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Evaluation of Compressive Strength of Concrete for Aci, Isi & Doe Mix Design Methods.

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ABSTRACT

Different concrete mixes are aimed at achieving desired properties of workability, durability, strength, etc. In order produce a concrete mix with proper pre-defined characteristics in fresh and hardened state, it is very essential to have a proper mix design which leads to selection and proportioning of constituents. The concrete mix design methods of American Concrete Institute (ACI-USA), Indian Standards Institution (ISI-India), Department of Environment (DOE-UK) are built on the same principles and their empirical relation are framed after various experiments made on locally available material. This report gives the variation of compressive strength of concrete for the various mix designs of ACI, ISI& DOE methods. The compressive strength of concrete for 14 days and 28 days curing is tested in a defined size of concrete cube and the reading are tabulated for the above stated mix designs. This report also gives the design calculation required for the various mix methods and compares the experimental results.

It is to be noted that these methods differ by the design calculations of cement content, aggregate content and water cement ratio. The test analysis is done for the designed target mean strength and results for the actual strength are observed. It is found that for 28 days curing strength for ACI method, ISI method & DOE method are 43.3N/mm^2,57.4 N/mm^2 and 46.3 N/mm^2 respectively.

Key words: Compressive strength, aggregate, mix design, workability, mix proportion, w/c ratio.

INTRODUCTION

Concrete mix design is process of deciding relative proportions of ingredients to achieve desired properties of fresh and hardened concrete. So, accordingly different countries have formed their own mix design of concrete suitable for their requirements. There are many mix designs methods which have come into existence, like American Concrete Institute (ACI), Indian Standards Institution (ISI), Department of Environment (DOE), Road Note 4, CP110, Rapid method mix design, etc. These methods have been made after various experiments and a standardized mix proportions have been stated and framed.

The basic requirements of concrete are same, but they only differ by their relative proportioning. A fresh concrete should have properties of good cohesiveness, workability and also retarded initial setting time. Whereas for hardened state, concrete should be strong, durable and also impervious. The proportioning is regulated by different methods of mix designs adopted in making of concrete. Good concrete mixture in not obtained unless proper proportioning of materials is taken, even though good quality materials, proper mixing, proper transporting and placing, sufficient compaction are done. Major importance of quality control in construction is given for proper mix design of concrete. Dubravka and Irina [1] have proposed two approaches in quality control namely; prescriptive approach and performance approach. The prescriptive approach is at the design stage where the necessary materials are prescribed, their appropriate proportioning is stated, and then the construction method is recommended. The performance approach emphasis is on proper construction so that desired strength and expected life is obtained without changes in volume. The concrete mix design considerations depends on the values of physical and geotechnical properties of materials. Salihu[2] stated the concrete grades and their recommended usage in the Table-1 below. The mix proportions are given by weight and equivalent proportions by volume. The mix proportions may vary with materials on different locations depending on their properties.

Table-1. Concrete grades, mix proportions and recommended use.

Concrete Grade (N/mm^2)	**Mix proportion** (Cement:Sand:Gravel)	**Recommended use**
10	1:4:8	Blinding concrete
15	1:3:6	Mass concrete
20	1:2.5:5	Light reinforced concrete
25	1:2:4	Reinforced concrete
30	1:1.5:3	Heavy reinforced concrete
35	1:1.5:2	Pre-stress concrete/precast
40	1:1:1	Very heavy reinforced concrete

According to Kong and Evans [3], durability of concrete is defined as ability to withstand various environmental conditions to which it is exposed. Curing should also be done in order to achieve proper design strength.According to Samir [4] and James [5] an improperly cured concrete leads to plastic shrinkage cracking and also drying shrinkage along with other side effects. According to Kong and Evans [3] ,the characteristic strength of the concrete as the value of compressive strength below which not more than a prescribed percentage of the test result shall fall. Hence the target mean strength shall exceed the characteristic strength by a small margin. Here different mix design methods are put at a target mean strength in different ways and also estimated for appropriate mix proportions in different ways. In this report three different mix design methods namely, American Concrete

Institute (ACI), Indian Standards Institution (ISI), Department of Environment (DOE) are taken into consideration. The procedures involved in these mix designs are explained below.

American Concrete Institute (ACI) mix design method

American Concrete Institute has framed the guidelines for normal, mass and heavyweight mix design in the year 1991.The ACI Method [6] was revisited and has framed the Absolute Volume Method of mix design. The following the steps involved in the mix design as recommended by the ACI committee:

1. The target compressive strength (f_t) at 28 days of mix design is calculated by adding design compressive strength and product of k and s.

$f_t = f_c + k.s$

where, k= Himsworth coefficient(1.64) and s = Standard deviation ($0.4f_c$)

2. The type of concrete (air entrained or non entrained) and also water to cement ratio is selected.

3. Air content is expressed as percentage of concrete volume, which is estimated depending upon the type of concrete.

4. Slump value which is a measure of workability is selected depending on the complexity and also type of structure of the pouring conditions.

