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Research Article

Study on concrete proportioning methods: a qualitative and economical perspective

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ABSTRACT

The various approaches, established for concrete mix design, are not universal because design mixes are explicit to local climate, available materials, and type of exposure. The new-generation mix design method should be developed based on the performance criteria. The concrete strength obtained from the designed concrete mix and optimum cement content should not be considered as the only parameter for the suitability of the concrete mix. This study was carried to compare the proportioning of concrete mixes obtained by following procedures of Indian Standard (IS), American Concrete Institute (ACI) and British Standard (BS) of concrete mix design without the use of admixtures to validate for use in a moderate climate like Kashmir, India. The concrete mixes have been prepared with the necessary 28 days resistance in compression as "15 MPa, 20 MPa, 25 MPa, 30 MPa and 35 MPa". The assessment of water-cement (w/c) ratio; cement, water, fine aggregate (FA) and coarse aggregate (CA) proportion was carried. The w/c ratio among all formulated mixes is significantly high in the BS method and low for IS method. The BS method uses less quantity and IS method uses the maximum quantity of cement. In addition, the ratio of total aggregate content (TAC) and the aggregate-cement ratio is higher in BS design method as compared to IS and ACI design methods. The aggregate content in ACI mix design appears to be consistent and it added to the relative high compressive strength. The specimens cast following BS guidelines failed to attain the target mean strength (TMS) due to a higher volume of aggregate content, high w/c proportion, less quantity of cement in the mix. The specimens cast by ACI and IS mix design upon compression testing showed higher results than the calculated TMS. The cost analysis per cubic meter of concrete revealed that IS and ACI mix proportioning are expensive than BS method. The IS procedure results in dense concrete followed by ACI procedure. It is expected that with a comprehensive investigation on selected design parameters concentrating more on local challenges, the present study will floor the way for the development and adoption of performance-based design mix selection for moderate climate.

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1. Introduction

The concrete mix proportioning is a well-defined way of identifying the mixture of ingredients essential to meet the required characteristics in the wet and solidified state. All developed and developing nations have quantified and fixed their concrete mix design procedures. These procedures are largely dependent on tables designed as the outcome of experiments and investigations of material properties, graphs, charts and empirical relations. Many factors found to affect the proportions of ingredients of concrete, such as specific gravity of materials, type and

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strength of cement, the minimum and maximum content of cement, water-to-cement ratio, mixing water requirements, aggregate-to-cement ratio, type, shape and maximum size of aggregates, grading of aggregates, the ratio of fine to total aggregate, entrapped air content, concrete exposure conditions, properties of concrete in green and hardened concrete. All the existing methods of concrete mix formulation follow the same basic trial and error fundamentals. Different methods can be found to design a concrete mixture under requirements that are workability, ingredients and a specific environment. Some of the prevalent approaches of mix design are framed by "Maximum Density Method, Fineness Modulus Method, American Concrete Institute (ACI), Bureau of Indian Standard (BIS), Road Research Laboratory procedure, and Department of Energy (DOE) or British Standard (BS) mix design system" (Raju, 2007). Nataraja et al. (1999) have presented a study from the thorough evaluation of experimental data, tables and graphs developed through in-depth experiments and studies in various mix design procedures. For enhancing the mix design procedures, many functions are noted, and updated mix design parameters have been suggested to generate an economical mixture for varying weather conditions. Mohammed et al. (2012) have proposed an "artificial neural network (ANN)-based design of concrete mixes considering six design parameters, namely w/c ratio, slump, percentage of fine to total aggregate, maximum aggregate size, fineness modulus of fine aggregate, and compressive strength. They concluded that fineness modulus of aggregates has a major effect on the properties of the concrete mix". Lamond (1997) from the analysis of concrete durability has revealed that "durability and strength of concrete are two different parameters; the strength of concrete is just one of the indications of the durability". Wadud and Ahmad (2001) studied the ACI mix design procedure. As per their study, if CA with greater voids is used in making the concrete, it fails to uphold a proper ratio between FA and CA. Al-khalaf and Yousif (1984) have concluded that "the correct proportioning of the aggregate-to-cement ratio is necessary to produce a consistent mix". The DOE method uses the compaction factor as a measure of workability, the ACI method uses the slump. Though the DOE method discusses the air entrainment, the selection of the w/c ratio is a sole function of the target mean strength whereas in ACI method, the determination of the w/c ratio, is a combination of both the target strength and the type of concrete (whether air entrained or non-air entrained).

