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Research Article

Comparative Analysis of Selected Concrete Mix Design Methods Based on Cost-Effectiveness

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Concrete is an amalgamated material that is composed of coarse granular materials embedded in a hard matrix of material that fills the void among the aggregate particles and binds them together. Concrete ingredients have to be properly classified and proportioned to build a mix that will be economical as well as meet the minimum requirements of functionality, safety, and economics. For this, there should be appropriate proportioning or mixing methods to arrive at the right combination of ingredients for making concrete according to the given specifications. Due to this, this study was intended to conduct a comparative analysis among selected concrete mix design methods, American Concrete Institute (ACI), British Department of Energy (DOE), Ethiopian Building Code of Standards (EBCS), and Indian standards (IS), by using experimental investigation for normal concrete production, focusing on cost-effectiveness. The concrete ingredients' physical properties were compared as a requirement, and concrete mechanical properties were examined as per the method of concrete mix design on the 7th, 14th, and 28th days of curing. The experimental result of compressive strength for those selected concrete mix design methods with the 7th, 14th, and 28th ages has fulfilled the desire for concrete strength. However, on the 28th day of curing, compressive strength results of ACI, DOE, EBCS, and IS methods were achieved at 133.68%, 121.04%, 124.56%, and 121.04%, respectively. On the one hand, regarding the material of concrete consumption, the EBCS, DOE, and ACI methods were cast-off in an excess amount (52.2 kg/m^3, 40 kg/m^3, and 20 kg/m3) of cement, respectively, concerning the IS method. But the IS method was consuming 300 kg of cement per m^3 of concrete. Finally, it is concluded that the result of the compressive strength test after 28 days showed that the specimens prepared using the mixing proportions obtained from the ACI standard met the extreme compressive strength requirement more than the other methods. On the other hand, the ACI, DOE, and EBCS methods are the most expensive to absorb an excessive quantity of cement when compared to the IS method. However, the overall result showed that the concrete designed as per the IS method is relatively easy to work with and cost-effective for developing countries such as Ethiopia for the production of normal grade concerts.

1. Introduction

Concrete is a mixture of cement, sand as fine aggregate, crushed rock as coarse aggregate, water, and admixture. To produce concrete of acceptable quality with a reasonable economy, it is important to determine the proper proportioning of its ingredients [1, 2]. Concrete is an extremely versatile engineering material used in most civil engineering structures and, like other engineering materials, needs to be designed for certain desirable properties in a fresh and hardened state [3].

The process of selecting suitable ingredients for concrete and determining their relative amounts to produce concrete of the required strength, durability, and workability as economically as possible that satisfies the job requirements is termed "concrete mix design" [4–8].

Most countries have their concrete mix design methods, which are based on empirical relations, charts, graphs, and tables developed as an outcome of extensive experiments and investigations of locally available materials and follow the same basic trial and error principles [3, 9]. Among those standards, the American (ACI), Indian (IS), and British

(DOE) are the most common methods of proportioning concrete ingredients [4, 6–8, 10–13]. Besides these, Ethiopia has its standards, EBCS, which were formulated and documented as a national norm for the industry by the government since 1992 and were modified in 2011.

