International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 02 Issue: 06 | Sep-2015 www.irjet.net p-ISSN: 2395-0072

Evaluation of M35 and M40 grades of concrete by ACI, DOE, USBR and BIS methods of mix design

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Abstract - This *paper presents a comparison of DOE, ACI, BIS and USBR methods of concrete mix design, combining the test results of these methods. The M35 and M40 grades of concrete have been designed for comparison using crushed aggregates. Designing same standard mixes by all these methods resulted in complete comparison in terms of proportioning parameters of different mix design methods, thus defining the effect of variation in proportion on the properties of concrete. In this experimental study the strength, durability and other mechanical properties of concrete, designed as per different mix design methods are compared. The study indicates that the outcomes of concrete designed as per USBR method are relatively a lot more eminent than that of the rest of the methods used for comparison. Whereas, the ACI method was failed to achieve the target mean strength in case of M40 and it was redesigned with an increased quantity of cement. However, the results of DOE method cannot be overlooked*.

Key Words: *Mix design, Compressive strength, Flexure, Split Tensile, Water Permeability etc.*

1. INTRODUCTION

Mix design is a process of specifying the mixture of ingredients required to meet anticipated properties of fresh and hardened concrete. Concrete mix design is a well established practice around the globe. The concrete mix design methods used in countries such as, Britain, India and USA are based on similar basic principles and empirical relations, developed after substantial experiments on locally available materials, notwithstanding just about small differences exist. These methods are mostly based on empirical relations, charts, graphs, and tables developed through extensive experiments and investigations using locally available materials. Some of the prevalent concrete mix design methods are: (a) ACI (American Concrete Institute) Mix Design Method, (b) USBR (United States Bureau of Reclamation) Mix design practice, (c) British Mix Design Method, and BIS (Bureau of Indian Standards) Recommended guidelines. Therefore, a detailed comparative analysis of these methods of mix design is warranted. This type of comparative study can help distinguish variations in either method or would otherwise substantiate their validity. The research will examine the similarities and differences between the ACI, BIS, USBR and DOE concrete mix designs. It is must study that how design calculations for aggregates content, cement content, and water cement (w/c) ratio are different in these four methods. In accordance with variation in these design procedures, the expected change in properties of concrete (either in fresh stage or in hardened concrete) shall be considered. Properly designed mix for a particular application, keeping in mind the specific requirements (workability, durability and strength, knowing the source and properties of aggregates, type of cement) effect a substantial saving in cost. Therefore, concrete mix design is the science, as considerably as the artistry of getting concrete to its desirable qualities at the cheapest costs. So while comparing different methods of concrete mix design economy is a factor which in addition to other properties shall be emphasized upon.

2. EXPERIMENTAL PROGRAM

The experimental program was planned to study the influence of Change in proportioning of aggregates on the properties of concrete when designed with different mix design methods. The main objectives of the present research are listed beneath

- To design the mixes for M35 and M40 grades by all the four methods (ACI, DOE, BIS and USBR)
- To test and compare the concrete specimens produced for properties i.e. Compressive strength, Flexural strength, Split tensile and Abrasion.
- To test and compare the concrete specimens for durability parameter based on water permeability.
- To compare the results for inferring the critical method in terms of strength parameters and cost analysis.

The experimental program consisted of laboratory test on concrete designed as per ACI, USBR, BIS and BRITISH mix design method to characterize and compare the properties such as compressive strength, flexure strength, split tensile strength, abrasion and water permeability. For this purpose cubes, beams and cylinders of M35 and M40

grades of concrete designed by ACI, USBR, BIS and BRITISH Mix design methods were cast and tested for the respective properties after a curing period of 7,28 and 56 days. For each curing age a set of three samples of each type was cast. In all cases the cement content and water/cement ratio was fixed, it was only proportioning of aggregates that were altered as per mix design methods, i.e. cement content was 415 kg for M35 and 430 kg for the M40.Similarly w/c ratio was 0.40 for M35 and 0.38 for M 40.