Nowadays massive concrete structures are constructed worldwide and to assure the safety of life and property, in-depth studies are carried out for promising strength, durability and overall performance of concrete. The present investigation was completed for suggesting the practicality, performance, basic principles of selection and further cost analysis on the concrete mixes formulated by different guidelines. The major drawbacks were included and the suitability for moderate climate conditions was discussed.

2. Summary of Mix Design Procedures

The Indian standard code IS 10262 (2009) presents an elementary assumption that "the compressive strength of concrete is governed by the w/c ratio. The w/c ratio is adopted as per the concrete grade and sort of exposure and water content is selected based on nominal CA size and slump value". The guidelines for the use of any type of admixture in concrete are available. The resilience, w/c proportion and cement quantity requirements are included in IS 456 (2000). The volume of CA is dependent upon the zone of FA as per IS 383 (1970) along with the nominal maximum size of aggregate. The other aspects which influence the property of concrete include the grade and quality of cement; water and aggregate dimensions. Therefore, the instructions mentioned in the proportioning of concrete ought to be considered only as a basis of trial which can be changed. The "compressive strength of hardened concrete is to be specified based on the cube compression test, determined at 28 days" as per IS 516 (1959).

The ACI 211.1 (1991) takes "workability, consistency, strength, and endurance into consideration. ACI suggests mixture design processes based on these principles" (Raju, 2007):

a) In the selection of mix proportion, a wet concrete mix of specified slump comprising a well-graded FA and CA of maximum dimensions will have essentially fixed water content no matter of varying w/c or cement proportion.
b) The w/c proportion is reliant on the concrete strength with a constraint from the durability parameter.
c) The proportion of CA per unit volume of concrete is reliant on the CA size and the FA grading, stated as fineness modulus.
d) Regardless of the process of compaction in concrete, some voids occupy the entrapped air which has indirect proportionality to the maximum dimension of FA and CA.

The disadvantage of ACI method is that for different cement contents the FA cannot be adjusted. There is also no guideline to mix the aggregates of varying sizes. No provisions for lightweight aggregate concrete, special admixtures for manufacturing concrete products and no defined provision for concrete using condensed silica fume. The cement strength perspective is not considered while framing the mix design. "The ACI method of mix design is applicable for normal and heavyweight concrete having 28-days cylinder compressive strength" as per ACI 318-08 (2008).

The BS procedure or Department of Energy (DOE) of concrete mix design method relies on these guidelines (Raju, 2007):

a) The aggregate of two forms of uncrushed and crushed is recognized.
b) Slump values and Vee-bee test time are considered as a measure of the workability of concrete mix.
c) The workability obtained by a specific water-content is proportional to the type of aggregate using different maximum sizes (10 mm, 20 mm, and 40 mm).
d) The FA content is reliant on desired workability, aggregate size and w/c ratio.

The disadvantages of BS method include the FA proportion is greater in the mix design and for varying cement content, the FA cannot be fixed. It doesn't take into account the flakiness of aggregate, FA, water proportion and the effect of aggregate texture. "No specific graphs are recommended to estimate fine aggregate content for a maximum size of aggregates between 10 mm and 20 mm and 20–40 mm. The compressive strength of hardened concrete is to be specified based on 150 mm cube test determined at 28 days in N/mm² or 150 mm diameter by 300 mm cylinder tests, determined at 28 days in N/mm²" as per BS EN 12390-3 (2019).

3. Experimental Program Summary

The concrete mix designs were formulated with basic material properties listed in Table 1.

The sieve analysis results of CA and FA are mentioned in Tables 2 and 3, respectively.

The proportioning of ingredients of a concrete mix by IS, ACI and BS methods are shown in Table 4. The ingredients of the mixes were weighed and casting was carried out using a tilted drum type concrete mixer. Precautions were taken to ensure uniform mixing of ingredients. The specimens were cast in steel moulds and compacted on a table vibrator following IS 516 (1959) guidelines. Cube specimens of size '150mmx150mmx150mm' were cast for cube compressive strength. Curing was done for 28 days by keeping the specimens completely immersed in water. All the test results reported representing the average value obtained from five specimens in each category.

The workability of concrete mix measured in terms of slump and vee-bee is reported in Table 5, including 7th day and 28th day compressive strength.

Table 1. Material properties.

