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CAPO TEST FOR PUBLIC WORKS DEPARTMENT, NEW DELHI, INDIA

Parampreet Singh, AE&C Test Systems

Public Works Department Delhi, India purchased CAPO Test equipment from AE&C, distributors for Germann Instruments in India in March 2007. The aim of this purchase was to use CAPO test as a quality assurance tool for in-situ concrete strength during construction of a major grade separator and connected flyover projects in Delhi.

The construction of these projects began in early 2007 and is to be completed by end of year 2008. The concrete for this project is being manufactured at contractor's own concrete batch mix plant near the project and is transported to the sites in transit mixers. Concrete is placed with a hopper or a concrete pump depending on the location.

As a standard practice, cube moulds samples are being taken at the concrete plant itself for compression testing at contractors own laboratory close to the concrete plant. There is an independent consultant employed by PWD to monitor the QC at contractors lab.

The design strength for majority of structures is typically 35Mpa. For piers, the design strength is 45MPa.

On April 16, 2007, the CAPO test was first put on use on a box structure cast using M35 grade concrete. The box had been cast over one month back and in-situ strengths around 35MPa were expected.

It was agreed by all (contractor, AE&C and PWD) that manufacturer's correlation table would be used to convert CAPO pull out force to cube strength in Mpa for these initial tests. A site specific correlation could be considered later if found necessary.

Four CAPO tests were performed on this structure, all the test results showed a concrete strength of average 25Mpa, about 30% lower than expected.

A set of CAPO tests were repeated on another structure and the CAPO Test consistently showed an average strength of 24Mpa on this structure.

The contractor's engineer argued his case by saying that the CAPO test takes only surface 25mm into account and the results are not representative of the concrete inside.

PWD's engineer in-charge then suggested that the cover be removed at three locations and CAPO tests be performed. The CAPO test results were again found to be in 24 Mpa range instead of 35Mpa expected.

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The contractor still very confident about the quality of his concrete was not ready to accept the CAPO test results and blamed it to poor co-relation of the CAPO pull out test to concrete strength.

PWD's engineer in-charge then asked AE&C that CAPO tests should be performed on standard cubes and compared to cube strength results by crushing the cubes in a compression testing machine in contractor's lab. Although a 20 cm cube would have been ideal for CAPO test to avoid radial cracks, AE&C agreed to do the CAPO test on 15cm cubes as 20cm cubes were not available on site

Out of the total six cubes from one batch to be tested for 28 days strength, three were tested with CAPO and balance three under a compression testing machine.

The three CAPO test results (converted to MPa) were:

Cube 1: 39.1 Mpa
Cube 2: 42.0 Mpa
Cube 3: 38.5 Mpa

Average: 39.9 Mpa

The three cube strength results in a CTM are:

Cube 4: 42.2 Mpa
Cube 5: 39.0 Mpa
Cube 6: 37.2 Mpa

Average: 39.5 Mpa

These tests confirmed the accuracy of CAPO tests and also the validity of the manufacturers co-relation for these strength range.

It also became very obvious that onsite strengths being achieved were actually lower than cube strength results achieved in the lab. No one including the contractor had ever imagined that poor onsite practices could have such a significant impact on strength of concrete on site

Now with more confidence on their new CAPO test method, PWD has asked the contractor to improve onsite practices to ensure a good in-situ strength by using CAPO test.

On May 5, 2007 two new structures were tested with CAPO, one after seven days of casting and second after ten days of casting. The results were as under:

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Mock Pier: M45 Grade concrete tested after 7 days of casting, proper compaction and curing ensured. Expected strength about 33 Mpa. Three CAPO test conducted. Results were found to be 39Mpa, 37MPa and 40 Mpa all exceeding the expected strength.

Top Slab of concrete drain: M35 Grade concrete tested after 10 days of casting, proper compaction and curing ensured. Expected strength about 28 Mpa. Only one CAPO test could be conducted due to shortage of time. CAPO Results was found as 30Mpa, exceeding the expected strength.

Although this started as a demonstration of the newly purchased CAPO test to PWD, the unexpected poor in-situ concrete strength results forced this to become a small experiment.

Not only did this experiment prove again the reliability of CAPO test as an accurate method for estimating in-situ concrete strength, it also showed how a good in-situ testing method can ensure good construction practices, automatically improving the quality.