3. DETAILS OF MATERIAL AND MIX DESIGNS

Portland pozolona cement (specific Gravity = 3.0) was used to carry out the research work. In this study the locally available sand was used. Its various physical properties were tested as per IS: 383 – 1970. The coarse aggregates used in this investigation were 20 mm and 12.5 mm graded aggregates. The aggregates were made free from silt content before use. The physical properties of aggregates are listed as

Fineness modulus of fine aggregates = 2.4, Grading zone of fine aggregates = zone 4, Specific gravity of fine aggregates = 2.54, Specific gravity of coarse aggregates = 2.72, Grading ratio of 20 mm aggregates to 12.5 mm = 2:1, Unit weight of Coarse aggregates = 1450

Using these aggregates M35 and M40 grades of concrete were designed. The proportions obtained using the design mix are given in the following tables

Table 1: Mix proportions of M35 obtained as per different Mix Design Methods (kg/m³)

Sr. No.	Type of mix design	DOE	ACI	BIS	USBR
1.	W/C	0.40	0.40	0.40	0.42
2.	Water content	166	166	166	175.34
3.	Cement content	415	415	415	415
4.	Fine aggregates	415.6	866.65	562.45	738.6
5.	Coarse aggregates	1246.8	957	1281.21	1075.86
6.	Plasticizer	3.32	4.15	3.32	4.15

Table 2: Mix proportions of M40 obtained as per different Mix Design Methods (kg/m³)

Sr. No.	Type of mix design	DOE	ACI	BIS	USBR
1.	W/C	0.38	0.38	0.38	0.40
2.	Water content	164	164	164	176.28
3.	Cement content	430	430	430	430
4.	Fine aggregates	413.86	838.96	553.01	743.10
5.	Coarse aggregates	1241.58	957	1283.55	1054.89
6.	Plasticizer	4.3	4.3	3.44	4.3

3. MIXING, CASTING AND CURING OF SPECIMEN

Materials were mixed in a pan mixer. All cubes, beams and cylinders were cast in the standard metallic moulds and vibrated to obtain required sample size. The moulds were cleaned off dust and oil was applied on all sides of moulds before concreting the sample. Thoroughly mixed concrete was poured into the moulds in three equal layers and the moulds were placed on vibrating table for a small period. Excess concrete is removed with a trowel and the top surface is finished with a smooth surface.

After 24 hour protection in mould the samples were demoulded and put in curing tank for the respective periods of 7, 28 and 56 days. A set of 3 samples was prepared for each stage curing. The temperature of curing tank was kept at 25° ± 2° c for 56 days.

4. TESTING

The following test procedures were conducted in order to compare the desired properties of concrete designed by different methods.

4.1. Compression Test

The compressive strength of different samples was tested after 7, 28 and 56 days of curing. The 150 mm cubes were tested on compression testing machine under continuously increasing load @ 14Mpa/min.

4.1.2 Observations

In comparison, of results it was observed that for M35 all cubical specimens of concrete tested achieved their target mean strength irrespective of the mix design method used. Nevertheless, the concrete designed as per USBR method attained the highest compressive strength either at 7 days or after 28 days, which was 123.31% of the target strength required. The DOE method achieved almost same compressive strength as that of USBR method, whereas strength achieved by ACI method was 104% and by BIS method it was observed 102.65% of the target mean strength. For M40 grade of concrete the ACI method was failing to achieve the target strength, whereas the rest of the methods achieved strength more than the target strength. The DOE, BIS and USBR methods attained 100%, 104% and 101.30% of strength respectively. The ACI method was redesigned with an increased amount of cement, which was 145 kg/m^3. The samples were cast repeating the same procedure and then tested at 28 days of curing age. From the observations it was remarked that the ACI method delivers the same compressive strength as obtained by other mix design methods, but using an excess amount (15 kilogram) of cement. With this increased quantity of cement, the compressive strength achieved with concrete designed as per ACI method is 50.55 N/mm^2. The mix proportions obtained as per USBR method of mix design resulted in most cohesive mix among the mix design methods used resulting in high compressive strength.

