October 1983

CRI TECHNOLOGY DIGEST

CEMENT RESEARCH INSTITUTE OF INDIA

MONITORING QUALITY OF FRESH CONCRETE IN STRUCTURES

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INTRODUCTION

Quality control in concrete constructions takes care of the problems of inherent variability of ingredients and ensures proper workmanship in the aspects of batching, mixing, placing, compaction and curing of concrete. Thus, monitoring characteristics of fresh concrete soon after it is placed in the forms and compacted are important from the point of view of quality control of in-place concrete and ensuring satisfactory performance at later ages. At present, it is held that there are no rapid and reliable methods of evaluating the quality of in-place concrete soon after its placement in the forms and compaction. Compressive strength tests (either accelerated or usual 28 days') on standard cube or cylinder specimens do not reflect the level of workmanship that goes in the placing of concrete in the actual structures, which is so vital for satisfactory performance. On the other hand, any test carried out on fresh concrete after it is placed in the forms and compacted, will prove immensely useful for quality control.

This Technology Digest presents methods for the evaluation of the quality of in-place concrete in the fresh state, evolved as a result of intensive R&D work at the Cement Research Institute of India (CRI).

APPROACH

For assessing the overall quality of in-place concrete, the density, composition and the rate of hardening of concrete are more relevant. The density would indicate the degree of compaction achieved in the concrete in the structure. The composition, ie, the cement and water contents would indicate whether the proportions of materials in the concrete mix used were the same as intended and were uniform throughout. The rate of hardening of concrete would indicate whether the hydration reactions were taking place at the expected rate and that the desired strength of concrete would be achieved at the time of stripping the forms as well as in service.

Tests evolved to measure these characteristics were of two categories: for monitoring the above mentioned characteristics of fresh concrete on

*Reprint of September 1982 issue.

the structure itself, and for obtaining representative samples of fresh concrete from the structure, on which tests can be carried out. The procedure of obtaining representative samples is described later.

METHODS OF TESTS ON THE STRUCTURE

Measurement of Rate of Hardening

For in-situ measurement of rate of hardening and setting times of concrete, an improvised pin pullout test was adopted. The test set-up (*see* Fig 1) consisted of a movable iron frame which could be placed around the formwork. A metallic support with holes was placed on top of the formwork, through which a number of 12 mm dia stainless steel pins could be embedded vertically in the concrete in the structural member, upto a depth of 150 mm from the top. Individual pins could be pulled out successively at suitable intervals of time, by means of a wire rope and pully arrangement mounted on the frame which could be moved along the length of the formwork, so as to correspond to the positions of various pins.

Simultaneous measurements of ultrasonic pulse velocity were obtained on fresh concrete. Since the wooden moulds for structural elements interfere with the measurement, openings were made on opposite faces of the

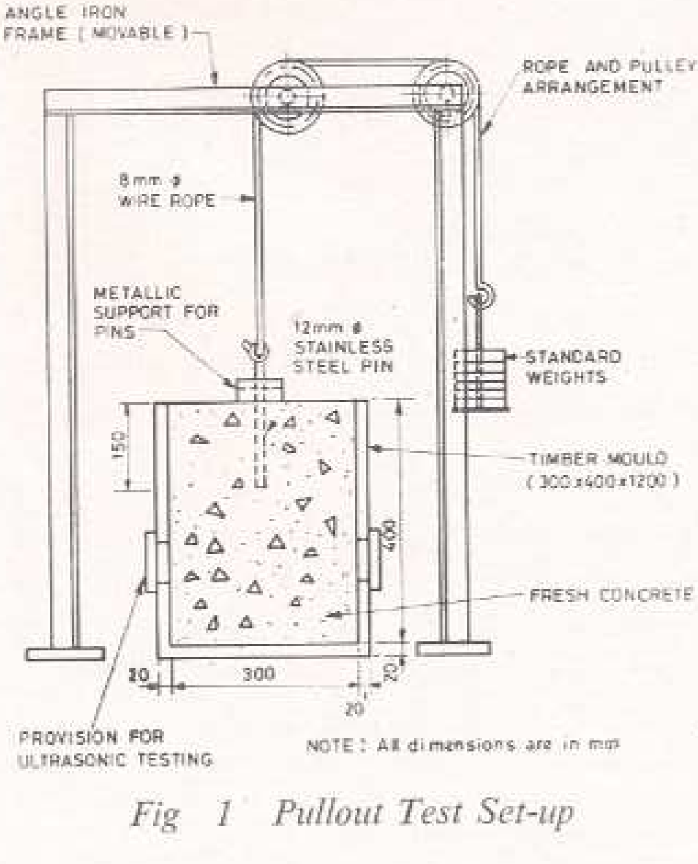

Fig 1 Pullout Test Set-up

formwork at predetermined locations and the transducers (frequency 54 KHz) of the ultrasonic pulse velocity equipment, were brought in contact with the fresh concrete after it was placed and compacted.