Property		Values
Mean target compressive strength		"15MPa, 20MPa, 25MPa, 30MPa and 35MPa"
Category of cement		Ordinary Portland Cement (OPC) 53 grade, make – Ambuja, in compliance to IS 12269 (1987) was used.
Nominal maximum dimension of CA		20 mm
Category of CA		Crushed natural stone aggregate
Category of FA		River Sand
Specific gravity :	Cement	3.15
	CA	2.62
	FA	2.59
Unit weight of :	CA	1600 kg/m³
	FA	1700 kg/m³
Fineness modulus (FM)	CA	7.30
	FA	2.44 (Zone II) as specified in IS 383 (1970)
Water absorption :	CA	0.57%
	FA	1.00 %
Surface moisture :	CA	0.00%
	FA	2.32%
Admixtures		Not used

Note: The experimental temperature was maintained between 25°C to 30°C; a condition of moderate climate temperature.

Table 2. Grading of coarse aggregates.

Sample = 5 kg						
Sieve size		Retained weight (kg)	Collective weight retained (kg)	Collective % retained	Collective % passing
(mm)	(micron)				
80		0	0	0	100
40		0	0	0	100
20		1.519	1.519	30.38	69.620
10		3.444	4.963	99.26	0.740
4.75		0.037	5	100	0
2.36		0	5	100	0
1.18		0	5	100	0
	600	0	5	100	0
	300	0	5	100	0
	150	0	5	100	0
Total Sum		5		729.64	
F M = (729.64/100) = 7.3					

Table 3. Grading of fine aggregates.

Sample = 1000 gram					
Sieve size		Retained weight (g)	Collective weight retained (g)	Collective % retained	Collective % passing
(mm)	(micron)				
4.75		11	11	1.1	98.9
2.36		63	74	7.4	92.6
1.18		141	215	21.5	78.5
	600	245	460	46.0	54.0
	300	214	674	67.4	32.6
	150	326	1000	100.0	0
Total Sum :		1000		243.4	
F M = (243.40/100) = 2.44 , Grading zone II as per IS 383 (1970) (Chaubey, 2020)					

Table 4. Proportioning of ingredients of concrete mix.

Grade of concrete	Standard	Proportion by volume (kg/m³)			Ratio (Cement:FA:CA)	Water content (litre/m³)	w/c ratio	Total aggregate-cement ratio
		Cement	FA	CA				
M15	IS	310.00	758.56	1124.92	1:2.44:3.62	182.63	0.59	6.08
	ACI	268.12	862.50	970.00	1:3.21:3.61	180.38	0.80	6.83
	BS	200.00	808.80	1092.00	1:4.04:5.46	165.13	0.86	9.50
M20	IS	338.18	730.02	1129.29	1:2.16:3.34	183.02	0.54	5.50
	ACI	308.33	787.08	1049.60	1:2.55:3.40	180.82	0.59	5.96
	BS	226.67	809.69	1187.00	1:3.57:5.24	166.32	0.73	8.80
M25	IS	372.00	700.90	1130.58	1:1.88:3.03	183.40	0.49	4.92
	ACI	349.06	751.53	1049.60	1:2.15:3.00	181.28	0.52	5.16
	BS	261.54	775.53	1185.51	1:2.96:4.53	166.76	0.63	7.49
M30	IS	413.33	800.62	991.99	1:1.93:2.40	183.78	0.45	4.33
	ACI	411.11	685.44	1115.50	1:1.67:2.71	181.92	0.55	4.38
	BS	283.33	644.38	1079.20	1:2.27:3.80	167.15	0.58	6.08
M35	IS	465.00	767.25	994.50	1:1.65:2.13	183.85	0.40	3.79
	ACI	462.50	560.05	1115.20	1:1.21:2.41	182.50	0.38	3.62
	BS	320.75	384.48	1217.50	1:1.20:3.79	167.57	0.44	4.99

Table 5. Test results.

Grade of concrete	Standard	Slump value (mm)	TMS (MPa)	Mean 7th day compressive strength (MPa)	Mean 28th day compressive strength (MPa)	Average weight of the specimen (kg)
M15	IS	35	20.78	14.67	20.81	8.330
	ACI	30	20.78	14.96	20.89	8.478
	BS	45	20.78	10.81	15.70	8.256
M20	IS	30	26.60	19.56	27.85	8.334
	ACI	35	26.60	19.41	27.78	8.339
	BS	30	26.60	16.81	24.37	8.305
M25	IS	40	31.60	22.30	33.11	8.335
	ACI	30	31.60	23.41	33.48	8.257
	BS	30	31.60	19.41	28.30	8.123
M30	IS	50	38.25	26.52	38.30	8.405
	ACI	30	38.25	26.96	38.59	8.352
	BS	45	38.25	20.44	29.02	8.269
M35	IS	30	43.25	30.81	43.33	8.443
	ACI	30	43.25	30.81	43.26	8.413
	BS	60	43.25	22.37	31.85	8.370

