers is based on ionic dispersion certain plasticizers are more effective with certain cements, thus requiring lower dosages. Non-compatible plasticizers if used, will not adversely affect the concrete, but its high dosage will make it uneconomical for use.

ii. Retarders:

They are used for retarding (delaying) the initial setting time of concrete. This is particularly required when longer placing times are desired as in case of ready mixed concrete. Retarders are commonly used to prevent formation of cold joints when casting large concrete. Retarders are normally added in lower dosages as large dosages can cause permanent retardation in concrete. Retarders are recommended in case of hot weather concreting to prevent early loss of slump. It is important to note that retarders reduce early strength of concrete e.g. 1-day and 3-day strength. However, 28 days strength is not affected.

iii. Accelerators

They are used for accelerating the initial strength of concrete. Typical accelerators increase the 1-day (up to 50 %) and 3-days (up to 30 %) strength of concrete. Most of the accelerators show little increase for 7 days strength. For this reason, accelerators are commonly used in precast concrete elements for early removal of moulds. Accelerators may not be much useful for early deshuttering where early strengths are required in range of 5 to 7 days. This is because accelerators are expensive and their ability to increase strengths decreases after 3-5 days. A better option for early deshuttering would be the use of plasticizers, reducing the water/cement ratio and achieving a higher grade of concrete. It is believed that accelerators may cause retrogression of strength after 28 days when compared with normal concrete.

iv. Waterproofing Compounds

These chemicals have double action of blocking capillary pores and reducing the size of capillaries that may act as conduits for water. Most waterproofing agents have plasticizing effect and help to reduce water/cement ratio. Lower water to cement ratio results in smaller size of capillaries and improved imperviousness. In this respect, even plasticizers will have reasonable water proofing ability. Waterproofing compounds may not be alternative to membrane waterproofing because they can not rectify casting defects, like honey combing, voids, cracks caused because of shrinkage. Actually normal concrete, if cast properly with low water/cement ratio is impervious and waterproofing compounds help to maintain low water to cement ratio.

V. Air Entraining Agents

They are chemicals that introduce small air bubbles of size less than 45microns in concrete. These air bubbles disperse uniformly in concrete and work like ball bearings to increase the workability of the concrete. Most of this entrained air is not expelled during compaction and becomes a permanent part of concrete. This is unlike plasticizers whose effect ceases after the setting of concrete. The entrained air has following advantages:

a) Helps to lower the water /cement ratio hence reduces permeability of concrete.
b) Make concrete mixes cohesive and increases compactability of Concrete.
c) Reduces bleeding in concrete.
d) It is particularly useful in freeze-thaw conditions for increasing durability of concrete in cold climatic conditions.

However, effect of air entrainment is to lower strength of concrete. Every 1% air entrained can reduce the strength of concrete by 5 %. Effect of air entrainment on strength can be negated by using lower water/cement ratio. This is possible because of high plastcizing effect of air entrainment. Oleic Acid, Reetha powder, etc are the commonly used air entraining agents. Air entraining agents ae economically available and improve quality of concrete. However, they should be used carefully where good concreting practices are followed. 3 to 6 % air entrainment is commonly used in concrete. Higher air entrainment may not result in increased beneficial effects.

2.0 Concrete Mix Design Methods

The basic objective of concrete mix design is to find the most economical proportions (Optimisation) to achieve the desired end results (strength, cohesion, workability, durability, etc.) As mentioned earlier the proportioning of concrete is based on certain material properties of cement, sand and aggregates. Concrete mix design is basically a process of taking trials with certain proportions. Methods have been developed to arrive at these proportions in a scientific manner**. No mix design method directly gives the exact proportions that will most economically achieve end results. These methods only serve as a base to start and achieve the end results in the fewest possible trials.**

The code of practice for mix design-IS 10262 clearly states following:-

The basic assumption made in mix design is that the compressive strength of workable concretes, by and large, governed by the water/cement ratio. Another most convenient relationship applicable to normal concrete is that for a given type, shape, size and grading of aggregates, the amount of water determines its workability. However, there are various other factors which affect the properties of concrete, for example the quality & quantity of cement, water and aggregates; batching; transportation; placing; compaction; curing; etc. Therefore, the specific relationships that are used in proportioning concrete mixes should be considered only as the basis for trial, subject to modifications in the light of experience as well as for the particular materials used at the site in each case.

Different mix design methods help us to arrive at the trial mix that will give us required strength, workability, cohesion etc. These mix design methods have same common threads in arriving at proportions but their method of calculation is different. Basic steps in mix design are as follows:

a. Find the target mean strength.
b. Determine the curve of cement based on its strength.
c. Determine water/cement ratio.
d. Determine cement content.
e. Determine fine and coarse aggregate proportions

We will now follow above steps and solve a mix design problem by different methods.

Illustration:

Consider a mix design for M30 grade of concrete, having moderate workability (Slump range 50mm to 75mm).

Material Properties

Cement 53 grade (Although, actual 28 days compressive strength = 63 N/mm^2)

Fine aggregate –

FM. = 3.26 (Zone I) 600 micron passing = 32 %
Specific gravity = 2.75

Coarse aggregate

20mm - Specific gravity - 2.95
Dry Rodded bulk density – 1600 Kg/m^3
10mm - Specific gravity 2.86

Dry Rodded bulk density – 1700 Kg/m^3

2.1 Find the target mean strength

Concrete is designed for strength higher than characteristic strength as a margin for statistical variation in results and variation in degree of control exercised at site. This higher strength is defined as the target mean strength.

It is calculated as follows:

Target mean strength = Characteristic strength + K * σ

K= Himsworth Coefficient is taken as 1.65 for 5 % probability of failure.

σ = Standard deviation

The values of σ are given in IS 10262 for fair, good and very good degree of control. However, IS 456-2000 has given revised values of σ to be considered for mix design. Better the degree of control lesser is the value of σ and lower is the target mean strength. In other words, the 'margin' kept over characteristic strength is more for fair degree of control to that of good degree of control.

Say for M30 grade of concrete, K=1.65 (for 5% failure) and Standard Deviation

σ = 5 N / mm^2.

Target Mean Strength = 30 + 1.65 * 5

= 38.25 N/mm^2

2.3 Determine water/cement ratio

AS per IS 10262-2009 in absence of established relationship between strength of concrete and water cement ratio take the water cement ratios given in IS 456 table 5 as a starting point.

Hence take water cement ratio as 0.45

(Refer Appendix B)

2.4 Finding cement content

Most of the mix design methods find cement content with following formula:

$$\text{Water /cement ratio} = \frac{\text{Weight of Water per } m^3}{\text{Weight of cement per } m^3}$$

$$\text{Weight of cement} = \frac{\text{Weight of Water per } m^3}{\text{Water/cement ratio}}$$

Weight of water required per m^3 also called as water demand.

Water demand depends on:

i. Required Workability of concrete: Higher the workability required greater is the water demand.

ii. Aggregate properties: Fineness and silt content of fine aggregate, size, shape and flakiness of coarse aggregate, type of aggregate e.g. crushed, uncrushed.

iii. Use of admixtures: Plasticizers will reduce the water demand

Different mix design methods give empirical relations to find the water demand
Say, we want to find water demand for 20 mm maximum size of crushed aggregate and natural sand of zone II (F.M. = 3.0) for a slump range of 60 to 80 mm (compaction factor = 0.9)

A. <u>IS method</u>

Refer annexure II (page no 61)
Water Demand =186 lit for 20 mm maximum size of aggregate.
Add 3% water for incremental slump of 25 mm.
Water demand = 186 + 5.58
= 191.58 Lit

Cement Content =191.58/0.46
= 416.47Kg/m3

B. <u>DOE Method</u>

Refer Annexure III – (page 65).
We will select water demand for 30 to 60mm range
Water demand for natural fine aggregate = 180lit
Water demand for crushed coarse 20mm max size aggregate = 210 lit
Water Demand = 2/3 x 180+ 1/3 x 210
= 120 + 70= 190 lit
Cement Content =190/0.46
=413.04

C. <u>ACI Method</u>

Refer Annexure IV – (page no 69)
Water demand for 30 to 50mm Slump =185 Lit
Water demand for 80 to 100 mm Slump = 200 Lit
Water demand for 50 to 80 mm can be interpolated as average of the above =192.5
Cement Content = 192.5 /0.46
= 418.47

D. <u>RRL Method</u>

Refer Annexure V (page no 71)
RRL method (Road Note 4) differs from rest of methods in calculation of cement content. RRL method gives tables for different water/cement ratio and degree of workability (Table 1 to 6)

These tables directly give aggregate to cement ratios from which cement content can be calculated.
For zone II sand and grading no 2 and medium workability
Aggregate to cement ratio = 3.7 for water cement ratio of 0.45

Aggregate to cement ratio = 4.2 for water cement ratio of 0.50
Aggregate to cement ratio for w/c of 0.46 is interpolated as 3.8
Cement content (Kg/m^3) = Plastic density /(1+Agg to cement ratio + w/c ratio)

Calculation for plastic density is shown in Sec 4.3

2.5 Determine fine and coarse aggregate content:

The fine aggregate to coarse aggregate ratio is determined in different methods as follows:

A. IS method

Sand percentage by volume for zone II sand, and water cement ratio 0.45 for 20mm down coarse aggregate = 62% (Refer table 2 Annexure III, page no 65 of Durocrete Mix Design Manual)

Corrections

Correction for zone 1 sand = +1.5%
Correction for water/cement ratio of 0.46= - 3%
Net Sand content = 35=1.5-3-33.5%
Weights of fine and coarse aggregates are calculated as
V = (W +C/S_c + 1/p*(fa/S_{fa})) x 1/1000
V = (W +C/S_c + 1/1-p x (Ca/S_{ca})) x 1/1000
V = Absolute volume of concrete = 1
W = water demand = 190Lit
C = cement content = 416Kg
p = ratio of fine aggregate to total aggregate =0.335
fa = total quantity of fine aggregate in Kg per m^3
ca = total quantity of coarse aggregate in Kg per m^3
S_c = Specific Gravity of Cement =3.15
S_{fa} = Specific gravity of fine aggregate =2.75
S_{ca} = Combined Specific Gravity of Coarse aggregate (Assuming 30% of coarse aggregate is 10mm down aggregate =2.90 x 0.7 + 2.86x 0.3=2.89

Fine aggregate content = 606 Kg/m^3

Coarse aggregate content =1278Kg/m^3

B. DOE Method

Refer Annexure III (page 65)
Sand Content for slump range of 30 to 60 mm and 30% 600 micron passing fraction in sand is calculated from fig 2 as 42%

Average specific gravity of combined aggregates is calculated as follows: -

= 0.42 x 2.75 + 0.58 x 2.89
= 2.83

Plastic Density of concrete is interpolated from fig 4 Annexure 4 as 2525kg/m^3.

Total aggregate content per m^3 is calculated as 2525 – 416 -190 =1919Kg
Sand content per m^3 = 1919 x 0.42 = 805 Kg/m^3
Total coarse aggregate content = 1919 x 0.58 = 1113 kg/m^3
Thus sand content in DOE method is much higher than that worked out in IS method

C. ACI Method

Refer Annexure IV Table 1 (page no. 69)
For F.M. = 3.0 Volume of dry rodded coarse aggregate = 0.6
For F.M = 3.26. Volume of dry rodded coarse aggregate per m^3 can be extrapolated as = 0.58

Dry rodded density of coarse aggregate is say *1800 kg/m^3
Total coarse aggregate content = 1800 x 0.5 = 1044 Kg.

First estimate of weight of fresh concrete is calculated from table2 as =2355Kg/m^3. (This plastic density is low for concretes with basaltic aggregates.)
Total sand content per m^3 = 2355 - 416 - 192.5 -1044
= 702.5 Kg per m^3

The above proportions need to be reworked on actual plastic density of concrete which is usually higher than 2500 for basaltic aggregates of Western Maharashtra

* should be dry rodded density of combined or graded coarse aggregate.

