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In-situ examination of the concrete quality European standard approach

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Abstract. The paper presents overview of European standard procedures related to determining concrete quality basing on the in-situ testing. Among other things following testing methods have been discussed: testing cored specimens, rebound measurements, "pull-out" method, "pull-off" method, ultrasonic pulse velocity measurements. Testing conditions, guidelines for calibration and crucial requirement for proper interpretation of the data obtained by means of rebound and ultrasonic measurements were shown. Independently "pull-out" and "pull-off" NDT methods have been introduced. Finally, the European procedures of assessment of in-situ concrete compressive strength in structures have been also presented.

1 Introduction

During last decade in EU countries several major changes were introduced regarding the legal status of concrete quality assessment. The "old" national standards were replaced by one join integrated system of standard procedures common for all Member States. The mile stone of changing engineering practice in this aspect was introduction of European Standard EN-206-1 [1] which is mainly focussed on the conditions ensuring durability of concrete. Among other things, this document specifies unified requirements for:

- the constituent materials of concrete,
- the properties of fresh and hardened concrete and their verification,
- the limitations for concrete composition,
- the specification of concrete,
- the delivery of fresh concrete,
- the production control procedures,
- the conformity criteria and evaluation of conformity.

A new European standard approach has been also introduced for traditional concrete quality control (laboratory testing) - package of related standards specified as EN 12390 [2]) and for testing concrete in existing structures (in-situ measurements, including NDT examinations) - group of standards specified as EN 12504 [3].

Complement the hole of this subject is European standard specified as EN-13791 [4], which provides procedures for proper testing data interpretation and assessment of the in-situ compressive strength of concrete in structures and precast concrete components.

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2 Assessment of concrete quality by testing cores

The strength test of cores taken directly from existing structures (Fig.1) is commonly considered as the most reliable source of information on the actual quality of concrete used in the construction. This opinion is only partly true. Although current European standard regulations allow applying core testing to determine the actual technical condition of structures without any limitations, at the same time they clearly stipulate that in-situ testing cannot replace concrete quality testing based on standard specimens according to [1]. The EN-13791 standard specifies cases in which the assessment of the concrete compressive strength can be made based on the results of core tests as follows:

- when an existing structure is to be modified or redesigned,
- to assess structural adequacy when doubt arises about the compressive strength in the structure due to defective workmanship, deterioration of concrete due to fire or other causes,
- when an assessment of the in-situ concrete strength is needed during construction,
- assessment of conformity of the in-situ concrete compressive strength when specified in a specification or product standard,
- to assess structural adequacy in the case of non-conformity of the compressive strength obtained from standard test specimens.

Fig.1. Example of cores taken from existing structure.

There are several important standard requirements concerning core testing. First of all, cores should be taken from a structure in accordance with the procedure defined by EN-12504-1 [5]. In order to ensure the maximum conformity of conditions of the core strength test it is recommended that cores are taken perpendicularly to the direction of casting.

The number of cores to be taken from one test region shall be determined by the volume of concrete involved and the purpose for testing cores. The most important rule which determines the obtaining of representative data, is to ensure randomness of choice of particular test locations. Each test location comprises one core. An assessment of in-situ compressive strength for a particular test region shall be based on at least 3 cores.

The European standards [4,5] recommends testing cores of nominal diameter equal to 100 mm. It primarily follows from the fact that the ratio of maximum size of aggregate grain to the core diameter should be no bigger than 1:3, which in fact means that for aggregate of up to 32 mm graining, the preferred diameter should amount to approximately

100 mm. Testing a core with a nominal diameter of 100 mm and equal length (L/D=1) gives a strength value equivalent to the strength value of a 150 mm cube manufactured and cured under the same conditions.

Simultaneously, it is worth to mention that testing a core with a nominal diameter at least 100 mm and not larger than 150 mm and with a length to diameter ratio equal to 2.0 gives a strength value of a 150 mm by 300 mm cylinder manufactured and cured under the same conditions.

Cores taken from structures should be carefully examined visually. The aim of the inspection is to obtain important information as to concrete quality, the type of aggregate, its graining, concrete structure and to find answers to questions such as:

- is the examined concrete porous,
- to what degree is the carbonatization process advanced on the surface layer (Fig.2),
- are there any inner defects within the structure.

Fig.2. Example of the core on which measurements of the carbonation depth were carried out by means of phenolphthalein and rainbow tests.

In order to carried out properly compression test of cores it is crucial to prepare the end surfaces of the specimens in the correct manner, so that the surfaces to which a load is to be applied are parallel. To do so, ends of specimens should be ground. Surface grinding is considered to be the basic method for ensuring parallelism. So called „capping" is also an accepted method as an alternative to grinding (Fig.3).

Capping can be also performed using calcium aluminates cement paste or sulfur mixtures. More details concerning capping can be found in EN-12390-3 [6]. To ensure the reliability of the concrete compressive strength assessment it is also very important to provide correct moisture content of the specimen at the moment of testing. To avoid influence of moisture gradient inside a tested specimen it recommended that cores shall be exposed to a laboratory atmosphere for at least 3 days prior to testing. However, in cases where a structure or precast concrete component is in wet conditions, the cores should be tested in the saturated condition. To fulfil this requirement, according to [5], the specimens must be moistened with water of a temperature of 20±2 °C for at least 40 hours before the test.

