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ESTABLISHING THE CORRELATION BETWEEN COMPRESSIVE STRENGTH OF SMALL SIZED WET SCREENED CONCRETE CUBES AND FULL SIZE LARGE CONCRETE CUBES FOR MASS CONCRETE OF DAM

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ABSTRACT

The concrete used in dams and other structures may vary in character depending on the use of ingredients and site conditions. All concretes generate heat as the cementitious materials hydrate. Most of this heat generation occurs in the first days after placement. For thin concrete sections such as pavements, heat dissipates almost as quickly as it is generated. For thicker concrete sections (mass concrete), heat dissipates more slowly than it is generated. The net result is that mass concrete can get hot. Management of these temperatures is necessary to prevent damage, minimize delays, and meet project specifications.

The most effective way to diminish the temperature rise of mass concrete is to reduce the heat generation. This can be achieved by using cement of low heat generation and/or by reducing the cement content. In this regard, the one cost-effective method is the choice of the largest possible size of coarse aggregate.

For a given weight, higher the maximum size of aggregate, lower is the surface area of coarse aggregates and vice versa. As the surface area decreases, the water demand also decreases to coat the particles and generate workability. Larger maximum size of coarse aggregate requires lesser fine aggregate content to maintain cohesiveness of concrete mix. Because of its lower water demand, advantage of higher maximum size of coarse aggregate can be taken to lower the cement consumption.

For quality control during construction, preparation of check specimens for determining compressive strength is necessary. This requirement in case of mass concrete using large size coarse aggregates is difficult to meet because of the lack of laboratory and testing equipment to handle large specimens. Therefore special measures had to be considered from which the “wet-screening” method is the most commonly used one.

To determine the relation of compressive strength between the large size cubes and small size cubes, 45cm cubes were cast using actual concrete mix which includes large size aggregates and 15 cm small size cubes were prepared from wet screened concrete mix.

KEYWORDS: Mass Concrete; Compressive Strength, Screening Factor, Quality Control of concrete; thermal expansion.

INTRODUCTION

Cement hydration is a common phenomenon during construction which produces a rise in internal temperature of concrete. According to the ACI (1997) definition, mass concrete is any large volume of cast-in-place concrete with large dimensions that hinders the heat dissipation.

A rapid rise in the temperature of mass concrete takes place during the phase when the concrete mass is in plastic stage and undergoes hardening. After hardening, the concrete gradually cools due to effect of atmospheric temperature, which tends to subject the concrete to high tensile stresses. Cracking occurs in the concrete when these tensile stresses exceed the tensile strength of the concrete. This cracking is undesirable because it affects the water tightness, durability and appearance of hydraulic structures. The cracking tendency maybe reduced to acceptable levels through appropriate design, construction and concrete placement procedures.

From the standpoint of thermal cracking, one way to lower it would be by reducing the cement content of the concrete provided that this can be done without compromising the minimum strength and workability requirements needed for the job.

It is a known fact that maximum size of aggregate affects the workability and strength of concrete. It also influences the water demand for getting a certain workability and fine aggregate content required for achieving a cohesive mix. In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate.

According to IS: 457, the maximum size of the aggregate for hydraulic structure's concrete is preferably 15 cm to 23 cm. During the construction, it is necessary to prepare check specimens for determining compressive strength. The compressive strength in this case is determined on 450 mm cubes i.e. three times more than the maximum size of aggregate. Preparation of large sized cubes lead to an increase of the volume of the concrete sample, which is appreasiable. The volume of concrete necessary for preparing three large size specimens is about 0.27 m^3. Suppose the total quantity of concrete in the dam amounting to 1 million m^3 and average volume for which sample to be taken is about 100 m^3, the volume of concrete necessary for preparing the check specimens during the entire construction period will amount to 2700m^3. Moreover, the tediousness of preparing, storing and testing the check specimens and easiness in determing the characteristics of mass concrete on small specimens compel seeking new methods of their determination. Therefore determing the compressive strength by wet screening has been considered in this study.