5. Then after water content is calculated based on the normal mean size of the coarse aggregate, type of concrete and slump value.

6. Cement content, is calculated depending on the water content and water cement ratio.

7. Coarse aggregate content, is calculated based on the normal mean size of the coarse aggregate and fineness modulus of sand.

8. Fine aggregate content, is calculated once the air content, water content, cement content and coarse aggregate content is known. It is given by

$F_{agg} = 1-Y$

where , Y=sum of all other ingredients(air,water,cement and coarse aggregate) in m^3 calculated for $1m^3$ of concrete.

9. Finally water content is adjusted depending on the absorption and moisture content of the aggregates.

Department Of Environment (DOE) mix design method

This mix design method is originated from the work carried out by the Building Research Establishment, Transport and Road Research Laboratory in UK.The work was published under the title "Design of Normal Concrete mixes". The following are the steps involved in DOE design,

1. The target compressive strength (f_t) at 28 days of mix design is calculated by adding design compressive strength and product of k and s.

$f_t = f_c + k.s$

where, k= Characteristic strength and s = Standard deviation .

2. Selection of water/cement ratio, depending on the target compressive strength obtained.

3. Selection of free water content.

4. Selection of cement content, depending on the w/c ratio.

5. Selection of slump value, depending on the nature of the concrete.

6. Calculation of aggregate content is obtained by subtracting sum of free water content and cement content from the concrete density.

7. Calculation of the fine aggregate, from the code proportioning depending on the w/c ratio.

8. Calculation of coarse aggregate, which is the difference of total aggregate content and fine aggregate content.

Indian standards Institution (ISI) mix design method

Indian Standards Institution (ISI) has given guidelines for the mix design based on the locally available materials of aggregates, cement and other required materials [7]. These guidelines are effectively used up to a limit of 60 N/mm^2 of the concrete strength. The steps involved in the ISI mix design method is as follows,

1. The target compressive strength (f_t) at 28 days of mix design is calculated by adding design compressive strength and product of k and s.

$f_t = f_c + k.s$

where, k= Characteristic strength and s = Standard deviation .

2. Selection of water to cement ratio, depending on the target compressive strength obtained.

3. Air content is expressed as percentage of concrete volume, which is estimated depending upon the type of concrete.

4. Then after water content is calculated based on the normal mean size of the coarse aggregate, type of concrete and slump value.

5. Cement content, is calculated depending on the water content and water cement ratio.

6. Sand content, depending on the total aggregate volume, normal mean size of the coarse aggregate and target strength.

7. Calculation of the coarse aggregate, depending on the fine aggregate and also water to cement ratio.

8. Adjustment of water content depending on the absorption and moisture content of the aggregates.

The basic data used in the above methods are stated in Table-2.

Table-2: Basic data used in ACI, ISI and DOE mix design methods.

Parameter	ACI method	DOE method	ISI method
Characteristic compressive strength for 28 days	Yes	Yes	Yes
Standard deviation of compressive strength	Yes	Yes	Yes
Degree of workability	Slump	Slump	Compacting factor
Type and maximum size of aggregates	Yes	Yes	Yes
Fine aggregates(sand)	Fineness modulus	Grading zone	Grading zone
Water absorption and moisture content adjustment	Yes	Yes	Yes
Type of construction	Yes	Yes	Yes
Exposure condition	Yes	Yes	No
Air/Non Air entrainment	Yes	Yes	No

Materials and Methods

Materials used in the experiment are ordinary portland cement, fine aggregate, coarse aggregate and water. The prepared concrete is put in cube block of size 150mm is casted for 14 days and 28 days curing. Each mix design is made for two sample blocks of each 14 days and 28 days curing. They are tested under ASTM standards for the compressive strength with the compressive testing machine. The readings are noted for further analysis.

Design Calculations

For the design, for a characteristics strength of 30 N/mm^2 with a maximum aggregate size of 20mm is taken. Different mix design proportions are calculated with the above stated steps for various methods.

ACI method

Choice of Slump = 20mm - 60mm

Maximum size of aggregate = 20mm

Mixing of water content (Non-air entrained concrete) =200kg/m^3

Target mean design strength, $f_t = f_c + k.s$

$f_t = f_c + (1.64 \text{ X } 0.4 \text{ X } f_c) = 30 + (1.64 \text{ X } 0.4 \text{ X } 30) = 49.68$ N/mm^2.

Water/Cement ratio=0.5

Cement content = 200/0.5 =400kg/m^3.

Bulk density of coarse aggregate = 1500 kg/m^3.

For 20mm size max aggregate and fineness modulus of fine aggregate is taken as 2.80, the dry bulk volume of the coarse aggregate will have 0.62 per unit volume of concrete.

Quantity of coarse aggregate = 0.62 X 1500 = 930 kg/m^3.

Density of non air entrained concrete = 2250 kg/m^3.

Mass of aggregate per unit volume = 2250-(200+400+930) = 720 kg/m^3.