D. RRL Method

Refer Annexure V (page no 71)
In RRL method the relative proportion of fine aggregates is so calculated, that combined grading of aggregates fits zone 1 or 2 of figs 1,2or 3 of Annexure 6.
A trial proportion is taken and combined gradation is worked out for e.g.
35% fine aggregate 20% 10mm down aggregate, 45% 20mm down aggregate.
The combined gradation is worked out as follows: -

Sieve size	Fine aggregate	Coarse aggregate 10mm	Coarse aggregate 20mm	Combined Grading
	30%	25%	45%	
	Cumulative passing %			
20mm	100	100	100	100
10mm	100	92	15	59.75 *
4.75mm	97%	7	0	37.6
2.36mm	74	0	0	22.2
1.18mm	56	0	0	16.8
600micron	33	0	0	9.9
300micron	12	0	0	3.6
150micron	2	0	0	0.6

* Calculated as 100x 0.3 + 92x 0.25 + 15x 0.45

Thus we find that combined gradation if plotted on fig 2 Annexure 5 goes near the lowest curve at lowest curve on 600micron 1.18 and 2.36 fractions.
The curve can be pushed towards 2 curves (Ideal curve) by increasing the sand content. After some trial runs it is observed that 38% Fine Aggregate, 20% 10mm down and 42% 20mm down aggregate gives grading close to curve2.Since aggregate to Cement ratio is 1: 3.8 .The relative proportion is worked as follows:
Cement: Fine aggregate: 10mm Aggregate: 20mm Aggregate
1: 1.45:0.75:1.6
If weight of cement is "C" the total weight per m^3 will be
C +1.45C + 0.75C +1.6C + 0.46C=5.26C
The plastic density of concrete is worked as follows
(1x Sc + 1.45x S_{fa} +0.75x S_{ca10} +1.6 x S_{ca20} + w/c)/5.26x 1000
S_c= Specific gravity of cement =3.15
S_{fa} =Specific gravity of fine aggregate =2.75
S_{ca10}=Specific gravity of 10mm coarse aggregate =2.86
S_{ca20}=Specific gravity of 20mm coarse aggregate =2.90
W/c = water to cement ratio = 0.46
Plastic density = 2593
Cement content = 2593/5.26
= 492.9 Kg /m^3
This is higher than max allowable cement content of 450Kg/m^3 as per IS 456 2000. We find that RRL method gives much higher cement content than other methods

3.0 Critical view of different mix design methods

3.1 IS Method

The IS method treats normal mixes (up to M35) and high strength mixes (M40 and above) differently. This is logical because richer mixes need lower sand content when compared with leaner mixes. The method also gives correction factors for different w/c ratios, workability and for rounded coarse aggregate. In IS method, the quantities of fine and coarse aggregate are calculated with help of yield equation, which is based on specific gravities of ingredients. Thus plastic density of concrete calculated from yield equation can be close to actual plastic density obtained in laboratory, if specific gravities are calculated accurately. Thus actual cement consumption will be close to that targeted in the first trial mix itself. The water cement ratio is calculated from cement curves based on 28 days strength of cement. This can be time consuming and impractical at times. **The IS method gives separate graphs using accelerated strength of cement with reference mix method. This greatly reduces the time required for mix design.**
The IS method suffers from following limitations: -

a. The IS method recommends 35 % sand content by absolute volume for zone II sand with correction of +1.5 % for zone I and –1.5 % for zone III. These zones have wide range and **this correction is not adequate** to achieve a cohesive mix. Some times a correction may be required even when fine aggregate varies from upper side to lower side of a particular zone.

b Though sand content is adjusted for lower water cement ratio there is no direct adjustment for cement content. As discussed earlier, the cement particles act, as fines in concrete and richer mixes often require lesser fine aggregate when compared to leaner mixes. A mix in which cement content has been lowered by use of plasticisers may require higher sand content to improve cohesion.

c) The IS method does not take into account the effect of the **surface texture and flakiness of aggregate** on sand and water content. It does not recommend any corrections when crushed fine aggregate is used against natural fine aggregate as in case of DOE method.

d) The IS method **does not easily account for blending of different fine aggregates or coarse aggregates** when they individually do not conform to IS requirements. On the other hand in RRL method, coarse sand can be blended with fine sand or stone dust to get the required gradation (Natural sand and stone dust will have different specific gravities). Even coarse aggregates of different sizes, gradation and specific gravities can be blended to achieve the required gradation in RRL method.

e) The IS method gives water demand and fine aggregate content for 10mm 20mm and 40mm down aggregate .In practice the maximum size of coarse aggregate is often between 20mm and 40mm, the estimation of water and sand content is difficult.

f) The quantities of fine aggregate and coarse aggregates are calculated from the yield equation. The yield equation is based on concept, that volume of concrete is summation of absolute volumes of its ingredients. Absolute volume of ingredients are function of specific gravities of ingredients .The plastic density of concrete if theoretically calculated on the basis of specific gravities, may not match with that actually measured from concrete.

g) The IS method does **not have a specific method of combining 10mm aggregates with 20 mm aggregates**. The grading limits for combined aggregates in IS383 are too broad and do not help much to arrive at particular ratio of different coarse aggregates. The combined grading curves of RRL method help us to arrive on particular ratio of coarse aggregates.

h) The IS method does not have an adjustment in fine aggregate content for different levels of workability. Higher workability mixes require more fine aggregate content to maintain cohesion of mix.

3.2 DOE Method

The DOE method overcomes some limitations of IS method. In DOE method, the fine aggregate content is a function of 600micron passing fraction of sand and not the zone of sand. The 600-micron passing fraction emerges as the most critical parameter governing the cohesion and workability of concrete mix. Thus sand content in DOE method is more sensitive to changes in fineness of sand when compared to the IS method. The sand content is also adjusted as per workability of mix. It is well accepted that higher the workability greater is the fine aggregate required to maintain cohesion in the mix. The water content per m^3 is recommended based on workability requirement given in terms of slump and Vee Bee time. It recommends different water contents for crushed aggregates and for natural aggregates. The quantities of fine and coarse aggregates are calculated based on plastic density plotted from fig 4 Annexure III (page no 68). However the DOE method allows simple correction in aggregate quantities for actual plastic density obtained at laboratory.

The DOE method also suffers from some limitations.

a) The fine aggregates content calculated from DOE method often is on the higher side resulting in **over sandy mixes**. For zone 1 coarse sand (600micron fraction 15 to 20%) the sand content may exceed 50% for moderate workability of 30mm to 60mm slump.
b) The fine aggregate content cannot be adjusted for different cement contents. Hence a rich mix with cement of 400Kg/m^3 will have the same fine aggregate proportion, as a lean mix with 300kg/m^3 cement for given sand. Thus richer mixes may not be as workable because of higher fines, when compared to mixes obtained from the IS method.
c) The DOE method also does not take into account the effect of the surface texture and flakiness of aggregate on sand and water content although it distinguishes between crushed stone aggregates and natural aggregates.
d) The DOE method does not have a specific method of combining 10mm aggregates with 20 mm aggregates.
e) No specific graphs are available (to estimate fine aggregate content) for maximum size of aggregates between 20and 40 mm.

3.3 ACI method

This method is based on determining the coarse aggregate content based on, dry rodded coarse aggregate bulk density and fineness modulus of sand. Thus this method takes into account the actual voids in compacted coarse aggregates that are to be filled by sand cement and water. This method also gives separate tables for **air-entrained concrete**. This method is most suitable for design of air-entrained concrete. This method gives separate values of water and sand content for maximum size of aggregate up to 150mm. Hence this is most suitable method for designing **plum concrete**. It also gives separate values for 12.5 & 25 mm down coarse aggregate.
This method suffers from following limitations: -

a) It gives coarse aggregate contents for sand with FM range of 2.4 to 3.0 .It is found that sand available in many parts of India is extremely coarse with FM more than 3.2.
b) In this method the density of fresh concrete is not given as function of specific gravity of its ingredients. In IS and DOE method the plastic density or yield of concrete is linked to specific gravity of ingredients.
c) The values of density of fresh concrete given in this method range from 2285 kg/m^3 for10mm down aggregate to 2505kg/m^3 for 150mm down coarse aggregate. It is found that in many parts of our country, the density of fresh

concrete (plastic density) of 20 and 10 mm down aggregates vary from 2400 to 2600kg/m^3. The weights calculated from the given densities often result in higher cement contents than that assumed.

d) The ACI method also does not take into account the effect of the surface texture and flakiness of aggregate on sand and water content, neither does it distinguish between crushed stone aggregates and natural aggregates.
e) The ACI method does not have a specific method of combining 10mm aggregates with 20 mm aggregates.
f) The fine aggregate content cannot be adjusted for different cement contents. Hence the richer mixes and leaner mixes may have same sand proportion, for a given set of materials.

3.4 The RRL Method (Road Note 4 Method)

In this method, the aggregate to cement ratios are worked out on the basis of type of aggregate, max size of aggregate and different levels of workability. The relative proportion of aggregates is worked on basis of combined grading curves. This method facilitates use of different types of fine and coarse aggregates in the same mix. The relative proportion of these can be easily calculated from combined grading curves. The values of aggregate to cement ratio are available for angular rounded or irregular coarse aggregate.

This method suffers from following drawbacks: -

a) This method leads to **very high cement contents** and thus is becoming obsolete.
b) In many cases use of gap graded aggregate becomes unavoidable. In many parts of the country the practice is to use 20mm coarse aggregates without 10mm aggregates. This is because of quality of 10mm aggregates produced from jaw crusher is very poor .Gap grading does not fit in to the standard combined grading curves of RRL method.
c) Sand available in some parts of country is graded that it is high on coarse fraction (1.18mm and above) and low on fines (600micron and below). It is difficult to adjust the sand content to match any of the standard combined grading curves .The combined grading curve often cuts across more than one standard curves in such cases.
d) Different aggregate to cement ratios are given for different levels of workability ranging from low to high. But these levels of workability are not defined in terms of slump, compaction factor or Vee Bee time as in case of other methods.
e) The fine aggregate content cannot be adjusted for different cement contents. Hence the richer mixes and leaner mixes may have same sand proportion, for a given set of materials.

4.0 Important points for implementation of mix design:

1) Cement brands to be used should be standardised in advance.

2) All materials should be accepted only after testing and only if they meet the acceptance criteria. Daily record of materials tested at site should be maintained at site.

3) A site trial of mix design should be taken to ensure the suitability of mix at site. Cubes should be cast during site trial and should be tested before commencing the concreting work using the mix design.

4) Every mix design is specific to materials used for mix design. Hence for any minor variation in material properties of sand, coarse aggregate received at site, corrections in mix proportions may be necessary at the site. Following corrections should be made regularly at site: -

a) Correction for surface moisture
b) Correction for Fineness Modulus of sand
c) Correction for size and shape of coarse aggregate
d) Correction for workability of concrete
e) Correction for Bulk density (Only in case of Volume batching)
f) Correction for yield

Daily record of corrections made in the mix proportions should be maintained in the concreting work data sheet.

5) Concrete mix design assumes that aggregates used in concrete are in saturated surface dry condition. Coarse aggregates should be wetted before concreting to bring them in SSD condition. Since correction for surface moisture is done on sand, water should not be spayed on sand.

6) If weigh batcher is used, its level & calibration should be checked daily before starting the work. Calibration can easily be checked by preparing sand bags of 25 Kg & 5 Kg.

7) In case of volume batching correction for bulk density is necessary. This is because every mix design is done by weight only. These weights are converted to volume based on loose bulk density found at site.

8) Concrete mix design is done not only for strength but also for workability. Hence changes in mix proportions may be necessary for changes in workability desired at site. The slump given in mix design should never be exceeded and strictly controlled on site. We recommend a slump reading to be taken for every 25 bags of cement concrete.

9) Since water cement ratio not only governs the strength but also the durability of concrete. The water cement ratio on the site should be strictly controlled. The water cement/ratio can be controlled by maintaining the slump as per the design specifications.

10) Use only measured cans for adding water in the mixer. Use of trapezoidal buckets for adding water should be strictly avoided as their typical shape results in either excess or lesser water being added to the mixer. Milk kettles are recommended because their

peculiar shape not only prevents water from falling off while addition but also ensures speed of water addition.

11) On starting the concreting work we recommend a process of calibration of water for first 3 batches. In this process exact quantity of water calculated after making moisture correction is added in the mixer during concreting. Slump of concrete after proper mixing is measured and average slump of first 3 batches is found out. This slump reading serves as the control slump entire concrete for the day and should never be exceeded. This will keep water cement ratio in control even if minor variation in moisture of sand is observed at site during the day.

12) Regularly check the average weight and freshness of cement bags. Average weight of at least 5 bags should be taken each day prior to concreting. If the average weight of cement bags is below 49 Kgs., proper correction should be made by reducing the weight of aggregates in order to maintain the cement consumption.

13) Mix design is based on the strength of cement tested at laboratory that is usually fresh. If age of cement is more than 1 month or if it is not stored properly, the strength of cement will be affected. In such cases, corrections in mix design may be required to account for reduced strength. Such a correction may be done by using lower cement curve in the standard graph. The effect of using a lower curve will be, a lower water cement ratio to achieve the same strength.

14) Ensure cement stocked properly in waterproof room and is not in direct contact with floor or the walls. Use first in first out system of keeping inventory to ensure that old stocks of cement are not used for concreting.

15) Cubes should be cast for every batch of concrete no matter how small is the quantity of concrete. The revised IS 456 2000 makes cube testing mandatory for every concreting shift. The minimum frequency of samples of cubes cast is given in IS 456 2000 Clause 15.2.2. **Ensure that minimum sample of 3 cubes is always available for 28 days testing.**

16) Every sample of cube reading should always be accompanied by slump reading of the batch from which cubes are taken. Slump reading helps us to correlate the strength with workability. For example if it is observed that cube results are low for a set of cubes and corresponding slump reading is found to be high, it may be concluded that low strengths are on account of high water cement ratio. If cube results are low for low slump reading of the batch, the problem may be with quality of sand, aggregates or cement.

17) Standard deviation of samples of cube results should be regularly checked. The revised IS 456 2000 assumes a standard deviation of 4 Mpa for concrete grades up to M25 and 5 Mpa for grades above M25. Higher standard deviation mean poor control at site on concrete operation. Acceptance criteria for accepting cube results are given in revised IS 456 2000. The cube results should be regularly checked for these acceptance criteria.

18) Cement consumption should be checked every day and proper record of cement actually consumed versus the design consumption should be maintained in the concreting work data sheet.

19) The exact cement consumption at site can be checked with help of a yield box. The yield box is a simple rectangular box made of mild steel or plywood. The concrete after mixing is poured in yield box and vibrated properly. The volume of concrete is measured in m^3. Reciprocal of this volume in m3 will give cement consumption in bags per m3 of concrete.

20)The mix design should be regularly revalidated from the laboratory for any changes in material properties.

5.0 Site Laboratory

5.1 Items necessary on site for Mix Design for medium size Project.

1. Set of 12 Cube moulds of size 150 x 150 x 150 mm.

2. A slump cone, tamping rod and a scale.

3. Weighing balance of 15 Kg. With accuracy of 2gms and corresponding weights up to 2 gm. Electronic Balance is highly recommended.

4. Spring balance of 100Kgs.

5. Milk cans of 5,2 & 1 litre capacity for addition of water.

6. 250 ml measuring cylinder for silt test.

7. Set of sieves as under:
   40mm, 25mm, 20mm, 12.5mm, 10mm along with a Pan & 4.75mm, 2.36mm, 1.18mm, 600 μ, 300 μ, 150 μ, 75 μ along with a pan and lid.

