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CRI TECHNOLOGY DIGEST

CEMENT RESEARCH INSTITUTE OF INDIA

NON-DESTRUCTIVE TESTING OF CONCRETE PART I

NON-DESTRUCTIVE TESTING OF CONCRETE

Part 1*

INTRODUCTION

There are occasions when the various performance characteristics of concrete in a structure are required to be assessed. In most of the cases, an estimate of strength of concrete in the structure is needed, although parameters like overall quality, uniformity, etc, also become important in others. The various methods that can be adopted for *in-situ* assessment of strength properties of concrete depend upon the particular aspect of strength in question. For example, if the load carrying capacity of a structural ensemble is to be assessed, carrying out a ful-scale load test is the most direct way; on the other hand when the actual compressive strength of concrete in the structure is to be measured, core testing is more reliable. However, both these methods are relatively cumbersome and the latter method leaves the structure damaged. Use is, therefore, made of suitable non-destructive tests, which not only provide an estimate of the overall strength and quality of concrete in the structure but also help in deciding whether more rigorous tests like load testing or core drilling at selected locations are required.

There are various such non-destructive testing methods which can be broadly classified as those which measure the overall quality of concrete, eg, dynamic or vibration methods like reasonance frequency and ultrasonic pulse velocity (UPV) tests; and those which involve measurement of parameters like surface hardness, rebound, penetration, pullout strength, etc, and are believed to be indirectly related to the compressive strength of concrete. In addition, radioactive and nuclear methods using X-ray and Gamma-rays, magnetic and electrical methods are also available. Since such non-destructive tests are at best indirect methods of monitoring the particular characteristic of concrete and the measurements are influenced by very many material, mix and environmental factor, proper interpretation of the results calls for certain degree of expertise. It is more so, when the data on the materials and mix proportions used in the construction are not available, as is often the case. This Technology Digest (Part I) deals with the principles, basic equipment and applications of ultrasonic pulse velocity and rebound hammer test methods for assessment of quality and strength of concrete *in-situ;* while Part 2 of the Technology Digest will describe the CRI approach and give substance of certain case studies.

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BASIC PRINCIPLES AND EQUIPMENT

Ultrasonic Pulse Velocity Test—This method is based on the principle that the velocity of an ultrasonic pulse through any material depends upon its density, modulus of elasticity and poisson's ratio. In this method, an ultrasonic pulse of longitudinal vibrations is produced by an electro-acoustical transducer which is held in contact with one surface of the concrete member under test. After traversing a known path length in the concrete, the vibration pulse is converted into an electrical signal by a second electro-acoustical transducer held in contact with the other surface of the concrete member and an electronic timing circuit enables the transit time of the pulse to be measured, from which the UPV can be calculated.

The natural frequency of transducers should preferably be within the range of 20 to 150 KHz. Generally, high frequency transducers are preferable for short path lengths and low frequency transducers where the path length is longer. Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angles to the face of the transmitting transducer and best results are, therefore, obtained when the receiving transducer is placed on the opposite face of the concrete member (direct transmission or cross probing). However, in many situations two opposite faces of the structural member may not be accessible for measurements. In such cases, the receiving transducer is also placed on the same face of the concrete member (surface probing). These arrangements are shown in Fig 1. Surface probing is not so efficient as cross probing, because the signal produced at the receiving transducers has an amplitude of only 2 to 3% of that produced by cross probing and the results are greatly influenced by the surface layers of concrete which may have different properties from that of concrete inside the structural element. In general, surface probing results in lower pulse velocity than in cross probing, but quantification of the difference is not possible.

Rebound Hammer Method—Schmidt's Rebound Hammer consists of a spring-controlled mass that slides on a plunger within a tubular housing. When the plunger is pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. For the purpose of this method, the surface hardness and, therefore, the rebound is taken to be related to the compressive strength of the material. The rebound is read off along a graduated scale and is designated as the 'rebound number' or 'rebound index'. Depending upon the impact energy, Schmidt's test hammers are classified into four types, ie, *N*, *L*, *M* and *P*. Type *N* test hammer is suitable for normal grades of concrete whereas type *L* having smaller impact energy is suitable for lightweight concretes or small and impact-sensitive parts of concrete. Type *M* hammer of comparatively greater impact energy is suitable for testing mass concrete, whereas type *P* is used for cement mortars and plasters.