Nowadays, in Ethiopia, construction activities are increasing at an alarming rate, with a huge volume of concrete demand. The cost of concrete constituents is rising all the time, and if not handled properly, it will have a significant impact on the quality and cost of the concrete [14]. The researcher observed that from four construction material testing laboratories, named "Addis Ababa University," "Bahir Dar University," "Debre Markos University," and "Jimma University," Ethiopia, 95%, 3%, 1.5%, and 0.5% of the concrete mix designs ordered by the customer were to be performed by using ACI, DOE, EBCS, and IS methods, respectively. This creates a question in the researcher's mind, "What is the reason behind this?" Hence, this research is focused on the ACI, DOE, EBSC, and IS methods of concrete mix design effects on the concrete properties and its cost. In addition to this, there are no comparative studies conducted on different mix designing methods based on the Ethiopian context. Based on this, the researcher was motivated to describe the specific, supplementary, and standardized knowledge and practice that are generally accepted as "good construction industry practice in concrete," lay down particular features, principles, steps, and requirements of selected concrete mix designing methods, and experimentally investigate and analyze the strength and material consumption of the selected methods. In general, the study focused on making a comparative analysis among the ACI, DOE, EBCS, and IS methods of concrete mix design from a cost-effective point of view by comparing ingredient quantity for production of a cubic meter of a normal grade of concrete. Beyond this, the study will assess the characteristic compressive strength, which is usually taken as an index for determining concrete quality interim water tightness, durability, and impermeability due to its easiness of measuring the cube after curing dates of 7, 14, and 28 days for selected methods.

2. Review of the Literature

Concrete is one of the economical and universally used construction materials [5]. Concrete needs to be designed for certain properties in the plastic stage and the hardened stage. Concrete mix design is the method of correct proportioning of the ingredients of concrete to optimize its properties as per site requirements [15–18]. In other words, it determines the relative proportions of ingredients in concrete to achieve the desired strength and workability most economically [3].

2.1. Constituents of Concrete. Concrete is a composite material that consists of essentially a binding medium (paste) that takes up 25% and embedded particles or fragments of relatively inert mineral fillers (aggregate) within 75% of a given mass [15].

Cement paste is the binder in concrete or mortar that holds the fine aggregate, coarse aggregate, or other constituents together in a hardened mass. The properties of concrete depend on the quantities and quality of its constituents. Because cement is the most active component of concrete and usually has the greatest unit cost, its selection and proper use are important in obtaining the most economical balance of properties desired for a particular concrete mixture. Cement, in general, can be defined as a material with adhesive and cohesive properties that allow it to bond mineral fragments into a hard, continuous, and compact mass [1–3, 19].

Cement is currently produced in three forms in Ethiopia: ordinary Portland cement (OPC), Portland pozzolana cement (PPC), and Portland lime cement (PLC), and there are approximately 26 cement factories with an average annual production of 26.21 tons of cement [20]. Dangote cement is the second-largest factory in terms of production capacity, and its chemical compositions are shown in Table 1.

Sources: aggregates [21] represent the major proportion of the volume of concrete. Hence, it has significant importance for the quality of concrete, especially in strength. This is because good aggregates are known to have better crushing strength and better resistance to impact. Not only do those aggregates affect the strength of concrete but their properties, such as their size and shape, affect the durability and structural performance of concrete. Aggregate is cheaper than cement. It is, therefore, economical to put into the mix as many proportions as possible [2, 5, 22].

The physical properties of aggregates such as size, shape, texture, porosity, absorption, moisture content, bulking of fine materials, and the presence of deleterious substances affect the quality of produced concrete [5]. Table 2 elaborates on the common physical properties of aggregates within their recommended ranges.

Source: coarse [4, 6, 10, 11] aggregates can have round, angular, or irregular shapes. Rounded aggregates, because of their lower surface area, will have the lowest water demand and mortar paste requirement. Flaky and elongated coarse aggregate particles increase the water demand and the tendency for segregation. The combined flakiness and elongation amount to 30% of the weight of coarse aggregates. On the one hand, the maximum size of aggregate affects the workability and strength of concrete and influences the water demand for getting certain workability and fine aggregate content required for achieving a cohesive mix [5]. On the other hand, fine aggregate, which accounts for about 35% of the volume of concrete, has a greater effect on the workability of concrete than coarse aggregates [1, 5, 19].

Water is the most important and least expensive ingredient of concrete, and it serves as mixing water, which is used in the hydration of cement to form the binding matrix, and as a lubricant between fine and coarse aggregate, and makes concrete workable. Its content must be kept to a minimum. If not, too much water in the mix leads to a reduction in strength, the formation of laitance on the surfaces of concrete through bleeding and honeycombing [2, 3].