8. Conical cans of 5 lit and 1 lit capacity for calibration.

9. If Weigh Batcher is not available at site, then following Farmas should be made available at site:

Capacity in litres	Nos.	L B H Size (in cm)
35	4	40 x 25 x 35
30	1	40 x 25 x 30
25	2	40 x 25 x 25
20	1	40 x 25 x 20
15	1	40 x 25 x 15
10	2	40 x 25 x 10

10. Electrical Hot plate with Pan.

11. Electrically operated Compression testing machine preferably 2000 kN capacity with Calibration.

12. A yield box of size 50cm x 50cm x 75 cm made of mild steel or plywood.

6.0 Standard Corrections for implementing mix design

6.1 Correction for surface moisture in sand

Sand contains some fraction of water as surface moisture. This moisture affects (increases) the water cement ratio of concrete. Water cement ratio takes into account the total water available for hydration of cement.

Water/ cement ratio = (Water added per batch + Surface moisture in sand)
Water to be added for every batch should be calculated only after deducting the surface moisture from the water quantity of water cement ratio

Water to be added per batch = (Water/ cement ratio * 50) - (surface moisture * wt of sand per batch)

If moisture content = 4%
Wt. Of sand = 135kgs.
Water / cement ratio = 0.55

Water to be added per batch = 0.55 *50 - 4%*135
= 27.5 - 5.4
= 22.1 1trs

Wt. Of sand per batch should be increased correspondingly by wt. of surface moisture in sand e.g. 5.4kgs.

Moisture content in sand will vary from day to day and also with different lots of sand. It is therefore very important to make correction for moisture in sand to maintain w/c ratio. If slump on site is kept under control, the w/c ratio is automatically controlled.

6.2 Correction for Aggregate absorption

For any mix design, the coarse aggregate is considered to be in saturated surface dry condition. Where as the metal on the site is often in bone-dry condition (especially during summers). This dry aggregate often absorbs the water added in concrete and reduces the workability of concrete. Correction for surface absorption is necessary to maintain the water cement ratio.
A correction of 1% to 2 % of wt. of coarse aggregate may be made in case of bone-dry condition of aggregate.
For example if the aggregate absorption is 2%, and total weight of aggregates is 180 Kg then
Aggregate absorption= 0.02 * 180
= 3.6 Litres
Hence quantity of water added (From previous example) =22.1 + 3.6
=25.7 lit

How ever it is recommended that the aggregate should be wetted thoroughly before concreting to make it in saturated surface dry condition instead of making correction for aggregate absorption.

6.3 Correction for bulk density

All though batching of materials by volume is not allowed by IS code for RCC work for information purpose following method of correction is given. This correction is to be done only in case of volume batching.

Every mix design is always done considering weights of different ingredients.
In unavoidable conditions, if In case volume batching is done on site, the weights of aggregates need to be converted into volumes. This is done with the help of bulk densities of aggregates.

$$\text{Volume of sand per batch} = \frac{\text{wt. of Aggregate per batch}}{\text{Bulk density}}$$

For example, if wt. of sand per batch = 135kgs.
Bulk Density =1.66Kg/lit

Vol. Of sand = 135/1.66 = 81.3litrs. Say 80litrs.

Hence, use 2 forms of 25litrs and one form of 30litrs. Bulk density of sand changes with bulkage. Hence correction for bulk density of sand should be made every day.
Bulk density of metal is between 1.4 Kg/Lit to 1.5 Kg/Lit where as bulk density of sand varies with bulkage and usually lies between 1.6 to 1.8 Kg/Lit.

6 .4 Correction for bulkage

This correction is done only in case of volume batching of concrete. When sand is moist it ‘bulks’ i. e. it occupies grater volume. Hence, less weight of sand is taken in the given volume. In other words, the bulk density of sand changes. Otherwise, volume of sand needs to be increased in proportion of bulkage.
If correction for bulk density is done, effect of bulkage is taken care of & correction for bulkage need not be done.

6.5 Correction for silt

Excessive silt in sand affects the bond between cement and sand. Silt particles are finer than 75 micron in size and have tremendous water demand. They increase the water cement ratio required for getting the same workability. Organic and inorganic impurities present in silt also affect the durability of concrete. This reduces the strength of concrete. This problem is quite severe during monsoon.

Since the effect of silt is to reduce the workability, if silt % at site is found to be more than that considered in mix design, then either the same mix should be used with reduced workability as found during calibration of water or workability should be increased by making field corrections.

6.6 Field corrections for increasing the workability of concrete.

a) Increase the workability by reducing the specific surface of concrete (reducing the % of sand, reducing % of 10mm down metal if it is flaky etc.). However, this correction is to be done only if sand is fine or coarse aggregate is flaky and done only to the limit of not loosing the cohesiveness of concrete mix.
b) Increase the workability by increasing the cement content. This can easily be done by reducing the total aggregate added per batch by approx. 10kg. This should be continued till the required workability is obtained. Sand and coarse aggregate should be reduced proportionately. Say if we are using 40% sand as proportion of total aggregate reduce the sand by 4kg and reduced the coarse aggregate by 6 kg.
c) By adding plasticiser – Dosage of plasticiser may be adjusted to get the required workability. However, It is important to check the compatibility of plasticiser with cement and also the maximum and minimum dosage of plasticisers as specified by he manufacturers.

6.7 Corrections for changes in gradation of sand

Sand shows lot of variation on sites because of change in source of supply.
If the sand received at site is finer than the one considered in mix design the excess surface area created by the fines will increase the water demand. This will either reduce the slump of concrete or increase the water cement ratio. Hence correction should be done to reduce the specific surface of fine aggregate. This can be done by reducing the fine aggregate by 5 kg and increasing the wt. of coarse aggregate by 5 kg keeping the total wt. of aggregate constant. This may be done till required workability is obtained. If correction of more than 10kg is required for sand consult the mix design laboratory.
Similarly, if sand received at site is coarser than the one considered in mix design the mix is likely to segregate because of lack of fines (Lack of cohesion). In such a situation increase the fine aggregate by 5 kg and reduce the total aggregate by 5 Kg keeping the total weight of aggregate constant. This may be continued till the mix becomes cohesive and the required workability is obtained for the given water cement ratio. If correction of more than 10kg is required for sand consult the mix design laboratory. An excessive correction may increase the water cement ratio or reduce the workability of concrete.

The fineness modulus of sand in Pune varies from 3.2 to 3.8 The IS specifies a limit of 2.2 (fine sand) to 3.2 (coarse sand) for fine aggregate. This means that sand available in Pune is extremely coarse. This is partly because of absence of fines in the sand and 10% to 15% is retained on 4.75mm sieve as *chal* or shingle present in the sand. In case of coarse sand, a part of sand may be replaced by fine crushed sand to increase the missing fines in concrete.

In case crushed sand is not available fine stone dust (600 μ passing more than 60 %and 150 μ passing not more than 20%) may be used to replace a part of sand. Such stone dust should not replace more than 15 Kg of sand under normal circumstances. Strict control on water cement ratio should be kept. Stone dust reduces the workability; hence, the water cement ratio is likely to increase.

6.8 Correction for changes in size and shape of coarse aggregate

If size of coarse aggregate is lower than that used for mix design sand content will have to be increased to account for increased surface area of coarse aggregate. This will in turn increase the water demand of concrete. This may necessitate increase in cement consumption to maintain workability. In such case the coarse aggregate may be reduced by 5 kg. This will not only increase the proportion of sand but also increase the cement consumption. This correction may be done to the extent of 10 kg. Consult mix design laboratory if satisfactory mix is not obtained even after making the above correction. Effect of flaky aggregate is also to increase the surface area hence the same correction as mentioned above may be applied in case of flaky aggregate.

7.0 Field Testing procedures

7.1 Finding surface moisture of sand

Take 500 gm of sand and heat it in a tray gently till sand is dry and starts flowing freely. Surface dry sand is weighed again to find the loss in weight.

$$\text{Surface moisture} = \frac{W}{(500 - W)}$$

NOTE: It is important not to over heat the sand, as it will make the sand bone dry. The sand particles should be in saturated surface dry condition after heating. To ensure this condition heat the sand only to the point it becomes free flowing and there is a colour change.

Moisture in sand results in bulkage (increase in volume of sand) To get a rough estimate of surface moisture following thumb rule may be used when sand is not extremely wet.

Moisture in Sand	**Bulkage**	
	Medium Sand	Coarse Sand
1%	8%	6%
2%	16%	12%
3%	22%	15%
4%	27%	17%
5%	29%	18%

Approximate quantity of surface water carried by fine aggregate is given in table 10 of IS 456-2000 (Page 24)

Condition of sand	**% Surface Moisture**
Very wet sand	7.5%
Moderately wet sand	5%
Moist sand	2.5%

Usually finer the sand greater is the surface moisture that it will carry.

7.2 Measuring Silt Content at site

Take 50ml. of water in 250ml. beaker and add some salt to it. Add sand to it till 100ml. mark is reached. Again add water up to 150ml. Stir the sand well to wash it in salt water. Keep the beaker still for 3 hours. Observe the thickness of the silt layer.

$$\text{Silt content} = \frac{\text{Height of silt layer (ml)}}{\text{Height of sand (ml)}} * 100$$

Sand with silt content greater then 8 % calculated by above method should not be used for concreting.
In laboratory the silt % is calculated as % weight of particles finer than 75 micron. The limit is given as 3% in IS383 (Refer Annexure I page no 59).

7.3 Measuring Bulk density at site

$$\text{Bulk density} = \frac{\text{weight of material in kg}}{\text{Volume in litres}}$$

Bulk density can be measured on site by filling a standard 35 litres form with aggregate and weighing the aggregate filled in the form.

e.g. wt. of sand in 35 litres form = 58kg.
Bulk density =58/35 = 1.66kgs./ litres.

7.4 Measuring Bulkage on site

Take 100ml. of sand in 250ml. beaker and add water so as to completely submerge the sand. Shake the beaker well and the keep it steady for some time. Note the level to which it settles.

$$\text{Bulkage \%} = \frac{\text{Original level - New level}}{\text{New Level}} * 100$$

7.5 The sieve analysis of fine aggregates and the fineness modulus

Apparatus:

Set of sieves ranging 40 mm, 25 mm, 20 mm, 16 mm, 12.5 mm, 10 mm, 6.3 mm, 4.75 mm, 2.36 mm, 1.18mm, 600 μ, 300 μ, 150 μ weighing balance, heating pan and stove.

Procedure:

i. Heat 1Kg of sand on stove to remove all the moisture. This will make the particles free from cohesion induced because of surface tension of free water in sand.
ii. Arrange all the sieves in order of size, with largest sieve size on the top.
iii. Place weighted material on the top most sieve and shake each sieve. Shaking shall be done with a varied motion backward and forward, left to right, circular – clockwise, anti- clockwise with frequent jerking, so that the

material is kept moving over the sieve surface. Shaking should be done till all the particles are given a chance to pass through the sieve.

iv. Weigh the material retained on each sieve on a weighing balance. The material retained on each sieve after shaking represents the fraction of aggregate coarser than the sieve size in question and finer than the sieve size above.

v. Calculate % retained and the cumulative % retained on each sieve. The summation of the % cumulative wt retained on all the sieve sizes **up to 150 micron**, divided by 100 gives the fineness modulus.

vi. The sieve analysis is recorded in following table

Observation:

IS sieve size	Wt. retained	% Of Wt. Retained	Cumulative % wt. Retained	Cumulative % wt. Passing
4.75 mm				
2.36 mm				
1.18 mm				
600 μ				
300 μ				
150 μ				
Passing 150 μ				

Calculation:

$$\textbf{F M} = \frac{\sum \text{ Cumulative \% weight retained (up to 150 } \mu)}{100}$$

7.6 Casting and testing of Concrete Cubes

Cubes of concrete should be cast for every shift of concreting work to estimate the strength of concrete. Concrete for filling the cubes should be taken from the middle discharge of concrete mixer. Concrete from beginning or at the end of discharge should be avoided. Cubes should be filled in 3 equal layers. Each layer should be uniformly tamped **at least 35 times** with a16mm blunt rod. The tamping should be done in such a manner that the rod penetrates through the layer up to the lower layer. Cubes should be properly levelled and finished using hand trowel. Cubes should be kept in shadow properly covered with wet gunny bags. Cubes should be demoulded after 24 hours and immersed in water for curing. It is important to keep the cubes away form the shocks or vibrations especially for initial 3 days of casting.

We recommend that minimum 6 cubes should be taken every day and the batch of 3 cubes be tested for 7 days and 28 days respectively.

As per IS 456 -2000 minimum frequency of sampling is as follows:-

Sr. No.	Volume of concrete (m^3)	Number of samples
1	0 to 5	1
2	6 to 15	2
3	16 to 30	3
4	31 to 50	4
5	51 and above	4 plus one additional for each additional 50 m^3.

A sample consists of three test specimens. Above sampling criteria is given for testing at 28 days only. If 3 and 7 day compressive strengths are required, additional samples should be taken, over and above mentioned in the frequency of sampling.

7.7 Measuring Slump at site

Slump test:
Slump cone for slump test, tamping rod of steel 16 mm in diameter, 0.6 m long and Bullet head rounded at one end.

Procedure:

i. The internal surface of the slump cone shall be thoroughly cleaned and should be free from any set concrete before commencing the test. The mould should be placed on smooth horizontal, rigid and non – absorbent surface such as carefully levelled metal plate. The mould is firmly held in position while filling it.

ii. The mould should be filled in 4 layers each approximately one quarter of the height of mould. Each layer shall be tamped with 25 blows. The stroke should be distributed in a uniform manner over the cross section of mould. For the 2nd and subsequent layers tamping rod should penetrate into underlying layer. The bottom layer should be tamped throughout its depth.

iii. After the top layer has been rodded the concrete shall be struck off level with trowel or rod. The mortar, which may have leaked out between mould and base plate, shall be cleaned away.

iv. The mould shall be removed from concrete immediately by raising it slowly and carefully in vertical direction. This will allow the concrete to subside and the slump shall be measured immediately by determining the difference between height of mould and that of highest point of slumped concrete specimen. The above operation shall be carried out in a place free from shock or vibration.

