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ARTICLE

Concrete Mix Design by IS, ACI and BS Methods: A Comparative Analysis

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ABSTRACT

Concrete is one of the most consumable construction materials on the earth. The concrete constitutes cement, sand, gravel, water and/or additives in definite proportions. The proportions of raw materials of concrete are decided by the concrete mix design. The mix design depends on the various factors. For mix design, most of the countries have their own specifications. In the present study, standard guidelines of India, Britain and America for the concrete mix design have been discussed. The concrete grades of M25, M35 and M45 were designed and compared. Indian Standards were also compared. It was concluded that a new revised version of Indian Standard code has the lowest value of water/cement ratio and highest quantity of cement as compared to other standards.

1. Introduction

Among all the construction materials, concrete is the prime material which is used in the construction of building elements, pavements, tanks, transmission towers etc. The reason of enormous use of concrete from many years is its universal versatility, economy, ease in mould to any shape and good durability. Also, ingredients of concrete are easily available in any part of the country. Concrete is made up of cement as binder, aggregates as inert materials, water and admixtures (optional) in a definite proportion. The proportions of ingredients in concrete mixtures are determined by mix design. Concrete mixes are classified as nominal mix and design mix. Nominal mix is adopted for small scale constructions while design mix concrete is adopted for important or large-scale construction work. Concrete mix design is a technical procedure to select the suitable proportions of ingredients to achieve the required strength or performance to satisfy the job requirements i.e. workability, strength and durability etc. This definite proportion of materials in the concrete mixtures has important role in quality of end product. This proportion of ingredients is expressed ratio wise i.e. 1:3:6 represents 1 part of cement, 3 parts of fine aggregate (FA) and 6 parts of coarse aggregate (CA). The water-cement ratio (w/c) or any additives are expressed separately [1-3].

The purpose of mix proportioning is to obtain the most economic and practical combination of readily available materials; which satisfy the performance of concrete. Basic data required for the mix proportioning are concrete grade, type and content of cement, maximum nominal size of aggregates, maximum water-cement ratio (w/c), slump,

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exposure conditions, type and properties of aggregates; and admixtures. Mix proportions of concrete depend on the input data required for design as mentioned above. The performance of concrete mixtures is affected by the various factors i.e. cement content, water, aggregates, batching, mixing, compaction and curing techniques. The mix proportioning is accomplished by use of certain empirical relations, which helps to find the best combination of ingredients to achieve the required properties. Mostly, mix design is based on empirical relationships, charts and graphs developed from extensive experimental investigations. Basically, all follow the same principles except some minor variations like various methods in selection of the mix proportions [1]. Some of commonly used mix design methods are as follows:

i) Mix design as per Indian Standard (IS)
ii) British DoE method (BS)
iii) American Concrete Institute method (ACI)

Santhosh and Shivananda [4] studied and compared the mix design of concrete for M15, M30 and M45 by using IS: 10262:2009, ACI and BS method. It was found that w/c for all grades of concrete was more in BS method and less in IS method. ACI method gives better results without superplasticizer as compared to IS code [5]. Mix design of M35 and M40 concrete was done by various standards with rounded aggregates [6].

In the present study, a comparative study of concrete mix design by the various countries standard (IS:10262-2009, IS:10262-2019, BS and ACI method) was conducted [7-10]. The grades of concrete were M25, M35 and M45 for different design parameters. The Indian standards were also compared with or without chemical admixtures. The comparison was made in terms of quantities of ingredients.

2. Methodology

In the concrete mix design, standard grades of concrete M25, M35 and M45 were designed by IS, BS and ACI; and compared.