Table 1: The chemical makeup of Dangote grade 42.5 R OPC cement.

No.	Chemical compositions	Amount within Dangote grade 42.5 R OPC (%)
1	Calcium oxide (CaO)	66.32
2	Silicon dioxide (SiO_2)	22.82
3	Aluminum oxide (Al_2O_3)	5.41
4	Ferric oxide (Fe_2O_3)	3.37
5	Magnesium oxide (MgO)	1.46
6	Alkalis	-

Table 2: Summary of the physical properties of aggregates commonly used in concrete.

Property	Typical range
Fineness modulus of fine aggregate	2.0 to 3.3
Absorption	0.5 to 4%
Bulk specific gravity (relative density)	2.3 to 2.9
Dry-rodded bulk density of coarse aggregate	1280 to 1920 kg/m^3
The surface moisture content of coarse aggregate	0 to 2%
The surface moisture content of fine aggregate	0 to 10%

2.2. Concrete Properties. Concrete needs to be designed for certain properties in the plastic stage (workability and consistency) and the hardened stage (mechanical property and durability) [1, 5, 19]. Due to the various factors involved in concrete production, such as materials, proportioning, and production process, the final product has shown variability from batch to batch. Therefore, this variability in properties must be considered when preparing concrete specifications [3, 13].

2.3. Factors Affecting the Quality of Concrete. When making concrete, we must consider two sets of criteria: (1) short-term requirements such as workability (water content, aggregates, mixing time, and temperature, cement characteristics, and admixtures); and (2) long-term requirements of hardened concrete, such as strength (water/cement ratio, age, concrete porosity, soundness of aggregate, and aggregate-paste bond), durability (chemical attack, weathering action, and abrasion), and volume stability [2].

3. Methods of Concrete Mix Design

Mix design is the process of determining the proportions of cement, water, fine and coarse aggregates, and admixtures to produce an economical concrete mix with the required fresh and hardened properties. The requirements for concrete are complex, but the ultimate aim is to produce the most economical combinations of concrete materials that will satisfy the performance requirements and specifications [14].

A concrete mix design can be proportioned from existing statistical data using the same materials, proportions, and concrete conditions. When there are no existing records or they are insufficient, the concrete mixture must be determined by trial mixtures. In concrete proportioning by the method of trial mixtures, certain design objectives must be established beforehand: the required 28-day compressive strength, for some other strength parameter such as the modulus of rupture, Portland cement content based upon water/cement (w/*c*) ratio, and under certain conditions, the minimum specified cement content, the maximum size of the coarse aggregates, the acceptable range of slumps, and the presence of air for an air-entrained concrete.

The water/cement ratio, cement content, the proportion of fine and coarse aggregates, and admixture dosage are the most important variables in producing concrete to specifications [5, 23]. The different mix design methods have some common threads in arriving at proportions, but their methods of calculation are different. Existing concrete mix design methods include the American Concrete Institute (ACI), British Department of Environment (DOE), Ethiopian Building Code Standards (EBCS), Indian Standards (IS), maximum density, fineness modulus, and Road Research Laboratory (RRL) methods [5, 15, 16, 23, 24]. These same things, which are common around the globe, are discussed as follows:

3.1. IS Method. The method treats normal mixes (up to M35) and high-strength mixes (M40 and above) differently. This is logical because richer mixes need lower sand content when compared with leaner mixes. The method also gives correction factors for different w/*c* ratios, workability, and rounded coarse aggregate. In the IS method, the quantities of fine and coarse aggregates are calculated with the help of the yield equation, which is based on the specific gravities of ingredients. Thus, actual cement consumption will be close to that targeted in the first trial mix itself. Also, the water-cement ratio is calculated from cement curves based on the 28-day strength of concrete. This can be time consuming and impractical at times. The IS method gives separate graphs using the accelerated strength of cement with a reference mix method, and this greatly reduces the time required for mix design. The zones have a wide range of IS, and their correction is insufficient to achieve a cohesive mix; there is no direct adjustment for cement content, and the compaction factor, as a measure of workability, does not account for the effect of aggregate surface texture and flakiness on sand and water content [8, 10, 15, 18, 24, 25].