8.0 Trouble Shooting at Site

8.1 The mix segregates: -

a. **Reduce the water cement ratio –** Higher workability often results in segregation hence reduce the workability by reducing the water added to mix.
b. **Increase the mixing time of mixer** – Poor quality of mixing often results in segregation. Segregating mix can be an indication of poor quality of mixer machine.
c. **Increase the sand proportion –** lack of fines often results in segregation. If sand is extremely coarse, a part of sand may have to be replaced by fine stone dust.
d. **Increase the cement content –** Richer mixes have lesser tendency for segregation. This may be the last resort as it adds to the cost**.**

8.2 The mix is not workable

a. **Reduce the sand content** – If sand available at site is much finer than the one used in design, higher specific surface will result in lower workability. A 10 to 15 kg reduction in sand per batch will increase the workability. The reduction of sand should be compensated by increasing the quantity of metal by equivalent amount.
b. **Check the silt content** – Silty sand will greatly reduce the workability of mix. The silt particles greatly enhance the specific surface and reduce the workability. Try replacing it by either non-silty sand or crushed sand. Sand washing can be adopted if sand washing machine is available.
c. **Check the mixer quality and mixing time** – Inadequate mixing often results in poor workability.
d. **Workability can be increased by adopting measures stated in 6.5**

8.3 Strength of Cube Results is low

a. Check whether the water/cement ratio used in the concrete mix was high. This is one of the most common reasons for low strength. This will be indicated by the slump reading of the concrete batch from which the cubes have been cast. We recommend that a slump reading be taken for every batch from which cubes are cast. A slump reading in excess of the slump given in the design mix indicates higher water cement ratio.
b. Check whether the cubes have been cast with proper compaction as mentioned in **Sec 7.6.** The weight of concrete cube less than 8 Kg may indicate poor compaction.
c. Check if dimensions of concrete cubes are within tolerance of +/- 0.2 mm. If the dimensions of cubes are not as specified above, the faces of the cube being crushed may not be parallel to each other. This may result in reduced area of contact between cube and plate of CTM and also eccentric loading.
d. Check if the raw materials used were satisfactory. Silty sand, flaky aggregates and cement with poor strength will result in low strength. If the above raw materials are available, cubes should be cast and tested to rule out the above possibility. A small sample of cement should always be kept aside for later testing for every major casting. This sample can be tested for

physical and chemical properties in case of failure. In many cases it is seen that no firm conclusion can be drawn because of non-availability of cement for testing.

e. Check if mixing was proper and variation amongst different cube samples is within the tolerance limit of 15% from the average. Improper mixing may result in non-uniform distribution of cement paste and lower strengths.
f. Check if the concrete cubes have not been subjected to some vibration or shocks in the early age.

8.4 The concrete does not set.

a. Check the physical and chemical properties of cement e.g. initial setting time, final setting time, 3, 7 & 28 days compressive strength.
b. Check if admixture used was proper and in correct dosage. A lignosulphonate base admixture added at high dosage can impart permanent retardation to concrete.
c. Check if the water used for concrete mix is not contaminated. Presence of sugar/molasses in water can result in retardation of concrete.

8.5 The concrete sets very fast

a. If the aggregates are bone dry, they will absorb water from the surrounding mix resulting in sudden drop in workability and early setting of concrete. This can be avoided by pre-wetting of coarse aggregates before concreting.
b. Check if the cement has a false set. This will be indicated by laboratory testing.
c. Concreting in hot weather and low humidity conditions can result in rapid moisture loss and sudden drop in workability and early set of concrete.
d. Check if the gypsum percentage in cement is proper by chemical analysis of cement.

8.6 There are cracks on the concrete surface immediately after casting.

Plastic shrinkage is the most common reason for surface cracks on concrete. Rapid loss of moisture in the plastic stage results in plastic shrinkage cracks. The phenomenon is common when concreting is done in windy condition. To prevent plastic shrinkage the concrete should be covered with plastic, immediately after casting.

9.0 Some common questions about mix design

9.1 How to get the most economical mix design: -

a. Cement content can be reduced by selecting appropriate raw materials
   i. Use of graded sand with low silt content
   ii. Aggregates should be equi-dimensional with min flakiness and elongation. For concretes up to M 40 grade rounded aggregates give best results.
   iii. By using higher size of aggregates where cover and reinforcement spacing permit.

a) By reducing the workability requirement of concrete: - Higher workability always comes at cost. Higher workability is achieved by increasing the cement content or by adding plasticisers.
b) By using pozzolonic materials like fly ash & ground granulated blast furnace slag etc. These materials not only bring economy but also increase the workability of concrete.
c) By correct use of compatible admixture. If admixtures are used judiciously after testing compatibility with cement, they substantially reduce the cement content. This is more so for higher grades of concrete and where higher workability is desired. The cost incurred on admixture in such cases is less than that required for additional cement.

9.2 Will use of 53 grade of cement result in lower cement consumption?

A higher grade of cement will enable us to use a higher order cement curve for calculating the water cement ratio. This means that a higher grade cement will allow us to use a higher water/cement ratio for achieving a given target strength. This will result in lower cement consumption for a given water demand. With advent of modern cement manufacturing technology the difference between 43 grade and 53 grade cement is reducing. Almost all the 43 grade cements available today have strengths required for E curve (strength range of 51.5 to 56.4N/mm^2) while some of the 43 grade cements give higher strengths to fit F curve (strength range of 56.4 to 61.3 N/mm^2). Most of the 53 grade cements fall in F curve while some give higher strengths for which curves are not defined (Some call them as G curve with strength above 61.3 N/mm^2).

9.3 Is use of rounded aggregate suitable for concrete?

For concrete grades up to M40, the failure pattern is mostly the mortar failure. As discussed earlier the round aggregate have the lowest water demand for a given workability. Hence they will either result in lower cement consumption or will give higher strength or result in higher workability. Hence they can certainly be used for making good quality concrete. Hence screened shingle normally available at site as waste material, if free from shells makes excellent replacement for 10mm aggregates.

9.4 Will use of higher size of aggregates always result in better strengths?

Again for concrete grades up to M 35 where mortar failure is predominant a higher aggregate size will reduce the water demand hence the water cement ratio and will result in better strengths. However, for higher grades where bond failure becomes predominant, a lower maximum size of aggregate will give better results by increasing the area of contact between mortar and metal and reducing the probability of bond failure.

9.5 How is pumpable concrete different than ordinary concrete? Is it always better than normal concrete?

Pumpable concrete requires high degree of workability (slumps above 100mm) and high degree of cohesion to prevent segregation. It also requires a higher mortar content to lubricate the pipeline. Higher workability is achieved by increasing the cement content and use of admixtures. Cohesion is achieved by use of higher fines. The fines are increased by increasing sand content or using finer sand or by increasing cement. Because of above reasons pumpable concrete always works out more expensive than ordinary concrete. If a concrete is made pumpable, it automatically means that mix is well graded and highly cohesive. However, the water demand of pumpable concrete is much higher. Some times there is a risk of inadvertently using higher water/cement ratio to make the concrete pumpable. This will reduce the durability of concrete. Also higher fines content increases the chance of drying shrinkage.

9.6 What is the harmful effect of bleeding in concrete?

Bleeding is the phenomenon of water added in concrete, coming to the top surface by forming capillaries. While some bleeding is normal and will replace the moisture loss occurring at the surface, excessive bleeding will adversely affect the durability of concrete. This is because the capillaries formed in the process will render the concrete porous. Excessive bleeding will also result in settlement of heavier particles. It will increase the water/cement ratio at the surface reducing the strength of top skin layer. Bleeding can be controlled by adopting correct gradation of aggregates, using lower water cement ratio and use of air entraining agents.

9.7 Does use admixture have any harmful effect on durability of concrete?

Admixtures have been commonly used to make good quality concrete for several decades in India and abroad. There is no evidence to suggest any negative impact of admixture on the durability of concrete if they comply basic requirement of sulphates and chlorides.

9.8 Can crushed sand make as good a concrete as that made from natural sand? How does it affect the economy of mix design?

Crushed sand can make as good a concrete as that made of natural sand .In fact use of crushed sand will become inevitable in near future because of dwindling sources of natural sand. Crushed sand particle though shaped, does not have the spherical shape of natural sand. Hence the crushed sand will have greater water demand than that of natural sand resulting in slightly higher cement consumption.

However, if crushed sand is properly graded with adequate fines the mix may have lower water demand when compared to poorly graded natural sand. Besides crushed sand can afford better control on gradation when compared to natural sand. Hence crushed sand may become an economical option if good quality natural sand is not available.

9.9 Can we eliminate use of 10 mm aggregate?

Concrete technology does not reject use of gap-graded concrete. At many sites 20 mm aggregates are used with natural sand without the 10 mm down aggregates. This is because the 10mm aggregates produced from jaw crusher is flaky and does not give a good mix. However, the gap-graded concrete has a higher tendency of segregation and bleeding. Hence it is not recommended where concrete of moderate or high workability is required.

10.0 A note on durability of concrete

10.1 Factors Affecting Durability of Concrete

External Factors

i. Sulphate attack
ii. Chloride attack
iii. Carbonation
iv. Effervescence (Leaching)
v. Shrinkage / Creep
vi. Alkali Aggregate Reaction

i. Sulphate attack

- $MgSO_4$, Na_2SO_4 when present in solution react with hardened cement paste.
- Result in volume changes and disrupts concrete
- Alternate wetting and drying is most harmful.

Remedy:

a) Use of sulphate resisting cement
b) Low Water/ cement ratio (W/C below 0.5)
c) Use of Puzzolona

ii. Chloride Attack

- Attacks the reinforcement resulting in corrosion
- The corroded reinforcement swells 2 to 3 times its original volume
- The swelling of reinforcement ruptures the concrete.
  Corrosion is Electro – Chemical process.

Remedy:

a) Use of low water/ cement ratio.
b) Use of Pozzolonic materials.
c) Proper design of concrete and good concreting practices.
d) Protective coating on steel.

Avoid:

a) Use of Sulphate resisting cement.
b) Use of Chloride based admixtures.

iii. Carbonation

- CO_2 in atmosphere reacts with concrete surface in presence of Moisture to form Carbonic Acids
- PH of concrete reduces from 13.5 to 8.5
- Loss of Alkalinity accelerates rusting of steel.

Depth of Carbonation mm	Age (Years)	
	M 20	M 40
5	0.5	4
10	2	16
15	4	36
20	7	64

Remedy:

a) Use of low w/c Ratio or Higher grade of concrete.
b) Increase cover to reinforcement.

iv. Leaching (Effervescence)

- Hydration of cement by water leads to formation of Cement Gel and Lime $CaOH_2$.
- Lime being water-soluble, dissolve in water and brought to surface by water.

Effect
a) Increase Permeability of concrete.
b) Reduces the PH of concrete – enhancing corrosion.
c) Affects the aesthetics of concrete surface.

Remedy
a) Use of low water/ cement ratio.
b) Use of Puzzolonic materials.

V. Shrinkage

- Plastic shrinkage
- Drying Shrinkage

Effect:
a) Cracking

Remedy:

a) Early curing
b) Protecting concrete from Wind/ Sun.
c) Wetting of Aggregates / Subgrade.

vi. Alkali Aggregate Reaction

- Alkalis present in cement react with reactive form of silica present in Aggregates.
- Alkali Aggregate Reaction results in 'Alkali Silicate Gel'.
- The gel is of unlimited swelling type – it imbibes water and swells resulting in cracking and disruption.

Remedy

a) Use of non – reactive aggregates.
b) Use of low Alkali cements with Alkali content less than 0.6 %.
c) Use of Puzzolonas
d) Use of low cement content.

11.0 Note on use of Fly Ash in concrete

Fly ash, known also as pulverized – fuel ash, is the ash precipitated electro-statically from the exhaust fumes of coal-fired power stations, and is the most common artificial pozzolana. During combustion of powdered coal in modern power plants, as coal passes through high temperature zone in the furnace, the volatile matter & carbon are burned off, where as most of the mineral impurities, such as clays, quartz, and feldspar, will melt at high temperature. The fused matter will be quickly transported to lower temperature zones where it solidifies as spherical particles of glass. Some of the mineral matter agglomerates forming bottom ash, but most of it flies out with the flue gas stream and is called fly ash. This ash is subsequently removed from the gas by electrostatic precipitators.

11.1 Use of Fly Ash In Concrete

Fly ash is the most commonly used pozzolona with cement. A Pozzolana is essentially a silicious material, which in itself -possessing no cementitious properties, will in finely divided form and in presence of water react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

The hydration of cement is an exothermic reaction resulting in formation of gel (binding material) & calcium hydroxide (free lime).

The two principle components of cement namely C3S and C2S react with water as follows: -

$C_3S + H_2O = Gel + Ca(OH)_2$

The corresponding weights involved are as follows

100 + 24 = 75 + 49

$C_2S + H_2O = Gel + Ca(OH)_2$

The corresponding weights involved are as follows: -

100 + 21 = 99 + 22

Thus we see that in hydration of C_3S almost 50% lime by weight of C_3S is generated as compared to only 20% in case of C_2S. C_3S is responsible for early gain of strength while C_2S results in later gain of strength. Today's cements in an effort to give high early strength contain higher proportion of C_3S.Thus lime generated in concrete as a result of hydration is as much as 30% by weight of reacting cement.

The free lime generated as a result of hydration is water-soluble and tends to leach out. This makes concrete porous and more vulnerable to further attack from water and other chemicals.

The reactive silica present in fly ash converts free lime into calcium silicate hydrates, which is insoluble in water and possesses cementitious properties. It leads to further gain of strength at later ages in concrete. The IS allows upto 35% replacement of cement by fly ash.

The fly ash particles are spherical (which is advantageous from the water requirement point of view) and are of least the same fineness as cement (although with fewer fine particles) so that the silica is readily available for reaction.