4. Results and Discussion

a) The BS method is comprehensive and tedious, whereas IS and ACI methods are relatively easy and precise.
b) The mix designed by IS and ACI methods attained the calculated TMS and were found to be consistent whereas the trial mixes designed by BS method failed to attain TMS as confirmed by Ejiogu et al. (2018). Fig. 1 displays a bar chart of comparison between 7th day compressive strength, 28th day compressive strength and TMS of all the three concrete mix designs.
c) The w/c ratio is in indirect relation with targeted mean strength in all three methods. The w/c ratio is highest in the BS method, whereas the lowest in IS method. The variation is shown in Fig. 2 (a, b).
d) The proportion of water-content in BS method is less as compared to the other two methods. It is nearly identical in IS and ACI methods. Fig. 3 displays a bar chart of water-content required in different grades of concrete in the respective mix design procedures.
e) The cement-content is directly proportional to the TMS. The IS method utilizes maximum cement proportion and the BS method uses the least which is a factor in the failure of BS mix proportioning method to achieve the TMS. Fig. 4 (a, b) indicates the amount of cement required in the specified concrete mixes as per the respective procedure.
f) The TAC and the aggregate-cement ratio in BS method are high as compared to IS and ACI methods. An indirect relationship between TAC and TMS is observed. Fig. 5 displays a bar chart of the ratio of total-aggregate and cement-content.
g) The CA content is maximum in mixes designed by BS procedure followed by IS and ACI mix designs. No such co-relation in CA content was found in the mixes from low to high TMS.
h) The FA content in IS mix design is inversely proportional to the targeted strength up to M25 and then increases. Whereas in ACI and BS mix design the FA content shows an indirect relationship with the TMS. The consistent proportion of CA: FA in ACI mix designs is a reason for a consistent compressive strength as maximum voids are filled. Fig. 6 (a, b) shows the variation of CA and FA content in different mixes as per IS, ACI and BS method of mix design.
i) The explanation of the failure of BS method is due to high values of w/c ratio, lower cement content and higher quantities of total aggregate than the other two methods. As a result, the proportion of cement appears to be inadequate to cover all the aggregates and bind them properly.

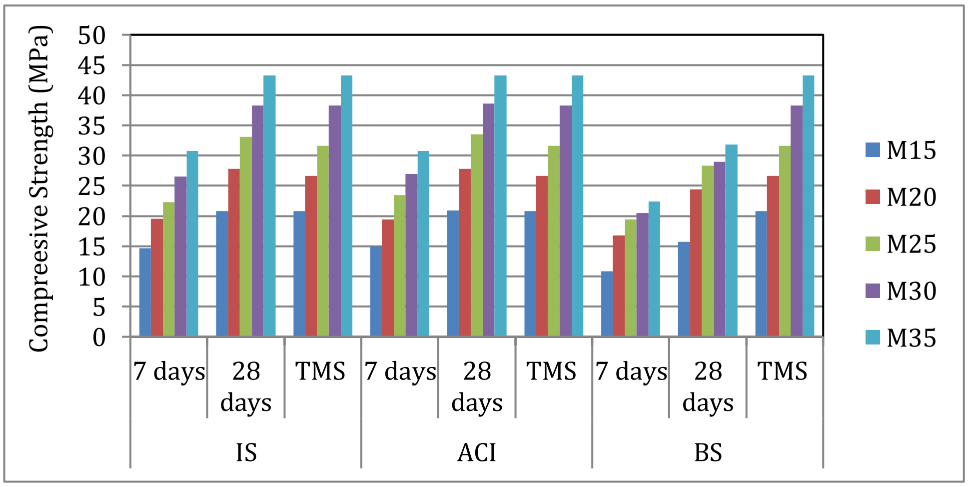

Fig. 1. Comparison of 7th day and 28th day compressive strength and TMS.

