Article

TESTING CEMENT AND CONCRETE: A STATE-OF-THE-ART REVIEW

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ABSTRACT

In this review, we described the current status of cement and concrete testing and standards, the macroscopic destructive and non-destructive testing of cement and concrete. Hardened concrete and mortar should not be considered in any sense as fundamental or intrinsic material properties. Instead, these are variables that affect the observed mechanical behavior of concrete. Thus, when defining any given mechanical property, it is also necessary to specify the test method relevant to the standard. Mechanical properties were assessed with conventional destructive tests and non-destructive tests.

Keywords: Cement, Concrete, Destructive tests, Non-destructive tests, Mechanical properties.

Introduction

Many test methods have been proposed as standards in an effort to minimize the confusion that would result if researchers and practitioners were to use different test procedures. For these procedures, the test parameters are fixed, though rather arbitrarily, so that different people working in different laboratories in different areas can nevertheless carry out comparable tests and generalize their results (Mindess et al., 2003).

The standard test methods most commonly used are those developed by the American Society for Testing and Materials (ASTM). The organization came into being in the wake of key initiatives, which laid the groundwork for its founding in 1898. Its original focus was the steel industry. However, within a few years, the ASTM had formed several new committees, thereby expanding its scope such that the organization could respond to the growing need for standards in many areas. For example, Committee C-1 on Cement, Lime and Clay Products, founded in 1902, played a key role in standardizing test methods in the cement and concrete sector. The work of this committee was part of an industry-wide effort to develop uniform test methods. The committee defined basic testing procedures for measuring tensile strength at 7 and 28 days after concrete is poured, researched the weather-resistance of various cement formulas, and developed compression test standards that were widely adopted across the industry. Following this work, Committee C-4 on Concrete and Aggregate was founded in 1914. However, some regions and even individual countries have their own standards, e.g., the European Standards Organisation, the British Standards Institution (BSI), and the Japanese Standards Association (JSA) (ASTM, 2015a).

Bear in mind that as cement and concrete technologies change, the standard test methods also change: old test methods are abandoned or modified, and new test methods are developed (Mindess et al., 2003).

Standards for cement and concrete testing: Current status

Standards for cement testing

The manufacture of cement requires stringent controls. Therefore, a number of tests are performed in a cement plant laboratory to ensure that cement has the desired properties such that it conforms to the relevant standards (Neville, 1995), as shown in Table 1.

Table 1 Test method standards for cement and mortar (ASTM, 2015b).

Designation	Standard
Additions	
Determination of pack-set index of Portland cement	ASTM C-1565
Air entrainment	
Air content of hydraulic cement mortar	ASTM C-185
Compositional analysis	
Chemical analysis of hydraulic cement	ASTM C-114
Determination using X-ray powder diffraction analysis of the proportion of phases in Portland cement and Portland-cement clinker using X-Ray powder diffraction	ASTM C-1365

Designation	Standard
Quantitative determination using a microscopical point-count procedure of phases in Portland cement clinker by microscopical point-count procedure	ASTM C-1356
Fineness	
Density of hydraulic cement	ASTM C-188
Fineness of hydraulic cement and raw materials by the 300 µm (No. 50), 150 µm (No. 100), and 75 µm (No. 200) sieves by wet methods	ASTM C-786
Fineness of hydraulic cement by air-permeability apparatus	ASTM C-204
Fineness of hydraulic cement by a 45-um (No. 325) sieve	ASTM C-430
Fineness of hydraulic cement by a turbidimeter	ASTM C-115
Heat of hydration	
Heat of hydration of hydraulic cement	ASTM C-186
Measurement of heat of hydration of hydraulic cementitious materials using isothermal conduction calorimetry	ASTM C-1702
Special cement	
Restrained expansion of expansive cement mortar	ASTM C-806
Strength	
Compressive strength of hydraulic cement mortars (using 2 in. or [50 mm] cube specimens)	ASTM C-109
Compressive strength of hydraulic cement mortars (using 2 portions of a prism broken in flexure)	ASTM C-349
Cement strength uniformity from a single source	ASTM C-917
Flexural strength of hydraulic-cement mortars	ASTM C-348
Sulfate content	
Approximation of optimum SO_3 in hydraulic cement using compressive strength	ASTM C-563
Expansion of hydraulic cement mortar bars stored in water	ASTM C-1038
Water-extractable sulfate in hydrated hydraulic cement mortar	ASTM C-265