The wet-screening is a procedure in which all aggregate particles larger than a certain size are removed from fresh concrete by sieving or hand picking of large aggregates. It is commonly used and ACI recommended procedure to remove the larger aggregates, cast smaller specimens with the remaining wet-screened concrete for the testing of the compressive strength. The maximum aggregate size is reduced but the strength of the aggregate; the strength of the cement matrix and the strength of the bond between both remain unchanged. This may lead to the conclusion that in case of the wet-screening procedure where the amount of the cement content per volume is increased and the water to cement ratio is kept constant, the strength of the concrete is unchanged. Although it has similar properties, the need for reliable relationships is essential for concrete quality control during construction, safety control and monitoring data analysis throughout service life.

The concrete used in the construction of dams contains maximum size of coarse aggregate up to 150 mm. The compressive strength which is a standard measure for characterizing concrete has to be measured with large specimens, for example cubes of 45 cm. In the present work, tests on cubes of 45 cm made with dam concrete (maximum aggregate size = 150 mm), and on cubes of 15 cm made with the wet-screened concrete (maximum coarse aggregate size = 40 mm and maximum fine aggregate size = 4.75 mm) were performed. The objective was to study the relations between the both compressive strengths to evaluate the actual compressive strength of the dam concrete.

EXPERIMENTAL DETAILS

The concrete used in the study corresponds to that used in the construction of Omkareshwar Project - a concrete gravity dam situated on the confluence of Narmada and Kaveri Rivers in Madhya Pradesh, India. The dam was commissioned in the year 2007.

PROPERTIES OF INGREDIENTS

The properties of concrete are significantly influenced by the basic properties of constituent materials. Therefore, the preliminary properties of Portland Pozzolana cement, fine aggregates, coarse aggregates, admixtures and mixing water are evaluated according to relevant codes. The materials proposed to be used in construction of dam, the same were used in the concrete mix design trials. Care has been taken to ensure that the same type of PPC, fine and coarse aggregates were used throughout this investigation.

Cement: Portland pozzolana cement of certain brand was tested before its use in concrete mix design. The results of test parameters are fineness 346 m^2/Kg, Soundness by Auto clave expansion 0.1 %, Compressive Strength at 3, 7 and 28 days is 309.3, 378.7 and 477.3 Kg/cm^2 respectively. The cement used in the mix design trials conforms to the specification requirements as per IS: 1489- 1991.

Coarse aggregate: Crushed coarse aggregates were tested for finding its suitability for use in concrete. The physical parameters of coarse aggregate are specific gravity 2.67, water absorption 0.58%, impact value 12.5%, crushing value 16 %, abrasion value 17 % and soundness loss (in Na_2SO_4 solution) 0.62%. Based on the test results, the coarse aggregate sample conforms to the specification requirements as per IS: 383-1970 for use in concrete both for wearing & non wearing surfaces.

Fine aggregate: Fine aggregate use in construction was manufactured sand after crushing the rocks. The physical parameters of fine aggregate used in the mix design trials are specific gravity 2.65 and fineness modulus 2.84 which falls under grading zone-II. The fine aggregates conforms to the specification requirements as per IS 383-1970.

Construction chemicals: Water reducing admixture and air entraining agent of standard brand were used in the mix design trials. The physical parameters for water reducing admixture are dry material content 36.7%, relative density 1.17 gm/cc, pH 7.45 and chloride content 0.022% at 27^0C and for air entraining admixture are dry material content 6.8%, relative density 1.01 gm/cc, pH 7.90 and chloride content 0.02%. The admixtures conform to the specification requirements as per IS: 9103-1999.

Water: Water used for mixing and curing was tested as per IS: 3025 – 1964 and IS: 456 – 2000.