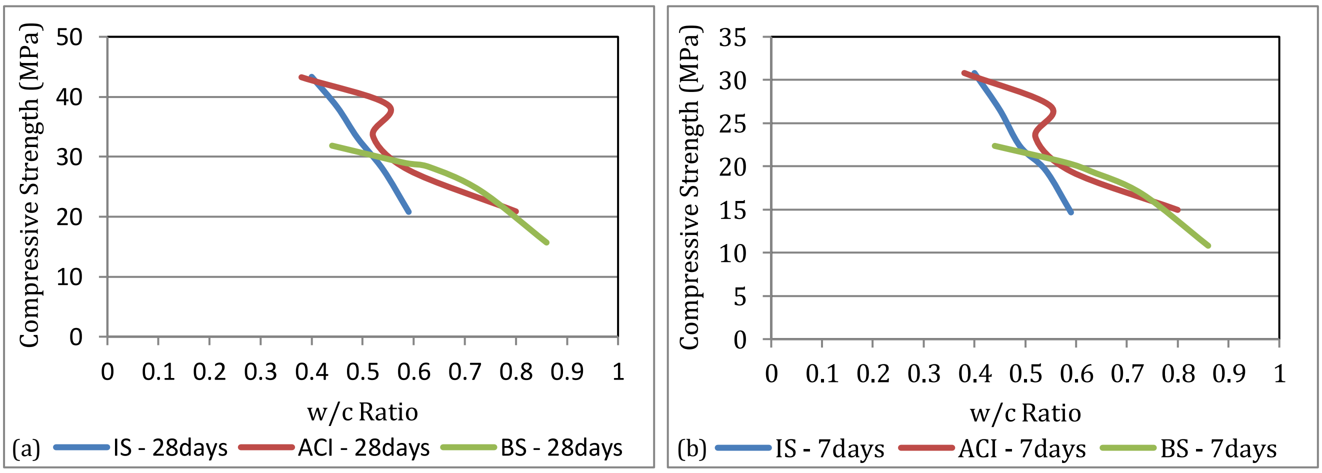

Fig. 2. Compressive strength vs w/c ratio.

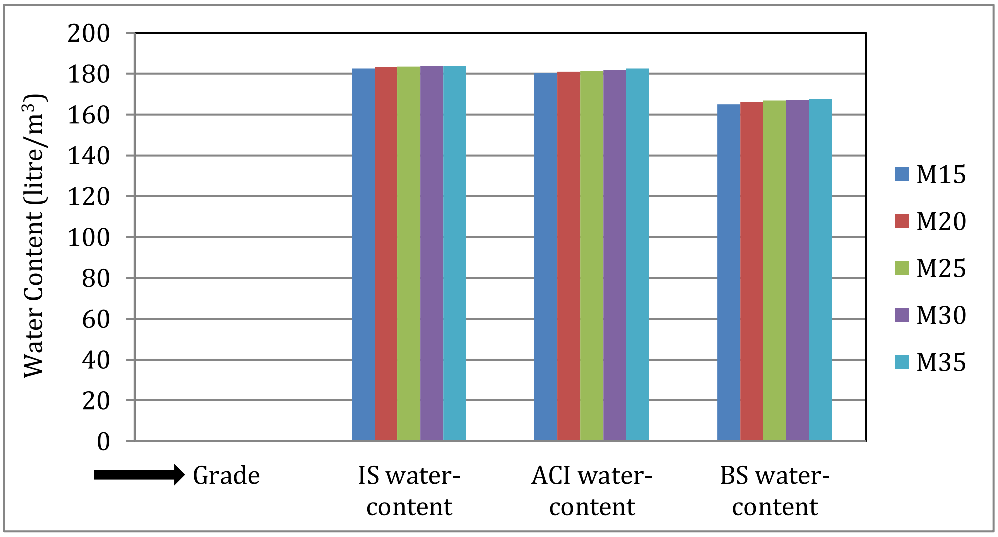

Fig. 3. Water-content required in specified concrete mixes.

