Concrete Mix Design for M35 Grade: Comparison of Indian Standard Codes, IS 10262: 2009 & IS 456:2000 with American Code, ACI 211.1-91

Dada S. Patil

Assistant Professor, Civil Engineering Department, Anjuman-I-Islam's Kalsekar Technical Campus, School of Engineering & Technology, Panvel, Navi Mumbai, Maharashtra, India

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Abstract - *A rational & logical Concrete Mix Design to cater to the practical requirements plays a key role in concrete engineering. It is well established fact that the concrete is highly consumed material throughout the world. With the exponentially high demand of infrastructure facilities, the concrete requirement is on a very huge scale. Therefore, using the optimum quantities of concrete making constituent materials is of utmost importance in order to achieve the desired fresh & hardened properties. Owing to an enormous utilization of concrete in day- to-day construction work, economy is a vital factor to be considered. In India, mix design is carried out by following the rules prescribed in IS 10262: 2009 & IS 456:2000. As a well known fact, every country has its own codes to design a concrete mix. In this paper, an attempt has been made to compare the Concrete Mix Design of M35 grade by the American Code; ACI 211.1-91 with Indian codes IS 10262: 2009 & IS 456:2000. The outcomes are critically reviewed & the comments are given.*

***Keywords**: OPC, (w/c) ratio, nominal maximum size of aggregate, workability, slump, target mean strength, etc.*

1. INTRODUCTION

Every country has a peculiar method of carrying out the Concrete Mix Design by following the various clauses, tables & figures given in the codes of that particular country. It is obvious that these codes give important guidelines for designing a concrete mix depending upon the basic properties of constituent materials, behaviour of individual constituent, economy & many other considerations. The guidelines are proposed in such a way that the concrete is workable enough for a particular type of field application when it is in a fresh state; moreover, it caters to the need of desirable strength & durability properties, when hardened. This paper critically compares the Concrete Mix Design of M35 grade carried out by using Indian Standard codes & American code. The vital observations are presented. Conclusions are drawn based on these observations.

2. MIX DESIGN BY USING IS 10262: 2009 & IS 456:2000

2.1 Stipulations for Proportioning

Grade designation: M 35

Type of cement: Ordinary Portland Cement (OPC), conforming to IS: 12269-1987

Maximum nominal size of aggregate:20 mm

Exposure condition considered: Moderate (for Reinforced Concrete)

For moderate exposure condition (from Table 5 of IS 456: 2000)

i) Minimum cement content: 300 kg/m^3

ii) Maximum water-cement ratio: 0.50.

Desired workability: 75 mm (slump)

Type of aggregate: Crushed angular aggregate

Maximum cement content: 450 kg/m^3 (Clause 8.2.4.2 of IS 456: 2000)

2.2 Test Data for Materials

Specific gravity of cement: 3.15

Chemical admixture: NA

Specific gravity of

i) Coarse aggregate: 2.72

ii) Fine aggregate: 2.68

Sieve Analysis (coarse aggregates; 20 mm & 10 mm): Conforming to grading requirements of table 4 of IS 383:1970.

Sieve analysis (Fine aggregates): Conforming to grading Zone I of table 4 of IS 383: 1970.

2.3 Target Strength for Mix Proportioning

$f_{ck}' = f_{ck} + (1.65\ S)$

Where:

f'_{ck} = Target average compressive strength at 28 days.

f_{ck} = Characteristic compressive strength at 28 days.

s = Standard deviation.

From Table 1 of IS 102602: 2009,

Standard deviation (S) = 5 N/mm^2, For M35 concrete

Therefore, target strength $=35 + (1.65 \times 5)$

$= 43.25\ N/mm^2$

2.4 Selection of Water - Cement Ratio & Water Content

From Table 5 of IS 456:2000, maximum water-cement ratio = 0.50

Adopt water-cement ratio as 0.45, since the target strength is 43.25 N/mm^2.

From Table 2 of IS10262:2009, maximum water content = 186 kg (for 25 to 50 mm slump range) for 20 mm aggregates.

As per clause 4.2 of IS 10262:2009, for every increase of slump of 25 mm, the water content has to be increased by 3%.

So, estimated water content for 75 mm slump =

$186 + [\left(\frac{3}{100} \times 186\right)]$

= 191.58 kg/m3

Consider it as 192 kg/m^3

2. 5 Calculation of Cement

Water-cement ratio = 0.45;

Cement content = (192/0.45) = 426.67 kg/m^3.

450 kg/m^3 (max. OPC permitted) > 426.67 kg/m^3 > 300 kg/m^3 (min. cement content). Its complying the requirements.

