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# Report on Methods for Estimating In-Place Concrete Strength

Reported by ACI Committee 228



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## **Report on Methods for Estimating In-Place Concrete Strength**

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# Report on Methods for Estimating In-Place Concrete Strength

Reported by ACI Committee 228

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*This report provides methods for estimating the in-place strength of concrete in new and existing construction. These methods include: rebound number; penetration resistance, pullout, pull-off, ultrasonic pulse velocity, maturity, and cast-in-place cylinders. The principle, inherent limitations, and repeatability of each method are reviewed. Procedures are presented for developing the relationship needed to estimate compressive strength from in-place results. Factors to consider in planning in-place tests are discussed, and statistical techniques to interpret test results are presented. The use of in-place tests for acceptance of concrete is introduced. The Appendix A provides information on the number of strength levels that should be used to develop the strength relationship and explains a regression analysis procedure that accounts for error in both dependent and independent variables.*

**Keywords:** coefficient of variation; compressive strength; construction safety; in-place tests; nondestructive tests; sampling; statistical analysis.

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## CHAPTER 1—INTRODUCTION

### 1.1—Scope

In-place tests are performed typically on concrete within a structure, in contrast to tests performed on molded specimens made from the concrete to be used in the structure. Historically, they have been called nondestructive tests because some of the early tests, such as rebound number and ultrasonic pulse velocity, were noninvasive and did not damage the concrete. Over the years, however, new methods have developed that result in superficial local damage. There-

fore, the terminology “in-place tests” is used as a general name for these test methods, which includes those that do not damage the concrete and those that result in some near-surface damage. In this report, the principal application of in-place tests is to estimate the compressive strength of the concrete. The pull-off test can be used to estimate the tensile strength of concrete or evaluate bond strength between layers. The significant characteristic of most of these tests is that they do not directly measure the compressive strength of the concrete in a structure. Instead, they measure some other property that can be correlated to compressive strength (Popovics 1998). The strength is then estimated from a previously established relationship between the measured property and concrete strength. The uncertainty of the estimated compressive strength depends on the variability of in-place test results and the uncertainty of the relationship between these two parameters. These sources of uncertainty are discussed in this report. An alternative approach for correlation between tests results and concrete strength is presented in EN 13791 (2007) and BS 6089 (2010).

In-place tests can be used to estimate concrete strength during construction so that operations requiring a specific strength can be performed safely or curing procedures terminated. They can also be used to estimate concrete strength during the evaluation of existing structures. These two applications require slightly different approaches, so parts of this report are separated into sections dealing with new and existing construction.

A variety of techniques are available for estimating the in-place strength of concrete (Malhotra 1976; Bungey et al. 2006; Malhotra and Carino 2004). No attempt is made to review all methods in this report; only those methods that have been standardized by ASTM International are discussed. Examples of methods not covered include internal fracture tests (Chabowski and Bryden-Smith 1980; Domone and Castro 1987) and torque tests (Stoll 1985).

### 1.2—Need for in-place tests during construction

In North American practice, the most widely used test for concrete is the compressive strength test of standard cylinders (ASTM C39/39M). This test procedure is relatively easy to perform in terms of sampling, specimen preparation (ASTM C31/C31M), and strength measurement. When properly performed, this test has low single-operator variation and low interlaboratory variation and, therefore, the method lends itself to use as a standardized testing procedure. The compressive strength so obtained is used to verify that the specified strength ( $f'_c$ ) used to calculate the nominal strengths of structural members has been achieved. Therefore, the compressive strength of standard cylinders is an essential parameter in design codes and project specifications.

When carried out according to standard procedures, however, the results of the cylinder compression test represent the potential strength of the concrete as delivered to a site. The test is used mainly as a basis for quality assurance of the concrete to ensure that contract requirements are met. It is not intended for determining the in-place strength of the concrete because it makes no allowance for the effects

of placing, consolidation, or curing. It is unusual for the concrete in a structure to have the same properties as a standard-cured cylinder at the same test age. Also, standard-cured cylinders are usually tested for acceptance purposes at an age of 28 days; therefore, the results of these tests cannot be used to determine whether adequate strength exists at earlier ages for safe removal of formwork or the application of post-tensioning. The concrete in some parts of a structure, such as columns, may develop strength equal to the standard 28-day cylinder strength by the time it is subjected to design loads. Concrete in flexural members, especially pretensioned members, can be required to support a large percentage of the design load before an age of 28 days. For these reasons, in-place tests are used to estimate the concrete strength at critical locations in a structure and at times when crucial construction operations are scheduled.