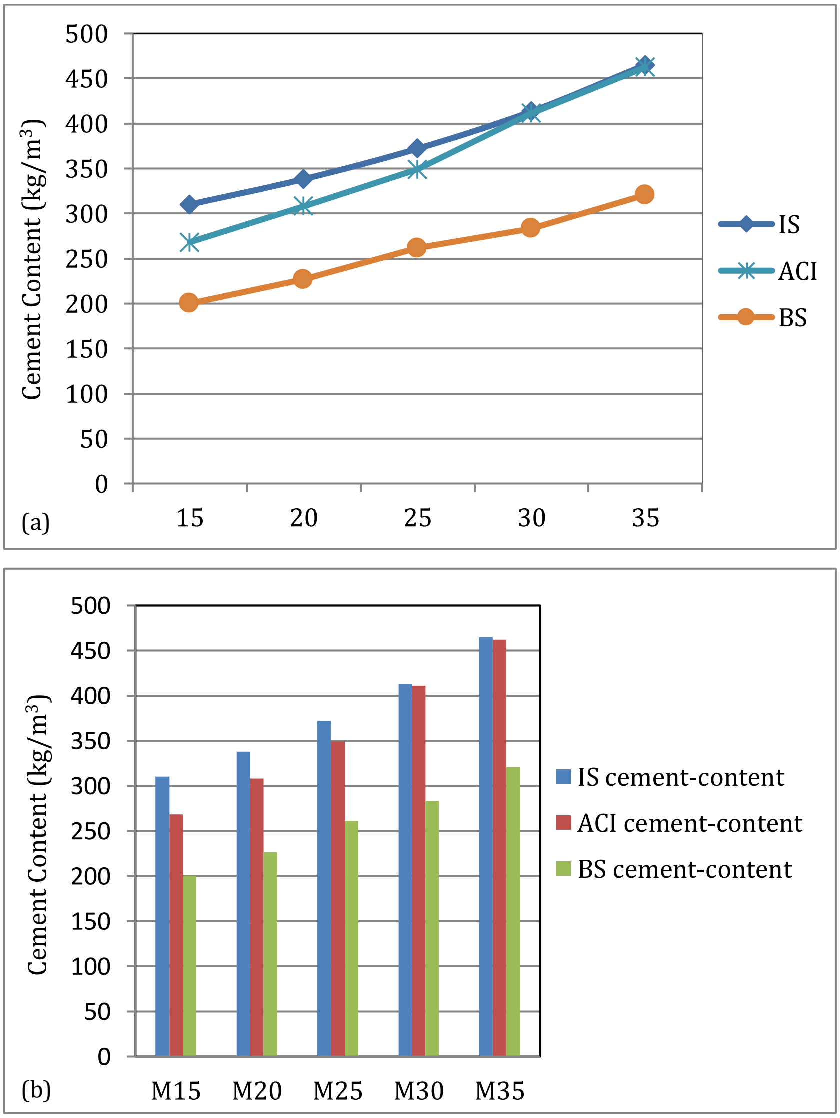

Fig. 4. Variation of cement-content in the designed concrete mixes.

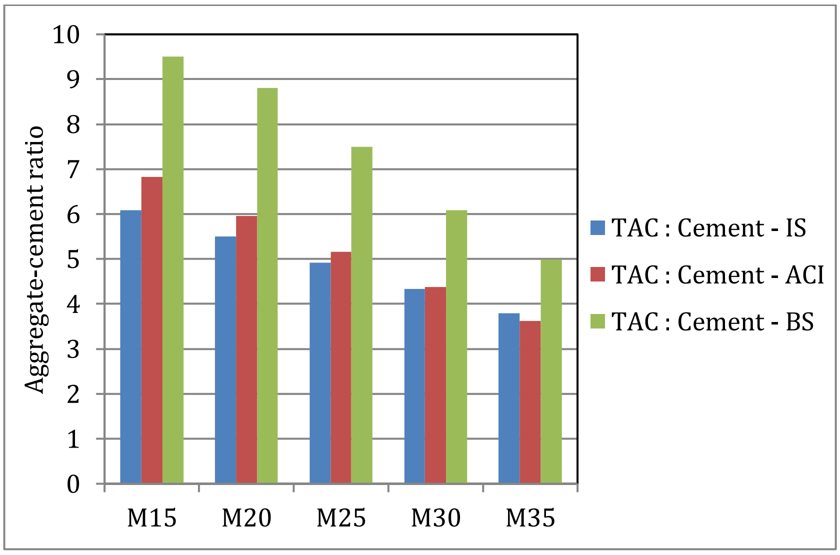

Fig. 5. Total aggregate content- cement content ratio.