2.6 Proportion of Volume of Coarse Aggregate & Fine Aggregate Content

From Table 3 of IS 10262: 2009, the volume of coarse aggregates corresponding to 20 mm size aggregates & fine aggregates of Zone I for (w/c) ratio of 0.50 is 0.60 .

(w/c) ratio adopted is 0.45. Therefore, Volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.05, the proportion of volume of coarse aggregate is to be increased by 0.01 (at the rate of -/+ 0.01 for every ± 0.05 change in water-cement ratio).

Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.45 = (0.60 + 0.01) = 0.61.

Volume of fine aggregate content = 1 - 0.61 = 0.39

2.7 Mix Calculations

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

Volume of concrete (a) = 1.0 m^3.

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

= (426.67 / 3.15) X (1/1000) = 0.135 m^3.

Volume of water (c) = (mass of water/ specific gravity of water) X (1/1000)

= (192/1) X (1/1000) = 0.192 m^3.

Volume of all in aggregate (d) = a – (b +c)

= 1 – (0.135 + 0.192) = 0.673 m^3.

Mass of coarse aggregate = (d) X volume of CA X specific gravity of CA X 1000.

= (0.673 X 0.61 X 2.72 X 1000) = 1116.64 kg.

Mass of fine aggregate = (d) X volume of FA X specific gravity of FA X 1000.

= (0.673 X 0.39 X 2.68 X 1000) = 703.42 kg.

Yield of concrete = (426.67 + 192 + 703.42 + 1116.64) = 2438.73 kg/m^3.

2.8 Mix Proportions (kg/m³), at SSD (Saturated Surface Dry) condition of Fine Aggregate & Coarse Aggregate

Table 1: Mix Proportions

Cement	Water	FA	CA	(w/c) ratio
426.67	192	703.42	1116.64	0.45
1	0.45	1.648	2.617	0.45

3. MIX DESIGN BY USING ACI 211.1-91

Let us carry out Mix Design by using ACI code. Let all the material properties be same as that in IS code method. Let dry rodded density of CA be 1640 kg/m³.

American code uses the concept of dry rodded density of CA.

3.1 Choice of Slump

Table 2: Recommended Slumps for various Types of Construction (SI Units)

Types of construction	Slump, mm	
	Maximum*	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	50	25

*May be increased 25 mm for methods of consolidation other than vibration.

Desired slump is 75 mm (25 mm to 75 mm category from table 2).

3.2 Choice of Maximum Size of Aggregate

From table 3, select Max. Aggregate Size = 19 mm, as it is closer to 20 mm size.

3.3 Estimation of Mixing Water & Air Content

From table 3, W=205 litres (i. e. kg) for 19 mm aggregates & entrapped air = 2%.

Table 3: Approximate Mixing Water & Air Content Requirements for Different Slumps & Nominal Max. Size of Aggregates (SI Units)

Slump, mm	Water, kg/m³ of concrete for indicated nominal maximum sizes of aggregate							
	9.5 mm*	12.5 mm*	19 mm*	25 mm*	37.5 mm*	50 mm*†	75 mm†‡	150 mm†‡
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2

3.4 Selection of Water-Cement Ratio

Table 4: Relationship Between (w/c) Ratio & Compressive Strength of Concrete (SI Units)

Compressive strength at 28 days, psi*	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

For target strength of 43.25 N/mm², (w/c) ratio for non-air entrained concrete is 0.54, by interpolation. This is more than the maximum (w/c) ratio of 0.50 for the moderate exposure condition, as given by the Indian Code. If the (w/c) ratio given by ACI method exceeds the maximum limit of 0.50 prescribed by the Indian Standard Code (moderate exposure), the value should be discarded & (w/c) ratio of 0.50 is to be used for further calculations. Though ACI method is used for the Mix Design, the concreting is to be done in India & therefore, the exposure conditions must be considered from the Indian Code from durability point of view. However, if the (w/c) ratio obtained by ACI method is less than the max. limit given by IS code table, it is obvious that the value obtained is to be adopted for further calculations.

3.5 Calculation of Cement Content

Mass of cement, M_C = Water/ {w/c ratio} = (205/0.50) = 410 kg/m³.

Here, the (w/c) ratio is marginally more than that in IS method. It is well established fact that, as the (w/c) ratio increases, the strength shows decline in its value. However, the cement quantity is less than that in IS method. After trial, if the required target strength is achieved & concrete is workable for a given application, it is acceptable.

Volume of cement, V_c = 410/(3.15X1000)=0.130 m^3.