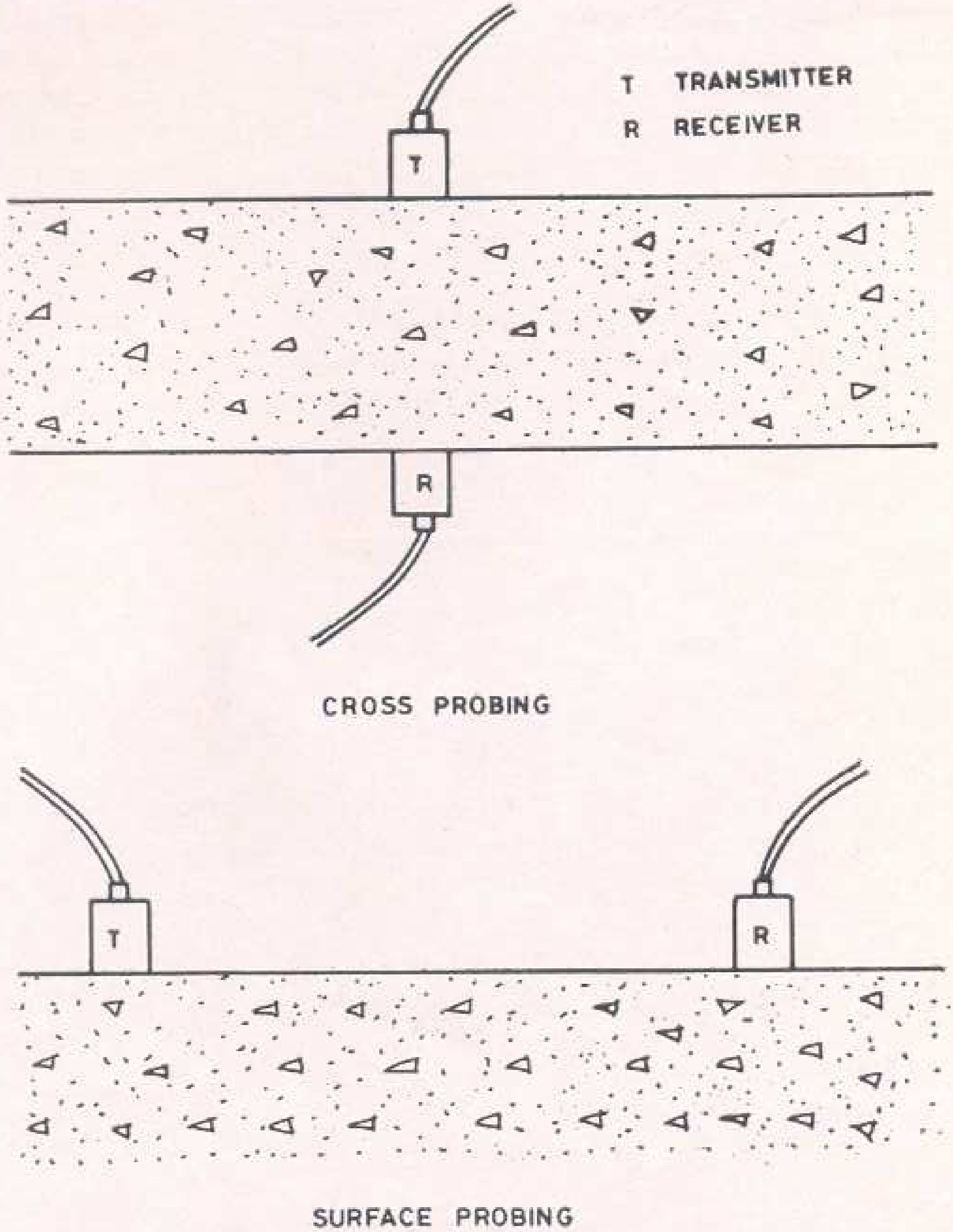

Fig 1 Methods of propagating and receiving ultrasonic pulses

For taking a measurement, the hammer should be held at right angles to the surface of the structure. The test can thus be conducted horizontally on vertical surfaces or vertically upwards or downwards on horizontal surfaces. If the situation demands, the hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete. It is necessary that the test hammer is frequently calibrated and checked against the test anvil to ensure reliable results.