3.2. DOE Method. The method overcomes some limitations of the IS method. The quantities of fine and coarse aggregates are calculated based on plastic density plotted. However, the DOE method allows simple correction in aggregate quantities for actual plastic density obtained at the laboratory. However, DOE has its shortcomings: it will result in a higher amount of sand, the fine aggregate content cannot be adjusted for different cement contents, and it does not take into account the effect of the surface texture and flakiness of aggregate on sand and water content [7, 11, 12, 15, 16].

3.3. ACI Method. This method is based on determining the coarse aggregate content, dry rodded coarse aggregate bulk density, and fineness modulus of sand. Thus, this method takes into account the actual voids in compacted coarse aggregates that are to be filled with sand, cement, and water. It also provides separate tables for air-entrained concrete and is the most suitable for the design of air-entrained concrete. Generally, it gives coarse aggregate content for sand with an FM range of 2.4 to 3.0. The density of fresh concrete is not given as a function of the specific gravity of its ingredients. In the IS and DOE methods, the plastic density or yield of concrete is linked to the specific gravity of ingredients, and the method also does not take into account neither the effect of the surface texture and flakiness of aggregates on sand and water content nor does it distinguish between crushed stone aggregates and natural aggregates [6, 15, 16, 18, 24].

3.4. EBCS Method. The EBCS method of mix design is a mix design method prepared to be used in Ethiopia for ordinary structural concrete. It does not have any figures or tables that show the different relationships between the factors affecting the quality of concrete and the different components of the mix design requirements. The EBCS method of mix design only specifies the materials to be used in concrete making. The proportion of constituent materials in concrete using the EBSC method depends on three factors: required workability (slump), required strength, and the nominal maximum size of aggregate [4, 13].

As a summary, on the one hand, ACI has four general steps: choice of a slump and nominal maximum size of aggregate, estimation of mixing water and air content, selection of an approximate w/*c*, calculation of cement content, estimation of course, and fine aggregate content. Similarly, DOE has followed these steps: determining the free water/cement ratio required for strength and workability, and determining the required cement and aggregate content. Steps for the IS method are determining target strength, selecting of water-to-cement and fine-to-total aggregate ratios, water, cement, and fine and coarse aggregate content. On the other hand, the EBCS mix design method specified only specifications about the materials to be used in concrete making.

Commonly, in all mix design methods, the following steps are analyzed and followed: grade designation of the target concrete, type of cement and aggregates to be used, maximum nominal size of aggregate, maximum water-cement ratio, minimum cement content, the required degree of workability, exposure conditions of the actual construction site, measurement method of ingredients, mixing, transporting, placing, and curing, and the tendency of admixture applications.

4. Materials and Method

4.1. Mix Design Programs. The experimental work embraced the design of normal concrete mixes of medium strength grades of C-25/25Mpa, which is the commonly used grade of concrete in Ethiopia for the construction of horizontal and vertical elements for low-rise buildings and other concrete structures, by ACI, DOE, EBCS, and IS mix design methods with their influence on the proportion of ingredients from a cost-effective point of view. In the mix design, only strength criteria were considered, notwithstanding durability requirements as it is site specific. The materials used were Dangote ordinary Portland cement (as shown in Table 3) without mineral or chemical admixtures, coarse aggregate-natural crushed angular stones from the Menkorer quarry of Debre Markos City with the existing supplied grading, and fine aggregate-natural deposited sand from the Abay River Gorge near to Degen City. Tap water supplied to Debre Markos University construction material laboratory by Debre Markos City municipality was used, and the workability of the mixes was measured in terms of the slump. The compressive strength of trial cubes was tested at 7 days, 14 days, and 28 days.

4.2. Concrete Mix Design Parameters. The properties of concrete-making ingredients were tested in the laboratory. Accordingly, the parameters used for concrete mix design are shown in Table 4. According to ACI-ASTM C 117, DOE 812-103.1, EBCS ES C.D3.201, and IS384-1970, the sieve sizes of 9 mm and 10 mm, 4.75 mm and 5 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.30 mm, and 0.15 mm were satisfied with the limitation of percentage passing. As shown in Figure 1, this result indicated that the sand type was in between the upper and lower limit on all sieve sizes, which means that the fine aggregate was fulfilling the specification of percentage passing according to their mix design methods, whereas for the coarse aggregate, the samples are found in the range of all the selected concrete mix designing methods, as elaborated in Figure 2.

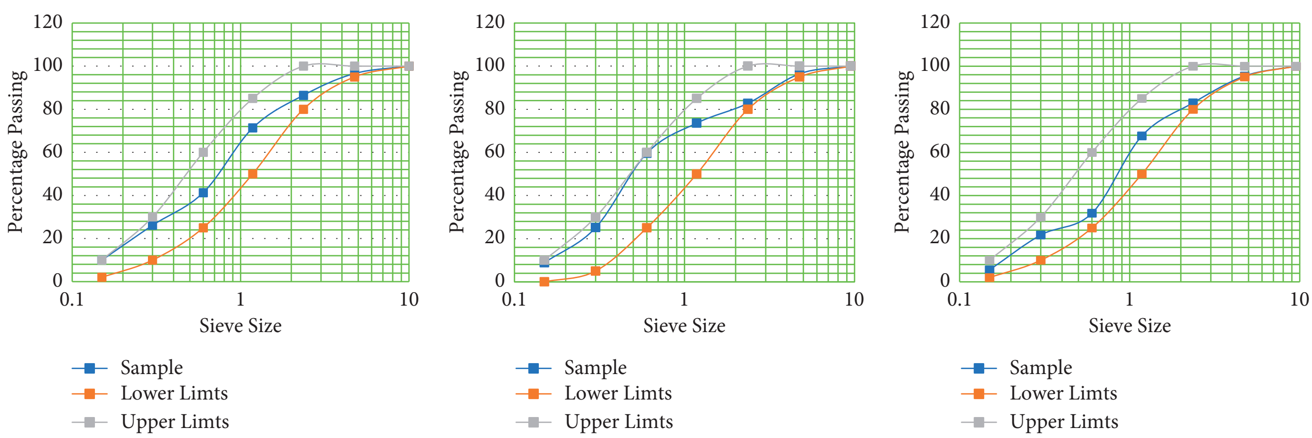
4.3. The Preparation Process and Test Methods of the Concrete Specimens. Cement and aggregates were batched by weight while water was by volume, and castings of all specimens were carried out under the same ambient conditions of average room temperature. An adjustment was made for the moisture content of the fine aggregate. After determining the relative quantity of materials to be used for the specimens, the aggregates and the cement were mixed for one minute without adding water. After the addition of water, all the materials were mixed for another two minutes by using a mixing machine, mixer. Immediately after mixing the concrete, the workability was measured by using a slump cone. The specimens were then placed on a firm and level surface of prepared molds ($150 \times 150 \times 150$ mm) for compressive cubes, which were compacted in three layers using 25 strokes of a 25 mm diameter steel rod and hammered into both sides of the mold using a plastic hammer. Then, a hand vibrator for 30 seconds until full compaction without

Table 3: Summary of cement proprieties.

Property	Typical range
Grade	42.5 R
Specific gravity (relative density)	3.15
Soundness	0.25 mm
Fineness	0.85
Initial setting time	75 minutes
Final setting time	250 minutes

Table 4: Summary of aggregate physical proprieties.