3.6 Estimation of CA & FA Contents

Table 5: Volume of CA Per Unit Volume of Concrete (SI Units)

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

Let us assume that the fineness modulus of FA is 3. The sand confirms to zone I as per IS code. From table 5, for 19 mm nominal max. size of aggregate, volume of dry rodded CA per unit volume of concrete is 0.60.

So, mass of CA, M_{ca} = (0.6 x dry rodded density of CA) = (0.6 X 1640) = 984 kg/m^3

So, volume of CA, V_{ca} = (M_{ca} /Sp. gravity X 1000)

= 984 / [2.72 x 1000] = 0.361 m^3.

Volume of FA, V_{fa} = 1 – (V_c + V_w + V_{ca} + V_{ea})

Here, V_c = cement volume, V_w = volume of water, V_{ca}= volume of CA & V_{ea} = volume of entrapped air (2%).

V_{fa} = 1 - (0.130+ 0.205 + 0.361 + 0.02) = 0.284

Mass of FA, M_{fa} = (0.284 x 1000 x 2.68) = 761.12 kg.

Yield of concrete = (410 + 205 + 984 + 761.12) = 2360.12 kg/m^3.

3.7 Mix Proportions (kg/m³), at SSD (Saturated Surface Dry) condition of Fine Aggregate & Coarse Aggregate

Table 6: Mix Proportions

Cement	Water	FA	CA	(w/c) ratio
410	205	761.12	984	0.50
1	0.50	1.85	2.40	0.50

4. COMPARISON OF IS METHOD & ACI METHOD FOR CONCRETE MIX DESIGN

Table 7: Materials Required kg/m³)

Method	Cement	Water	FA	CA	(w/c) Ratio
IS	426.67	192	703.42	1116.64	0.45
	1	0.45	1.69	2.57	0.45
ACI	410	205	761.12	984	0.50
	1	0.50	1.85	2.40	0.50

4.1 Observations

- The cement content obtained by IS method is 426.67 kg/m^3; whereas, it is 410 kg/m^3 as per ACI method.
- With the same constituent materials, water per m^3, calculated by ACI method is 13 kg (or litres) more than that obtained by IS method.
- Fine Aggregate quantity/m^3 obtained by ACI method is 57.70 kg more than that obtained by IS method.
- Coarse Aggregate quantity/m^3 obtained by ACI method is 132.64 kg less than that obtained by IS method.
- Yield (i. e. density of concrete) is more in IS method of Mix Design.

5. CONCLUSIONS

- Looking at the proportions, it can be said that the Mix design by IS code is in line with that by ACI method.
- From table 4 (ACI method), it can be depicted that (w/c) ratio to be used depends upon the required compressive strength. However, IS code gives the max. limits for free (w/c) ratios depending upon the exposure conditions for plain concrete & RCC work from durability point of view.
- Coarse Aggregates are more in IS method of mix design.
- Fine Aggregates are comparatively more in case of ACI method.
- More quantity of Fine Aggregates, obtained by ACI method, should presumably lead to more workability, owing to the fact that the fine aggregates act as ball bearings & provide lubricating effect to the mix.
- As the Fine Aggregates have the tendency of filling the voids, ACI method should give more strength due to enhanced particle packing.
- From table 5 (ACI method), it can be clearly seen that if the nominal maximum size of CA & fineness modulus of FA are not varied then volume of dry rodded CA per unit volume of concrete is same for any grade of concrete. In such a case, mass of the CA is a function of dry rodded density of CA. If CAs are well graded with all size factions, there will be less voids. This will lead to higher dry rodded density of CA. In ACI method, the mass of CA to be incorporated in concrete is independent of the (w/c) ratio.
- In IS method, as the (w/c) ratio decreases, the volume of CA increases. Vice versa is also true. Less the (w/c) ratio, more will be volume of CA which, in turn, leads to greater mass of CA.
- As the strength requirement increases, the (w/c) ratio lowers & CA content becomes comparatively more in IS method. At the same time, FA content becomes less.
- This sounds contradictory theoretically, because of the possibility that more the CA, more would be the voids, thereby decreasing the strength of the concrete.
- This paper was an attempt of comparing the two methods of Concrete Mix Design by randomly picking up a grade of M35. In doing so, certain modifications were done by manual judgment to fit to the requirements.
- The results obtained just show a general trend in connection with both the methods. The different assumptions & modifications, using experience & manual judgment, while carrying out Concrete Mix Design may lead to somewhat deviating results.
- One has to meticulously carry out Concrete Mix Design by both the methods & conduct a large number of trials in the laboratory for various grades of concrete in order to simultaneously satisfy strength & workability requirements.

REFRENCES

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