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Concrete mix proportioning as per IS 10262:2009 – Comparison with IS 10262:1982 and ACI 211.1-91

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The Bureau of Indian Standards (BIS) has released the final code on concrete mix proportioning in December 2009. Before this, the draft code was circulated among practitioners. Significant changes have been made in the new code adapting from international codes on concrete mix design. The new code can now be used for designing a variety of concrete mixes using both mineral and chemical admixtures. With this code RMC having high degree of workability facilitating pumping can also be designed. In this paper an effort has been made to examine the major differences between BIS and the American Concrete Institute (ACI) methods of concrete mix design. Using both these methods, step-by-step procedure for calculating the ingredients is given. The difference between the old BIS (IS 10262:1982) and new BIS (IS 10262:2009) is also highlighted.

Mix design is a process of specifying the mixture of ingredients required to meet anticipated properties of fresh and hardened concrete. Concrete mix design is a well established practice around the world. Adapting from developed countries, many developing countries have standardised their concrete mix design methods.[1] These methods are mostly based on empirical relations, charts, graphs, and tables developed through extensive experiments and investigations using locally available materials.[2] Some of the prevalent concrete mix designs are: (a) ACI (American Concrete Institute) Mix Design Method, (b) USBR (United States Bureau of Reclamation) Mix design practice, (c) British Mix Design Method, and d) BIS (Bureau of Indian Standards) Recommended guidelines.[3]

The concrete mix design methods used in countries such as, Britain, India and USA are based on similar basic principles and empirical relations, developed after substantial experiments on locally available materials, yet some minor differences exist.[3]

This paper examines the similarities and differences between the ACI and BIS concrete mix designs.[4,5,6,7] The studies shows that design calculations for aggregates content, cement content, and water cement (w/c) ratio are different in these methods. In the ACI method, sand content is calculated after calculating coarse aggregate content, while in the old BIS method the process is other way around.[5] However, in the new BIS, coarse aggregate calculation sequence follows the ACI method.[6] The results show that old BIS code consumes more cement content when generalised w/c curve is used. It is due to the relatively low grade of cement available at that point of time in India and also due to the limited research data. The ACI mix design method results in a higher w/c ratio. Although in both the methods, the sand content decreases as the strength requirement increases, a lower sand content in the old BIS method differentiates it from the ACI mix design method.

The IS 10262:2009 is an adaption of ACI method. It requires a designer to develop the w/c curve for the type of materials to be actually used to form the basis for the mix design rather than using any available curves. In the absence of such a data, the w/c ratio is to be assumed based on such available relationship as already established to start the process. Table 5 of IS 456:2000 can also be used to select the w/c ratio.[8] It means one should be careful while selecting the initial w/c ratio, as it decides the calculated cement content. For example, for an M20 concrete mix, one can assume w/c as 0.5 or 0.55 to start with and accordingly cement content will vary. The scope of this study is to compare BIS and ACI recommended mix design guidelines. The calculation processes in the two codes are summarised by illustrating the design steps. A typical M20 mix design is presented using these methods. Table 1 shows the basic data used in illustrating the methods.

Table 1. Basic data used in the old and new BIS and ACI mix design methods

Parameter	BIS Method Old [IS 10262:1982]	BIS Method New [IS 10262:2009]	ACI Method [ACI 211.1]
Characteristic compressive strength at 28 days	yes	yes	yes
Standard deviation of compressive strength	yes	yes	yes
Degree of workability	Compacting factor	Slump	Slump
Type and maximum size of aggregates	yes	yes	yes
Nominal maximum size of coarse aggregates (NMSA)	yes	yes	yes
Dry rodded unit weight of coarse aggregates (DRUW)	no	yes	yes
Fine aggregates (sand)	Grading zone	Fineness modulus (FM), Zone	Fineness modulus (FM)
Specific gravity of cement, coarse and fine aggregates	yes	yes	yes
Water absorption and moisture content adjustment	yes	yes	yes
Type of construction	yes	yes	yes
Exposure condition	no	yes	yes
Air/Non-air entrainment	no	no	yes
Superplasticiser, mineral admixtures	no	yes	yes

Salient feature of new BIS approach (IS 10262:2009)

The new code explains the mix proportioning procedure using a typical mix design problem. Table 1 shows that the basic data required for new BIS method is similar to that of the ACI method of mix design. The new BIS is applicable to ordinary and standard concrete grades only.[6] The durability requirements, limitations on w/c ratio and maximum cement contents are as per IS 456:2000. The requirements for selecting w/c ratio, water content and estimating coarse aggregate content and fine aggregate content have been modified accordingly. Considering that the air content in normal concrete (non air entrained concrete) is not of much significance, the consideration of air content has been deleted. The air content is not part of IS 456:2000 either.