Designation	Standard
Sulfate resistance	
Length change of hydraulic-cement mortars exposed to a sulfate solution	ASTM C-1012
Potential expansion of Portland-cement mortars exposed to sulfate	ASTM C-452
Time of set	
Early stiffening of hydraulic cement (mortar method)	ASTM C-359
Early stiffening of hydraulic cement (paste method)	ASTM C-451
Time to setting of hydraulic cement by Vicat needle	ASTM C-191
Time to setting of hydraulic cement mortar by modified Vicat needle	ASTM C-807
Time to setting of hydraulic cement paste by Gillmore needles	ASTM C-266
Volume change	
Autoclave expansion of hydraulic cement	ASTM C-151
Chemical shrinkage of hydraulic cement paste	ASTM C-1608
Drying shrinkage of mortar containing hydraulic cement	ASTM C-596
Workability	
Amount of water required for normal consistency of hydraulic cement paste	ASTM C-187
Flow of hydraulic cement mortar	ASTM C-1437
Water retention of hydraulic cement-based mortars and plasters	ASTM C-1506

Standards for concrete testing

As shown in Table 2, fresh concrete is subjected to testing largely as a quality control measure and to help ensure that the correct mix proportion is maintained. By far the most common test to which fresh concrete is subjected is the slump test described in ASTM C-143. The strength, durability, and other mechanical properties of concrete should not be considered in any sense to be fundamental or intrinsic material properties. Instead, these are variables, and as such they affect the observed mechanical behavior of concrete. Thus, when any given mechanical property, such as compressive strength, is measured, it is also necessary to specify the test method that was used to obtain the measurement (Mindess et al., 2003).

Table 2 Test method standards for concrete (ASTM, 2015c)

Designation	ASTM
Fresh concrete	
Time of setting of concrete mixtures by penetration resistance	ASTM C-403
Air content of freshly mixed concrete by the pressure method	ASTM C-231
Air content of freshly mixed concrete by the volumetric method	ASTM C-173
Bleeding of concrete	ASTM C-232
Density (unit weight), yield, and air content (gravimetric) of concrete	ASTM C-138
Slump of hydraulic-cement concrete	ASTM C-143
Temperature of freshly mixed hydraulic-cement concrete	ASTM C-1064
Volume change	
Autogenous strain of cement paste and mortar	ASTM C-1698
Change in height at early ages of cylindrical specimens of cementitious mixtures	ASTM C-827
Determining age at cracking and induced tensile stress characteristics of mortars and concrete under restrained shrinkage	ASTM C-1581
Length change of hardened hydraulic-cement mortar and concrete	ASTM C-157
Measuring changes in height of cylindrical specimens of hydraulic-cement grout	ASTM C-1090
Restrained expansion of shrinkage-compensating concrete	ASTM C-878
Strength	
Compressive strength of concrete cylinders cast in place in cylindrical molds	ASTM C-873
Compressive strength of cylindrical concrete specimens	ASTM C-39
Creep of concrete in compression	ASTM C-512
Flexural strength of concrete (using simple beam with center-point loading)	ASTM C-293
Flexural strength of concrete (using simple beam with third-point loading)	ASTM C-78

Designation	ASTM
Measuring early-age compressive strength and projecting later-age strength	ASTM C-918
Obtaining and testing drilled cores and sawed beams of concrete	ASTM C-42
Splitting tensile strength of cylindrical concrete specimens	ASTM C-496

Macroscopic destructive testing of cement and concrete

The purpose of destructive testing is to obtain information about material or structural properties through actions that destroy the integrity of these. That is, destructive testing is a technique applied in order to find the point of failure. The standard destructive test used to assess the strength of concrete is that of crushing specimens. The main purposes of destructive testing are to determine any design weaknesses that may or may not show up under normal working conditions and to determine the service life of a product. Strength refers to the point of stress at which a material yields.

(i) Compressive strength: Two types of compression test specimens are used. Cubes are used in Great Britain and other European countries, whereas cylinders are the standard specimens in the United States, France, Canada, Australia, and New Zealand (Neville, 1995).

As the European standard, the Cube Test is a part of the BS EN 12390 series. Part 3 of BS EN 12390-3 specifies a method for determining the compressive strength of test specimens of hardened concrete (BSI, 2002). The standard size of the cube specimen is 150 × 150 × 150 mm (height/width ratio = 1). At least five surfaces are exposed to the mold, which can generate smooth surfaces on the specimen. Hence, a cube specimen can be tested without surface preparation (Li, 2011).