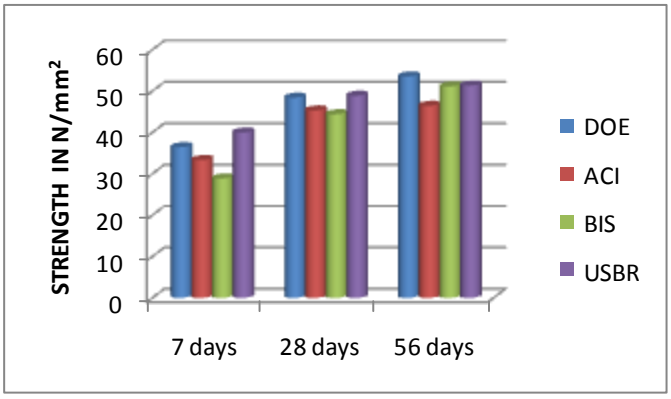


Chart 1: Test Results for Compressive Strength of M35

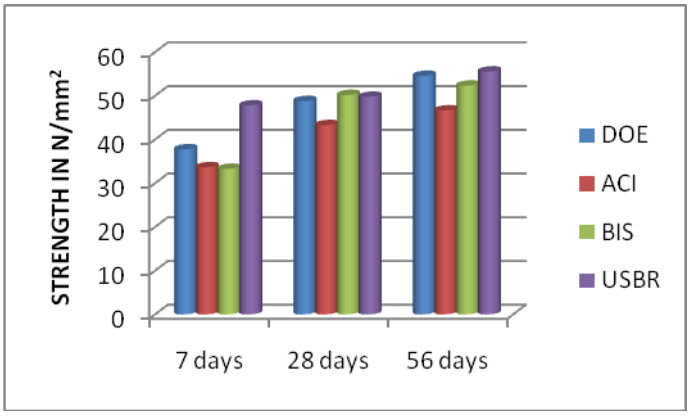


Chart 2: Test Results for Compressive Strength of M40

4.2 Flexure test of beams

The flexural strength of different samples was tested after 7, 28 and 56 days of curing. The beams were tested on a flexure testing machine under continuous increasing load @ 1kN/min. From experimental investigations, it was observed that flexure strength attained by concrete designed as per USBR method increased with time and is highest among the methods used after 56 days of curing. After 28 days of curing both DOE and USBR methods attain a higher amount of flexural strength than rest of the methods. The BIS method achieved the least flexural strength even then it meets the minimal requirements of flexural strength. For M40 grade of concrete the BIS method delivers the best results in terms of flexural strength. Even the USBR and DOE method exhibit a much higher flexural strength than the ACI method which was redesigned with an increased amount of cement to meet the minimum requirements of strength.

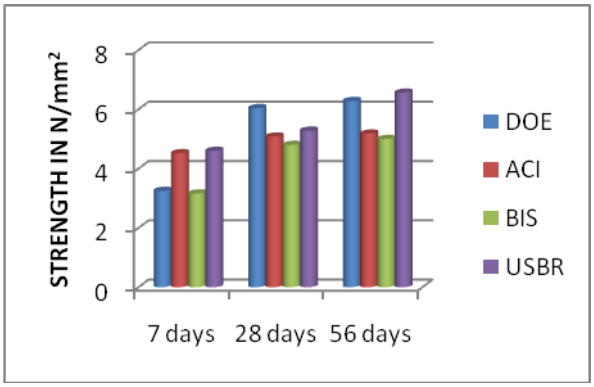


Chart 3: Test Results for Flexural Strength of M35

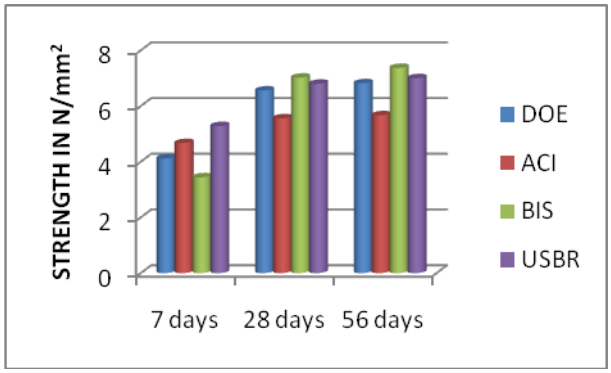


Chart 4: Test Results for Flexural Strength of M40

4.3 Split tensile strength

The split tensile strength of different cylinders was tested after 7, 28 and 56 days of curing. The cylinders were tested on compression testing machine when loaded in a split tensile testing assembly under monotonic loading @ 1kN/min. After analyzing the outcomes of split tensile test of concrete it was observed that for M35 grade, the concrete designed with DOE method exhibits maximum split tensile strength and that of by ACI method has the least among the four methods used for comparison. The split tensile strength of USBR and BIS method has a marginal difference. For M40 grade the BIS method shows a vast increment in the split tensile strength as compared to M35 and has achieved highest strength among the rest of the methods, whereas, the ACI method shows a marginal increase in split tensile strength again having the least strength as in case of M35. Turning down the pattern of M35, the marginal difference between USBR and BIS is converted to a reasonable difference in the split tensile strength for M40 grade. As the primary attributes of crushed aggregates that are of importance are the interlock and better quality of paste - aggregate bond. Presumably, the higher content of coarse aggregate in DOE and BIS method are responsible for higher values of split tensile strength.