CONCRETE MIX DESIGN

The design of concrete mixes was carried out in accordance with the latest technology as per BIS i.e. on the basis of estimation of absolute volume of different ingredients of concrete mix. The grading of coarse aggregate and ratio between coarse aggregate and fine aggregate for different mixes were fixed for achieving maximum density and desired workability with minimum bleeding and segregation. The mix design was finalized on the basis of 28 days compressive strengths of 15cm & 45 cm size concrete cubes. The target mean compressive strength for this grade of concrete has been calculated as per IS: 456-2000.

M15 Grade of concrete with 40 ± 10mm slump requirement: Several trials were carried out for this grade of concrete with cement contents 165, 170, 175, & 177 Kg/m^3 and water cement ratio varying from 0.58 to 0.62 using 150 mm MSA well graded crushed coarse aggregate and fine aggregates of the Omkareshwar project. Water reducing admixture and air entraining agent both of standard brand were used @ 0.5% and 0.12% by weight of cement respectively.

Preparation of Specimens

The dam concrete was sieved to remove coarse aggregates of size larger than 40 mm, and is denoted as wet-screened concrete. The concrete was prepared at the site of the dam. Standard cubes of 45 cm were cast in steel moulds for the dam concrete (maximum aggregate size = 150 mm) and cubes of 15 cm were cast in steel moulds using wet-screened concrete as per procedure laid down in IS: 516 -1959 (Reaffirmed 2004) for each mix of concrete to determine the compressive strength. These specimens were air dried for 24 hr before they were cured for 7 and 28days for performing compressive strength test.

Curing of the Specimens

The cube specimens of size 15 cm and 45 cm were removed from the moulds after 24hr from the time of adding the water to the ingredients. The specimens then marked for identification. These specimens were then stored in water for the required period of curing.

Compressive Strength Test Procedure

Compressive strength of a material is defined as the value of uni-axial compressive stress reached when the material fails completely using universal testing machine. In this investigation, the cube specimens of size 15 cm and 45 cm were tested in accordance with IS: 516 – 1969. The tests were performed at 7 and 28 days after casting.

RESULTS & DISCUSSION

For this grade of concrete, 5 trials (of 6 cubes each) have been carried out using varying cement content, and admixture content to arrive at the required concrete mixes. The Recommended mix proportions for M15 grade of concrete are given in Table 1.

Based on the test results of different trials, it is seen that concrete mix trials cast with 177.0 Kg/m^3 cement content yielded best average compressive strength at 28 days i.e. for 15cm concrete cube comes out to be 215.0 Kg/cm^2 and the for 45cm concrete cube comes out to be 189.0 Kg/cm^2. The correlation factor also termed as screening factor or correction factor computed as ratio between compressive strength of 15cm concrete cube and 45cm concrete cube respectively at 28 days work out to be 1.14.

On perusal of the test results, it is seen that 15cm concrete cubes cast with 177.0 Kg/m^3 yield 215 Kg/cm^2 at 28 days against the required 28 days target mean strength of 208 Kg/cm^2. The said mix with 177Kg/cm^3 cement content meets the strength and workability requirements.

Acceptance Criteria

In order to ensure quality control during the construction works, certain guidelines have been given in IS:456-2000 by the Bureau of Indian Standard. There are certain shortcomings in the acceptance criteria given in clause 15 & 16, IS:456-2000. In order to avoid higher cement content for strictly meeting acceptance criteria as per clause 15, IS:456-2000, the norms given in Table 2 may be followed to ensure proper quality control at the site:-

VERIFICATION OF AUTHENTICITY OF SCREENING FACTOR FOR PREDICTION OF COMPRESSIVE STRENGTH

To verify the validity of the proposed screening factor for prediction of compressive strength, additional specimens were prepared with concrete having same grade of concrete i.e. M15. The concrete cube specimens 3 each of size 15 cm and 45 cm were prepared and cured in water and then tested at the age of 28 days. The Actual Compressive Strength of 15 cm wet screened cubes was used to predict equivalent compressive strength by using a screening factor. The equivalent strength was compared with the actual strength obtained from a compressive test on the 45 cm cube specimen. The comparative results were given in Table 3. The results show that almost all the comparison results are ranged between (-) 2.07% to 3.14%. This verifies the suitability of the proposed relationship for prediction of equivalent strength using compressive strength of 15 cm screened cubes.