The Cylinder Test is performed in accordance with ASTM C-39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. This test method is used to determine the compressive strength of prepared and cured cylindrical specimens (ASTM, 2015c). The standard cylinder size for compression testing is 150 × 300 mm (length/diameter ratio = 2). The upper surface of the cylinder is never smooth; hence, grinding or capping is needed to level and smooth the compression surface before a test (Li, 2011).

For a concrete of normal strength, the cylinder test will typically result in a lower compressive strength (approximately 0.8 of the cube strength) due to the confining effect of the testing machine plates and the aspect ratio of the specimen (Hassan and Jones, 2012).

(ii) Tensile strength: The standard test for tensile strength is performed in accordance with ASTM C-496: Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. This test method is used to determine the splitting tensile strength of cylindrical concrete specimens, such as molded cylinders and drilled cores. Splitting tensile strength is important in the design of structural lightweight concrete members and the related test is used to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement (ASTM, 2015c).

(iii) Flexural strength: The standard test for flexural strength is performed in accordance with ASTM C-78: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). This test method is used to determine the flexural strength of concrete by using a simple beam with third-point loading. The results are calculated and reported as the modulus of rupture. The strength thus determined varies where there are differences in specimen size, preparation, moisture condition, and/or curing, as well as when the beam has been molded or sawed to size. The results of this test method can be used to determine compliance with specifications or as a basis for proportioning, mixing, and placement operations. It is used in testing concrete for the construction of slabs and pavements (ASTM, 2015c). A related test is ASTM C-293: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading) (ASTM, 2015c). This method covers determining the flexural strength of concrete specimens specifically and only by using a simple beam with center-point loading, whereas ASTM C-293 is for determining this same kind of strength, but by using a simple beam with third-point loading. Therefore, these tests cannot be substituted for each other. However, like ASTM C-78, the results of ASTM C-293 can be used to determine compliance with specifications or as a basis for proportioning, mixing, and placement operations (ASTM, 2015c). This test method produces the modulus of rupture, which reflects the flexural strength value. The modulus of rupture determined by three-point loading is lower than the modulus determined by center-point loading, sometimes by as much as 15% (NRMCA, 2016).

One of the reasons that compressive strength is often used as a quality-control test for concrete is that the latter's characteristics are directly related to this kind of strength. In addition, the tensile strength of concrete is low, and for this reason, concrete is used principally under compression loading in designs. Therefore, concrete's function is directly related to compressive strength from the design point of view. Further, compression tests are both cost-efficient and easy to carry out (Başyiğit et al., 2012).

The conventional method for determining the compressive strength of concrete relies on the destructive method of preparing standard cylindrical or cubic specimens from fresh concrete and then loading them at various ages until failure. The destructive method used most often in this endeavor consists of taking specimens by making bore-holes in the material to be tested (Bohdan and Tomasz, 2013). One draw-back of determining compressive strength via destructive testing methods is that doing so results in a reduction in the cross-section of the concrete's structural elements and, therefore, a reduction in the concrete's load-bearing capacity (Başyiğit et al., 2012).

The most widespread method for determining the in situ strength of concrete is to drill cores from its structural elements. In particular, it is clearly stated that the mechanical properties should be evaluated on the basis of specific destructive tests, which comprise extracting concrete cores from the structural elements and subjecting the specimens thus obtained to laboratory compression tests (Uva et al., 2013). In any discussion pertaining to determining the compressive strength of in situ concrete, it should be remembered that several factors can affect measurements taken of drilled concrete cores. These factors include consolidation, curing quality, the concrete's age, the type of structural element from which the specimen was extracted, and the position of the specimen. Any or all of these could function as a random variable and thus induce significant deviations in-and even characterize-the actual strength of the in situ concrete (Uva et al., 2013). Furthermore, it is not always possible to find and test standard specimens in late-age concrete. It may, therefore, be necessary to assess the current strength of a structure in order to determine whether its strength and durability are adequate to continued use-especially when the structure is used under high-stress conditions. For these special situations, the core test is the most useful and reliable way to assess the properties of the concrete in a structure. For these reasons, the standard way to determine the in situ strength of concrete is to drill and test cores (Khoury et al., 2014).

To assess existing reinforced concrete (RC) buildings, an important question pertains to reliably appraising in situ concrete strength. And, on this point, one parameter can be determined by using the destructive test of concrete core drilling (Uva et al., 2013). According to ASTM C-42: Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, this test method provides standardized procedures for obtaining and testing specimens in order to determine the compressive, splitting tensile, and flexural strength of in-place concrete (ASTM, 2015c). From a general perspective, as set out by (Khoury et al., 2014), the core test is needed to assess one or a combination of the following:

1) The quality of the concrete used in a structure (potential strength);

2) The quality of the concrete in the construction (in situ strength), known as actual strength;

3) The ultimate capacity of the structure to carry the imposed loads, actual loads, design loads, and new additional loads;

4) The deterioration in a structure (e.g., bridge structures, machine bases), due to overloading, fatigue, chemical reactions (e.g., aggregate silica reaction (ASR) or chemical spillage), fire or an explosion, and/or weathering.

In contrast of, only the exterior body is inspected. Coring is then usually required. Several tests, such as those for compressive strength, can be performed on cores, although the sensitivity and reliability of these tests in regard to ASR may vary significantly (Sargolzahi et al., 2010). For example, for concrete that has sustained internal damage from an aggregate silica reaction (ASR) or an aggregate alkali reaction (AAR), compressive strength tests on cored cylinders do not produce satisfactory results in terms of revealing the condition of the concrete (Tay and Tam, 1996). The most widespread method for determining the in situ strength of concrete is to drill cores from the structural elements. In particular, ASTM C-42 clearly states that the mechanical properties should be evaluated via specific destructive tests, consisting of extracting concrete cores from structural elements and performing laboratory compression tests on the specimens thus obtained (Uva et al., 2013). In any discussion pertaining to determining the compressive strength of in situ concrete, it should be remembered that several factors performed on drilled concrete cores could affect the measurements. These factors include consolidation, curing quality, and the concrete’s age, the type of structural element from which the specimen was extracted, and the position of the specimen. Any or all of these could function as a random variable and thus induce significant deviations in-and even characterize-the actual strength of the in situ concrete (Uva et al., 2013).

The diameter and length of the core to be taken depend on the tests to which the specimen is to be subjected. For compressive strength tests, the core should have a minimum diameter of three times the maximum nominal size of the coarse aggregate. The recommended minimum length-to-diameter ratio of two in North American practice is modified in British practice to a ratio of not less than one. Both practices, however, allow cores to be taken from structural members with a thickness of less than 200 mm. In all cases, the core length to be tested should be free of reinforcing steel (Tay and Tam, 1996). In regard to the method used to select the coring positions, Pfister et al. (2014) presented a new method within a more general and well-established procedure. This procedure can be summarized in reference to the following steps: (i) determine the number of cores needed (depending on the standards or guidelines followed); (ii) execute a large preliminary NDT measurement campaign; (iii) analyze the NDT measurements and determine the coring positions; (iv) perform the destructive test in the indicated positions, and (v) assess the strength of the specimens. Bartlett and Macgregor (1994) studied the effect of specimen diameter on the magnitude and precision of the compressive strength of concrete cores. It is found that the large variability commonly attributed to small-diameter specimens is often caused by the large variability in the strength of the in situ concrete strength within the element from which cores are taken. The data also indicate that the effect of the core length-to-diameter ratio on compressive strength is more significant for 2 in. diameter cores than for 4 in. diameter cores. Moreover, core compressive strength increases with the decrease in the core aspect ratio (l/d), although this effect becomes negligible for high-strength concrete. Further, the effect of the core diameter on core strength varies considerably-for example, this effect is completely different for a molded concrete cylinder. It is generally agreed for molded concrete that the concrete's compressive strength decreases as the specimen size increases. However, in the case of drilled cores, as the diameter decreases, the ratio of cut surface area to volume increases, and hence the possibility of a reduction in strength due to cutting damage increases. Strength reductions of up to 17% have been recorded in cores with a diameter of less than 100 mm. On the other hand, for cores with a diameter larger than 100 mm, this damage effect is minimal, although it should still be taken into account (Khoury et al., 2014).

Macroscopic non-destructive testing of cement and concrete

Non-destructive testing (NDT) obtains information without destroying the integrity of a material or structure. To give a more complete definition, NDT can be defined as the measurement, inspection, or analysis of materials, existing structures, and processes of manufacturing without destroying the integrity of the materials and structures. ASTM E-1316: Standard Terminology for Non-Destructive Examinations defines the terminology used in the standards prepared by the E07 Committee on Nondestructive Testing. These NDT methods include acoustic emission testing, electromagnetic testing, gamma- and X-radiology, leak testing, liquid penetrant testing, magnetic particle testing, neutron radiology and gauging, ultrasonic testing, and other technical methods. The reference standards are shown in Table 3.