Determination of Concrete Compressive Strength with Pullout Test

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ACI fellow **Lennart Elfgren** is a professor at the Division of Structural Engineering, Department of Civil & Environmental Engineering at Luleå University of Technology, Luleå, Sweden. He received his PhD from Chalmers University of Technology, Göteborg, Sweden in 1971. He is a member of ACI Committees 355 (Anchorage to Concrete), 445 (Shear and Torsion) and 446 (Fracture Mechanics).

ABSTRACT

A pullout test method, the Capo-test, has been examined as an alternative to drilled cores to determine the in-place concrete compressive strength. Tests have been carried out on eight railway bridges from 1965 to 1980 and on a one year old slab.

A strength relationship is proposed between the compressive strength of a drilled core with the diameter and the height of 100 mm, f_{core}, and the pullout force, F, from the Capo-test. It is a power function and has the form, $f_{core} = 0.98F^{1.14}$. The relation is valid for concrete compressive strengths up to 105 MPa. It gives higher concrete strengths than earlier proposed functions.

Keywords: Capo-test; pullout test; drilled cores; concrete; bridges; compressive strength

INTRODUCTION

A pullout test method, the Capo-test, is examined for its ability to determine the in-place concrete compressive strength in old bridges. The method has primarily been intended for estimating the strength of the cover-layer of new structures, see Germann Petersen & Poulsen[1] or Carino[2]. Here the ability to predict the concrete compressive strength in old concrete structures is also studied.

The project was initiated in 1995 when an increase of the axle load was planned for a railway line and its bridges in northern Sweden, see Paulson et al [3,4]. The object of the axle load increase, from 25 tons to 30 tons, was to reduce transportation costs for carrying iron ore from the mine fields in the mountains to the harbours in Luleå on the Gulf of Bothnia and in Narvik on the Norwegian Sea. The railway line has a length of 473 km and was built between 1884 and 1902. There are 112 bridges on the line, most of them rebuilt between 1950 and 1980. In order to check the present concrete strength in the bridges a study was carried out by Thun et al. [5,6].

RESEARCH SIGNIFICANCE

During the last few decades, it has become more and more important to assess, maintain and strengthen structures like bridges, dams and buildings due to a combination of increased loads, time-dependent deterioration, increasing age of many structures and the high costs to build new infrastructure. Therefore it is of great interest to find methods to evaluate existing concrete structures in an efficient way. In this paper the focus is concentrated on examining a test method to determine the in-place concrete compressive strength – the so-called Capo-test.

METHODS

The methods that have been used in this investigation to determine the in-place concrete compressive strength of the reinforced concrete railway trough bridges are drilled cores and Capo-tests.

To drill out and test cores is a common method to estimate the in-place strength of a structure. Most countries have adopted standard procedures for how a core should be prepared, stored, etc. before testing. In this study the preparation, the storage etc. have been made according to the Swedish concrete recommendations, BBK94[7]. A water-cooled drill with diamond edges has been used. The cores have then been air-cured for at least three days before testing, see Möller et al. [8] or prEN 13791[9]. The reason for this is that the cores are moistened by water during the drilling and cutting process and this inflicts a reduction of the strength (about 10-15%) that needs to be considered, see Möller et al. [8]. The ratio between the length and the diameter has been 1.0 (approximately a diameter of 100 mm). The cores have been marked with a drill hole number and a serial number. The cores have been used for uniaxial tensile tests, splitting tensile tests and compressive tests.

The Capo-test (from "**c**ut **a**nd **p**ull **o**ut"-test) is a method to determine the concrete strength of the cover-layer for an existing structure. It was developed in Denmark by Germann Petersen & Poulsen[1] in the middle of the 1970s. The test procedure consists of drilling a 65 mm deep hole with a diameter of 18 mm using a water-cooled diamond bit, see **Fig. 1**. Then a 25 mm recess is made at a depth of 25 mm using a portable router. An expandable split steel ring is inserted through the hole in the recess and expanded by means of a special tool. Finally the ring is pulled through a 55 mm counter pressure placed concentrically on the surface. A description of the method can also be found in e.g. Bungey & Millard[10]. The pullout force, F, is measured by the pull machine and can be converted into concrete compressive strength, f_c', by means of calibration charts provided by Germann Petersen & Poulsen[1]. In **Fig.2** the suggested general correlation for standard 150 mm cubes is presented and the equations are:

$$F = 0.71 \cdot f_c' + 2 \quad \leq 50 \text{ kN} \qquad (1)$$

$$F = 0.63 \cdot f_c' + 6 \quad \geq 50 \text{ kN} \qquad (2)$$

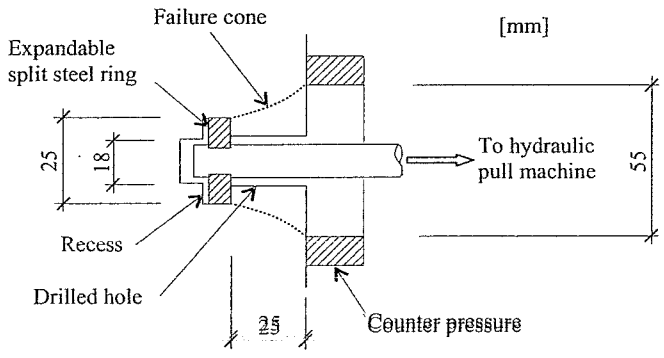

Fig. 1 - Schematic drawing of the Capo-test, based on Germann Petersen & Poulsen[1], Bungey & Millard[10] and Carino[2].

The background to the correlation charts is several laboratory and field studies made by the manufacturer as well as by other researchers. The Capo-test is a further development of an earlier developed test method, the Lok-test (from Danish for "punch-out test"). In this method a bolt is embedded in fresh concrete and then pulled out when the concrete has hardened, see Germann Petersen[11].

If the two methods are compared in general, the Capo-test is a simpler and less expensive test to perform compared to drilled cores on the bridges. The Capo-test has the advantage that the equipment is lighter and easier to transport to the bridge compared with the equipment used for drilling cores. This was one of the key-advantages since many of the bridges in this investigation could only be reached by train or on foot. Important in this case was also the less damage the Capo-test inflicts on the bridges.

Rockström & Molin[12] have shown that the relation suggested by Germann Petersen[11], Eqs. (1) and (2), can be improved when the test object is an old structure, i.e. an old road bridge. They got higher concrete strengths according to Eq. (3) in **Fig.2**, when they performed tests with both the Capo-test and drilled cores on six road bridges that had ages up to 54 years. The equation proposed by Rockström & Molin is:

$$F = 0.55 \cdot f_c' + 3.16 \quad (3)$$

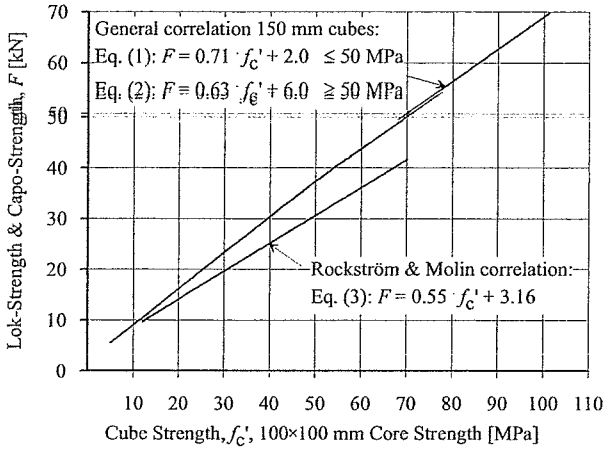

Fig. 2 - Correlation between Capo-test and drilled cores with the height and the diameter of 100 mm, trimmed and air-cured 3 days before testing, made by Rockström & Molin[12] based on 5 old Swedish bridges. The correlation is compared with the general correlation for 150 mm standard cubes suggested by the manufacturer. From Germann Petersen[11].

The reasons for this discrepancy for old structures could according to Rockström & Molin be due to: *(a)* Difference in concrete strength of the cover-layer and concrete further into the structure, *(b)* For older structures the aggregate size may vary greatly and *(c)* Risk for irregular and insufficient concrete compaction. These three reasons are probably valid also for newly cast concrete – at least reasons *(a)* and *(b)*. Worth mentioning is that the study in Rockström & Molin[12] was based on five objects where the Capo-test and cores were taken from the same test spot. Rockström & Molin rejected the results from one bridge because of the great difference between the Capo-test and the drilled cores due to low strength of the cover-layer (high porosity). The result by Rockström & Molin was commented by Germann Petersen[11] who suggested that the difference between the Capo-Test measured at the 25 mm surface layer and the core strength 75-100 mm deep found by Rock-

ström & Molin may be explained partly by the 3-day air-curing of the cores prior to crushing, and partly by actual different concrete qualities at the two depth levels.

The failure mechanism when an anchor bolt is pulled out has been investigated extensively both with experimental and analytical studies and an overview could be found in e.g. Eligehausen et al. [13]. Results from fracture mechanics analyses and a Round-Robin study of plane stress and axi-symmetric tests are presented by Elfgren et al. [14-17], see **Fig. 3** and an example of a specific study could be found in Ohlsson & Olofsson[18]. In these it is shown that the geometry, the boundary conditions and the material properties are very important for the outcome of the results. For the pullout-test method an overview is presented in e.g. Carino[2] or Bungey & Millard[10] and specific studies could be found in e.g. Yener[19], Ottoson[20] or Stone & Carino[21,22]. The pullout test subjects the concrete to a nonuniform three-dimensional state of stress. A primary stable crack system is initiated from the insert at an early stage and propagates into the concrete at a large apex angle. Then, governed by the distance to the supports, which gives a counter pressure to the pull-out force, a second system arises. This second system develops to form the shape of the extracted cone, see **Fig. 1**. In the literature, different hypotheses for the failure mechanism at the ultimate load have been suggested. Some researchers argue that compression failure is the main reason for failure, some say aggregate interlocking and others shear/tensile failure of concrete, see surveys in e.g. Carino[2] or Yener[19].

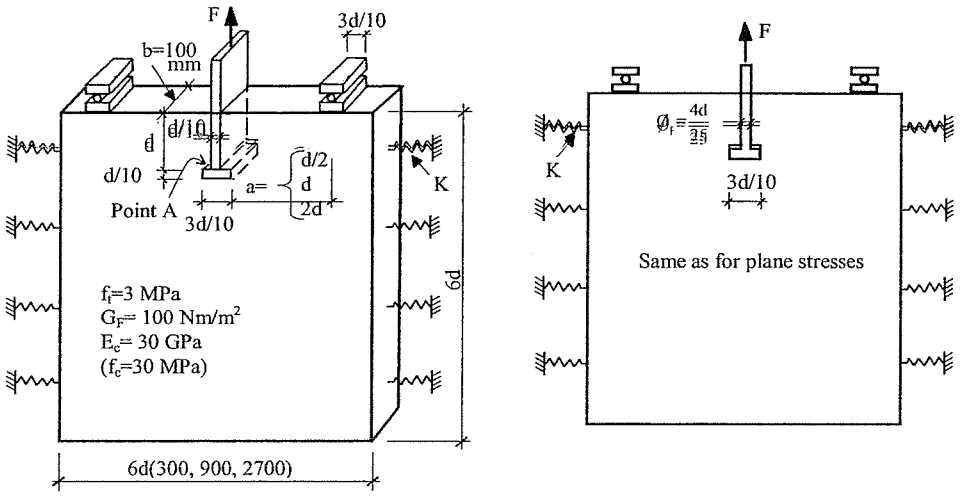

Fig. 3 - Round Robin Analyses and Tests of Anchor Bolts for Plane Stresses (left) and Axi-symmetric Stresses (right) for varying embedment depths d = 50 mm, 150 mm and 450 mm. Elfgren et al. [14,15].

Initially in this study, the general correlation for the pullout force and standard 150 mm cubes suggested by the manufacturer of the Capo-test-system, was used to calculate the compressive strength. This strength was then compared with the compressive strength of tested cores with the height and diameter of 100 mm taken from old bridges. This choice of comparison by the authors of this paper was based on the established relationship between the compressive strength of a horizontally drilled core with the height and diameter of 100 mm and the compressive strength of a 150 mm cube, see Möller et al. [8] or prEN 13791[9]. Furthermore, the compressive strength determined from drilled cores has in this study been regarded to represent the "true compressive strength" since it constitutes the reference method in the new standard for assessment of in-situ compressive strength in structures and precast concrete components (see e.g. prEN 13791[9]).

A thing common for all studies of the Capo-test, is that a fairly good correlation has been found to exist between the pullout force and the concrete compressive strength. In this paper this correlation between the pullout force and the concrete compressive strength has been accepted and utilized to determine the in-place concrete compressive strength.