2.1 Mix Design as Per IS

IS: 10262-2009 presents the guidelines for the design of concrete mix. The second revision i.e. IS: 10262-2019 "Concrete Mix Proportioning-Guidelines" confirms the design of high strength concrete, self-compacting concrete and mass concrete along with standard strength of concrete upto 60MPa. This new code also implemented the new revised code of fine and coarse aggregates. A graph between w/c and 28 days compressive strength has been introduced which depend on type and grade of cement, for the selection of w/c. The w/c has an important role on the compressive strength of concrete mixtures and; selected on the basis of grade of concrete and type of exposure. The steps involved in the mix design of concrete are as follows:

i) Selection of w/c
ii) Selection of free water content
iii) Determination of cement content
iv) Determination of fine and coarse aggregates

2.2 Mix Design as Per ACI

In 1991, American Concrete Institute (ACI) published the guidelines for the mix design of normal, heavy-weight and mass concrete. The absolute volume method of mix design as described by the ACI Standard 211.1 "Recommended Practice for Selecting Proportion for concrete" and design steps is given as below [1]

i) Selection of slump
ii) Selection of maximum aggregates size
iii) Determination of mixing water and air content
iv) Computation of target mean compressive strength
v) Selection of w/c
vi) Determination of cement content, coarse aggregate and fine aggregate
vii) Adjustments for aggregates moisture

2.3 BS DoE Method

British DoE method was first published in 1975 and was revised in 1988. It is a general method developed by the Department of Environment that can be applied to produce designed concrete, using cement and aggregates which conform to the relevant British Standards. The mixes are specified by the mass of the different materials contained in a cubic metre. The basic mix design approach is same and based on the characteristics value approach for strength, target mean for slump and air, the minimum target mean for cement content and maximum target mean for w/c. Design steps for the concrete mix design are as follows [1]:

i) Selection of w/c
ii) Determination of free water content followed by cement content
iii) Computation of total volume of aggregates followed by determination of fine and coarse aggregate content
iv) Adjustments for aggregates moisture
v) Determination of final proportions

The properties of concrete mixtures depend on the quality of the raw materials i.e. cement, aggregates and w/c used. The parameters which were considered during the

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mix design were given in Table 1.

Table 1. Parameters considered in mix design

Sr. No.	Parameters	Value	
1	Characteristics compressive strength	25MPa, 35MPa, 45 MPa	
2	Cement	OPC 43	
3	Specific gravity	Cement	3.15
		Sand	2.65
		Coarse aggregates	2.74
4	Nominal maximum size of aggregates	20 mm	
5	Nature of aggregates	Natural crushed aggregates	
6	Workability	50-100mm	
7	Admixtures	0%-2% @1%	
8	Oven dry rodded bulk density	1600 kg/m^3	

3. Results and Discussion

The mix design for concrete of grades M25, M35 and M45 was carried out and, compared with IS: 10262-2009 and IS: 10262-2019. During mix design, the design parameters were same.The water content of a particular grade for both Indian standards was kept same. Similar for 28 days compressive strength of concrete was designed by ACI and BS method. The mix proportions i.e. ratio of ingredients in the concrete mixtures has been given in Table 2 and the quantities of various ingredients have been given in Table 3. Table 2 showed the mix proportions i.e. ingredients by parts for all grade of concrete by different standards. Cement part is taken as unity and aggregates and water parts accordingly.

For M25 concrete, cement content was high and aggregates for the same content of water for mix design by IS: 10262:2019. From the graph of compressive strength and w/c ratio, w/c ratio chosen was lower than the taken from experience as in case of IS: 10262:2009.In the absence of chemical admixtures or ordinary concrete, w/c was little higher and cement content was low in case of ACI method of mix design. IS: 10262:2019 and BS method have similar content of ingredients as depicted in Table 3.

For M35 concrete, addition of superplasticizer (1%) in the concrete mixture reduced the content of water and increased the cement content as shown in Table 3. In absence of superplasticizer, new IS code recommends high content of cement with a lower w/c ratio. According to old IS method of mix design, the cement content found to be lowest among all the mix design methods. While, for the same grade of concrete, cement and water content for BS method was higher than new IS methods.

For 45 MPa concrete, having 2% superplasticizer w/c for new IS code was found lower than that of old IS code in respect of 28 days compressive strength; while, corresponding cement content was found higher as found in. Moreover, the cement content and water content were higher for both the standard in case of without superplasticizer. For high strength concrete with lowest w/c 0.28 had highest cement content of around 704 kg/m^3 according to new IS code while, for similar grade old IS code had lowest quantity of cement and highest w/c.