No.	Parameters		Results
1	Characteristic compressive strength		C-25
2	Nominal maximum size of coarse aggregate		20 mm
3	Coarse aggregate		Natural crushed stone aggregate
4	Fine aggregate		Natural deposited sand from Abay River
5	Silt content of sand		4.5%
6	Water absorption	Coarse aggregates	0.2%
		Fine aggregates	0.98%
7	Unit weight of	Coarse aggregates	1650 kg/m^3
		Fine aggregates	1750 kg/m^3
8	Specific gravity of	Fine aggregate/sand	2.64
		Coarse aggregates	2.89
9	Fineness modulus (FM) of sand		2.45 for ACI, DOE, EBCS, and grading zone II for IS
10	Desired workability		25 mm to 50 mm slump
11	Chemical/mineral admixtures		Not used at all mix



(a) (b) (c)

Figure 1: Fine aggregate gradation curves for selected methods.

segregation was achieved. After compaction of the final layer, the top surface was finished using a trowel. Placing, compaction, and finishing were completed within 15 minutes. After 24 hours, the specimens were demolded from the mold and were curried by completely immersing in a water curing tank for 7, 14, and 28 days at the room temperature of the laboratory. Finally, all methods of concrete mix design of hardened concrete density and compressive strengths were checked at the ages of 7, 14, and 28 days by using the universal testing machine with a 13.5 N/mm^2 per second loading rate. All experimental results reported in this study represented the average value of three specimens.

4.4. Concrete Mix Design. The process of selecting suitable concrete ingredients and determining their relative amounts to produce concrete of the required strength, durability, and workability as economically as possible that satisfies the job requirements is referred to as "concrete mix design" by Nwofor T. and Eme D. [17]. The mix proportion for control mixes was done by using the property of standardized aggregate. The ACI, DOE, EBCS, and IS mix design methods were used to proportion the control mixes. The proportions obtained using the design mixes are given in Table 5, and the calculation was performed per cubic meter of concrete.

The ratio of total aggregate to cement indicates the quality of concrete. For a good-quality concrete mix, this

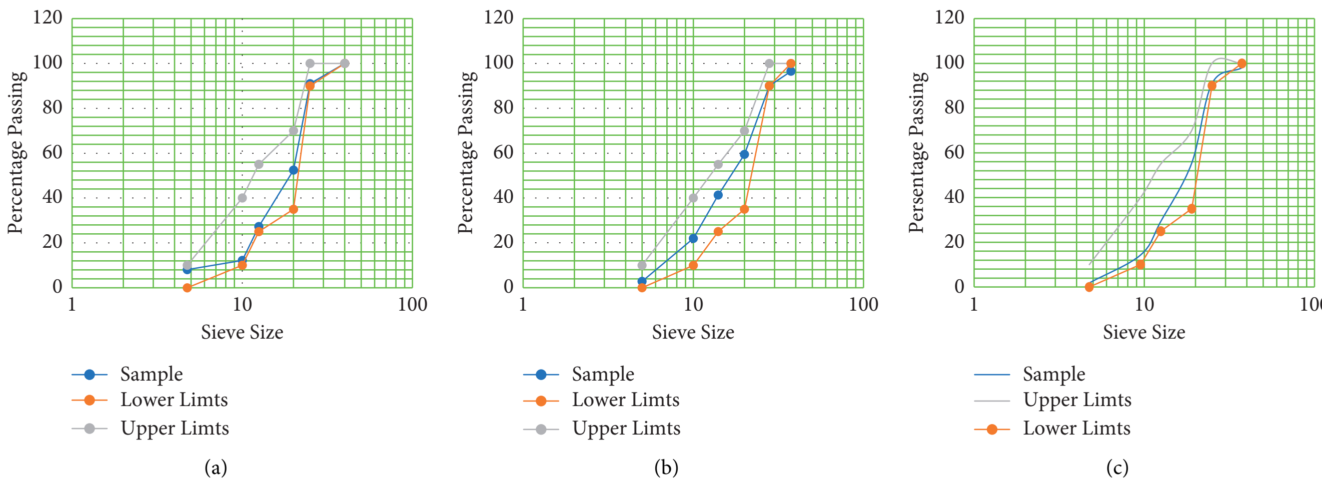


Figure 2: Coarse aggregate gradation curves for selected methods.