Measurement of initial and final setting times of concrete were simultaneously carried out on mortars sieved from the concrete mixes by penetration resistance methods as per ASTM C 403-77 or IS : 8142-1976 for the purpose of comparison.

The initial and final setting times of concrete were characterised by pullout strengths of 0·04 N/mm^2 and 0·10 N/mm^2 respectively; these corresponded well to the values, determined by standard penetration resistance tests on mortars. These limits of pullout strength can be used to delineate initial and final setting times of concrete, using the test set-up described. Regarding ultrasonic pulse velocity measurement, it was concluded that at the time of final setting, fresh concrete should have an ultrasonic pulse velocity of the order of 2 km/sec and any inordinate delay in obtaining pulse velocity of this magnitude would indicate large variation or error in the materials, mix proportions or the workmanship adopted, especially compaction.

The nearest application of the setting time of concrete is in slipform construction, where the optimum slipping time and the rate of rise of forms are determined on the basis of an arbitrary stage of hardening of concrete which can be set at a penetration resistance of 0·70 N/mm^2. This would correspond to a pullout strength of 0·01 N/mm^2. In so far as portland pozzolana cement (PPC) is concerned, it was found that for M 15 grade, the slipping time was longer by 45 minutes compared to ordinary portland cement (OPC). This means slowing down the rate of rise of 1m high forms by about 20 percent, if PPC is used instead of OPC. However, for grades M 20 and above, the differences in the slipping time using OPC and PPC were less significant. Rapid hardening cement (RHC), of course, always gave the fastest slipping time. Thus, it was concluded that use of PPC will not present unsurmountable problems for slipform constructions.

It is sometimes apprehended that use of PPC would lead to delayed removal of formwork. IS : 456 recommends removal of vertical side forms in structural concrete members made of OPC after 1 to 2 days. In a tropical country like India, it is necessary that at the time of removal of side forms, concrete should have attained such compressive strength as would withstand mechanical damage on striking the forms so that the concrete surface is not impaired. Compressive strength of the order of 2 N/mm^2 has been suggested for such purposes. Investigations carried out at CRI showed that concretes of all grades made with PPC reached compressive strength of 2 N/mm^2 or more at 24 hours. Hence, it would be possible, in practice, to remove side forms in structural concrete members made with PPC after 1 to 2 days as in the case of concretes made with OPC.

TESTS ON REPRESENTATIVE SAMPLES OF FRESH CONCRETE

Sampling

For drawing representative samples, perforated cylindrical metal containers (10 cm dia × 10 cm ht) were placed in the forms at different locations before or at the time of concreting. Perforations were of 5 mm diameter throughout the surface which facilitated concrete in the containers being similar to that in the structure, by flow of mortar under vibration. That the samples of concrete obtained by means of pre-placed perforated metal containers were representative of the parent concrete in the structure, was corroborated by comparison of properties of fresh and hardened concrete obtained from both. This method of sampling of concrete was adopted for carrying out tests for the evaluation of density and composition of in-place concrete with satisfactory results.

Measurement of Density

The wet density of concrete obtained from the pre-placed metal containers can be readily obtained by weighing the containers along with the concrete. Investigations carried out at CRI indicated that density of concrete obtained from the metal containers, pre-placed in well-compacted mass of concrete, compared well with that of concrete well-compacted in standard moulds. Partially compacted concrete when sampled had density lower than that of well-compacted conctete, indicating that the degree of compaction achieved in the parent concrete was low. Incomplete compaction can thus be easily detected by differences in the densities of the concrete samples.

Test for Cement Content of Fresh Concrete

For determining the cement content of fresh concrete, the HCI heat of solution method was used. In this method, the cement content was obtained by virtue of the temperature difference which arose because of the heat evolved by the reaction between the diluted concrete sample and the hydrochloric acid added to it. The cement contained in the sample decomposed upon addition of HCI. The heat of reaction reached a fixed temperature very quickly and there existed a relationship between the temperature difference and the cement content of the sample of concrete.

The experimental set-up (*see* Fig 2) consisted of a wooden box in which a 5-litre capacity polyethylene bottle surrounded by glass wool was placed. Each sample of concrete (about 1 kg) was first diluted with 800 cc water, to which 500 g of HCI was added. The mixture was stirred with a rod and the temperature of the mixture was measured with a thermometer. The time required for conducting the test was about 10 minutes. The experimental investigation resulted in the following regression equation:

$$Y = 12{\cdot}28 + 3X$$

where Y = cement content (in g) of the sample of concrete, and
X = temperature difference in °C.