CONCLUSIONS AND RECOMMENDATIONS

The objective of this paper is to investigate the relationship between the compressive strength of 45 cm cubes made with dam concrete (maximum aggregate size = 150 mm), and 15 cm cubes made with the wet-screened concrete (maximum coarse aggregate size = 40 mm). The attempts are made towards either developing new procedures of estimating the actual compressive strength of concrete for getting more reliable and dependable information of the quality of concrete of the structures under reference in the years to come without casting large size cubes which overcomes the difficulty in handling large specimens and non availability of big capacity testing machines. Based on the extensive experimental works and studies, the following conclusions are drawn:

- When the above relations/ screening factors are used for mixes with same concrete grades but different materials from different projects i.e. CA, FA and varying cement paste content, the predicted strength of concrete shows more variation from the actual strength of the specimens.
- These relations/ screening factors were verified to be suitable for estimation of equivalent concrete strength for the concrete with same materials and cement paste content only.
- The derived relation/ screening factors can be used for prediction of concrete strength in the health monitoring of structures under reference during its service period.

For the massive structures such as dam receiving full loading after 365 days, the design of mass concrete mixes is finalized on full size cube compressive strength at 365 days, instead of 15cm cube compressive strength at 28 days.

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Table 1: Recommended concrete mix proportions for M15 grade of concrete

Description of mix	Recommended Mix for 15 cm size cubes	Recommended for 45cm size cubes
Lab. designed compressive strength at 28 days for 15 cm size concrete cubes , Kg/cm^2 (as per IS:457 -1991) (as per IS:456-2000, taking standard deviation 1.86 established by the project authority)	208.0 kg/cm^2	-
Lab. designed compressive strength at 28 days for 45 cm size concrete cubes , Kg/cm^2	-	181.0 kg/cm^2
Cement supplied	PPC	
Fine aggregate supplied	Natural sand	
Coarse aggregate supplied	Crushed C.A.	
Admixture (WRA) supplied	Standard company	
Admixture (AEA) supplied	Standard company	
C.A. Gradation, % 150-80mm 80-40 mm 40-20 mm 20-10 mm 10-4.75 mm	 32.0 24.0 18.0 14.0 12.0	
CA: FA (By absolute volume)	78 : 22	
Recommended Mix proportion, By wt. (Cement: F. A : C. A)	1 : 2.635 : 9.398	
Cement content, Kg/ m^3	**177.0**	
Water Cement Ratio	**0.576**	
W. R A., % by wt. of cement	0.5	
A.E.A , % by wt. of cement	0.18	
Slump observed, mm	45	
Compressive strength of concrete cubes at the age of –**28 days, Kg/ cm^2**	**215.0**	**189.0**
Screening Factor	**1.14**	

Table 2: Acceptance criteria as per clause 15 as per IS:456-2000

Grade	Mean of the group of 4 non-overlapping consecutive test results in N/mm^2	Individual test results in N/mm^2
M15	$\geq$ f_{ck} + 0.825x established standard deviation (rounded off to the nearest 0.5N/mm^2) or f_{ck}+3 N/mm^2	$\geq$ f_{ck} - 3 N/mm^2
	In no case, more than 5% individual test results of 15cm concrete cube should fall below f_{ck} N/mm^2	

Table 3: Shows the calculated equivalent strength from 15cm cubes and actual strength of dam concrete

Sl. No	Screening Factor	Actual Compressive Strength of 15 cm wet screened cubes (MPa)	Equivalent Compressive Strength calculated from 15 cm cubes (MPa) [3 divide 2]	Actual Compressive Strength of 45 cm cubes (MPa)	Percent Variation [(4-5)/5]

1	2	3	4	5	6
1.	1.14	210.0	184.0	190.0	- 3.15%
2.		225.0	197.0	191.0	3.14%
3.		215.0	189.0	193.0	- 2.07%