Hence the mix design proportion in kg/m^3 is 400:200:720:930 for cement, water, sand and granite respectively. In its reduced form the mix design proportion is 1:0.5:1.8:2.3 for ACI method.

DOE method

Choice of Slump = 30mm - 60mm

Maximum size of aggregate = 20mm

Mixing of water content (Non-air entrained concrete) =210kg/m^3

Target mean design strength, $f_t = f_c + k.s$

$f_t = f_c + (0.67 \text{ X } f_c) = 30 + (0.67 \text{ X } 30) = 50.1$ N/mm^2.

Water/Cement ratio=0.5

Cement content = 210/0.5 =420kg/m^3.

Bulk density of coarse aggregate = 1500 kg/m^3.

Density of non air entrained concrete = 2300 kg/m^3.

Mass of aggregate per unit volume = 2300-(210+420) = 1670 kg/m^3.

Fine aggregate content = Total aggregate content X 35% = 1670 x 0.35 = 584.5 kg/m^3

Coarse aggregate content = Total aggregate – fine aggregate = 1670-584.5 = 1085 kg/m^3.

Hence the mix design proportion in kg/m^3 is 420:210:584.5:1085.5 for cement, water, sand and granite respectively. In its reduced form the mix design proportion is 1:0.5:1.4:2.58 for DOE method.

ISI method

Maximum size of aggregate = 20mm

Mixing of water content (Non-air entrained concrete) =186 kg/m^3

Target mean design strength, $f_t = f_c + k.s$

$f_t = f_c + (1.65 \text{ X } 0.5 \text{ X } f_c) = 30 + (1.65X0.5X\ 30) = 54.6$ N/mm^2.

Water/Cement ratio=0.5

Cement content = 186/0.5 =372 kg/m^3.

Bulk density of coarse aggregate = 1500 kg/m^3.

Density of non air entrained concrete = 2425 kg/m^3.

Mass of aggregate per unit volume = 2425-(186+372) = 1867 kg/m^3.

Fine aggregate content = Total aggregate content X 35% = 1867 x 0.35 = 653.45 kg/m^3

Coarse aggregate content = Total aggregate – fine aggregate = 1867-653.45 = 1213.55 kg/m^3.

Hence the mix design proportion in kg/m^3 is 372:186:653.45:1213.55 for cement, water, sand and granite respectively. In its reduced form the mix design proportion is 1:0.5:1.75:3.26 for ISI method.

Experimental Results

With proper design, close monitoring of the test the following results yielded for different mix designs taken. The readings are tabulated in the Table-3, 4, 5 for ACI, DOE and ISI method respectively.Table-6 gives the summary of all the methods for their mix proportions.

Table-3: ACI mix design compressive strength test result.

Cube No.	Curing days	Size of cube (mm)	Wt. of cube (kg)	Concrete density (kg/m^3)	Test Load (KN)	Crushing strength (N/mm^2)	Avg. Crushing strength. (N/mm^2)
1	14	150	8.5	2519	630	28	27.8
2	14	150	8.4	2489	622	27.6	
1	28	150	8.6	2548	980	43.5	43.3
2	28	150	8.4	2489	968	43	

Table-4: DOE mix design compressive strength test result.

Cube No.	Curing days	Size of cube (mm)	Wt. of cube (kg)	Concrete density (kg/m^3)	Test Load (KN)	Crushing strength (N/mm^2)	Avg. Crushing strength. (N/mm^2)
1	14	150	8.8	2607	645	28.6	28.3

2	14	150	8.4	2488	630	28	
1	28	150	8.7	2577	1090	48.4	46.3
2	28	150	8.4	2488	995	44.2	

Table-5: ISI mix design compressive strength test result.

Cube No.	Curing days	Size of cube (mm)	Wt. of cube (kg)	Concrete density (kg/m^3)	Test Load (KN)	Crushing strength (N/mm^2)	Avg. Crushing strength. (N/mm^2)
1	14	150	8.5	2519	732	32.5	32.15
2	14	150	8.4	2489	716	31.8	
1	28	150	8.7	2578	1320	58.6	57.4
2	28	150	8.6	2548	1265	56.2	

Table-6: Summary of Compressive strength and the mix proportions.

Mix Design method	Mix proportion	Target mean strength(N/mm^2)	28 days strength(N/mm^2)
ACI	1:0.5:1.8:2.3	49.68	43.3
DOE	1:0.5:1.4:2.58	50.1	46.3
ISI	1:0.5:1.75:3.26	54.6	57.4

Conclusions

Based on the observations taken from the tests, the following conclusions can be drawn:

1. The compressive strength of the concrete cubes for 28 days curing differs for the different mix designs taken for same water/cement ratio.
2. There is no effect of mixing of water quantity on the moisture content of sand which is exposed to air.
3. The ISI method gives better compressive strength results compared to other methods as observed.
4. It is suggested for the contractors to take note of the above mix designs for better results.

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