11.2 The Specifications

The pozzolanic activity of fly ash is in no doubt, but it is essential that it has a constant fineness and constant carbon content. The two are often interdependent since the carbon particles tend to be coarser. Modern boiler plant produce fly ash with a carbon content of about 3 percent but much higher values are encountered in fly ash from older plants. British Standard BS 3892: 1965 lays down a maximum loss of ignition of 7 percent, but probably a carbon content upto 12 percent is acceptable. It is not clear why carbon may be harmful but, of course, it is not pozzolanic and is therefore no more than a filler The importance of uniformity of properties of fly ash can not be overestimated, as otherwise it is difficult to maintain the uniformity of the resulting concrete. British Standard BS 3892: 1965 specifies three zones of fineness so that uniform supply can be assured. The residue on 45 ∝m sieve is convenient basis of classification of size. **The main requirements of ASTM Standard C 618-78 are: a minimum content of 70 percent of silica, alumina and ferric oxide all together, a maximum SO_3 content of 5 per cent, a maximum loss on ignition of 12 per cent, and a maximum alkali content(expressed as Na_2o of 1.5 per cent.** The latter value is applicable only when the fly ash is to be used with reactive aggregate. British standard BS 3892:1965 specifies a maximum MgO content of 4 per cent and SO_3 of 2.5 per cent.

It should be noted that fly ash might affect the colour of the resulting concrete.

Portland- pozzolana cements show also good resistance to sulphate attack and to some other destructive agents. This is so because the pozzolanic reaction leaves less lime to be leached out and also reduces the permeability of concrete. It should be remembered that pozzolanas vary very considerably in their effects, both good and bad, and it is advisable to test any untried pozzolanic material in combination with the cement and aggregate, which are to be used in actual construction. The use of fly ash with sulphate-resisting Portland cement is not allowed according to British code of Practice CP 110:1972 and BS 5328:1976 when resistance to sulphate attack is required. This view is not necessarily correct.

When pozzolanas are used as a partial replacement for cement, the cement and pozzolanas are batched separately and mixed with the other ingredients in the concrete mixer. The required properties of pozzolanas for such a purpose are prescribed by ASTM Standard C 618-78.

With replacement, concrete mixes have a lower early strength than when Portland cement is used, but beyond about three months there is no less of strength. With lean mixes, there may even be a long-term gain of strength due to the replacement. If equal early strength is required and pozzolana to be used (e.g. because of alkali-aggregate reactivity) then addition of pozzolana rather than replacement of cement is necessary. **Because the continuing formation of hydrates fills the pores and also because of the absence of free lime**

which could be leached out, partial replacement of Portland cement by pozzolana reduces the permeability of concrete: a 7 to 10- fold reduction has been reported. The US Government encourages the use of fly ash in all appropriate construction involving the Federal Funds.

11.3 Applications

A) Improvement in workability

With fresh concrete mixtures that show a tendency to bleed or segregate, it is well known that incorporation of finely divided Flyash generally improves workability by reducing the size and volume of voids. It will also enhance cohesiveness of freshly made concrete. The small size and the glassy texture of fly ashes makes it possible to reduce the amount of water required for a given consistency. In a review paper on the use of fly ashes it was reported in one case that a concrete made by substituting 30% of cement with a Canadian flyash required 7% less water.

B) Durability to thermal cracking

Use of pozzolona results in lower heat of hydration hence reduces thermal cracking and shrinkage. As a thumb rule the total heat of hydration produced by pozzolanic reactions involving mineral admixtures (Fly ash) is considered to be half as much as average heat produced by hydration of Portland cement.

The portland cement replacement by fly ash has been practiced in the united states since the 1930s. In mass concrete construction, where low cement contents and fly ash proportions as high as 60 to 100 % by weight of cement are commonly employed with, the first successful application was in 1948 for building the Hungary Horse dam, Montana more than 2 million m^3 of concrete was used, some cement contained as much as 32% of cement replaced by fly ash.

Use of fly ash is particularly beneficial when concrete is exposed to considerably higher than normal temperatures, because of high heat of hydration and extremely hot weather conditions in tropical countries like India. Compared to specimens cured in laboratory, field concrete with out the presence of admixtures are likely to undergo a strength loss due to micro cracking on cooling, but concrete containing mineral admixtures frequently show a gain of strength.

C) Durability to Chemical Attacks

The permeability of concrete is fundamental to determining the rate of mass transfer related to destructive chemical actions such as attack by acidic and sulphate solutions. The published literature contains sufficient evidence that in general the incorporation of mineral admixtures in to concrete improves the resistance of material to acidic sulphate water (moderate sulphate attack) and seawater. This is mainly due to pozzolonic reaction, which is accompanied by a reduction in permeability and as well as reduction in the calcium hydroxide content of the hydrated product.

It has been observed that reduction of $Ca(OH)_2$ only marginally reduces the alkalinity of concrete and pH value of concrete is sufficient to prevent rusting of steel. The chloride ion which initiates rusting, gets ‘fixed’ in concrete with pozzolana. This results in reduction in chloride ion diffusion in concrete and thus delays corrosion of steel. Thus use of fly ash as pozzolana enhances durability of concrete structures.

D) Environmental Considerations

Not only is the manufacture of Portland cement highly energy intensive it also is a significant contributor of the green house gases.

The production of every tonne of Portland cement contributes about one tonnes of CO_2 into the atmosphere. Minor amount of NO_2 and CH_4 are also released into the atmosphere. The total CO_2 emissions per tone of cement range from about 1.1 tones of CO_2 from the wet process to 0.89 tonnes from a pre-calcination kiln. Hence every tonne of cement replaced by fly ash, saves the environment from release of approximately one tonne of CO_2 in the atmosphere.

Thus today environmental and energy considerations also advocate use of fly ash in concrete.

IS requirements for Fly Ash for use in concrete.

Sr. No.	Characteristics		As per IS: 3812, 1987
1.	LOI	(%)	MAX 12.00
2.	$SiO_2+Al_2O_3+Fe_2O_3$	(%)	MIN 70.00
3.	SiO_2	(%)	MIN 35.00
4.	CaO	(%)	--
5.	MgO	(%)	MAX 5.00
6.	SO_3	(%)	MAX 2.75
7.	Specific Surface	m^2/Kg	MIN 320
8.	Lime Reactivity	Mpa	MIN 4.0
9.	Compressive Strength	(%)	MIN 80 % (of control)
10.	Drying Shrinkage	(%)	MAX 0.15

References:

Concrete Microstructures, properties and materials – P.Kumar Mehta &Paulo J.M. Monteiro

Properties of Concrete – A.M. Neville

Annexure I

IS requirements for fine and coarse aggregates (based on IS 383)

Table 1 : Grading limits for fine aggregates :

IS Sieve DESIGNATION	PERCENTAGE PASSING FOR			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

Source: Refer Table No. 4 (Clause 4.3) Page no. 11 of IS 383 -1970

Table 2 : Grading limits for single size coarse aggregates

IS Sieve Designation	PERCENTAGE PASSING FOR SINGLE – SIZED AGGREGATE OF NOMINAL SIZE					
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm
80 mm	100	-	-	-	-	-
63 mm	85 to 100	100	-	-	-	-
40 mm	0 to 30	85 to 100	100	-	-	-
20 mm	0 to 5	0 to 20	85 to 100	100	-	-
16 mm	-	-	-	85 to 100	100	-
12.5 mm	-	-	-	-	85 to 100	100
10 mm	0 to 5	0 to 5	0 to 20	0 to 30	0 to 45	85 to 100
4.75 mm	-	-	0 to 5	0 to 5	0 to 10	0 to 20
2.36 mm	-	-	-	-	-	0 to 5

Source: TABLE 2 page no 9 (Clauses 4.1 and 4.2) IS 383 – 1970

Table 3 Grading limits for graded coarse aggregate:

IS Sieve Designation	PERCENTAGE PASSING FOR GRADED AGGREGATE OF NOMINAL SIZE			
	40 mm	20 mm	16 mm	12.5 mm
80 mm	100	-	-	-
63 mm	-	-	-	-
40 mm	95 to 100	100	-	-
20 mm	30 to 70	95 to 100	100	100
16 mm	-	-	90 to 100	-
12.5 mm	-	-	-	90 to 100
10 mm	10 to 35	25 to 55	30 to 70	40 to 85
4.75 mm	0 to 5	0 to 10	0 to 10	0 to 10
2.36 mm	-	-	-	-

Source: TABLE 2 page no 9 (Clauses 4.1 and 4.2) IS383 – 1970

Table 4 Grading limits for combined aggregates:

IS Sieve DESIGNATION	PERCENTAGE PASSING FOR ALL-IN AGGREGATE GRADING	
	40 mm Nominal Size	20 mm Nominal Size
80 mm	100	
40 mm	95 to 100	100
20 mm	45 to 75	95 to 100
4.75 mm	25 to 45	30 to 50
600 micron	8 to 30	10 to 35
150 micron	0 to 6	0 to 6

Source: IS383 – 1970 TABLE 5 page 11 (Clause 4.4) All in Aggregate Grading

Quality of aggregates:
Aggregates Crushing Value – The aggregate crushing value, when determined in accordance with IS: 2386 (Part IV) –1963 shall not exceed 45 percent for aggregate used for concrete other than for wearing surfaces, and 30 percent for concrete for wearing surfaces, such as runways, roads, and pavements.

Aggregates Impact Value – As an alternative to 3.3 the aggregate impact value may be determined in accordance with the method specified in IS : 2386 (Part IV)-1963. The aggregate impact value shall not exceed 45 percent by weight for aggregates used for concrete other than for wearing surfaces and 30 percent by weight for concrete for wearing surfaces, such as runways, roads and pavements.

Aggregates Abrasion Value – Unless otherwise agreed to between the purchaser and the supplier, the abrasion value of aggregates when tested in accordance with the method specified in IS: 2386 (Part IV) – 1963 using Los Angels machine, shall not exceed the following values: -

b) For aggregates to be used in concrete for wearing surfaces 30 percent
c) For aggregates to be used in other concrete

Table 5 Limits of Deleterious materials for fine and coarse aggregates: (IS 383-1970)

Sr. No.	DELETERIOUS SUBSTANCES	FINE AGREGATE PERCENTAGE BY WEIGHT, Max		COARSE AGGREGATE PERCENTAGE BY WEIGHT, Max	
(1)	(2)	(4)	(5)	(6)	(7)
		Natural	Crushed	Natural	Crushed
i)	Coal and lignite	1.00	1.00	1.00	1.00
ii)	Clay lumps	1.00	1.00	1.00	1.00
iii)	Material finer than 75 μ IS Sieve	3.00	15.00	3.00	3.00
iv)	Soft fragments	-	-	3.00	-
v)	Shale	1.00	-	-	-
vi)	Total of percentages of all deleterious materials (except mica) including SI No. (i) to (v) for col 4,6 and 7 and SI No. (i) and (ii) for col 5 only	5.00	2.00	5.00	5.00

Note I –

The presence of mica in fine aggregate has been found to reduce considerably the durability and compressive strength of concrete and further investigations are underway to determine extent of mica. It is advisable. Therefore, to investigate the mica content of fine aggregate and make suitable allowances for the possible reduction in the strength of the concrete or mortar.

Note II –

The aggregate shall not contain harmful organic impurities (tested in accordance with IS 2386 Part II –1963) insufficient quantities to affect adversely the strength or durability of concrete. A fine aggregate which fails in the test for organic impurities may be used, provided that when tested for the effect of organic impurities on the strength of the Mortar, the relative strength at 7 and 28 days, reported in accordance with IS 2386 Part VI –1963, is not less than 95 %.

Annexure II

Table 1 Suggested values of standard deviation

GRADE OF CONCRETE	STANDARD DEVIATION FOR DIFFERENT DEGREE OF CONTROL IN N/mm^2		
	Very Good	Good	Fair
M 10	2.0	2.3	3.3
M 15	2.5	3.5	4.5
M 20	3.6	4.6	5.6
M 25	4.3	5.3	6.3
M 30	5.0	6.0	7.0
M 35	5.3	6.3	7.3
M 40	5.6	6.6	7.6
M 45	6.0	7.0	8.0
M 50	6.4	7.4	8.4
M 55	6.7	7.7	8.7
M 60	6.8	7.8	8.8

Source: Table I from page 5 IS 10262-2009

Note: Appendix A provides guidance regarding the different degrees of quality control to be expected, depending upon the infrastructure and practices adopted at the construction site.

Table 2 - Approximate water content per m^3 of concrete

Nominal maximum size of aggregate, mm	Water content per m^3 of concrete Kg
	For Grades upto M 35
10	208
20	186
40	165
	For Grades above M 35
10	200
20	180

Source: Table 4 and 5 page no 9 IS 10262-1982

Table 3 Approximate sand per M^3 of concrete

Nominal maximum size of aggregate, mm	Sand as percentage of total aggregate by absolute volume
	For Grades upto M 35
10	40
20s	35
40	30
	For Grades above M 35
10	28
20	25

Source: Table 4 and 5 page no 9 IS 10262-1982

Table 4 Adjustment of values in water content

Change in condition stipulates in Table 2 and 3	Adjustment required in water content
For sand confirming To grading zone I, zone III or zone IV of IS: 383 - 1970	0
Increase or decrease in the Value of compacting factor by 0.1	± 3 percent
Each 0.05 increase or decrease in free water cement ratio	0
For rounded aggregate	-15 kg / m^3

Source: Table 6 page no 11 IS 10262-1982

Table 5: Adjustment of Values in Sand Percentage

Change in condition stipulates in Table 12	Adjustment required in sand in total aggregate
For sand confirming To grading zone I, zone III or zone IV of IS: 383 - 1970	+1.5 percent for zone I -1.5 percent for zone III -3.0 percent for zone IV
Increase or decrease in the Value of compacting factor by 0.1	0
Each 0.05 increase or decrease in free water cement ratio	± 1 percent
For rounded aggregate	-7 percent

Source: Table 6 page no 11 IS 10262-1982

Annexure III

Tables & Graphs from DOE Method

Table 1 Approximate water demand for different workability

Slump, mm		0-10	10-30	30-60	60-180
V-B time, sec		> 12	6-12	3-6	0-3
Maximum size of aggregate	Type of aggregate				
10 mm	Uncrushed Crushed	150 180	180 205	205 230	225 250
20 mm	Uncrushed Crushed	135 170	160 190	180 210	195 225
25 mm	Uncrushed Crushed	130 166	155 186	175 206	190 221
40 mm	Uncrushed Crushed	115 155	140 175	160 190	175 205

Source: Design of Normal Concrete Mixes, DOE, 1988

Notes:

i) For different types of coarse and fine aggregate, the free water content is estimated as 2/3 W_{FA} + 1/3 W_{CA}

where,

W_{FA} = free water content appropriate to the type of the fine aggregate, and

W_{CA} = free water content appropriate to the type of the coarse aggregate

ii) Values interpolated for 25 mm maximum size of aggregate.