Traditionally, a measure of the strength of the concrete in the structure has been obtained by using field-cured cylinders prepared and cured in accordance with **ASTM C31/C31M**. These cylinders are cured on or in the structure under, as nearly as possible, the same conditions as the concrete in the structure. Measured strengths of field-cured cylinders may be significantly different from in-place strengths because it is difficult, and often impossible, to have identical bleeding, consolidation, and curing conditions for concrete in cylinders and concrete in structures (**Soutsos et al. 2000**). Field-cured specimens should be handled with care and stored properly to avoid misleading test results.

Construction schedules often require that operations such as form removal, post-tensioning, termination of curing, and removal of reshores be carried out as early as possible to keep the project on schedule. To enable these operations to proceed safely at the earliest possible time requires the use of reliable in-place tests to estimate the in-place strength. The need for such strength information is emphasized by several construction failures that possibly could have been prevented had in-place testing been used (**Lew 1980; Carino et al. 1983a**). In-place testing not only increases safety but can result in substantial cost savings by permitting accelerated construction schedules (**Bickley 1982a**).

### 1.3—Influence of ACI 318

Before 1983, ACI 318 required testing of field-cured cylinders to demonstrate the adequacy of concrete strength before removal of formwork or reshoring. In 1983, ACI 318 first allowed the use of other procedures instead of tests for field-cured cylinders, if approved by the building official (**ACI Committee 318 1983**). The design professional, when requested by the building official, however, was required to approve the alternative procedure before its use. Since 1983, ACI 318 has permitted the use of in-place testing as an alternative to testing field-cured cylinders if approved by the licensed design professional and, if requested, approved by the building official. The commentary to **ACI 318-14** (Section R26.11.2.1(e)) lists four procedures, which are covered in this report, that may be used provided there are sufficient correlation data.

Most design provisions in ACI 318 are based on the compressive strength of standard cylinders. Thus, to evaluate

structural capacity under construction loading, it is necessary to have an estimate of the equivalent cylinder strength of the concrete as it exists in the structure. If in-place tests are used, a valid relationship between the results of in-place tests and the compressive strength of cylinders is required. At present, there are no standard practices for developing the required relationship.

### 1.4—Recommendations in other ACI documents

After the 1995 version of this report was published, other ACI documents incorporated in-place tests as alternative procedures for estimating in-place strength. One of these documents is ACI 301, a specification for new concrete construction. In the 2016 version of **ACI 301**, Section 1.6.4.2 on in-place testing of hardened concrete includes the following:

Use of the rebound hammer in accordance with ASTM C805/C805M or the pulse-velocity method in accordance with ASTM C597 may be specified by Architect/Engineer to evaluate uniformity of in-place concrete or to select areas to be cored. These methods shall not be used to evaluate in-place strength.

Regarding the validity of in-place strength tests, ACI 301-16 states in Section 1.6.5.3(a):

Results of in-place strength tests will be evaluated by Architect/Engineer and are valid only if tests are conducted using properly calibrated equipment in accordance with recognized standard procedures and an acceptable correlation between test results and concrete compressive strength is established and submitted.

Section 1.6.6.4 of ACI 301-16, however, restricts the use of these tests in acceptance of concrete by stating that, “In-place tests shall not be used as the sole basis for accepting or rejecting concrete,” but they may be used if specified to “evaluate” concrete if standard-cured cylinder strengths fail to meet the specified strength criteria.

ACI 301-16 also mentions in-place tests in Section 2.3.4 dealing with required strength for removal of formwork. Specifically, it is stated that if specified in Contract Documents, the following methods may be used to estimate in-place strength:

- (a) **ASTM C873/C873M** (cast-in-place cylinders)
- (b) **ASTM C803/C803M** (penetration resistance)
- (c) **ASTM C900** (pullout)
- (d) **ASTM C1074** (maturity method)

These same methods may be used, if specified, as alternatives to testing field-cured cylinders for estimating in-place strength for the purpose of terminating curing procedures.

**ACI 562-16**, the repair code for existing concrete buildings, allowed the use of in-place test methods for assessment of concrete strength. Section 6.4.3.2 states: