Non-destructive testing of concrete
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Non-Destructive Testing of Concrete

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Please note

The standard method of evaluating the quality of concrete in buildings or structures is to test specimens cast simultaneously for compressive, flexural and tensile strengths. The main disadvantages are that results are not obtained immediately; that concrete in specimens may differ from that in the actual structure as a result of different curing and compaction conditions; and that strength properties of a concrete specimen depend on its size and shape.

Although there can be no direct measurement of the strength properties of structural concrete for the simple reason that strength determination involves destructive stresses, several non-destructive methods of assessment have been developed[1]. These depend on the fact that certain physical properties of concrete can be related to strength and can be measured by non-destructive methods. Such properties include hardness, resistance to penetration by projectiles, rebound capacity and ability to transmit ultrasonic pulses and X- and Y-rays. These non-destructive methods may be categorized as penetration tests, rebound tests, pull-out techniques, dynamic tests, radioactive tests, maturity concept. It is the purpose of this Digest to describe these methods briefly, outlining their advantages and disadvantages.

Penetration Tests

The Windsor probe is generally considered to be the best means of testing penetration. Equipment consists of a powder-actuated gun or driver, hardened alloy probes, loaded cartridges, a depth gauge for measuring penetration of probes and other related equipment. A probe, diameter 0.25 in. (6.5 mm) and length 3.125 in. (8.0 cm), is driven into the concrete by means of a precision powder charge. Depth of penetration provides an indication of the compressive strength of the concrete. Although calibration charts are provided by the manufacturer, the instrument should be calibrated for type of concrete and type and size of aggregate used.

Limitations and Advantages. The probe test produces quite variable results and should not be expected to give accurate values of concrete strength. It has, however, the potential for providing a quick means of checking quality and maturity of in situ concrete. It also provides a means of assessing strength development with curing. The test is essentially non-destructive, since concrete and structural members can be tested in situ, with only minor patching of holes on exposed faces.

Rebound Tests

The rebound hammer is a surface hardness tester for which an empirical correlation has been established between strength and rebound number. The only known instrument to make use of the rebound principle for concrete testing is the Schmidt hammer, which weighs about 4 lb (1.8 kg) and is suitable for both laboratory and field work. It consists of a spring-controlled hammer mass that slides on a plunger within a tubular housing. The hammer is forced against the surface of the concrete by the spring and the distance of rebound is measured on a scale. The test surface can be horizontal, vertical or at any angle but the instrument must be calibrated in this position.

Calibration can be done with cylinders (6 by 12 in., 15 by 30 cm) of the same cement and aggregate as will be used on the job. The cylinders are capped and firmly held in a compression machine. Several readings are taken, well distributed and reproducible, the average representing the rebound number for the cylinder. This procedure is repeated with several cylinders, after which compressive strengths are obtained.

Limitations and Advantages. The Schmidt hammer provides an inexpensive, simple and quick method of obtaining an indication of concrete strength, but accuracy of ±15 to ±20 per cent is possible only for specimens cast cured and tested under conditions for which calibration curves have been established. The results are affected by factors such as smoothness of surface, size and shape of specimen, moisture condition of the concrete, type of cement and coarse aggregate, and extent of carbonation of surface.

Pull-Out Tests

A pull-out test measures, with a special ram, the force required to pull from the concrete a specially shaped steel rod whose enlarged end has been cast into the concrete to a depth of 3 in. (7.6 cm). The concrete is simultaneously in tension and in shear, but the force required to pull the concrete out can be related to its compressive strength. The pull-out technique can thus measure quantitatively the in-situ strength of concrete when proper correlations have been made. It has been found, over a wide range of strengths, that pull-out strengths have a coefficient of variation comparable to that of compressive strength[2].

Limitations and Advantages. Although pullout tests do not measure the interior strength of mass concrete, they do give information on the maturity and development of strength of a representative part of it. Such tests have the advantage of measuring quantitatively the strength of concrete in place. Their main disadvantage is that they have to be planned in advance and pull-out assemblies set into the formwork before the concrete is placed. The pull-out, of course, creates some minor damage. The test can be non-destructive, however, if a minimum pull-out force is applied that stops short of failure but makes certain that a minimum strength has been reached. This is information of distinct value in determining when forms can be removed safely.