Fig 1

Recommended proportions of fine aggregate passing a 600μ sieve.

Maximum aggregate size : 40 mm

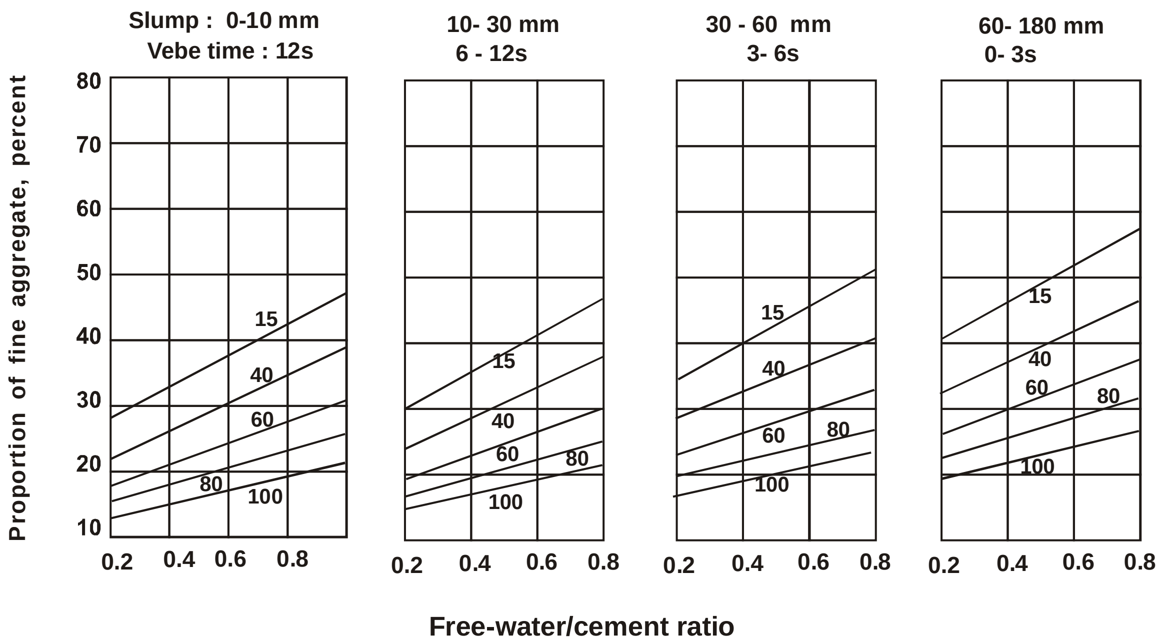


Fig 2

Recommended proportions of fine aggregate passing a 600μ sieve.

Maximum aggregate size : 20 mm

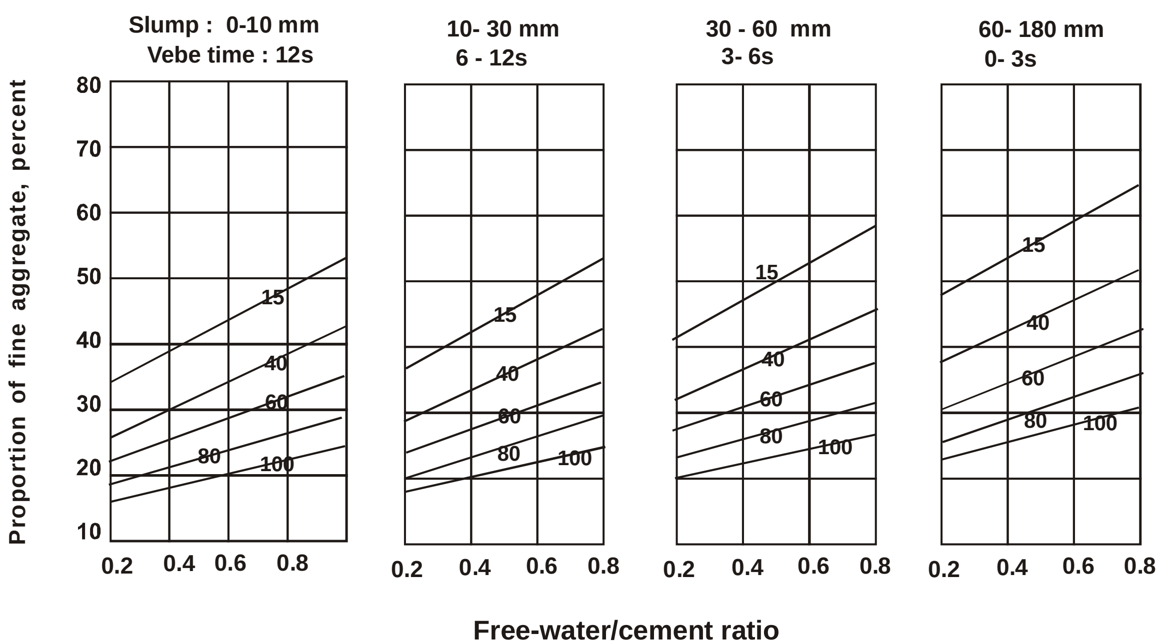


Fig 3

Recommended proportions of fine aggregate passing a 600µ sieve.

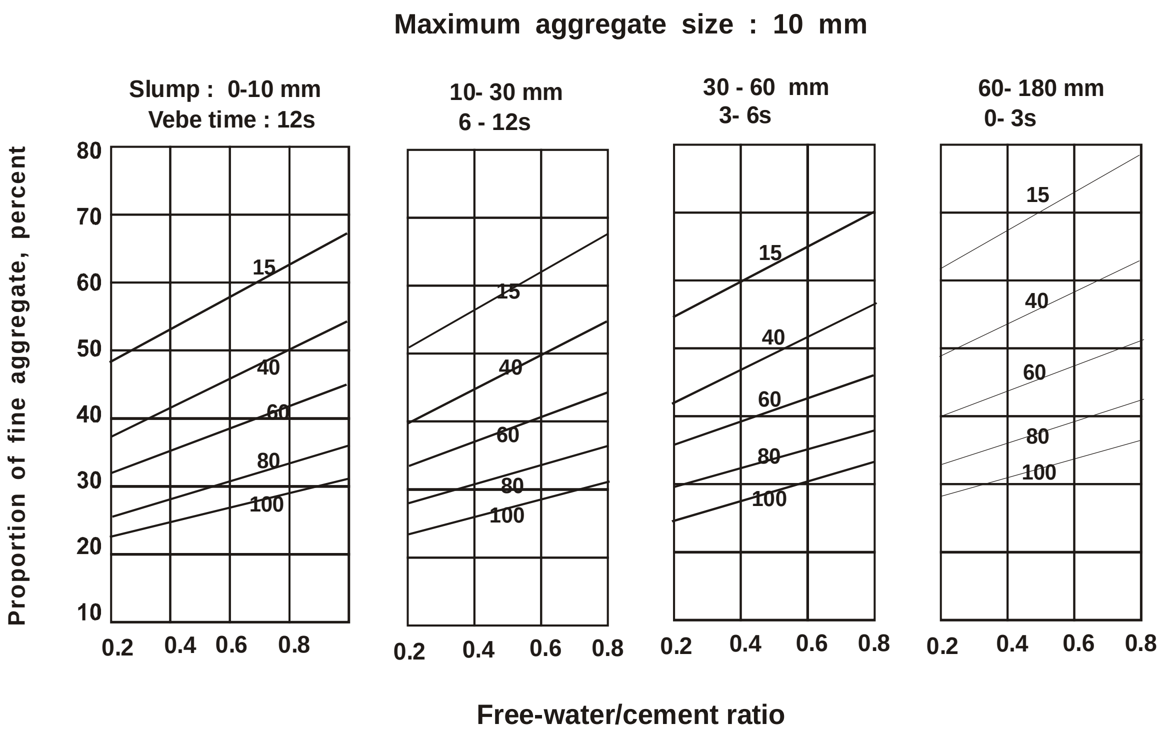
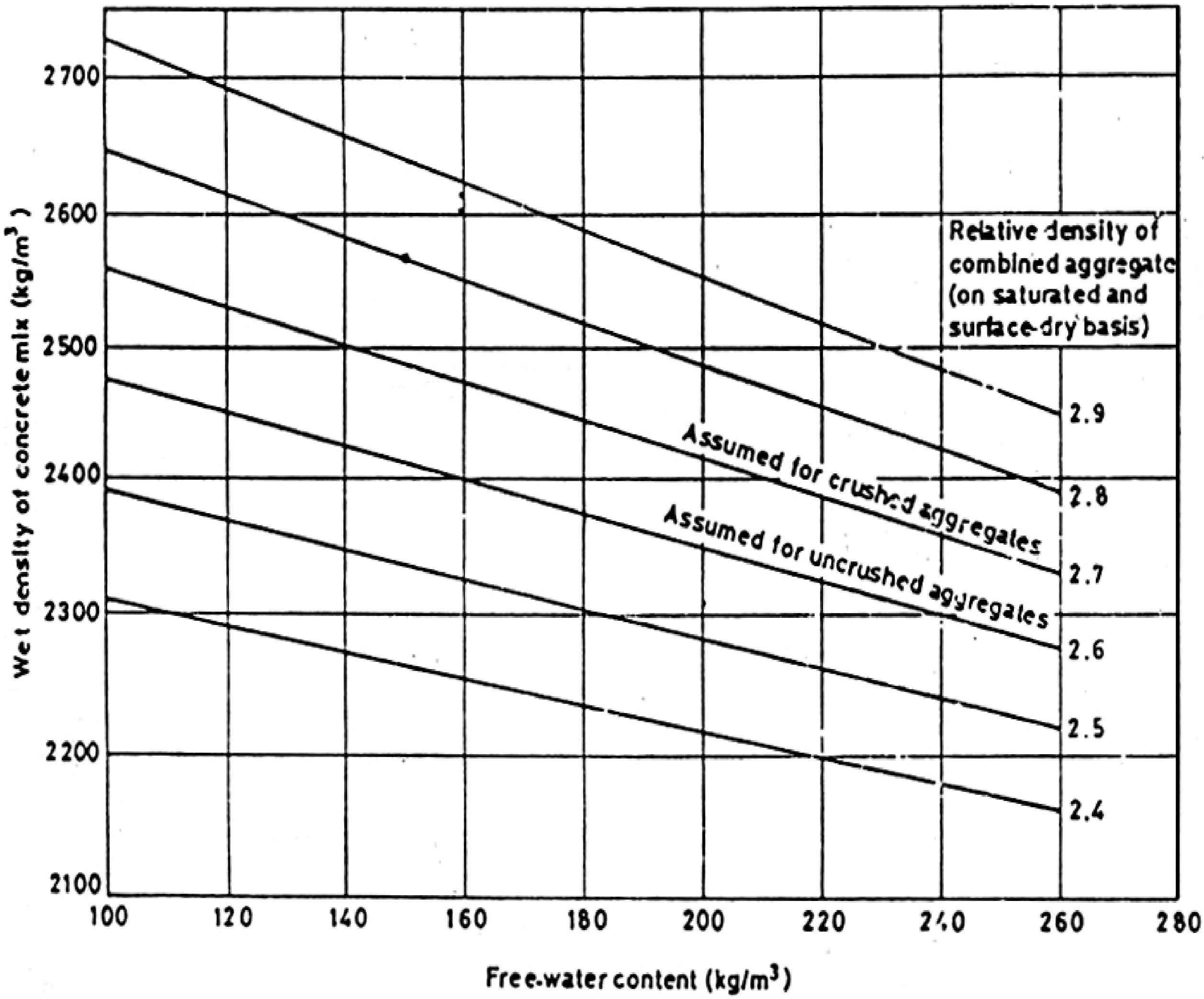


Fig 4

Wet density of fully compacted concrete for varying relative densities of aggregate



Annexure IV

Tables from ACI Method

Table 1 Approximate mixing water requirements for different slumps and maximum size of aggregate (ACI Manual 21.1.8.1)

Slump Mm	Water, kg/m^3 of concrete, for the maximum sizes of coarse aggregates							
	10mm	12.5 mm	20 mm	25 mm	40 mm	50 mm	70 mm	150 mm
	NON-AIRENTRAINED CONCRETE							
30 To 50	205	200	185	180	160	155	145	125
80 to 100	225	215	200	195	175	170	160	140
150 to 180	240	230	210	205	185	180	170	-
Approximate entrapped air content, percent	3	2.5	2	1.5	1	0.5	0.3	0.2

The above values are maximum for reasonably well-shaped angular coarse aggregate graded within acceptable limits. The quantities of mixing water can be used to compute cement factors for trial batches. For aggregate greater than 40 mm, the slump values are based on slump tests after removal of particles greater than 40 mm by wet screening.

Table 2 Volume of Course Aggregate Per Unit Volume of Concrete

Maximum size of aggregate	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness moduli of sand			
	2.40	2.60	2.80	3.00
10 mm	0.50	0.48	0.46	0.44
12.5 mm	0.59	0.57	0.55	0.53
20 mm	0.66	0.64	0.62	0.60
25 mm	0.71	0.69	0.67	0.65
40 mm	0.76	0.74	0.72	0.70
50 mm	0.78	0.76	0.74	0.72
70 mm	0.81	0.79	0.77	0.75
150 mm	0.87	0.85	0.83	0.81

Source: ACI Manual 211.1-81

Notes :

I) These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual RC construction; for less workable concrete, such as that required for concrete pavements they may be increased by about 10 percent; for more workable concrete, such as that required for pumped concrete, they may be decreased by about 10 percent.

ii) Fineness modulus of sand = sum of cumulative ratios retained on sieves with square openings of about 0.15, 0.3, 0.6, 1.18, 2.36 and 4.75 mm

Annexure V

Tables and graphs from RRL Method (Road note 4 method)

Table 1 Aggregate – Cement Ratios for Different Degrees of Workability, Water – Cement Ratios and Gradings – for 40 – mm Rounded Gravel Aggregate

Water Cement Ratio, by Weight	Degree of Workability															
	Very low				Low				Medium				High			
	Grading number				Grading number				Grading number				Grading number			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.35	5.0	4.5	3.9	3.4	4.3	3.9	3.5	3.1	3.4	3.1	2.9	2.7				
0.40	7.0	6.5	5.7	4.9	5.9	5.6	5.0	4.4	4.7	4.6	4.3	3.8	4.1	4.0	3.9	3.5
0.45	8.9	8.6	7.7	6.5	7.6	7.4	6.7	5.8	6.0	6.1	5.7	5.0	5.2	5.3	5.0	4.6
0.50				8.0			8.2	7.2	7.5	7.6	7.1	6.3	6.3	6.5	6.2	5.7
0.55								8.4		8.9	8.1	7.3	S	7.7	7.4	6.7
0.60																7.6

Source: Road Note No. 4

Notes : (i) S indicates that the mix will segregate

(ii) Values have been obtained by extrapolation of other data and are not based directly on results of the trial mixes

Table 2

Aggregate – Cement Ratios for Different Degrees of Workability, Water – Cement Ratios and Gradings – for 40 – mm Crushed Rock Aggregate

Water Cement Ratio, by Weight	Degree of Workability															
	Very low				Low				Medium				High			
	Grading number				Grading number				Grading number				Grading number			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.35	3.4	3.4	3.2	2.9												
0.40	4.9	4.6	4.2	3.8	4.0	3.8	3.6	3.3	3.3	3.3	3.2	3.0	3.1	3.1	2.9	2.7
0.45	6.0	5.7	5.2	4.7	4.9	4.7	4.4	4.2	4.1	4.1	3.9	3.8	3.7	3.8	3.7	3.4
0.50	7.2	6.8	6.2	5.6	5.8	5.6	5.3	5.0	4.8	4.8	4.7	4.6	4.4	4.5	4.5	4.2
0.55	8.1	7.7	7.1	6.4	6.6	6.4	6.1	5.8	5.5	5.5	5.4	5.3	S	5.2	5.2	4.8
0.60		8.6	8.0	7.2	7.4	7.2	6.9	6.6	6.1	6.2	6.1	6.0		S	5.9	5.6
0.65			8.8	7.9	8.1	7.9	7.6	7.3	S	6.9	6.8	6.6			6.5	6.2
0.70				8.6		8.5	8.3	7.9		7.5	7.5	7.3			7.1	6.8
0.75								8.5			8.1	7.8				7.4

Source : Road Note No. 4

Notes : (i) S indicates that the mix will segregate

(ii) Values have been obtained by extrapolation of other data and are not based directly on results of the trial mixes

Table 3

Aggregate – Cement Ratios for Different Degrees of Workability, Water – Cement Ratios and Gradings – for 20 – mm Rounded Gravel Aggregate

Water Cement Ratio, by Weight	Degree of Workability															
	Very low				Low				Medium				High			
	Grading number				Grading number				Grading number				Grading number			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.35	4.5	4.2	3.7	3.2	3.8	3.6	3.3	3.0	3.1	3.0	2.8	2.6				
0.40	6.6	6.1	5.4	4.5	5.3	5.1	4.6	4.1	4.2	4.2	3.9	3.6	3.7	3.8	3.6	3.3
0.45	8.1	7.6	6.7	5.8	6.9	6.6	5.9	5.1	5.3	5.3	5.0	4.6	4.6	4.8	4.5	4.1
0.50			8.0	7.0	8.2	8.0	7.0	6.0	6.3	6.3	6.0	5.5	5.5	5.7	5.4	4.8
0.55				8.1			8.2	6.9	7.3	7.3	7.0	6.3	6.3	6.5	6.1	5.5
0.60								7.7			8.0	7.1	S	7.2	6.8	6.1
0.65								8.4				7.8		7.7	7.4	6.6
0.70															7.9	7.1
0.75																7.6

Source : Road Note No. 4

Notes : (i) S indicates that the mix will segregate

Table 4

Aggregate – Cement Ratios for Different Degrees of Workability, Water – Cement Ratios and Gradings – for 20 – mm Crushed Rock Aggregate

Water Cement Ratio, by Weight	Degree of Workability															
	Very low				Low				Medium				High			
	Grading number				Grading number				Grading number				Grading number			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.40	4.5	4.1	3.8	3.5	3.5	3.5	3.2	3.0								
0.45	5.5	5.0	4.6	4.3	4.3	4.2	3.9	3.7	3.7	3.7	3.4	3.3	3.5	3.5	3.2	3.1
0.50	6.5	5.9	5.4	5.0	5.0	4.9	4.5	4.3	4.2	4.2	3.9	3.8	S	3.9	3.8	3.5
0.55	7.2	6.6	6.0	5.7	5.7	5.5	5.0	4.8	4.7	4.7	4.5	4.3		S	4.3	4.0
0.60	7.8	7.2	6.6	6.3	6.3	6.0	5.6	5.3	S	5.2	4.9	4.8			4.7	4.5
0.65	8.3	7.7	7.2	6.9	6.9	6.5	6.1	5.8		5.7	5.4	5.2			5.2	4.9
0.70	8.7	8.2	7.7	7.5	7.4	7.0	6.6	6.3		6.2	5.8	5.8			5.5	5.3
0.75			8.2	8.0	7.9	7.5	7.0	6.7		S	6.2	6.1			5.8	5.7
0.80							7.4	7.2			6.6	6.5			6.1	6.0

Source: Road Note No. 4

Notes : (i) S indicates that the mix will segregate

Table 5

Aggregate – Cement Ratios for Different Degrees of Workability, Water – Cement Ratios and Gradings – for 10 – mm Rounded Gravel Aggregate

Water Cement Ratio, by Weight	Degree of Workability															
	Very low				Low				Medium				High			
	Grading number				Grading number				Grading number				Grading number			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.40	5.6	5.0	4.2	3.2	4.5	3.9	3.3	2.6	3.9	3.5	3.0	2.4	3.5	3.2	2.8	2.3
0.45	7.2	6.4	5.3	4.1	5.5	4.9	4.1	3.2	4.7	4.3	3.7	3.0	4.2	3.9	3.4	2.9
0.50		7.8	6.4	4.9	6.5	5.8	4.9	3.8	5.4	5.0	4.3	3.5	4.8	4.5	4.0	3.4
0.55			7.5	5.7	7.4	6.7	5.7	4.4	6.1	5.7	4.9	4.0	5.3	5.1	4.5	3.9
0.60				6.5		7.5	6.4	5.0	6.7	6.3	5.5	4.5	5.8	5.6	5.0	4.3
0.65				7.2			7.1	5.6	7.3	6.9	6.1	5.0	S	6.1	5.5	4.7
0.70							7.7	6.2	7.9	7.5	6.7	5.5		6.6	6.0	5.1
0.75								6.7			7.2	5.9		7.1	6.5	5.5
0.80								7.2			7.7	6.3		7.6	6.9	5.9

Source: Road Note No. 4
Notes : (i) S indicates that the mix will segregate

Table 6

Aggregate – Cement Ratios for Different Degrees of Workability, Water – Cement Ratios and Gradings – for 10 – mm Crushed Rock Aggregate

Water Cement Ratio, by Weight	Degree of Workability															
	Very low				Low				Medium				High			
	Grading number				Grading number				Grading number				Grading number			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0.40	3.7	3.3	2.8	2.0												
0.45	4.5	4.1	3.5	2.6	3.8	3.6	3.0	2.2	3.3	3.1	2.7	2.1				
0.50	5.2	4.9	4.2	3.2	4.4	4.2	3.6	2.7	3.8	3.7	3.2	2.6	S	3.2	2.9	2.4
0.55	5.9	5.6	4.9	3.8	4.9	4.8	4.2	3.2	S	4.2	3.7	3.0		3.7	3.4	2.8
0.60	6.6	6.3	5.5	4.3	S	5.3	4.7	3.7		4.7	4.2	3.4		4.2	3.8	3.2
0.65	7.3	7.0	6.1	4.8		5.8	5.2	4.2		5.1	4.6	3.8		4.6	4.2	3.6
0.70	7.9	7.6	6.7	5.3		6.3	5.7	4.6		5.6	5.1	4.2		5.0	4.6	4.0
0.75			7.3	5.8		6.8	6.2	5.0		6.0	5.5	4.6		5.4	5.0	4.4
0.80			7.8	6.3		7.2	6.6	5.5		6.4	5.9	5.0		5.8	5.4	4.7

Source: Road Note No. 4
Notes : (i) S indicates that the mix will segregate
(ii) With crushed aggregate of proper shape than tested, segregation may occur at a lower aggregate –cement ratio.

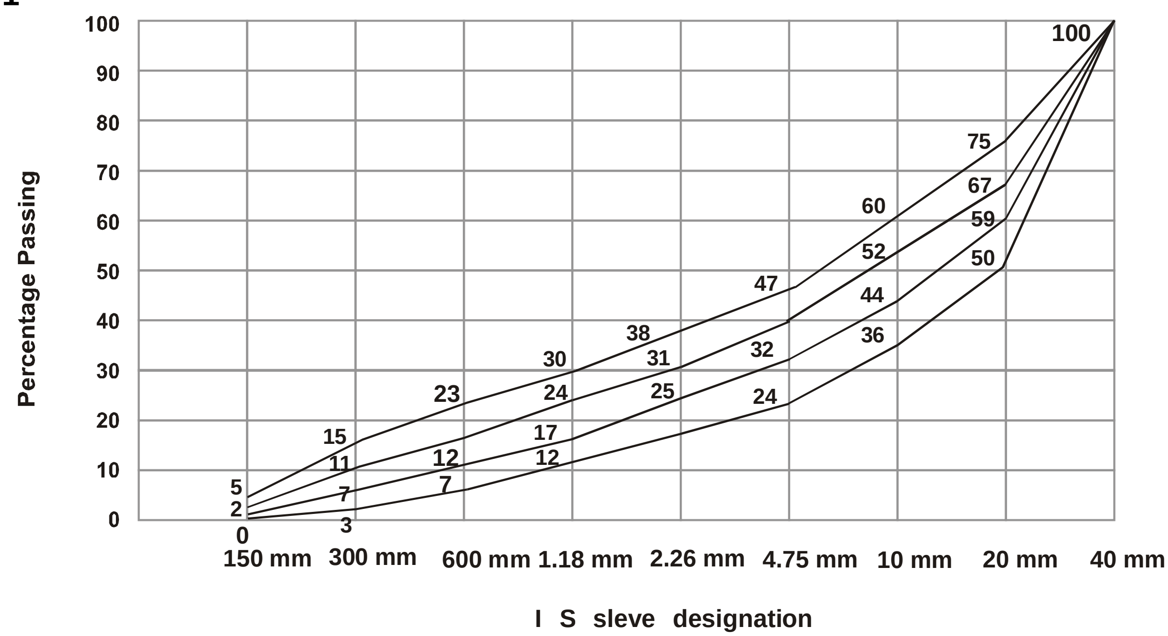
Table 7

Values of Absorption of Water by Aggregate

Type of aggregate	Time	Absorption, percent					
		Particle Size, *IS* sieve designation					
		600 to 300 - µm	1.18 mm to 600 - µm	2.36 to 1.18 mm	4.75 to 2.36 mm	10 to 4.75 mm	20 to 10 mm
Rounded	10 min	1.7	2.0	1.9	1.6	1.2	0.5
Gravel	24 hr.	1.9	2.2	2.2	2.0	1.5	0.8
Irregular	10 min	0.4	1.1	2.0	2.8	3.2	1.4
Gravel	24 hr.	0.5	1.3	2.4	3.4	3.7	1.9
Crushed Rock	10 min	1.1	1.2	1.2	0.9	0.6	0.3
granite	24 hr.	1.1	1.3	1.3	1.0	0.7	0.4

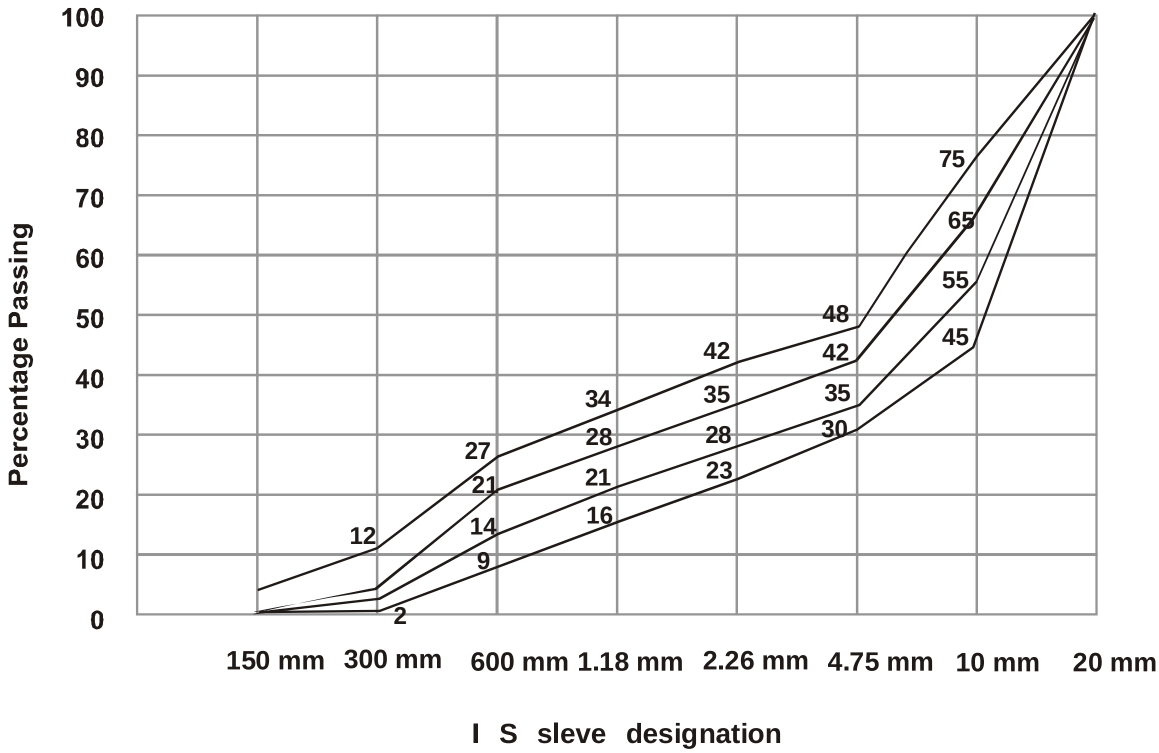
Source: Concrete Mix Design by J. D. McIntosh.

