Experimental Investigation on Grades of Cement in the Nominal and Design Concrete Mixes

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Abstract. In India, the experience in the use of concrete in housing is more than seven decades old. Concrete mix is a combination of cement, water and aggregates of sand and stone. The relative merits of using 33, 43 & 53 grades of cement in the nominal and design concrete mixes are studied, by testing to destruction hundreds of cubes, cylinders and prisms made using these three grades of cement, the concrete mix having been designed as per the relevant Indian Standard code of practice. The objective of this paper is to make awareness among researchers, engineers and the public about the latest scientific and technical developments in cement, and how to achieve economy in concrete. The foremost objective of concrete mix design is to hand-pick the optimum proportions of various ingredients of the concrete to satisfy the required properties in its fresh and hardened state. As per the investigation, if concrete mixes are designed for different grades adopting separately 33, 43, & 53 grades of cements, grade 53 gives the highest 28 days cube strength, whereas 33 grade cement gives the lowest value. The relative cost of using these three grades is also discussed in the paper.

1. Introduction

Concrete with nominal mix is acceptable for grades M5, M7.5, M15 and M20, Design mix concrete is preferred by the code for all grades from M10 to M60, lower then M20 grades of concrete shall not be preferred for reinforced concrete as per IS 456: 2000, lower than M30 grades of concrete shall not be preferred in post- tensioned concrete and M40 in pre- tensioned concrete as per IS 1343:1984. A lumpy guide for the concrete mix proportion of nominal mix by volume will be 1:1.5:3, 1:2: and 1:3:6 for M20, M15 and M10 grade of concretes respectively, provided that the 20mm nominal maximum size of aggregate is preferred. It is precise that the manufacturer of cement will guarantee the quality of cement in a manner analogous to that of steel, so the methodology developed to design the concrete mix of desired properties using the relationship developed between the water cement ratio and compressive strength of concrete for 28 days for different grades of cement can be effective used.

Concrete mix grades such as M5, M7.5, M15 and M20 are permitted as nominal mixes, Design mix concrete is preferred by the code for all grades from M10 to M60. As per IS 456 2000, for reinforced
concrete grade of concrete must be greater than M20. Similarly, for pre- and post-tensioned concrete grade of concrete must be greater than M30 as per IS 1343 1984. The approximate proportion in the nominal mixes of M20, M15, M10 are 1:1.5:3, 1:2:4 and 1:3:6 respectively, against the 20 mm maximum nominal size of aggregate. Cement manufacturers will guarantee the quality of cement to be supplied as like the reinforcement supply, so the methodology developed to design the concrete mix of desired properties using the relationship developed between the 28-day characteristic compressive strength of the concrete and water-cement ratio for different grades of cement, can be effectively used. [5] [6] [7].

In September 1988, Mr. Kaushal Kishore had written a paper in ICI BULLETIN, in the Title “Concrete Mix Design”. In that paper he mentioned about Design of Concrete Mixes with aggregates of normal density and without any admixtures, in the paper he reproduced all the related Tables from the relevant IS Standards with the permission of Bureau of Indian Standards. While mentioning about the materials used for concrete, he said that about 90% of cement being used in the construction consists of PPC, OPC and PBFS. These three types of Portland Cement were inter changeable for mix design. He also recommended that if increasing cement content beyond a certain value say 550 kg/m$^3$ might not rise the compressive strength and the concrete mixes taking high cement content may results to shrinkage and cracking; creep of cement paste content. Aggregates were occupied about 3/4th of the total volume concrete. As the water-cement ratio decreased from 0.65 the crushed coarse aggregate gave a high strength to concrete. The portable water was generally considered satisfactory for concrete mixing. Water to be used for concrete development and curing should be done by the potable water, free from hurtful amounts of salts, sugar, oils, alkalis, acids, organic materials. The Author was given step-by-step procedure for Concrete Mix Design [1].

In January 1992, Maj (Retd.), M.D. Apte. Discussed about “Concrete Mix Design” as a Concrete Engineer. Maj (Retd.) M.D. Apte had been designing mixes for various structures by trial-and-error method and had achieved satisfactory results. Manufacturers like Macinkgash and Vasavdatta brands claimed their cements to be having compressive strength of about 750 kg/cm$^2$ as against 330 kg/cm$^2$ required by BIS. This should make concrete structures cheaper by needing lesser cement quality per cubic meter of concrete, with all precautions taken. He said we should go on designing concrete mixes with minimum cement content for the designed strength and let the hardened concrete fight as effectively as possible. He also gave a Mix Design Example, how to design a Concrete Mix with minimum quantity of cement [2]. In Year 1992, P.C. Jain, Executive Engineer and R. Chalisgoankar, Assistant Engineer, Irrigation Research Institute Roorkee developed a Software package, according to the Guidelines recommended by Bureau of Indian Standards. The various curves, charts presented in relevant BIS Codes of practice had been included in the package in the digitized form and linear interpolation technique is used for calculating intermediate values. The package was Menu driven interactive computer software package in Fortran-77 language. In this package the Concrete Mix Grade given were M15, M20, M25, M30, M35 and M40, (i.e.) only above mentioned six Concrete Mix Grade can be designed. They highlighted that by using this package we could save considerable computational time, there by affecting the economy in design cost. The software package eliminated human error in reading charts, graphs and tables [3].

In May 1999, Dr. N. Arunachalam, presented a paper on “High strength concrete without Admixtures” in “National Symposium on Recent Trends in Concrete Technology” held at Karunya Institute of Technology. In the paper he had discussed about different Mix-Design methods of developing high strength concrete and the various phases involved in the development are briefly discussed. He had also compared the different Mix Proportions and Tabulated the requirements of Cement and Mix Proportion by weight upto M50 by A.C.I. Method, British Method, I.S. Method and Erutroy and Shaclock Method. From Results he had concluded. The I.S.I. Method requires more cement and less water cement ratio and this method was not applicable for getting strength greater than M45, when compared with the other methods. In June 2001, Mr. Mallick, Prof. S. Bhanja and Dr. S.K. Sarkar, presented a paper in the name of “Determination of the optimum size of coarse Aggregate”. In that paper they reported that, concrete properties would be influenced by the coarse aggregate’s sizes, along with
the same mix proportions. The examination had done for obtaining the optimum aggregate size. The experiments had been carried out for 0.35, 0.40 and 0.45 water-cement ratios along with 20mm, 16mm and 12.5mm size of coarse aggregate respectively. The 20 mm size of aggregates showed better results with respect to maximum strength increase against the unit workability decrease. Regarding the strength properties, 16mm size aggregates showed better results in compressive strength and 12.5mm size aggregates showed better results in tensile strength. [4].

2. Properties of Ingredients

2.1. Cement:
The cements commonly available in the construction industry are Portland-Pozzolona Cement (PPC), Ordinary Portland Cement (OPC) and Portland Blast Furnace Slag Cement (PBFS). These are three types of Portland Cements interchangeable for mix design. In portland cement, we come across 33 Grade, 43 Grade and 53 Grade cement. The above grades of cement are recognized by Bureau of Indian Standards, as given below
For 33 Grade Cement-IS: 1489 (Part – 1) 1991
For 43 Grade Cement-IS: 8112 – 1989
For 53 Grade Cement-IS: 12269 – 1987
The cements used for experimental works of this investigation were purchased from GRASIM INDUSTRIES LTD. (Cement Division).

| Cement Type          | Grade |
|----------------------|-------|
| Birla Star Cement    | 33    |
| Rajashree Cement     | 43    |
| Birla Super Cement   | 53    |

2.2. Fine and Coarse Aggregate:
The properties of fine and coarse aggregates used in this investigation are as follows:
Specific Gravity of Sand = 2.78
Specific Gravity of Coarse aggregate = 2.83
Water absorption of coarse aggregate = 0.5 %
Water absorption of fine aggregate = 1 %
Free surface moisture of coarse aggregate = Nil
Free surface moisture of fine aggregate = 0.5 %

Sieve Analysis of Sand:
The fineness modulus of the given fine aggregate is 2.652 and so it can be termed as medium sand. The fine aggregate falls in the grading zone II, IS code IS:383-1970.

Fine Aggregate:
The natural river sand was used as fine aggregate in this investigation conforming to Zone-II, IS: 383-1970. It was dried and sieved through IS sieve of 4.75mm size and stored inside the laboratory. The Fine Aggregate was hard, strong, dense, and durable and did not contain any harmful materials.