APPLICATIONS

Ultrasonic Pulse Velocity Method—The method can be used to determine the homogeneity of the concrete, the presence of cracks, voids and other imperfections, changes in the structure of the concrete which occur with time, the quality of the concrete in relation to standard requirements, the quality of one element of concrete in relation to another, or to determine the value of elastic modulus of the concrete. The underlying principle of assessing the quality of concrete in either of the modes described above is that comparatively higher velocities are obtained when the quality of concrete, in terms of density, homogeneity and uniformity, is good. In case of poorer quality, lower velocities are obtained. More importantly, if there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained and the strength of the signal also becomes weaker. The actual pulse velocity obtained depends primarily upon the material and mix proportions of concrete; aggregates, through their density and modulus of elasticity, making significant contribution. Other parameters like the age, surface conditions, the moisture content and temperature of concrete, the amount and orientation of reinforcement bars in relation to the direction of propagation of pulses as well as the level of stresses to which the concrete is subjected, all influence the value of pulse velocity obtained. The shape and size of the specimen do not influence the pulse velocity unless the least lateral dimension is less than a certain minimum value—say 80 mm for 50 KHz transducer frequency. Because of so many variables, it is difficult to set a specific value of pulse velocity for any concrete structure, unless all the parameters are well-known. The major applications of pulse velocity test of concrete have been to establish the degree of uniformity, or lack thereof throughout the structure, to follow progressive changes in the quality of concrete and to determine the presence or absence of discontinuities, eg, cracking in

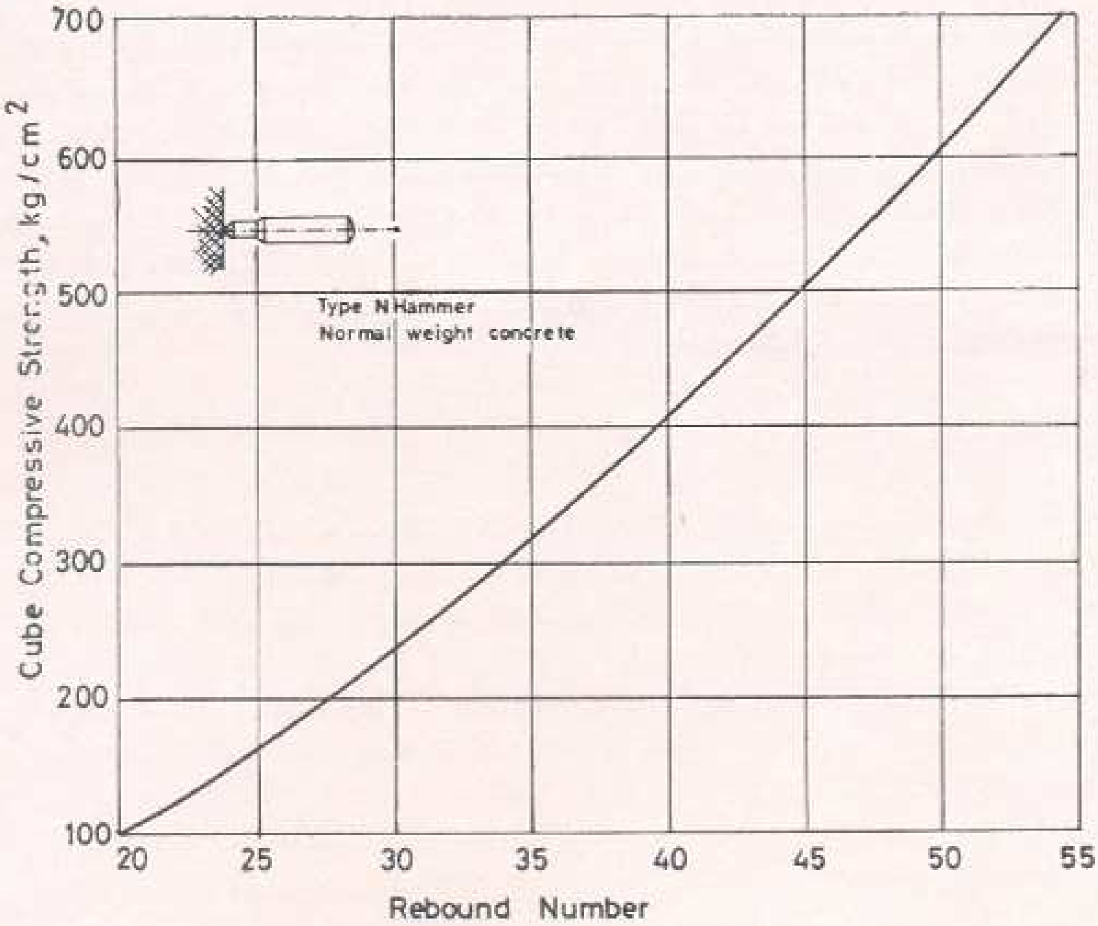

Fig 2 Typical correlation curve between compressive strength and rebound number

structures. For this purpose, criteria of pulse velocity corresponding to different levels of quality of concrete are established and made use of.

Because of these reasons, the use of UPV method for estimation of strength of concrete is not favoured. However, if actual concrete materials and mix proportions adopted in a particular structure are available, then estimate of concrete strength can be made by establishing suitable correlation between the UPV and the compressive strength of concrete specimen made with such materials and mix proportions, under environmental conditions similar to that in the structure. Even in such cases, the correlation so obtained may not be applicable for concrete of another grade or made with different types of materials.