Fig-1



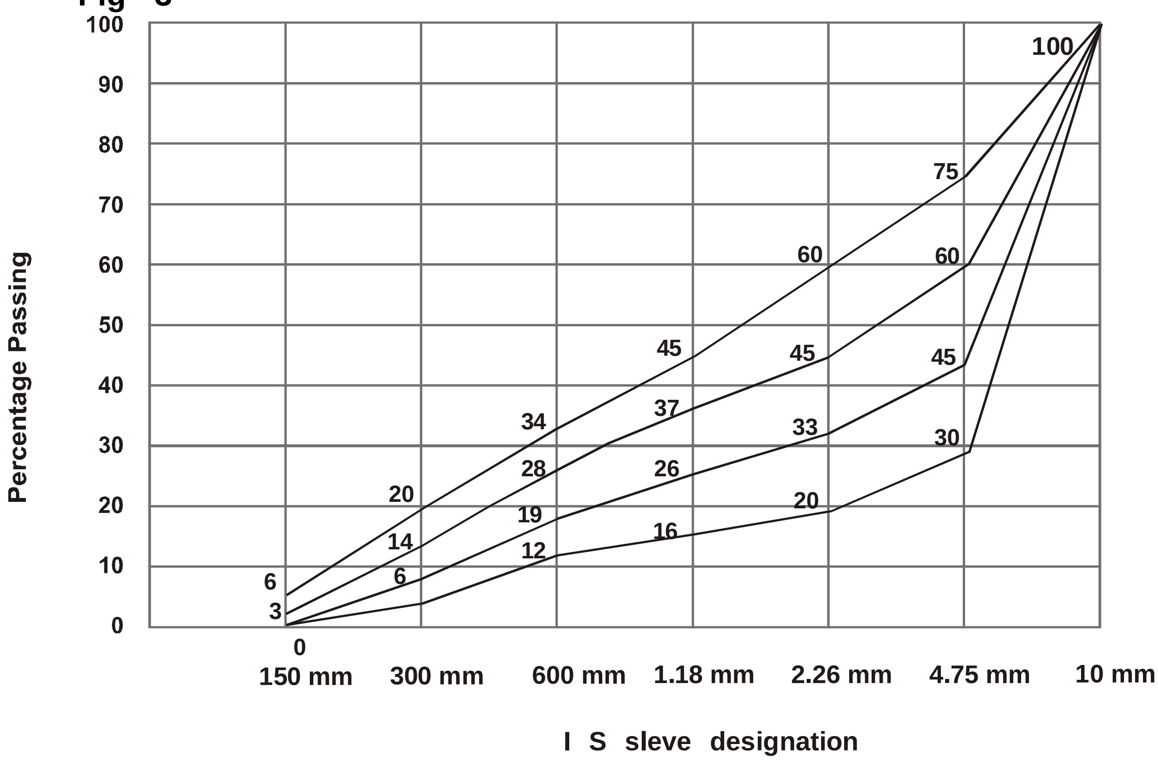
Grading curves for 40-mm maximum size of aggregate

Fig – 2



Grading curves for 20-mm maximum size of aggregate

Fig - 3



Grading curves for 10-mm maximum size of aggregate

Annexure VI

References from IS 456: 2000

Table 1 : **Acceptance criteria for compressive strength of concrete.**

Specific 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 nearest 0.5 N/mm^2 or f_{CK} + 2 N/mm^2, whichever is greater	$\geq f_{CK}$ -2 N/mm2
M 20 Or above	$\geq f_{CK}$ + 0.825 x established standard deviation (rounded off to nearest 0.5 N/mm^2 or f_{CK} + 3 N/mm^2, whichever is greater	$\geq f_{CK}$ - 3 N/mm2

Source: (Table 11 Page 30 IS 456-2000)

Note: In the absence of established value of standard deviation, the values given in Table 8 may be assumed, and attempt should be made to obtain results of 30 samples as early as possible to establish the value of standard deviation.

Source : Characteristic Compressive Strength Compliances Requirement
(Clauses 16.1 and 16.3)

Table 2: Surface moisture in sand

Sr. No.	Aggregate	Approximate Quantity of Surface Water	
		Percent by Mass	l/m^3
i)	Very wet sand	7.5	120
ii)	Moderately wet sand	5.0	80
iii)	Moist sand	2.5	40
iv)	Moist gravel or crushed rock	1.25 – 2.5	20 - 40

Source: Table 10 Surface Water Carried by Aggregate (Clause 10.2.5 IS 456-2000)

Table 3

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

Sr no	Exposure	Plain concrete			Reinforced concrete		
		Min cement content Kg/m^3	Max free w/c ratio	Min grade of concrete	Min cement content Kg/m^3	Max free w/c ratio	Min grade of concrete
1	Mild	220	0.60	-	300	0.55	M 20
2	Moderate	240	0.60	M 15	300	0.50	M 25
3	Severe	250	0.50	M 20	320	0.45	M 30
4	Very severe	260	0.45	M 20	340	0.45	M 35
5	Extreme	280	0.40	M 25	360	0.40	M 40

1. Concrete mix proportioning (Ref: IS 456 2000 Point no.9 Page No. 22)

1.1 Mix Proportion

The mix proportions shall be selected to ensure the workability of the fresh concrete and when concrete is hardened, it shall have the required strength, durability and surface finish.

1.1.1 The determination of the proportions of cement, aggregates and water to attain the required strengths shall be made as follows:

a) By designing the concrete mix; such concrete shall be called ‘ Design mix concrete’, or

b) By adopting nominal concrete mix; such concrete shall be called ‘Nominal mix concrete.’

Design mix concrete is preferred to nominal mix. If design mix concrete cannot be used for any reason on the work for grades of M 20 or lower, nominal mixes may be used with the permission of engineer-in-charge, which, however, is likely to involve a higher cement content.

(Source: Clause 9 from IS 456 Page No.22)

2. Production of concrete – Quality Assurance Measures
(As recommended by IS 456 – 2000)

In order that the properties of the completed structures are consistent with the requirements and the assumptions made during the planning and the design, adequate quality assurance measures shall be taken. The construction should result in satisfactory strength, serviceability and long term durability so as to lower the over all life cycle cost. Quality assurance in the construction activity relates to proper design, use of adequate materials and components to be supplied by the procedures, proper workmanship in the execution of works by the contractor and ultimately proper care during the use of structure including timely maintenance and repair by the owner.

Quality assurance measures are both technical and organizational. Some common cases should be specified in general Quality Assurance Plan which shall identify the key elements necessary to provide fitness of the structure and measured with the overall purpose to provide confidence that the realized project will work satisfactorily in service fulfilling intended needs. The job of quality control and quality assurance would involve quality audit of both inputs as well as the outputs. The inputs are in the form of materials for concrete; workmanship in all stages of batching, mixing, transportation, placing compaction and curing; and the related plant, machinery and equipments; resulting in the output in the form of concrete in place. To ensure proper performance, it is necessary that each step in concreting which will be covered by the next step is inspected as the work proceeds.

Each party involved in the realization of a project should establish and implement a Quality Assurance Plan, for its participation in the project. Supplier's and sub contractor's activities shall be covered in the plan. The individual Quality Assurance Plan. Quality Assurance Plan shall define the tasks and responsibilities of persons involved, adequate control and checking procedures, and the organization and maintaining adequate documentation of the building process and its results. Such documentation generally includes:

a) Test report and manufacturer's certificate for materials, concrete mix design details;
b) Pour cards for site organization and clearance for concrete placement.
c) Record the site inspection of workmanship, field test;
d) Non-conformance reports, change orders;
e) Quality control charts and
f) Statistical analysis.

(Source: Point no.10 from Is 456 –2000 Page No.23)

3. Batching of Concrete

To avoid confusion and error in batching, consideration should be given to using the smallest practical number of different concrete mixes on any site or in any one plant. In batching concrete, the quantity of both cement and aggregate shall be determined by mass; admixture, if solid, by mass; liquid admixture may however be measured in volume or mass; water shall be weighed or measured by volume in a calibrated tank. (See also IS 4925) Ready-mixed concrete supplied by ready-mixed concrete plant shall be preferred. For large and medium project sites the concrete shall be sourced from ready-mixed concrete plants or from on site or off site batching and mixing plants.(see IS 4926)

3.1.1 Except where it can be shown to the satisfaction of the engineer-in-charge that supply of properly graded aggregate of uniform quality can be maintained over a period of work, the grading of aggregate should be controlled by obtaining the coarse aggregate in different sizes and blending them in the right proportions when required, the different sizes being stocked-piled for several hours preferably a day before use. The grading of coarse and fine aggregate should e checked as frequently as possible, the frequency for the job being determined by the engineer-in-charge to ensure that the specified grading is maintained.

3.1.2 The accuracy of the measuring equipment shall be within ± 2 percent of the quantity of cement being measured and within ± 3 percent of the quantity of aggregate, admixtures and water being measured.

3.1.3 Proportion/Type and grading of aggregates shall be made by trial in such a way so as to obtain densest possible concrete. All ingredients of the concrete should be used by mass only.

3.1.4 Volume batching may be allowed only where weigh batching is not practical and provided accurate bulk densities of materials to be actually used in concrete have earlier been established. Allowance for bulking shall be made in accordance with IS 286 (Part 3). The mass volume relationship should be checked as frequently as necessary, the frequency for the given job being determined by engineer-in-charge to ensure that the specified grading is maintained.

3.1.5 It is important to maintain the water-cement ratio constant at its correct value. To this end, determination of moisture contents in both fine and coarse aggregates shall be made as frequently as possible, the frequency of given job being determined by the engineer-in charge according to weather conditions. The amount of added water should be adjusted to compensate for any observed variations in the moisture content in the aggregates, IS 2386 (Part III) may be referred to. To allow the variation in mass of aggregate due to variation in their moisture content, suitable adjustments in the masses of aggregates shall also be made. In the absence of exact data, only in the case of nominal mixes the amount of surface water may be estimated from the values given in Table 10.

3.1.6 No substitutions in material used on the work or alterations in the established proportions, except as permitted in 10.2.4 and 10.2.5 shall be made without additional tests to show that the quality and strength of concrete are satisfactory.

4. Stripping Time for form work:

Forms shall not be released until the concrete has achieved strength of at least twice the stress to which the concrete may be subjected at the time of removal of formwork. The strength referred to shall be that of concrete using the same cement and aggregates and admixtures, if any, with the same proportions and cured under conditions of temperature and moisture similar to those existing on the work.

	Type of Formwork	Minimum Period Before Striking Formwork
a)	Vertical formwork to columns, walls, beam	16 – 24 h
b)	Soffit formwork to slabs (Props to be refixed immediately after removal of formwork)	3 days
c)	Soffit formwork to beams (Props to be refixed immediately after removal of formwork)	7 days
d)	Props to Slabs: 1) Spanning up to 4.5m 2) Spanning over 4.5 m	 7 days 14 days
e)	Props to beams and arches: 1) Spanning up to 6 m 2) Spanning over 6 m	 14 days 21 days

(*Source*: Page 25 IS 456 2000)

Annexure VII

IS Requirements for Cement and Water

IS Requirements for Cement

Compressive strength			
	33 Grade	43 Grade	53 Grade
3 days (N/mm^2)	16	23	27
7 days (N/mm^2)	22	33	37
28 days (N/mm^2)	33	43	53

Fineness: By Blaine's air permeability	
For OPC and Portland Slag	Minimum 2250 cm2/gm
For PPC Fly ash based	Minimum 3000 cm2/gm

Setting time	
Initial setting time	Minimum 30 minute
Final setting time	Maximum 600 minute

Soundness	
By Le-Chatlier's method	Maximum 10 mm
By Auto Clave method	Maximum 0.8 %

IS Requirements for Water

Test Description	Acceptance Criteria	Test Method
Total suspended solids	2000 mg/lit	IS 3025 (Part 17) – 1984
Organic solids	200 mg/lit	IS 3025 (Part 18) – 1984
Inorganic solids	3000 mg/lit	IS 3025 (Part 18) – 1984
Sulphates	400 mg/lit	IS 3025 (Part 24) – 1986
Chlorides	500 mg/lit (For RCC) 2000 mg/lit (For PCC)	IS 3025 (Part 32) – 1988
pH	Not less than 6	IS 3025 (Part 11) – 1983
To neutralize 100 ml sample using Phenolphthalein indicator 0.02 Normal, NaOH required	5 ml.	IS 3025 (Part 22) – 1984
To neutralize 100 ml sample using Methyl orange indicator 0.02 Normal, H_2SO_4 required	25 ml.	IS 3025 (Part 23) – 1984