Fig.3. View of the test specimens prepared by means of capping using send boxes.

The procedure of testing the concrete compressive strength is in itself analogical to those of standard specimens and should fulfil the requirements defined in EN 12390-3 [6]. This standard, closely related to concrete standard [1], among other things, recommends that the load should grow at a uniform velocity within the range 0,2 MPa/s to 1,0 MPa/s.

In the case of in-situ concrete quality assessment, criteria for core tests evaluation are significantly differ when compared to the standard conformity procedures defined by [1]. According to [4] in-situ characteristic compressive strength is assessed using two approaches. First one (Approach A) applies where at least 15 core test results are available. Approach B applies where 3 to 14 cores are available.

Procedure related to Approach A estimate the value of characteristic strength of the particular test region as a lower value of:

$$f_{ck,\,is} = f_{m(n),\,is} - k_2 \text{ x } s \tag{1}$$

or

$$f_{ck,\,is} \leq f_{is,lowest} + 4 \tag{2}$$

where: $f_{ck,\,is}$ – characteristic in-situ compressive strength
$f_{m(n),\,is}$ – mean in-situ compressive strength of n test results
$f_{is,lowest}$ – lowest in-situ compressive strength test result
s – standard deviation of test results, but not lower than 2,0 N/mm²
k_2 – coefficient that is given in national provisions or, if no value is given, taken as 1.48

Approach B contains estimation procedure according to which the value of characteristic strength of the particular test region is considered as a lower value of:

$$f_{ck,\,is} = f_{m(n),\,is} - k \tag{3}$$

or

$$f_{ck,\,is} \leq f_{is,lowest} + 4 \tag{4}$$

The margin k depends on the number n of test results and the appropriate value selected from Table 1.

Table 1. Value of margin „*k*” – small numbers of results

Number of test results	Value of margin „*k*”
from 10 to 14	5
from 7 to 9	6
from 3 to 6	7

In both cases the strength class is defined according to European standard [4] using the estimated in-situ characteristic strength. It is worth of mention, that the same standard introduces also a correction factor which represents ratio of in-situ characteristic strength to characteristic strength of standard specimens equal to 0.85. This reduction is partly attributed to the process of drilling which in itself incurs the risk of small damage to the core material, and partly to the fact the conditions of curing on the construction site are usually worse than conditions in a laboratory.

The assessment of concrete compressive strength, based on core testing should, according to many authors [7,8], take also into consideration the fact that concrete strength in construction is in generally lower than the strength determined for the specimen obtained from the same batch of concrete. This is partly attributed to the process of drilling which in itself undoubtedly incurs the risk of small damage to the core material, and partly to the fact the conditions of curing on the construction site are nearly always worse than conditions in a laboratory.

3 Rebound hammer measurements

Rebound hammer measurements are most popular of NDT methods commonly used in engineering practice. The main principle of this technique it is to use the relationship between hardness and compressive strength of concrete. Rebound number, which supposed to be a measure of hardness, is used for the nondestructive testing of the uniformity of concrete and for estimating its compressive strength. The test is quite simple and fast. However, several factors have been recognized as seriusly influencing the results obtained by means of so-called Schmidt hammer. Among other things, it is worth of mention that rebound numbers obtained on the concrete surface usually are different than numbers measured on the surface of cores (influence of stress situation, quality of cover layer and carbonation). As a result, it should be noted that it does not exist any general calibration curve relating rebound numbers to strength.

Relationships between rebound numbers and concrete strength that are provided by instrument manufacturers shall be used only to provide indications of relative concrete strength at different locations in a structure. To use this test method to estimate strength of concrete, it is necessary to establish a relevant relationship by correlating rebound numbers measured on the structure with a strength of cores taken from corresponding locations.
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Details concerning testing procedures can be found in EN-12504-2 [9]. Among other things, it is important to mention following standard recommendations which are crucial for proper performance of the measurements:

- before and after tests, hammer has to be checked on the verification anvil to ensure that readings are within the range recommended by the manufacturer,

- the hammer should be operated at a temperature within the range 10 to 35 ^{0}C,
- each test area shall be approximately 300 x 300 mm,
- a proper surface preparation by grinding is required,
- to obtain a reliable estimate of the rebound number for a particular test area, at least 9 readings have to be made,
- rebound numbers obtained on the concrete surface usually are different than numbers measured on the surface of cores (influence of stress situation, quality of cover layer and carbonation).

A few years ago a new development (Silver Schmidt) was proposed (Fig.4). This new device combines innovative ideas with the advantages of the classical rebound hammer. Instead rebound number the value of rebound energy (Q) is registered. This parameter is independent of the measurement direction relative to the direction of gravity. In this case measurements are also not affected by friction between hammer mass and guide rod and the one of the pointer.

$$\boxed{Q = \sqrt{\frac{\text{Rebound Energy}}{\text{Impact Energy}}} = \frac{V_R}{V_i} \times 100} \tag{5}$$

where: Vi – impact velocity
V_R – rebound velocity

Fig.4. View of the Silver Schmidt hammer.