The old BIS method (IS 10262:1982)

The BIS recommends designing mixes based on locally available cement and other materials.[5] These guidelines are applicable for normal concrete (less than about 45 MPa) mix design. Use of gap graded aggregates, various admixtures, and pozzolana was beyond the scope of this specification. The design steps for mix proportioning were as under :

1. The target average compressive strength (f'_{ck}) at 28 days was determined by using equation 1:

$$f'_{ck} = f'_{ck} + ks \qquad ......(1)$$

where,

f_{ck} = characteristic compressive strength at 28 days,

s = standard deviation of compressive strength,

t = a statistic, depending upon the accepted proportion of low results and the number of tests.

2. The water cement (w/c) ratio was chosen from an empirical relationship (generalized graph or graphs based on the strength of cement or accelerated strength of concrete) for the given 28-day target mean strength. The w/c ratio was checked against the limiting w/c ratio to satisfy the durability requirements.

3. Air content, amount of entrapped air in fresh concrete, as percentage of volume of concrete, was estimated based on the nominal maximum size of aggregate (NMSA).

4. Initially, water content, as mass (kg) per unit volume (m^3) of concrete, was selected based on the target

strength. Then, the initially determined water content was adjusted for workability conditions depending upon the compacting factor and types of aggregates.

5. Sand content, as percentage of total aggregate volume, was selected based on the NMSA and the target strength. Then, the initially determined sand content was adjusted for workability conditions depending upon the sand grading zone, w/c ratio, and type of aggregates.

6. The cement content was calculated from the w/c ratio and the water content. The cement content, thus calculated, was then checked against the minimum cement content to satisfy the durability requirement.

7. With the quantities of water and cement per unit volume of concrete and the percentage of sand in the total aggregate already determined, the coarse and fine aggregate contents per unit volume of concrete was calculated from the following equations, respectively:

Calculation for C.A. & F.A

$V = [\ W + (C/S_c) + (1/p)\ .\ (f_a/S_{fa})\ ] \times (1/1000)$

$V = [\ W + (C/S_c) + \{1/(1\text{-}p)\}\ .\ (ca/S_{ca})\ ] \times (1/1000)$

where,

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

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

C = mass of cement (kg) per m^3 of concrete

S_c = specific gravity of cement,

(p) = Ratio of fine aggregate to total aggregate by absolute volume,

(f_a), (c_a) = total mass of fine aggregate and coarse aggregate (kg) per m^3 of concrete respectively,

and S_{fa} , S_{ca} = specific gravities of saturated surface dry fine aggregate and coarse aggregate respectively.

8. Finally, water content was adjusted based on the absorption and the current moisture content to generate equivalent of saturated surface dry condition of the aggregates.

ACI Method

In 1991, the American Concrete Institute (ACI) published guidelines for normal, heavyweight and mass concrete mix design. The Absolute Volume Method of mix design as described by ACI Committee 211 is presented:[5]

1. The required (target) average compressive strength (f'_{cr}) at 28 days for mix design is determined by adding up an empirical factor (k) to the design compressive strength (f'_c) as per equation 2:

$$f'_{cr} = f'_c + k \qquad ......(2)$$

2. The W/C ratio is selected based on the target strength and the type of concrete (air-entrained or non air-entrained).

3. Air content, as percentage of the concrete volume, is estimated depending upon the air-entrained or non-air-entrained type of concrete, exposure conditions, and NMSA.

4. Slump, as measure of workability, is selected depending upon the type of structure and complexity of the pouring conditions.

5. Water content, is determined based on the NMSA, type of concrete (air-entrained or non-air entrained), and specified slump. Then it is adjusted for the types of aggregates.

6. Cement content, is calculated based on the w/c ratio and the water content.

7. Coarse aggregates content, as dry rodded bulk (percentage) of concrete unit volume, is determined based on the NMSA, and the fineness modulus of sand.

8. Once the water content, cement content, air content, and the coarse aggregate content per unit volume of the concrete is determined, the fine aggregate (F_{agg}) is calculated by subtracting the absolute volume of the known ingredients from unit volume of the fresh concrete (in this case 1 m^3) as following:

$$F_{agg} = 1 - X \qquad ......(3)$$

where, X = sum of all other ingredients (air, water, cement and coarse aggregates) in cubic meter calculated for 1 m^3 of concrete.

9. Finally, water content is adjusted based on the absorption and the current moisture content of the coarse and fine aggregates, in account of saturated surface dry condition of the aggregates.