Coarse Aggregate:
The coarse aggregate is the toughest and minimum porous constituent of concrete. The possible large maximum size of aggregate will reduce the bulk of cement paste, consequential in an economic mix design. The size of Coarse Aggregate used in this experimental Investigation was 20mm and 40mm downgraded aggregate, which was hard, strong, dense and durable and did not contain any harmful materials.

2.3. Water
Water is a significant ingredient in the concrete mix as it actively involving in the chemical reactions with cement. Potable water is generally considered. Water to be used for concrete
development and curing should be done by the potable water, free from hurtful amounts of salts, sugar, oils, alkalis, acids, organic materials. The water mixing and curing of concrete as per IS 456: 2000 recommendations.

3. Mix Proportions
The quantity of the fine aggregate to coarse aggregates was accustomed from higher limit to lower limit, gradually as the grading of fine aggregates turn into satisfactory and the maximum size of coarse aggregate turn into larger. Graded proportion of coarse aggregate was used. Proportion of nominal concrete mix is given in Table 1. Proportions of nominal and design concrete mixes adopted in the experimental investigation are given in Table 2 and Table 3 respectively.

Table 1. Proportion of Nominal Concrete Mix

| Concrete Grade | Maximum quantity of Aggregates, kg (Mass per 50 kg of cement) | Mass Proportion of Fine to Coarse Aggregate | Max. quantity of water, litres (per 50 kg of Cement) |
|----------------|---------------------------------------------------------------|--------------------------------------------|--------------------------------------------------|
| M5             | 800                                                           | Normally 1:2 but subject to a higher limit of 1:1.5 and a lower limit 1:2.5 | 60                                               |
| M7.5           | 625                                                           |                                            | 45                                               |
| M10            | 480                                                           |                                            | 34                                               |
| M15            | 330                                                           |                                            | 32                                               |
| M20            | 250                                                           |                                            | 30                                               |

Table 2. Proportion of Nominal Concrete Mixes adopted in this examination

| Concrete Grade | Cement Grade | Aggregate Size | Type of Batching | W/C ratio used | Mix proportion by volume |
|----------------|--------------|----------------|-------------------|----------------|--------------------------|
| M10            | 33           | 20mm           | Volume            | 0.68           | 1:3:6                    |
| M10            | 43           | 20mm           | Volume            | 0.68           | 1:3:6                    |
| M10            | 53           | 20mm           | Volume            | 0.68           | 1:3:6                    |
| M15            | 33           | 20mm           | Volume            | 0.64           | 1:2:4                    |
| M15            | 43           | 20mm           | Volume            | 0.64           | 1:2:4                    |
| M15            | 53           | 20mm           | Volume            | 0.64           | 1:2:4                    |
| M20            | 33           | 20mm           | Volume            | 0.60           | 1:1 ½ :3                |
| M20            | 43           | 20mm           | Volume            | 0.60           | 1:1 ½ :3                |
| M20            | 53           | 20mm           | Volume            | 0.60           | 1:1 ½ :3                |
Table 3. Proportion of Design Concrete Mixes adopted in this examination

| Concrete Grade | Cement Grade | Aggregate Size | W/C ratio used | Mix proportion by Weight |
|----------------|--------------|----------------|----------------|--------------------------|
| M15            | 33           | 20             | 0.5759         | 1: 1.9320: 3.7239        |
| M15            | 43           | 20             | 0.6086         | 1: 2.1204: 3.9714        |
| M15            | 53           | 20             | 0.6320         | 1: 2.2525: 4.1339        |
| M20            | 33           | 20             | 0.4827         | 1: 1.4831: 3.1062        |
| M20            | 43           | 20             | 0.5211         | 1: 1.6830: 3.4057        |
| M20            | 53           | 20             | 0.5506         | 1: 1.8348: 3.6169        |
| M30            | 33           | 20             | 0.3650         | 1: 0.9747: 2.2741        |
| M30            | 43           | 20             | 0.3980         | 1: 1.1292: 2.5550        |
| M30            | 53           | 20             | 0.4390         | 1: 1.3137: 2.8630        |
| M40            | 33           | 20             | 0.3072         | 1: 0.6486: 2.0700        |
| M40            | 43           | 20             | 0.3285         | 1: 0.7350: 2.2935        |
| M40            | 53           | 20             | 0.3658         | 1: 0.8727: 2.6192        |
| M50            | 53           | 20             | 0.3074         | 1: 0.6694: 2.1366        |