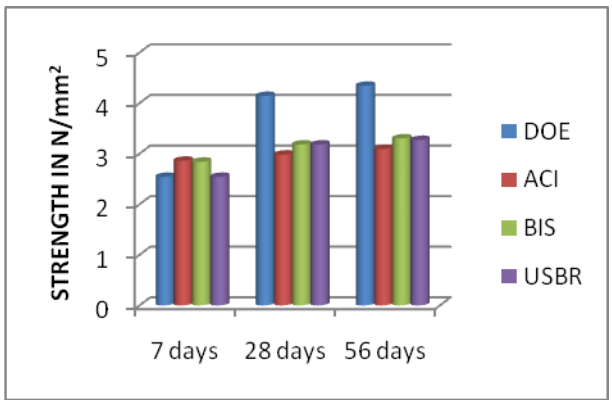


Chart 5: Test Results for Split Tensile Strength of M35

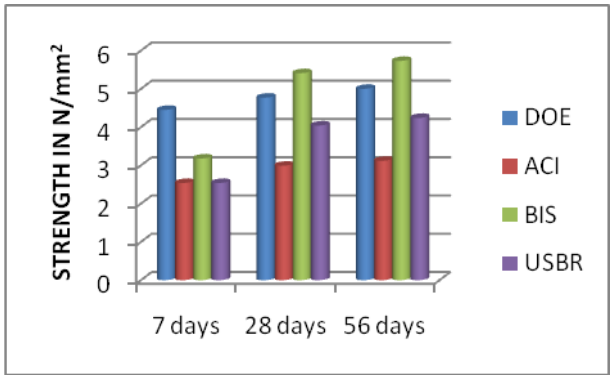
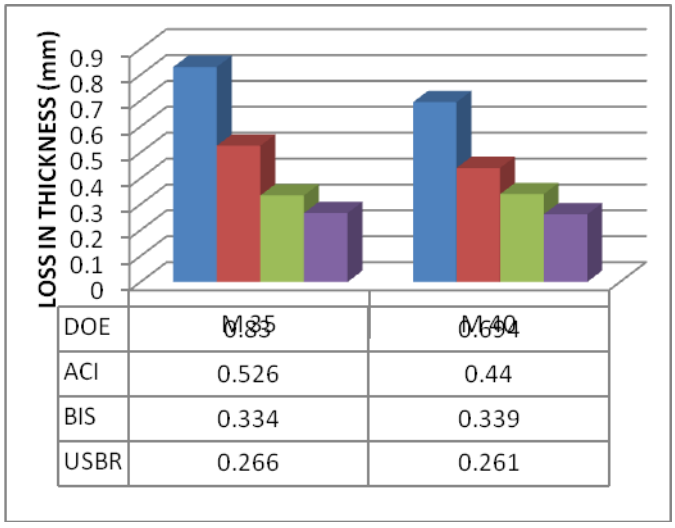


Chart 6: Test Results for Split Tensile Strength of M40

4.4 Abrasion test values for M35 and M40 grade of concrete

To compare the toughness of concrete, when designed with different prevalent mix design methods, abrasion test was performed on concrete samples (70*70*25 mm). The loss of thickness was observed in each case. From the experimental investigation, it is clear that the concrete mix designed with USBR method Show an increase in the toughness of concrete. An increasing pattern of abrasion is observed as we move to mixes designed with BIS, ACI and DOE respectably. Moreover, the M40 is more resistant to abrasion than M35 irrespective of mix design method used. It is likewise noted that there is a reduction in the loss of thickness in the concrete samples having a larger amount of FA. As the ratio of F.A increases the cohesiveness and compaction level of mix obtained also increases resulting in more tough concrete.



	M35	M40
DOE	0.85	0.694
ACI	0.526	0.44
BIS	0.334	0.339
USBR	0.266	0.261

Chart 7: Test Results for Abrasion of Concrete

4.5 Permeability test

The test was performed to study the durability of concrete when designed as per DOE, ACI, BIS and USBR methods. The test was performed on M35 and M40 grades of concrete. The test was set about by applying a pressure of 5kg/cm2 and gradually increasing up to 16 kg/cm2. The observations are tabulated in table 3. It was observed that up to a pressure of 16 kg/cm^2 the concrete designed was totally impermeable irrespective of the design method used.

Table 3: Test Results of Water Permeability Test

S. No	Method of design mix	Coefficient of permeability (in 10^{-12} m/Sec)	
		M35	M40
1.	DOE	Nil	Nil
2.	ACI	Nil	Nil
3.	BIS	Nil	Nil
4.	USBR	Nil	Nil

4.6 Cost comparison of various mix design methods

The cost comparison in this research is based upon the quantity of aggregates (fine and coarse) used in various mix design method, as the cement content is fixed for all the methods that is 415 kg/m^3 for M35 grade and 430 kg/m^3 for M40 grade of concrete. The cost of aggregates used to carry on the comparison is computed on the basis of the cost of locally available aggregates without the transportation cost which was (Rs. 1078) for one cubic meter of aggregates. The comparison is executed for one cubic meter of concrete designed.