4 Ultrasonic pulse velocity measurements

As in the case of rebound measurements for an unknown concrete, the estimation of compressive strength, on basis of pulse velocity alone, is not reliable. The important physical properties of materials that influence pulse velocity are the elastic modulus and the density. In concrete, these properties are mainly related to the type of aggregates, their proportions and physical properties of the cement paste, which relate mainly to the original water/cement ratio and maturity. Thus correlations between the pulse velocity and strength of concrete are physically indirect and have to be established for the specific concrete mix. As a result it is necessary to calibrate regression curve by core tests.

Testing procedure and relevant recommendations for ultrasonic pulse velocity measurements in hardened concrete are presented in EN-12504-4 [10]. The most important recommendations include following requirements:

- the natural frequency of the transducers should normally be within the range 20 to 150 kHz,
- a viscous material shall be used to obtain adequate acoustical coupling between the concrete and the face of each transducer (it could be petroleum jelly, grease, or soft soap),
- the transducers should be pressed firmly against the concrete surface,
- when the concrete surface is very rough and uneven the surface should be ground or special point transducers can be used,

- the resultant determination of the pulse velocity shall be expressed to the nearest 10 m/s,
- moisture content has two effects on the pulse velocity, one chemical, the other physical; these effects are important in the production of correlations for the estimation of concrete strength,
- the path length over which the pulse velocity is measured should be long enough not to be significantly influenced by the heterogeneous nature of concrete: at least 100 mm, for nominal aggregate size less than 20 mm and at least 150 mm, for nominal aggregate size between 20 and 40 mm,
- when possible, measurements in close proximity to steel reinforcing bars, parallel to the direction of pulse propagation should be avoided.

5 Pull-out measurements

One of the most promising NDT measurements which could be applied for testing concrete quality in existing structures seems to be pull-out technique, in particular CAPO-Test. The CAPO-TEST is a post-installed pull-out test conforming requirements of EN-12504-3 [11] and ASTM C900 [12]. The term "post-installed" means that the CAPO-TEST does not require pre-placing inserts in fresh concrete. The test can be performed on an existing structure at any accessible location. In this case, for insert preparation, special technique has to be applied.
The fundamental principle behind pull-out testing is that accurate estimation of the in-situ strength can be obtained, as the peak-force (the pull-out force) correlates accurately to the concrete compressive strength measured by standard cylinders or cubes in the laboratory (Fig.5).

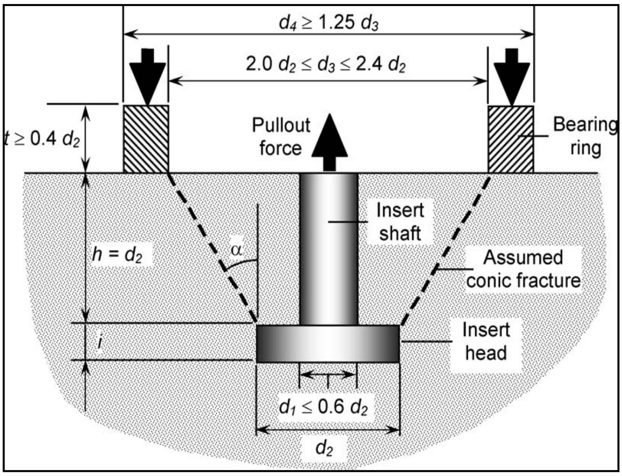

Fig.5. General principles of the pull-out test

The measurement can be used to estimate in-situ strength, to determine when post tensioning can proceed, when formworks can be removed, when winter protection and curing can be terminated, or for comparative testing. Several investigations have shown that the „pull-out" measurements provides an accurate estimate of „in-situ" strength because the peak pullout force has a well-defined correlation to compressive strength measured using standard cylinders or cubes [13,14] and that a general correlation (Fig.6) can be used with reasonable accuracy. A special correlations are only required for lightweight concretes or other concretes with less common constituents.

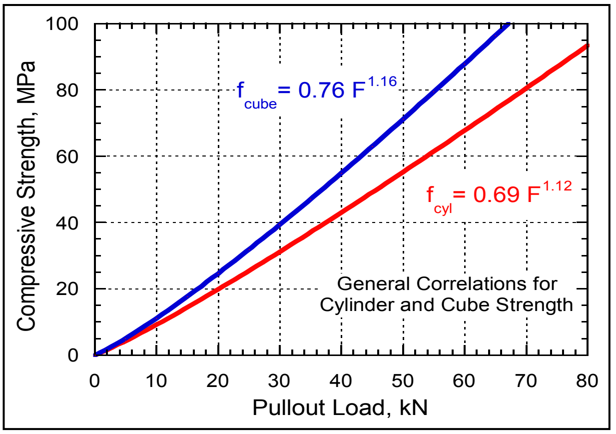

Fig.6. General corelation for pull-out measurements

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