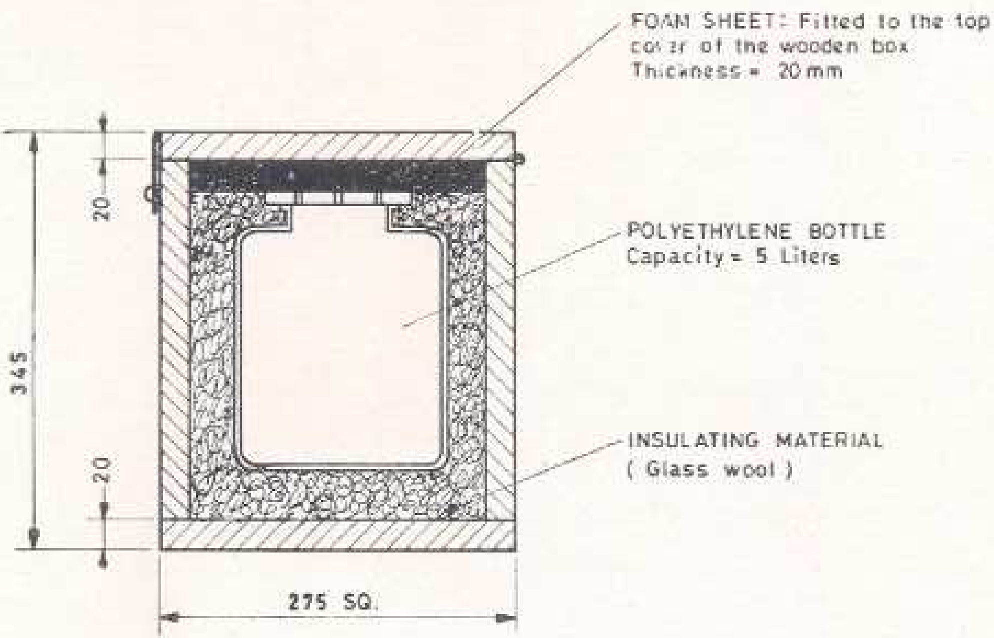

Fig 2 Details of the Experimental Set-up for HCI Heat of Solution Method

The regression equation was used to estimate the cement content of concrete mixes using cements from 16 different sources. The actual and the estimated cement contents were found to be in fair agreement, the variation being within ± 10 percent (Fig 3). However, this method is applicable only for concretes made with OPC. If the pozzolana content in PPC is known, then this method can be used after making due corrections for the amount of pozzolana in the cement content so determined.

The HCI heat of solution method was found suitable and convenient for its adoption in practice because it uses simple set-up, is rapid and at the same time reasonably accurate like other methods, eg, the EDTA titration method, Rapid Analysis Machine method or the method of analysis as per IS : 1199-1959.

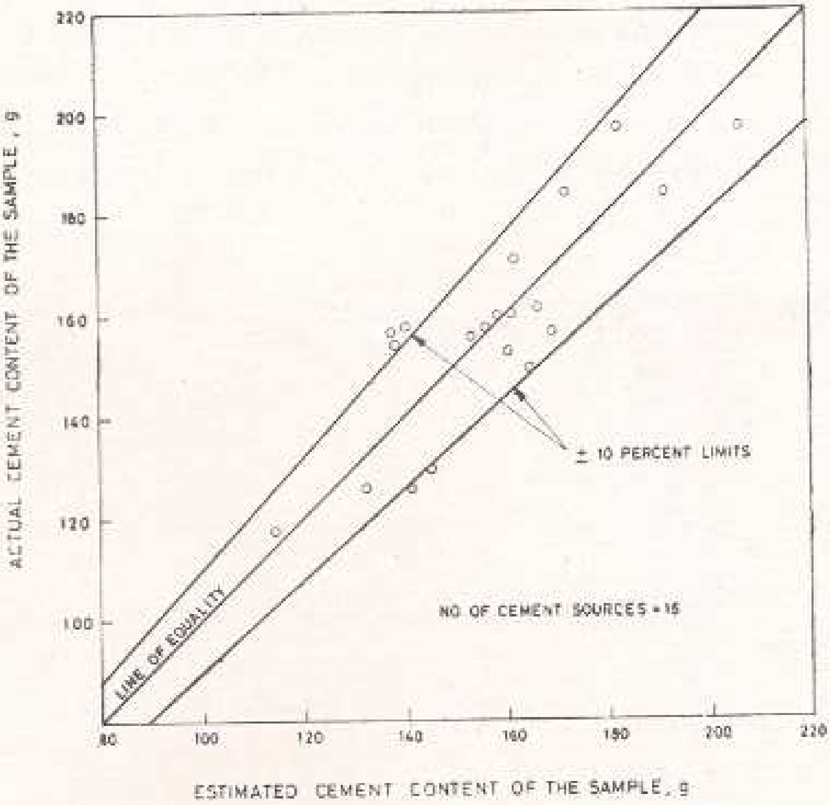

Fig 3 Estimated Vs Actual Cement Content of Concrete Samples Employing HCl Heat of Solution Method