By comparing cost it is quite clear that either for M40 or for M35 the concrete designed with DOE method came out as the cheapest and that by the BIS method by being most expensive, when a fix quantity of cement used for all the mixture design methods.

In case of M40 grade the ACI method became out of the race as it is redesigned by using a higher quantity of cement. As for same grade, an extra cost of 15 kg/m^3 cement is added to the cost of materials.

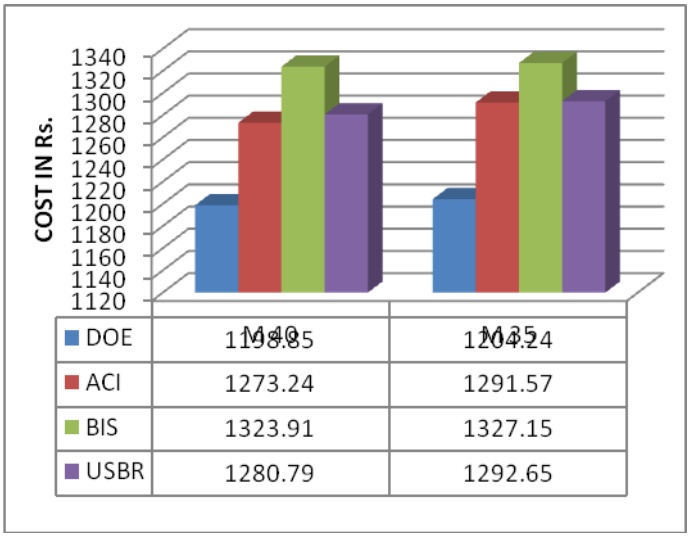


Chart 8: Cost Analysis of Different Mix Design Methods

5. DISCUSSIONS

The experimental program was carried out to compare ACI, BIS, Doe and USBR method of mix design. M35 and M40 grades of concrete were used to carry out the comparison based on the mechanical properties of concrete. The observations showed that all the methods achieved the target mean strength either, in case of M40 or M35 except the ACI method in case of M40 for which the cement content has to be raised by an amount of 15 kg/m^3, to fulfill the minimum requirements of compressive strength. Nevertheless, the USBR method attained the highest compressive strength either at 7 days or after 28 days, which was 123.31% of the target strength required. Whereas, the outcomes obtained by BIS and DOE method cannot be overlooked. The USBR method attained maximum flexure strength for M35 grade, whereas, BIS achieved highest values of flexure for M40 grade. In case of split tensile the DOE and BIS methods have performed better than the other two methods. The DOE method is holding the highest value of split tensile for M35 and BIS attained highest strength for M40 grade.

The study showed that concrete mix designed with USBR method Show an increase in the toughness of concrete. Moreover, the M40 is more immune to abrasion than M35 irrespective of mix design method applied. For durability studies it was observed that up to a pressure of 16 kg/cm^2 the concrete designed was totally impermeable irrespective of the design method used. Overall behavior of M35 in terms of mechanical properties of concrete was observed much better than that of the M40. Even the performance of concrete designed as per ACI method was admirable for M35 grade of concrete which has to be redesigned for M40 grade.

6. CONCLUSION

Various literatures have been reviewed in order to generalize the effect of change in proportions of aggregates, on the properties of concrete when designed by different mix design methods. The experimental program was carried out to compare ACI, BIS, Doe and USBR method of mix design. M35 and M40 grades of concrete were used to carry out the comparison based on the mechanical properties of concrete. It was observed that all the methods achieved the target mean strength either, in case of M40 or M35 except the ACI method in case of M40 for which the cement content has to be raised to fulfill the minimum requirements of strength. The overall comparison shows that the USBR method comes out with the best results among the four mix design methods compared in terms of strength, toughness and durability, but the method is little more expensive than DOE method. The DOE method has been recognized for delivering optimum performance in a relative economic budget except when toughness of concrete is not a mandatory concern. So in daily concrete practice where only strength and durability is required in a comparatively low budget, DOE method of concrete design should be practiced with the stipulation that the toughness of concrete is not a prime requirement, and where site conditions require strength, toughness and durability side by side irrespective of the budget, the USBR method can be practiced for optimum results.

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BIOGRAPHIES

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