Apart from the proportions and quantity of materials in concrete mixtures, it is well known fact that the production of concrete contributes to greenhouse gases emission and is not eco-friendly end product. Also, cost of cement is high. On the other side, the mining for the aggregates has bad impact on the environment. Practitioners should focus on the environment friendly materials to save the natural resources. To conserve the environment, the locally available waste materials should be introduced in the construction industries as substitution to cement and aggregates.

Table 2. Mix proportions of grades of concrete by IS, ACI and BS methods

Chemical admixture			
Sr. No.	**Characteristic strength (MPa)**	**Standards**	**Proportions (Cement : FA : CA : w/c : SP)**
1.	25	IS (Old)	1 : 2.32 : 4.09 : 0.46 : 0.01
2.		IS (New)	1 : 2.22 : 3.95 : 0.44 : 0.01
3.	35	IS (Old)	1 : 2.39 : 3.27 : 0.42 : 0.01
4.		IS (New)	1 : 1.48 : 2.87 : 0.34 : 0.01
5.	45	IS (Old)	1 : 2.0 : 2.82 : 0.38 : 0.02
6.		IS (New)	1 : 1.1 : 2.21 : 0.28 : 0.02
Without chemical admixture			
Sr. No.	**Grade**	**Standard**	**Proportion (Cement: FA: CA: w/c)**
1.	25	IS (Old)	1 : 1.60 : 2.18 : 0.45
2.		IS (New)	1 : 1.54 : 2.74 : 0.44
3.		ACI	1 : 1.89 : 2.55 : 0.47
4.		BS	1 : 1.60 : 2.73 : 0.45
5.	35	IS (Old)	1 : 1.63 : 2.23 : 0.42
6.		IS (New)	1 : 1.01 : 1.96 : 0.34
7.		ACI	1 : 1.39 : 2.15 : 0.43
8.		BS	1 : 1.26 : 1.54 : 0.39
9.	45	IS (Old)	1 : 1.36 : 1.92 : 0.38
10.		IS (New)	1 : 0.72 : 1.47 : 0.28
11.		ACI	1 : 0.89 : 1.50 : 0.3
12		BS	1 : 1.01 : 1.40 : 0.35

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Table 3. Quantities of materials of concrete mixtures

Sr. No.	Grade	Standard	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	w/c	SP (%)
1	M25	IS (Old)	318	739	1302	143	3.18	0.45	1
		IS (New)	325	723	1283	143	3.25	0.44	1
2		IS (Old)	413	660	1162	186	0	0.45	0
		IS (New)	423	653	1160	186	0	0.44	0
3		ACI	404	763	1024	190	0	0.47	0
4		BS	422	676	1152	190	0	0.45	0
5	M35	IS (Old)	352	840	1151	148	3.52	0.42	1
		IS (New)	436	646	1251	148	4.36	0.34	1
6		IS (Old)	457	744	1020	192	0	0.42	0
		IS (New)	564	571	1106	192	0	0.34	0
7		ACI	477	662	1024	205	0	0.43	0
8		BS	577	728	890	225	0	0.39	0
9	M45	IS (Old)	400	802	1127	152	8	0.38	2
		IS (New)	543	588	1201	152	5.43	0.28	2
10		IS (Old)	518	707	993	197	0	0.38	0
		IS (New)	704	507	1035	197	0	0.28	0
11		ACI	683	610	1024	205	0	0.30	0
12		BS	643	652	900	225	0	0.35	0

4. Conclusions

The concrete mix design adopted in various countries has been done and compared. As a thumb rule, lower will be the w/c, higher will be the cement content. New IS code suggests higher cement content and lower w/c than old IS code. For good strength and durability properties of concrete, lower w/c is the main requirement. The difference may be justified by the fact that new IS code introduced a graph between w/c and compressive strength while, old IS code dictates that the w/c may opt from experience of the practitioner/engineer. The quantity of cement and w/c ratio were found close in case of BS and IS codes for 25MPa and 35MPa characteristics strength while, IS and ACI codes recommend same input design parameters for 45MPa strength characteristics concrete mix. The new IS code advocates higher content of cement that leads to a higher cost of end product and huge carbon dioxide emission. For sustainable construction, industrial waste materials can be used as partial replacement of cement or aggregates.

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