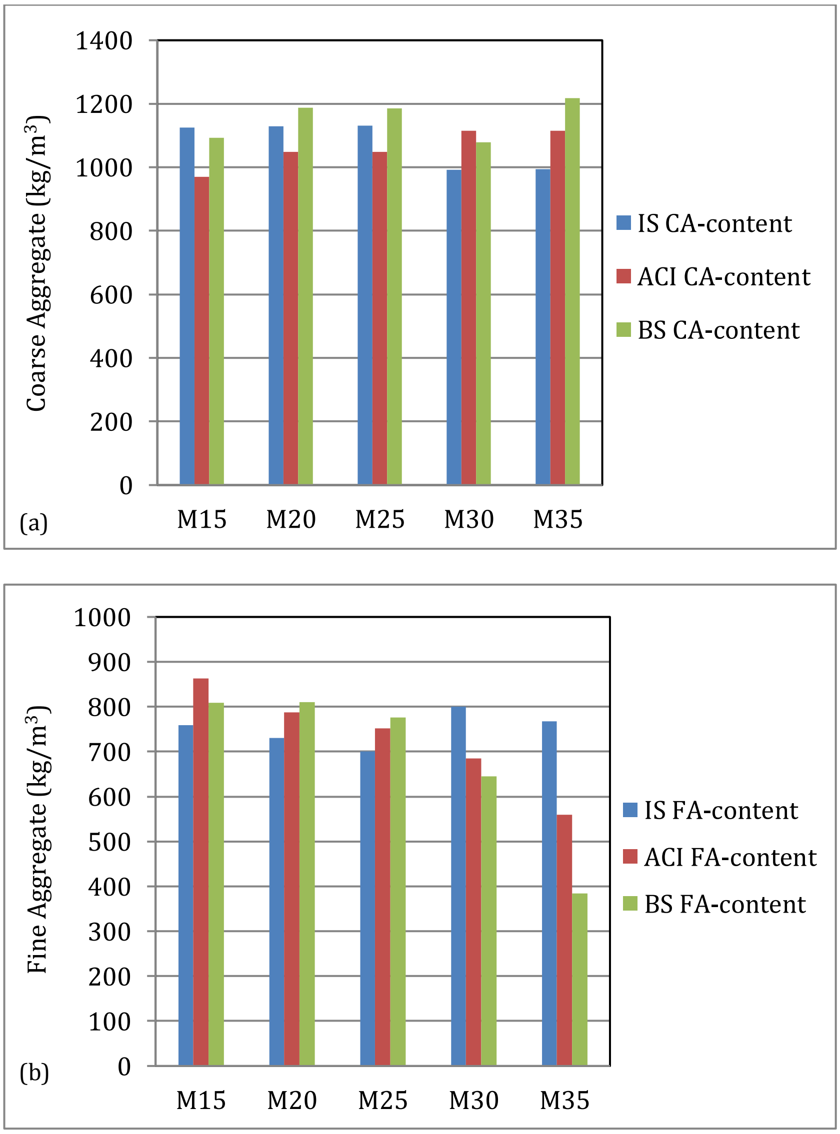

Fig. 6. Variation of coarse aggregate and fine aggregate in designed concrete mixes.

5. Density of Concrete

The "density of the formulated concrete mix was estimated with the attained weight of concrete ingredients per unit volume" (Ahmed et al., 2016) and represented in Table 6. The density of the mix characterizes the compactness of the mix and concrete formed with higher density will be more suitable to harsh conditions.

From Table 6 it is evident that the wet density of fresh concrete and hardened density of concrete specimens (28th day) by mix proportion weight is maximum for IS specimens followed by ACI specimens in all the formulated mix proportions. Therefore, for lower grades of concrete (M15, M20 and M25), ACI concrete proportioning method can be recommended and for higher grades (M30 and M35), IS concrete proportioning method will be more suitable for a moderate climate.

6. Cost Analysis

The basic cost of cement, FA and CA was taken from location Srinagar city (Jammu & Kashmir) as on May 2020. The transportation cost was excluded from the total cost. Table 7 shows the costs of concrete ingredients. The cost per cubic meter of concrete is given in Table 8 and Fig. 7 specifies the cost bar chart.

Table 6. Evaluation of density of fresh concrete and hardened concrete.

Grade of concrete	Standard	Slump value (mm)	Average fresh concrete density	Average weight of the cube specimens (kg)	Average hardened concrete density
M15	IS	35	2297.3	8.33	2468.15
	ACI	30	2261.4	8.478	2512.00
	BS	45	2254.7	8.256	2446.22
M20	IS	30	2369.7	8.334	2469.33
	ACI	35	2343.4	8.339	2470.81
	BS	30	2335.6	8.305	2460.74
M25	IS	40	2384.4	8.335	2469.63
	ACI	30	2352.7	8.257	2446.52
	BS	30	2343.1	8.123	2406.81
M30	IS	50	2387.4	8.405	2490.37
	ACI	30	2359.7	8.352	2474.67
	BS	45	2349.5	8.269	2450.07
M35	IS	30	2399.7	8.443	2501.63
	ACI	30	2368.7	8.413	2492.74
	BS	60	2356.8	8.37	2480.00

Table 7. Material cost.

Material	Cost	Quantity	Unit	Cost of 1kg (₹)
Cement	1500	150	kg	10
FA	2800	2	m^3	1.4
CA	2100	2	m^3	1.05

Table 8. Cost estimation per 1m^3 of concrete.