Table 5: the proportions of concrete ingredients as determined by the ACI, DOE, EBCS, and IS methods.

Method	W/C	Water content (litre)	Cement content (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Total aggregate (kg/m^3)	Total aggregate-to-cement ratio
ACI	0.5	129.05	320	1242.36	740	1982.36	6.20
DOE	0.5	138	340	1302.8	551.5	1854.3	5.45
EBCS	0.55	162.8	352.2	1204.66	606.202	1810.862	5.14
IS	0.5	155.086	300	1446.144	530.87	1977.014	6.59

Table 6: Concrete's average compressive strength and density.

No.	Method	Slump (mm)	Target mean strength	Average of compressive strength of three samples (N/mm^2) at the age of			Average weight of three cube samples (kg)	Average density of concrete of three samples (kg/m^3)
				7 days	14 days	28 days		
1	ACI	30	33.4	26.61	27.08	33.42	8.557	2535.41
2	DOE	30	38.2	27.45	26.53	30.26	7.903	2341.63
3	EBCS	35	31	26.12	28.44	31.14	8.143	2412.74
4	IS	40	32	27.47	29.42	32.5	8.336	2469.93

Table 7: Summary of cost analysis for different mix design methods.

Methods		Ingredients			
		Cement (kg/m^3)	Coarse aggregates (kg/m^3)	Fine aggregates (kg/m^3)	Water (litre/m^3)
ACI	Quantity	320	1242.36	740	129.05
	Cost	$55.49	$11.02	$6.76	$0.06
	Cost per m^3 of concrete	$73.33			
DOE	Quantity	340	1302.8	551.50	138
	Cost	$58.96	$11.18	$5.80	$0.06
	Cost per m^3 of concrete	$76.00			
EBCS	Quantity	352.2	1204.66	606.202	162.8
	Cost	$61.07	$10.36	$5.24	$0.08
	Cost per m^3 of concrete	$76.75			
IS	Quantity	300	1446.144	530.87	155.086
	Cost	$52.02	$11.89	$4.84	$0.07
	Cost per m^3 of concrete	$68.82			

ratio should be higher. The highest value of the total aggregate-to-cement ratio is obtained using the IS method, while the ratio is the least for the EBCS method. The reason for getting the low ratio of total aggregate and cement with the EBCS method may be due to the high amount of water in the mix. It is recommended that for extreme environments, a lower size of aggregate with appropriate workability should be used to provide a lower total aggregate-to-cement ratio.

5. Result and Discussions

The workability of concrete mixes was measured in terms of vee bee and slump. After water curing of cubes, compressive strengths at 7 days, 14 days, and 28 days were tested for an average of three samples for each age. The experimental test results were obtained, as shown in Table 6.

From Table 6, except for the DOE mix design method, all other methods fulfill the required target mean strength, and the IS mix design method is more workable than others, and it takes more water for mixing. In a comparison of results, it was observed that for C-25, all cubical specimens of concrete tested achieved their required compressive strength, concerning the requirements of compressive strength of different mix design methods. However, the concrete designed as per the ACI method attained the highest compressive strength at 28 days, but the DOE method achieved the least. The IS method has one advantage, and that is that it is good for early strength development.

The EBCS and DOE methods are more comprehensive and more tedious as compared to the ACI and IS simple methods. Beyond this, all four methods of trial mixes were found to nearly achieve the designed slump, which is a 25-50 mm slump.

The density of the designed concrete mix is estimated with the obtained weight of concrete ingredients per unit volume and is represented in Table 6. The concrete mix design using the ACI method is denser than the mix designed using the other methods.