4. Results and discussion

Compression test was approved out on specimens with cubes and cylinders. The size of the cube specimens was of 15cm x 15cm x 15cm. The sizes of coarse aggregate used were 20mm and 40mm. The sizes of cylinder specimens were 15cm diameter and 30cm height. The compression testing machine involved for calculating the strength properties was of reliable type. The compression testing machine was equipped with top and bottom steel bearing plates with hardened surfaces. The bearing surface of plates was bigger than the size of the specimens to which load was applied. The capacity of the machine was 2000 kN. The test specimens were tested on the 7th and 28th days. The age of concrete mix was calculated from the day of mixing of concrete for casting the specimens. For calculating the strength at each age, three sets of specimens were required. Percentage increase in strength of all the nominal concrete mix proportions is given in Table 4. Percentage increase in strength of all the nominal concrete mix proportions is given in Table 5.

Table 4. Percentage of increase in strength for all nominal mix proportions

| S. No. | Grade of Concrete | Type of Cement | Strength on 7 days in MPa | Strength on 28 days in MPa | Percentage increase in strength on 7 days in MPa | Percentage increase in strength on 28 days in MPa |
|--------|-------------------|----------------|---------------------------|----------------------------|-----------------------------------------------|-----------------------------------------------|
| 1      | M 10              | 33             | 6.358                     | 11.336                     | -                                             | -                                             |
| 2      | M 10              | 43             | 7.266                     | 13.673                     | 14.28                                         | 20.61                                         |
| 3      | M 10              | 53             | 7.724                     | 14.475                     | 21.48                                         | 27.69                                         |
| 4      | M 15              | 33             | 5.740                     | 15.027                     | -                                             | -                                             |
| 5      | M 15              | 43             | 8.502                     | 15.202                     | 48.12                                         | 1.17                                          |
| 6      | M 15              | 53             | 9.083                     | 18.021                     | 58.24                                         | 19.92                                         |
| 7      | M 20              | 33             | 9.196                     | 17.614                     | -                                             | -                                             |
| 8      | M 20              | 43             | 10.533                    | 19.779                     | 14.54                                         | 12.29                                         |
| 9      | M 20              | 53             | 11.481                    | 22.512                     | 24.85                                         | 27.81                                         |
| S. No. | Grade of Contract | Type of Cement | Strength on 7 days in MPa | Percentage increase in strength on 28 days in MPa |
|-------|-------------------|----------------|--------------------------|------------------------------------------|
| 1     | M15               | 33             | 13.803                   | -                                        |
| 2     | M15               | 43             | 14.663                   | 6.231                                    |
| 3     | M15               | 53             | 16.088                   | 16.55                                    |
| 4     | M20               | 33             | 16.495                   | -                                        |
| 5     | M20               | 43             | 20.317                   | 23.17                                    |
| 6     | M20               | 53             | 23.688                   | 43.61                                    |
| 7     | M30               | 33             | 25.679                   | -                                        |
| 8     | M30               | 43             | 31.862                   | 24.1                                     |
| 9     | M30               | 53             | 39.53                    | 53.94                                    |
| 10    | M40               | 33             | 33.281                   | -                                        |
| 11    | M40               | 43             | 35.025                   | 5.24                                     |
| 12    | M40               | 53             | 45.425                   | 36.47                                    |

5. Conclusions

The investigation on the strength of concrete with nominal mixes made of 20mm size aggregate and on the strength of design concrete mixes adopting 33, 43 and 53 grades of cement. The following conclusions are drawn.

Conclusions on concretes of Nominal Mixes:

Three grades of cement, namely 33, 43 and 53 grades have been used independently in the nominal mixes 1:3:6, 1:2:4 and 1:1½:3 in all these cases 53 grade cement gives the highest strength of concrete.

Conclusion on Design Concrete Mixes:

If concrete mixes are design for the grades M15 to M40 adopting separately 33, 43 and 53 grades of cements, grade 53 gives the highest 28 days cube strength, whereas 33 grade cement gives the lowest value. For given grade of concrete, 53-grade cement requires the lowest quantity of cement, whereas 33 grade cement requires the highest quantity of cement.

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