Similarities of BIS (old and new) and ACI mix design process

Both these methods are based on the empirical relations. These relations are derived from extensive experiments done with the locally available materials. Thus, both methods extensively use tables and graphs and follow logical determination of the ingredients by establishing the targeted strength for trial batch. Trial batch strength is derived from the required design strength of the structural concrete and statistical analysis, ensuring that the mix design meets or exceeds the design strength. Once the target mix design strength is established, both methods determine the w/c ratio. It is common in both methods that the cement content is calculated based on the relationships of two parameters; the w/c ratio and the cement content. Both of these parameters are checked against the limiting values in order to ensure compliance with durability conditions.

Differences of BIS and ACI mix design process

The following are the major differences in the design process.

Target strength: The BIS and ACI methods use Equation (1) and Equation (2) respectively to determine the target average compressive strength. Although both methods utilise standard deviation to calculate the target strength, techniques of calculation is not the same. When sufficient data are not available to establish standard deviation, the ACI method recommends empirical values to determine the target calculating strength. On the other hand, the old BIS method suggests the value of standard deviation to be based on the quality control. In the new BIS method, standard deviation is to be calculated separately for each grade of concrete. The procedure for doing this is discussed. When sufficient test results for a particular grade of concrete are not available, the value of standard deviation given in Table 1 of the code may be assumed for the first trial mix.

Measure of workability: The old BIS Method uses the compacting factor as a measure of workability, whereas the new BIS and ACI use the slump.

W/C Ratio: In the ACI method, w/c ratio is determined in combination with the target strength and the type of concrete (air/non-air entrainment). Although, old BIS method discuss the air entrainment, the selection of w/c ratio in this method is a function of target strength. w/c specific curves are given for different cements based on their strengths. Generalized w/c curve is also proposed. However, the new BIS suggests that the w/c curve be developed based on the type of materials to be used in the project. Alternatively, the w/c values given in IS 456:2000 based on durability conditions can also be used to start with the mix design.

Water content: The old BIS method determines the water content based on target strength, type of aggregates, Nominal maximum size of aggregate (NMSA) and compacting factor. Different tables are given for medium and high strength concretes. In the case of the ACI method, water content is dependent on air-entrainment, types of aggregates, slump, and NMSA. However, water content can be determined independent of target strength, whereas in the old BIS method, target strength influences the water content. The new BIS is similar to ACI method wherein a table for maximum water content per cubic meter of concrete for nominal maximum size of aggregate (Clauses 42, A-5 and B-5) is given.

Coarse and fine aggregate content: In the ACI method, coarse aggregate content is determined without knowing the absolute volume of fine aggregates. Contrary to the ACI method, the old BIS method determines the fine aggregate content, as percentage of total aggregate by absolute volume, first, and the coarse aggregate content is then determined once the proportion of all other ingredients are known. In the new BIS method, sand grading zones are used as the governing parameter for sand content determination, whereas the fineness modulus is used in the ACI method for selecting the bulk volume of dry rodded coarse aggregate. The old BIS method does not utilise fineness modulus and dry rodded unit weight of aggregates. The new BIS procedure is same as that of ACI method, wherein the volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate (Clause 4.4 and A-7) is calculated based on maximum size of aggregate.

The authors have published work on proportioning of normal and high strength concrete using the provisions of draft code IS 10262 and other methods using cement as well as supplementary cementitious materials elsewhere.[9-13]

Numerical example of the mix design

The procedure for designing concrete mix as per new code is highlighted using an M20 concrete. This mix is designed using both the new BIS and ACI methods.

Design stipulations for proportioning

a. Grade designation : M20

b. Type of cement : OPC 43 grade, IS 8112

c. Max. nominal size of agg. : 20 mm

d. Minimum cement content: 320 kg/m^3

e. Maximum water cement ratio : 0.55

f. Workability : 75 mm (slump)

g. Exposure condition : Mild

h. Degree of supervision: Good

i. Type of agg. : Crushed angular agg.

j. Maximum cement content : 450 kg/m^3

k. Chemical admixture : Not used

Test data for materials

i. Cement used : OPC 43 grade

ii. Specific gravity of cement : 3.15

iii. Specific gravity of

a. Coarse aggregate : 2.68

b. Fine aggregate : 2.65

iv. Water absorption

a. Coarse aggregate : 0.6 percent

b. Fine aggregate :1.0 %

v. Free (surface) moisture

a. Coarse aggregate : Nil (absorbed moisture full)

b. Fine aggregate : Nil

vi. Sieve analysis

a. Coarse aggregate : Conforming to Table 2 of IS 383

b. Fine aggregate : Conforming to Zone I of IS 383

Target strength for mix proportioning

$f'_{ck} = f'_{ck}$ +ks

From Table 1 standard deviation, s = 4 N/mm^2

Therefore target strength = 20+1.65 x4 = 26.60 N/mm^2

Selection of w/ c ratio

From Table 5 of IS 456:2000, maximum water cement ratio = 0.55 (Mild exposure)