Grade of concrete	Standard	Cement Qty. (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Total Cost per m^3 (₹)
M15	IS	310.00	758.56	1124.92	5343.15
	ACI	268.12	862.50	970.00	4907.20
	BS	200.00	808.80	1092.00	4278.92
M20	IS	338.18	730.02	1129.29	5589.58
	ACI	308.33	787.08	1049.60	5287.29
	BS	226.67	809.69	1187.00	4646.62
M25	IS	372.00	700.90	1130.58	5888.37
	ACI	349.06	751.53	1049.60	5644.82
	BS	261.54	775.53	1185.51	4945.93
M30	IS	413.33	800.62	991.99	6295.76
	ACI	411.11	685.44	1115.50	6241.99
	BS	283.33	644.38	1079.20	4868.59
M35	IS	465.00	767.25	994.50	6768.38
	ACI	462.50	560.05	1115.20	6580.03
	BS	320.75	384.48	1217.50	5024.15

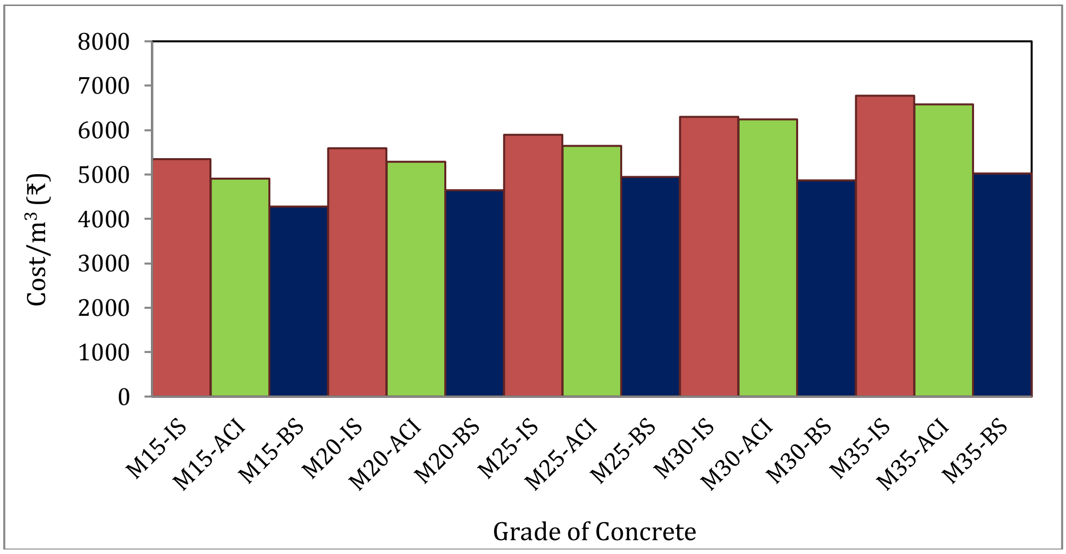

Fig. 7. Graphical representation of cost analysis.

7. Conclusions

Based on the comparative study of mix design procedure as per IS, ACI and BS for quality and economical perspective, the significant conclusions were drawn as follows:

- The method that considers the strength of cement, entrapped air and grading of aggregates with a wide-ranging aggregate size will be more appropriate for the moderate climate conditions as it will yield compact and durable concrete.
- The BS method of mix design is considerably more complex and repetitive and appears to be inconsistent for moderate climate (Kashmir, India).
- The water-content specifies direct proportionality with initial compressive strength and setting time. Less is the water proportion; more will be the 7th day compressive strength and vice versa.
- In the three mix design procedures, the general observations can be summed as: compressive strength is indirectly proportional to w/c ratio; compressive strength shows direct relation with cement-content and indirect relationship with FA content.
- The TAC and the aggregate-cement ratio in BS method are high as compared to IS and ACI methods. This is one of the few reasons for the failure of BS mix design specimens in achieving TMS in 28-days.
- The quality of a concrete mix is determined by the ratio of TAC and cement content. IS and ACI mix design procedures followed indirect relation with TAC and cement ratio from low to high TMS.
- The wet density of fresh concrete and hardened density of concrete specimens (28th day) by mix proportion weight is maximum for IS specimens followed by ACI specimens. For lower grades (M15, M20 and M25) of concrete, ACI concrete proportioning method can be followed and for higher grades (M30 and M35), IS concrete proportioning method can be recommended for a moderate climate.
- The cost analysis per cubic meter of concrete reveals that IS and ACI mix proportioning are costly than BS mix proportioning. The total cost estimation of a concrete mix revealed that cost increases with a decrease in w/c ratio. However, it showed direct proportionality with TMS.

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