Dynamic Tests

At present the ultrasonic pulse velocity method is the only one of this type that shows potential for testing concrete strength in situ. It measures the time of travel of an ultrasonic pulse passing through the concrete. The fundamental design features of all commercially available units are very similar, consisting of a pulse generator and a pulse receiver. Pulses are generated by shock-exciting piezo-electric crystals, with similar crystals used in the receiver[3]. The time taken for the pulse to pass through the concrete is measured by electronic measuring circuits.

Pulse velocity tests can be carried out on both laboratory-sized specimens and completed concrete structures, but some factors affect measurement:

1. There must be smooth contact with the surface under test; a coupling medium such as a thin film of oil is mandatory.
2. It is desirable for path-lengths to be at least 12 in. (30 cm) in order to avoid any errors introduced by heterogeneity.
3. It must be recognized that there is an increase in pulse velocity at below-freezing temperature owing to freezing of water; from 5 to 30°C (41 - 86°F) pulse velocities are not temperature dependent.
4. The presence of reinforcing steel in concrete has an appreciable effect on pulse velocity. It is therefore desirable and often mandatory to choose pulse paths that avoid the influence of reinforcing steel or to make corrections if steel is in the pulse path.

Applications and Limitations. The pulse velocity method is an ideal tool for establishing whether concrete is uniform. It can be used on both existing structures and those under construction. Usually, if large differences in pulse velocity are found within a structure for no apparent reason, there is strong reason to presume that defective or deteriorated concrete is present.

High pulse velocity readings are generally indicative of good quality concrete. A general relation between concrete quality and pulse velocity is given in Table I[4].

Table I. Quality of Concrete and Pulse Velocity

General Conditions	Pulse Velocity ft/sec
Excellent	Above 15,000
Good	12,000-15,000
Questionable	10,000-12,000
Poor	7,000-10,000
Very Poor	below 7,000

Fairly good correlation can be obtained between cube compressive strength and pulse velocity. These relations enable the strength of structural concrete to be predicted within ±20 per cent, provided the types of aggregate and mix proportions are constant.

The pulse velocity method has been used to study the effects on concrete of freeze-thaw action, sulphate attack, and acidic waters. Generally, the degree of damage is related to a reduction in pulse velocity. Cracks can also be detected. Great care should be exercised, however, in using pulse velocity measurements for these purposes since it is often difficult to interpret results. Sometimes the pulse does not travel through the damaged portion of the concrete.

The pulse velocity method can also be used to estimate the rate of hardening and strength development of concrete in the early stages to determine when to remove formwork. Holes have to be cut in the formwork so that transducers can be in direct contact with the concrete surface. As concrete ages, the rate of increase of pulse velocity slows down much more rapidly than the rate of development of strength, so that beyond a strength of 2,000 to 3,000 psi (13.6 to 20.4 MPa) accuracy in determining strength is less than ±20%. Accuracy depends on careful calibration and use of the same concrete mix proportions and aggregate in the test samples used for calibration as in the structure.

In summary, ultrasonic pulse velocity tests have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects. Its use for predicting strength is much more limited, owing to the large number of variables affecting the relation between strength and pulse velocity.

Radioactive Methods

Radioactive methods of testing concrete can be used to detect the location of reinforcement, measure density and perhaps establish whether honeycombing has occurred in structural concrete units. Gamma radiography is increasingly accepted in England and Europe. The equipment is quite simple and running costs are small, although the initial price can be high. Concrete up to 18 in. (45 cm) thick can be examined without difficulty.

Maturity Concept

The basic principle of concrete maturity is that increase in strength is a function of time and temperature, and that any standard of maturity in terms of strength must include both temperature and period of curing. The maturity of the concrete at any instant can be calculated by integration of temperature as a function of time if complete records of time-temperature changes are kept. The datum temperature is usually taken as -10°C (14°F). The technique can be of great use in winter concreting operations where monitoring of strength at early ages is very important. It must be emphasized, however, that in measuring maturity no property of the concrete itself is measured. If the concrete design and placing are good, the test will tell when the concrete has been adequately cured; it will not indicate the quality of the concrete.

Concluding Remarks

Although efforts are continuing to improve non-destructive testing methods and the tests themselves are not difficult to perform, test data are not always easy to interpret because concrete is a most complex material. The tests must not, therefore, be regarded as a substitute for standard compression tests. What they do provide are data on actual structures that would not be possible with standard tests; and they should be valuable during winter concreting for ensuring safety and determining time for the possible early removal of forms. They are excellent, also, for determining relative strengths of concrete in different parts of the same structure. If used properly they can provide a very important link in the chain of testing and evaluating concrete and concrete structures.

References

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