Based on experience adopt water cement ratio as 0.50

0.5 < 0.55, hence ok

Selection of water content

From Table 2, maximum water content = 186 litres (for 25 mm – 50 mm slump range and for 20 mm aggregates)

Estimated water content for 75 mm slump
= 186 + 3/100 x 186 = 191.6 litres

Calculation of cement content

Water cement ratio = 0.50

Cement content = 191.6/0.5

=383 kg/m^3 >320 kg/m^3(given)

From Table 5 of IS 456, minimum cement content for mild exposure condition = 300 kg/m^3, Hence OK

Proportion of volume of coarse aggregate and fine aggregate content

From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60

Mix calculations

The mix calculations per unit volume of concrete shall be as follows

a) Volume of concrete = 1 m^3

b) Volume of cement
= mass of cement/specific gravity of cement x 1/1000
= [383.16/3.15] x [1/1000] = 0.122 m^3

c) Volume of water = [192/1] x [1/1000] = 0.192 m^3

d) Volume of all in aggregates (e)
= a – (b + c)
= 1 – (0.122 + 0.192) = 0.686 m^3

e) Volume and weight of coarse aggregates
Volume = 0.686 x 0.6 = 0.412 m^3
Weight = Volume of CA (0.412 m^3) x specific gravity (2.68) of CA = 1103 kg

f) Volume and weight of fine aggregates
= e x Volume of FA (0.274 m^3) x specific gravity of FA
Volume = 0.686 x 0.4 = 0.274 m^3
Weight = Volume of FA (0.274 m^3) x specific gravity (2.65) of FA x 1000 = 727 kg

Mix proportions for trial number 1

Cement = 383 kg/m^3
Water = 191.6 kg/m^3
Fine aggregate = 727 kg/m^3
Coarse aggregates = 1103 kg/m^3
Water cement ratio = 0.50
Yield = 2404.6 kg

Aggregates are assumed to be in Saturated-Surface-Dry (SSD). Otherwise corrections are to be applied while calculating the water content. Necessary corrections are also required to be made in mass of aggregates.

ACI method of concrete mix design

Design M20 concrete based on the provisions of ACI 211.1 for the following data

Dry rodded density of coarse aggregate = 1640 kg/mm^3. All other details remain same. The details of the mix design is as follows,

The seven steps, which are laid down in ACI211.1-9 for concrete mix design, are briefly described below as implemented in First mix:

Step 1. Choice of Slump

75 mm, range 25-75 category

Step 2. Choice of Maximum Size of Aggregate

20 mm, From Table the MAS= 19 mm

Step 3. Estimation of Mixing Water and Air Content

W=205 l and entrapped air = 2%

Step 4. Selection of Water/Cement or Water/ Cementitious Materials Ratio

For target strength of 26.6 MPa, w/c from Table of ACI 211.1 = 0.58. This is limited to 0.55 from durability (BIS requirement for mild exposure).

Step 5. Calculation of Cement Content

W_C= Water/0.55 = 372.2 kg, therefore

V_c = 372/3.15 = 0.118

Steps 6 & 7. Estimation of Coarse Aggregate and Fine Aggregate Contents

W_{ca}=0.6 x1640 = 984 kg/m^3

V_{ca} = 984/[2.68 x 1000] = 0.367

V_{fa} = 1-0.118-0.205-0.367-0.002 = 0.308

W_{fa} = 0.308 x 1000 x 2.65 = 816kg

Yield = 372 + 205 + 984 + 816 = 2377 kg

Conclusions

Based on the analysis of the above methods of mix design, following conclusions can be drawn:

1. The mix design as per IS 10262:2009 is in line with ACI 211.1. The code permits the use of supplementary materials such as chemical and mineral admixtures.
2. Provisions of IS 456:2000 are applicable for durability requirements with all types of exposure.
3. The flowing concrete for RMC applications can be designed. The code illustrates this with an M40 concrete with and without fly ash.
4. A typical mix design (first mix) for commonly used M20 grade is illustrated in the paper based on the properties of the ingredients using the new BIS and ACI methods.
5. The fine aggregate content in ACI method is higher compared to new BIS method. Coarse aggregate is substantially more with BIS method. Thus, ACI mix will lead to higher workability. Presumably, it would also contribute to increased strength as the voids are filled by fine aggregate. In the case of BIS, fine aggregate content is reduced as the design strength requirement goes up. Therefore voids are likely to be higher for high strength concrete which may lead to decreased strength in such cases. These observations are to be verified by actual tests. Experimental work is in progress for better understanding of the procedure as per new code.

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