Rebound Hammer Method—The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between the rebound index and strength of concrete. Such a typical correlation curve is shown in Fig 2. In general, the rebound number increases as the strength increases but it is also affected by a number of other parameters like the age, moisture content, texture, form materials, aggregate type, type of cement and extent of carbonation on concrete surface. As such, the estimation of strength of concrete by rebound hammer method cannot be held to be very accurate and the probable accuracy of prediction of concrete strength in a structure is ±25 percent. If the relationship between rebound index and compressive strength can be checked by tests on core samples obtained from the structure or standard specimens made with the same concrete materials and mix proportion, then the accuracy of results and confidence thereon are greatly increased. It can be used with greater confidence for differentiating between the questionable and acceptable parts of a structure or for relative comparison between two different structures.

Combined Method—In view of the relative limitations of either of the two methods for predicting the strength of concrete in the structure, both UPV and rebound hammer methods are sometimes used in combination

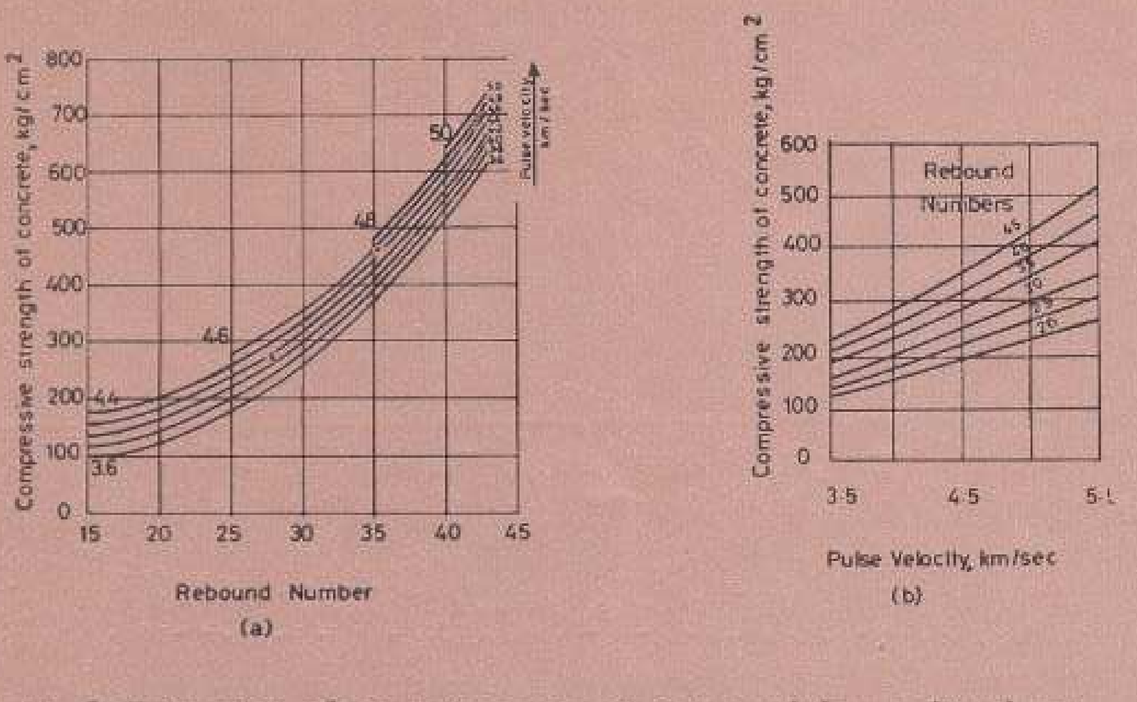

Fig 3 Estimation of concrete compressive strength by combined non-destructive test methods

to alleviate the errors arising out of influence of material, mix and environmental parameters on the respective measurements. Relationships between UPV, rebound number and compressive strength of concrete of the nature shown in Fig 3 are obtained by multiple regression of measured values on laboratory test specimens. Better accuracy on the estimation of concrete strength is claimed by use of such combined method. However, this approach also has the limitation that the correlations of the type shown in Fig 3 are valid only for the materials and mix proportions used in the trials. The intrinsic difference between the laboratory test specimens and *in-situ* concrete (eg, surface texture, moisture condition, presence of reinforcements) also affect the accuracy of results. The correlation is valid only within the range of values of pulse velocity, rebound number and compressive strength employed and any extrapolation beyond these is open to question, eg, for structures where the pulse velocity may be lower due to poorer workmanship or presence of cracks, voids, etc.

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