Table 3 Standards for non-destructive examinations (ASTM, 2015d).

Standard	Descriptions
ASTM E-127	Practice for fabricating and checking aluminum alloy ultrasonic standard reference blocks
ASTM E-215	Practice for standardizing equipment for electromagnetic examination of seamless aluminum-alloy tube
ASTM E-494	Practice for measuring ultrasonic velocity in materials
ASTM E-566	Practice for electromagnetic (Eddy-current) sorting of ferrous metals
ASTM E 664	Practice for measurement of the apparent attenuation of longitudinal ultrasonic waves by immersion method
ASTM E-750	Practice for characterizing acoustic emission instrumentation E-804 Practice for calibration of the ultrasonic test system by extrapolation between flat-bottom hole sizes
ASTM E-1033	Practice for electromagnetic (eddy-current) examination of Type F-continuously welded (CW) ferromagnetic pipe and tubing above the curie temperature
ASTM E-1067	Practice for acoustic emission examination of fiberglass reinforced plastic resin (FRP) tanks/vessels

Standard	Descriptions
ASTM E-1118	Practice for acoustic emission examination of reinforced thermosetting resin pipe (RTRP)
ASTM E-1213	Test method for minimum resolvable temperature difference for thermal-imaging systems

Concrete structures submitted to repeated service loads, weathering, or chemical attack may display surface-breaking cracks. To estimate the depth of such cracks, NDTs destructive techniques are suitable candidates because (1) the cracks have already been tested successfully via other applications such as subsurface geophysical imaging, and (2) NDTs allow for in situ inspection with high spatial resolution, whereas tests on drilled cores can only be performed at a limited number of measurement points (Goueygou et al., 2008). The application fields of NDT include the following: (a) Quality control of concrete materials and structures, including hydration processing monitoring, evaluation of strength development, curing-process monitoring of concrete, welding quality evaluation of reinforcing steel, and porosity assessment in matured concrete members; (b) In-service inspections of concrete materials and structures, including inspections of the rate and degree of corrosion, residual strength, fatigue damage, existing crack length, debonding of an interface, and impact damage as shown in Table 4.

Table 4 Non-destructive testing for concrete (ASTM, 2015c)..

Standard	Descriptions
ASTM C-215	Standard test method for fundamental transverse, longitudinal, and torsional resonant frequencies of concrete specimens
ASTM C-1383	Standard test method for measuring the P-wave speed and the thickness of concrete plates using the impact-echo method
ASTM C-803	Standard test method for penetration resistance of hardened concrete
ASTM C-900	Standard test method for pullout strength of hardened concrete
ASTM C-597	Standard test method for pulse velocity through concrete
ASTM C-805	Standard test method for rebound number of hardened concrete

The use of an NDT leads to increased safety and allows better scheduling of construction, thereby making it possible to progress more quickly and more economically. Broadly speaking, these tests can be categorized into those that assess the strength of the concrete in situ and those that determine other characteristics of the concrete, such as voids, flaws, cracks, and deterioration (Neville, 1993).

NDT in concrete engineering is an important tool for assessing the quality and maturity of a concrete structure during construction, information about which helps to guide decision-making in regard to construction procedures and speed according to which to implement them. For new constructions, NDT in concrete engineering can act as a quality-control tool to evaluate reliability, assess integrity, and monitor the conditions of a construction as a whole or in part. The problems to which NDT has been applied in concrete engineering can be usefully considered in regard to load-carrying and environment-resistance ability (Li, 2011), as shown in Table 5.

Table 5 Test problems to which NDT has been applied in concrete engineering.

Testing Criteria	Description
Strength	The strength of a concrete cast on site can be very different from the strength measured in a laboratory. Moreover, the strength of concrete can vary over its service life. Hence, the determination of concrete strength on site is an issue of some importance for NDT in concrete engineering. In addition, if a concrete structure has gone through a fire, the residual strength of the damaged concrete must be determined in order to make decisions in regard to renovation work. The true steel yield stress of a concrete structure during service and after a natural disaster must be determined using NDT in concrete engineering, for maintenance purposes.