The average density of concrete mixes is the lowest for mixes designed with the DOE modulus method. The maximum density of concrete mix is obtained as 2535.41, 2469.93, 2412.74, and 2341.63, respectively, in kg/m^3, for ACI, IS, EBCS, and DOE methods.

Generally, all the methods are applicable for the design of concrete mixes. They give guidelines using normal and heavyweight aggregates. The water-cement ratio of the mix rules the compressive strength of concrete; the selection of the water-cement ratio is principally based on the generalized relationship between the compressive strength of concrete and the water-to-cement ratio. It specifies different exposure conditions to meet the durability requirements. The selection of water to content is based on the workability of the mix desired. Workability is stated in terms of slump, vee bee, or compacting factor. Cement content is projected based on the water-to-content ratio and checked against minimum cement requirements for durability.

5.1. Cost-Benefit Analysis of Concrete Mix Design Methods. The cost-effectiveness analysis of concrete mix design has been carried out by calculating the unit cost of concrete per cubic meter for each mix design method using the cost of concrete ingredients in Debre Markos City, Amhara Region, Ethiopia, with a current cost of cement of $8.67 per bag, the coarse aggregate of $20 per cubic meter, the fine aggregate of $22.22 per cubic meter, and water of $0.44 per litre, as shown in Table 7.

The comparison was performed for one cubic meter of C-25 grade concrete designed. The concrete designed with the IS method came out as the cheapest due to the smallest amount of cement content, and EBCS was the most expensive method because of the high amount of cement consummation per cubic meter of concrete.

In Table 7, the cost did not include the cost of transportation from the market to the site; mixing, transporting, placing, currying, profit, and tax.

Generally, the EBCS, DOE, and ACI mix design methods raised extra cement content by an amount of $52.2\,kg/m^3$, $40\,kg/m^3$, and $20\,kg/m^3$, respectively, compared to the IS method for the production of C-25 grade concrete. On the one hand, since cement is the most expensive ingredient of concrete, adding too much *t* to concrete is increasing project costs. On the other hand, when cement paste increases, it can cause durability problems such as drying shrinkage.

6. Conclusions

The experimental program was carried out to compare the ACI, DOE, EBCS, and IS methods of mix design regarding strength and budget cost of concrete for C-25 grades of concrete required per cubic meter. As a result, compressive strength indicates that, at 7 days of curing, the IS and ACI methods recorded the highest compressive strength, and the EBCS and DOE methods attained the least result. After 14 days of curing, the IS and ACI methods were recorded as having the highest compressive strength, while the DOE method attained the lowest result in compressive strength. On the 28^{th} day of curing, the ACI and IS methods were to meet the maximum compressive strength and the DOE and EBCS methods were to meet the minimum. However, all the mix design methods for compressive strength satisfied their requirements at the ages of 7^{th}, 14^{th}, and 28^{th} days.

The ACI, DOE, and EBCS methods of concrete mix design are the most expensive methods other than the IS method regarding the excess amount of cement and fine aggregate used per m^3 of concrete. As a result of the overall comparison of different mix design methods, the IS method produced higher results in terms of strength and cost-effectiveness for the C-25 grade of concrete.

7. Recommendations

In the Ethiopian construction industry, necessary attention has not been given to IS concrete mix design standards. But it is too easy to prepare the mix as well as be cost-effective. In the EBCS method, the factors and parameters considered for trial mix preparation are not clear. For example, specific gravity, bulk density of course aggregate, fineness modulus of fine aggregate, type of cement, grade of concrete and exposure, amount of water, and concrete density.

To solve the EBCS problem regarding concrete production practice, the federal research institution, professional association, and different universities in Ethiopia have to contribute to preparing and revising this concrete mix design method. In addition to this, there should be one national concrete mix design method and guidelines with enforcing regulations. Generally, the IS method is found suitable for developing countries such as Ethiopia to deliver the required result at a normal grade of concrete production at a cost-effective rate.

Data Availability

The datasets used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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