Test for Water Content of Fresh Concrete

For determining the water content of fresh concrete, the NaCl titration method was used. This method was based on the principle that the water content of the sample of fresh concrete was available as free water to act as a diluent when an aqueous solution of NaCl (0·2 N) was added. A fixed volume (500 ml) of NaCl solution was added to a fixed weight (1 kg) of concrete, and the dilution factor was found by estimating the concentration of the final solution. The chloride strength of the mixture was determined by titration using 0·02 N ammonium thiocyanate solution. The volume of thiocyanate solution required for the titration determined the water content of the sample of fresh concrete. The time required for conducting the test was about 10 minutes. Concrete mixes having water content in the range of 200 to 330 liters per m^3 of concrete were tested. The estimated water contents were found to be in close agreement with the actual water contents of the concrete mixes, the variation being within ±5 percent.

The NaCl titration method was preferred as it was rapid and more accurate than the other methods, eg, the oven drying method or the method of analysis stipulated in IS : 1199.

Estimation of Water-Cement ratio of Concrete

Combination of the two methods (ie, cement content by HCI heat of solution method and water content by NaCl titration method) was found suitable for checking the water-cement ratio of in-place concrete. The estimated water-cement ratios were found to be in close agreement with the actual water-cement ratios of concrete, the variation being within ± 5 percent (Fig 4).

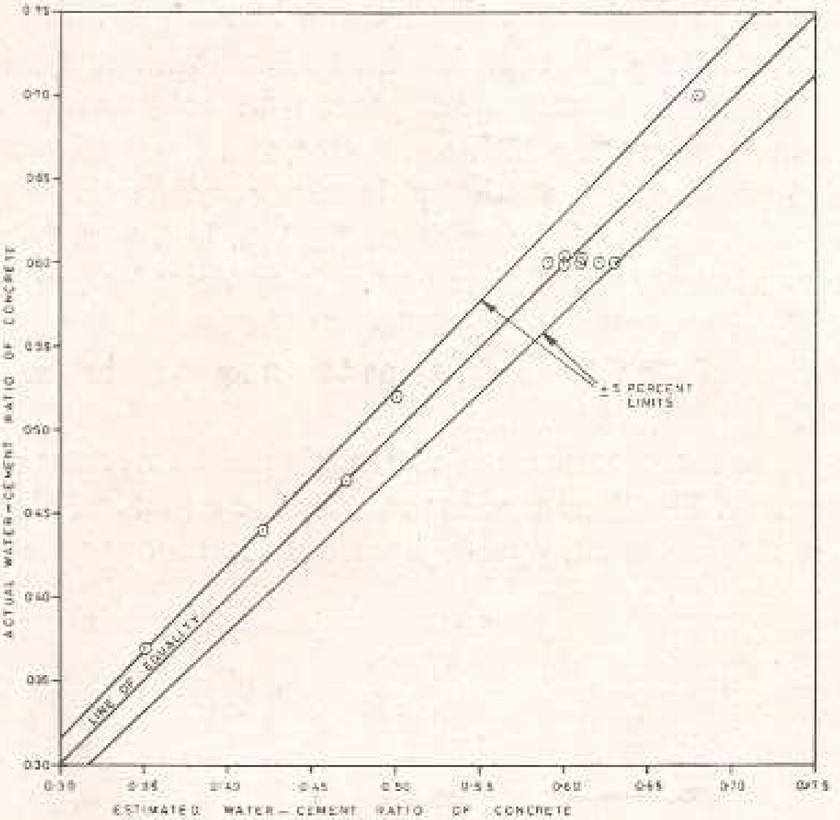

Fig 4 Estimated Vs Actual Water-Cement Ratio of Concrete

CRI renders necessary help in the wide adoption of such methods in various construction projects in the country to evaluate the quality of in-place concrete in the fresh state.

Prepared by : Dr A K Mullick, Dr S C Maiti and Shri R C Wason
Edited by : Shri S S Kalra

Published by Shri S K Khanna on behalf of Cement Research Institute of India, M 10 South Extension II, New Delhi 110 049 and Printed at Indraprastha Press (CBT), Nehru House, New Delhi 110 002

Regd. No. R.N. 40434/82