Testing Criteria	Description
Cracks and fractures	Concrete is a quasi-brittle and tension-weak material. In addition, due to its boundary constraints in terms of shrinkage and creep, large tensile stresses can be generated in concrete. When subjected to stress of this natures in excess of its tensile strength, concrete will crack. The existence of cracks can induce many durability problems, as they can channel many harmful agents into the concrete. Thus, detecting the properties of cracks in concrete constitutes a major challenge. The detection of a crack includes determining its length, width, position, and propagation rate. From these parameters, it is possible to determine whether the crack is active or not, or dangerous or not.
Thickness	The thickness measurement of a pavement, a restraining wall, the cover of a reinforcing steel, and slab is an important quality-assurance issue in the construction and maintenance of concrete structures.
Moisture	Moisture or water in a concrete structure can cause significant deterioration. Specifically, it can cause numerous problems that undermine the durability of the concrete, such as corrosion, calcium hydroxide (CH) leaching, alkali aggregate reaction (AAR) expansion, and leakage. Hence, detecting the location and amount of any moisture present in concrete is a common problem for NDT in concrete engineering.
Corrosion	Corrosion is the most serious and dangerous durability problem, and it is also the most common problem relating to durability. Corrosion can crack the concrete cover and make it spall. Further, corrosion can also significantly reduce the effective area of the reinforcing steel, thereby putting a concrete structure in danger-especially a prestressed concrete structure. It is obvious that detecting corrosion and determining the rate and extent of it one of the most important NDT issues in concrete engineering.

Testing Criteria	Description
Debonding	Debonding, which refers to the separation of two adjacent materials that were originally bonded together, is usually an indication of serious damage to or deterioration of a concrete structure. Frequently encountered debonding problems include those caused by corrosion whereby the adhesive effect has been lost and interfaces damaged by shear stress.

In regard to the compressive strength of concrete, it should be noted that this can only be only assessed, rather than measured, because NDT tests are, for the most part, comparative in nature. Thus, it is useful to establish an experimental relationship between the property being measured by a given test and the strength of the specimens (cores) taken from the actual concrete. Such a relationship thus established can then be used to convert NDT results into strength values (Neville, 1993).

Assessing the strength of existing buildings is a key challenge for structural engineers, who require material data in order to complete structural computations. Assessments of this nature are required in various contexts: (a) when some damage has developed over time, (b) when new requirements must be addressed, because of changes in regulations or in the loads to be supported, (c) when the material condition must be checked because of some suspicion, e.g., when the concrete in the control cast cylinders differs from the concrete used for the building itself! In any case, NDT techniques offer what can be an effective approach, as they provide access to material properties yet can be completed quickly and at a moderate cost. As the assessment can have a significant impact on decisions regarding maintenance, its quality is of central importance. However, NDT techniques are sensitive first to physical properties and provide only an indirect way to consider the mechanical performance of any given material. Quantifying a mechanical property such as strength, rather than detecting or ranking a problem, is the most important aspect of an assessment, as values are necessary, even with some range of uncertainty (Breysse, 2012).

Determination of compressive strength by means of destructive testing methods re-duces the cross-section of structural elements and the load-bearing capacity.

In addition, these techniques are time-consuming and expensive (Başyiğit et al., 2012). The most reliable method for the in-situ measurement of concrete strength is compression testing on cores ex-tracted from the concrete structure. This method is not errorless and requires the use of cor-rection factors to account for the dimensions of the core and the method of sampling. Never-theless, in the following sections, values measured by a direct compression test will be assumed to be the actual concrete strength at the measuring point. Unfortunately, this type of test is invasive and expensive, particularly for structures in service conditions. For these rea-sons, the number of cores extracted from the structure might be extremely limited (Giannini et al., 2014). Less time-consuming and more economical solutions to estimate the compressive strength of concrete are needed (Başyiğit et al., 2012). Nondestructive testing of concrete allows the inspection of larger areas of concrete samples at a lower cost than coring and pro-vides more information than visual inspection (Wankhade and Landage, 2013). Destruction of the test object usually makes destructive testing more costly, and it is inappropriate in many cir-cumstances. NDT plays a crucial role in ensuring cost-effective operation, safety, and relia-bility (Khan, 2012).

Conclusions

In this paper, we described the standards of cement and concrete testing, including destructive and non-destructive testing of concrete. The evaluation of the concrete properties in a structure is of fundamental importance to assessments of safety and structural integrity. Adequate knowledge of the structural performance of concrete can be obtained from a large number of cores by performing destructive tests. Non-destructive ultrasonic waves test can be performed before other kinds of tests in order to provide a basis for improving assessments of the structural performance of concrete and to extend the results to the same kinds of elements of the structure, not directly investigated by destructive tests. Moreover, it is worth considering whether concrete specifications can readily and safely allow conformity testing to be based on early-age strength results linked to an agreed correlation continuously monitored by actual 28-day strength test results.

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