COMPARISON OF METHODS OF MIX DESIGN(ISI &ACI)AS PER IS 10262:2009 AND ACI 211.1-91

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ABSTRACT

Concrete for civil construction works, being a prime component has many applications owing to its properties. As the main component of any construction concrete is used. It is generally designed by IS method in India but comparatively in other countries various methods for mix design are adopted. Use of mix designed concrete has mainly increased in this era as it contributes more strength with minimum utilization of materials especially cement. In this research the use of ACI method of mix design has proven to be better than IS methods in almost all aspects, mainly economy, strength & time consumption.

The paper deals with the comparative study of IS & ACI methods for mix design.

1. INTRODUCTION

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. All developed countries, as well as many developing countries, have standardized their concrete mix design methods. These methods are mostly based on empirical relations, charts, graphs, and tables developed as outcomes of extensive experiments and investigations of locally available materials. All of those standards and methods follow the same basic trial and error principles. Some of the prevalent concrete mix design methods are: a) ACI Mix Design Method, b) USBR Mix design practice, c) British Mix design Method, and d) ISI Recommended guidelines. The scope of this study is to compare ACI and ISI recommended mix design guidelines. A major part of concrete used in rural and semi-urban areas in India falls in the range of 15 - 40 MPa. Therefore, similar ranges of concrete strengths are widely applicable in both India and USA. The scope of this paper is limited to absolute volume and concrete mix design for compressive strengths less than 40 MPa. In order to compare the two methods, calculation processes are briefly summarized, flow charts are made to illustrate the design steps, and sample tests are performed with the two techniques to produce 20, 30, and 40 MPa concrete. Basic data used in both methods is illustrated in Table 1 below:

TABLE 1: Basic data used in the ISI and ACI Mix Design Methods

Parameter	ISI Method	ACI Method
Characteristic compressive strength at 28 days	Yes	Yes
Standard deviation of compressive strength	Yes	Yes

Type and maximum size of aggregates	Yes	Yes
Degree of workability	Slump	Slump
Dry rodded unit weight of coarse aggregates	No	Yes
Fine aggregates (sand)	Fm(zone)	Fm
Specific gravity of cement, coarse and fine aggregates	Yes	Yes
Water absorption and moisture content adjustment	Yes	Yes
Type of construction	Yes	Yes
Exposure condition	No	Yes
Air/Non-air entrainment	No	Yes

THE ISI METHOD (10262:2009)

The BIS recommends designing mixes based on locally available cement and other materials. 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:

$f'ck = fck + 1.65s$ .... (1)

Where,

f'ck = Target average compressive strength at 28 days,

fck = characteristic compressive strength at 28 days,

s = standard deviation of compressive strength.

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. Table-5 of IS 456-2000 suggest the maximum value of w/c ratio. Least w/c ratio is selected.

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 .

4. Initially, water content, as mass (kg) per unit volume (m3) 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. 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.

6. Volume of coarse aggregate is found out from Table 3 according to size of the aggregate and zone. Correction should be done as per w/c ratio.

Volume of sand is estimated by deducting the volume of coarse aggregate from one(1).

7. Volume of cement , water and total aggregate is found out using following formulas:

a)Volume of Cement=Mass of cement x 1
SG of cement 1000

b)Volume of water = Mass of water x 1

SG of water 1000

Total volume of Aggregate = [1-(a+b)]

8. With the quantities of water, cement per unit volume of concrete and volume of coarse aggregate, mass of coarse and fine aggregate is found out using its specific gravity by using given formula:

Mass of Coarse Agg = volume of Coarse Agg x total volume of agg x specific gravity x 1000

Mass of Fine Agg = volume of Fine Agg x total volume of agg x specific gravity x 1000

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:

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. Determine the slump h required for the condition of placing. A concrete of the stiffest consistency (lowest slump) which can be placed efficiently to provide a homogenous mass should be used.

3. Determine the maximum size of the aggregate that is available and consistent with satisfactory placing of concrete

4. Determine the water content, for obtained values of slump and maximum size of aggregate.

5Select the water-cement ratios from consideration of characteristics compressive strength. Similarly for durability maximum the maximum permissible w/c ratio range from about 0.45 to 0.55 for reinforced concrete structure.

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 nominal maximum size of aggregate, 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 (*Fagg*) is calculated by subtracting the absolute volume of the known ingredients from unit volume of the fresh concrete (in this case 1 m3) as following:

$$Fagg=1-X \qquad ......(3)$$

where, X = sum of all other ingredients (air, water, cement and coarse aggregates) in cubic meter calculated for 1 m3 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 IN ISI 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 IN ISI AND ACI MIX DESIGN PROCESS

The following are the major differences in the design process.

Target strength: The ISI and ACI methods use Equation (1) and Equation (2) respectively to determine the target average compressive strength. Although both methods utilize 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 ISI method suggests the value of standard deviation to be based on the quality control. 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.

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, ISI 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 ISI 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 ISI method, target strength influences the water content.

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 ISI method determines the fine aggregate content by, sand grading zones 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 ISI method does not utilise fineness modulus and dry rodded unit weight of aggregates. Whereas the fineness modulus is not used in ISI method.

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 ISI and ACI methods.

ISI METHOD

A. Design stipulations for proportioning

a. Grade designation : M20

b. Type of cement : OPC 43 grade, IS 8112 with 28 days strength of 51 Mpa

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

d. Minimum cement content: 300 kg/m3

e. Maximum water cement ratio: 0.55

f. Workability: 100 mm (slump)

g. Exposure condition: Mild

h.Method of Concrete Placing :Hand placing

i. Degree of supervision: Good

i. Type of agg. : Crushed angular agg.

k. Maximum cement content : 450 kg/m3

l. Chemical admixture: Not used

B. Test data for materials

i. Cement used : OPC 43 grade

ii. Specific gravity of cement : 3.15

iii. Specific gravity of

a. Coarse aggregate : 2.82

b. Fine aggregate: 2.64

iv. Water absorption

a. Coarse aggregate: 0.5 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 II of IS 383

C. Target strength for mix proportioning

$f'ck = fck + ks$

From Table 1 standard deviation, s = 4 N/mm2

Therefore target strength = 20+1.65 x4 = 26.60 N/mm2

D. Selection of w/ c ratio

From Table 5 of IS 456:2000, maximum water cement

ratio = 0.55 (Mild exposure)

From Graph = 0.56

Given in Data = 0.55

Least w/c ratio is selected.

Adopt w/c ratio as 0.55

0.55 < 0.56 , hence ok

E. Selection of water content

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

Assuming 6% increase in water content per 50 mm slump.

Estimated water content for 100 mm slump

= 186 + 6/100 x 186 = 197.16 litres Say 197

F. Calculation of cement content

Water cement ratio = 0.55

Cement content = 197/0.55 =358.2 kg/m^3 >300 kg/m3(given)

From Table 5 of IS 456, minimum cement content for mild exposure condition = 300 kg/m3

358.2kg/m^3>300 kg/m^3, Hence OK.

G. 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 II) for water-cement ratio of 0.55 =0.62(Zone II)

Corrected Proportion of volume of coarse Aggregate = 0.61

Volume of Fine Aggregate = 1- 0.61 = 0.39

H. Mix calculations

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

a) Volume of concrete = 1 m3

b) Volume of cement = mass of cement/specific gravity of cement x 1/1000

= [358.2/3.15] x [1/1000] = 0.113 m3

c) Volume of water = [197/1] x [1/1000]

= 0.197 m3

d) Volume of all in aggregates

=[a – (b + c)]

= 1 – (0.113 + 0.197) = 0.690 m3

e) Volume and weight of coarse aggregates

Volume = 0.690 x 0.61 = 0.420 m3

Weight = Volume of CA (0.420 m3) x specific gravity of CA x 1000 = 1186.93 kg

f) Volume and weight of fine aggregates = volume of total agg x Volume of FA (0.269 m3) x specific gravity of FA x 1000

Volume = 0.686 x 0.39 = 0.269 m3

Weight = Volume of FA (0.269 m3) x specific gravity (2.64) of FA x 1000 = 710.42 kg

Mix proportions for trial number 1

Cement = 358.2 kg/m3

Water = 197 kg/m3

Fine aggregate = 710.42 kg/m3

Coarse aggregates = 1186.93 kg/m3

Water cement ratio = 0.55

Proportions:

Cement : Sand : Aggregate : Water

358.2 : 710.42 : 1186.93 : 197

1 : 1.98 : 3.31 : 0.55

ACI method of concrete mix design

Design M20 concrete based on the ACI Method for the following data Dry rodded density of coarse aggregate = 1840 kg/mm3. 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

100mm, range 75-100 category According to type construction.

Step 2. Choice of Maximum Size of Aggregate 20 mm, From Table the MAS= 20 mm

Step 3. Estimation of Water from maximum Size of Aggregate and Slump= 144

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

WC= Water/0.55 = 261.8 kg, therefore

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

Wca=0.6 x1840 = 1104 kg/m3

Vca = 1104/[2.64 x 1000] = 0.41

Vfa = 1-0.118-0.205-0.367-0.002 = 0.308

Wfa = 0.308 x 1000 x 2.65 = 816kg

EXPERIMENTAL ANALYSIS

Concrete Cubes of size 15 cm x15 cm x15 cm were casted in our institutee laboratory. They were tested on Compression testing machine.

The results are tabulated below:

Target Strength	ISI Mpa			ACI Mpa		
	7 days	14 days	28 days	7 days	14 days	28 days
20 MPa	18.36	24.03	27.09	16.28	26.08	29.40
25 Mpa	21.25	34.06	38.39	20	35.09	39.56
30 Mpa	26.67	41.36	46.62	25.63	43.69	49.25

(Note: 28 days strength is obtained from eqn: 14 days strength / 0.887)

Analysis of the Experimental Results

The test results indicate that the ISI 20 MPa design has significantly higher strength than anticipated.

MPa results show that the ISI technique makes for slower strength gain compared to the ACI, in spite of increased cement use, and may not meet the strength requirements, as well. Basic statistical analysis, such as deviation measurement and correlation analysis were undertaken for 28-day compressive strength results.

CONCLUSIONS

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

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.

Provisions of IS 456:2000 are applicable for durability requirements with all types of exposure. The flowing concrete for RMC applications can be designed. The code illustrates this with an M40 concrete with and without fly ash.

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. 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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