In-Situ Strength by CAPO-TEST

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In-Situ Strength, why?

- Strength of existing structures for calculation of load carrying capacity
- Timing of safe and early loading operations
- Control of effects of transportation, compaction and curing, in-place
- Quality of the cover layer protecting the reinforcement
- Low strength of laboratory specimens
- Changed mixes, intentionally / not intentional
Evaluation of in-place strength

- Pull-out test (LOK-TEST and CAPO-TEST)
- Testing cores
- Rebound hammer
- Ultrasound (UPV)
- Pull-off test
- Maturity method
Examples

London, UK
Strength of industrial floor

Translink, UK,
Residual strength of tunnel segments

Trinity Square, Toronto, CA,
Strength for early loading

Bridge Leznow, Poland
Residual strength

Cigar Lake Uranium Mine, CA
Strength of gunite concrete

Great Belt Link, Denmark
Strength of cover layer

Test smart – Build right
What is measured in a LOK-TEST and CAPO-TEST?
Analysis by Jensen & Bræstrup

• Jensen, B.C. & Bræstrup, M.W.: “LOK-Test Determine the Compressive Strength of Concrete”, Nordisk Betong, 3-1976

Conclusion:
“Plastic analysis may be applied to determine the load-carrying capacity of the concrete embedded bolt which is pulled out under application of a counterpressure (LOK-TEST). It is shown that when the angle between the direction of deformation and the failure surface is equal to the angle of friction for the concrete, then the pull-out force is proportional to the concrete compressive strength”
Analysis by Ottosen

Stress curves at 70% loading

Stresses in MPa (negative when stresses are compressive). Dotted lines give the direction of the principal stress.

Calculations are made for a uniaxial compressive strength of 31.8 MPa. Note the much higher stresses (up to 50 MPa) are present right below the disc due to concentrated tri-axial loading in this area.
Compressive cracking, 98% loading, Finite element analysis and experimental analysis


Conclusion by Ottosen

“It has been shown that large compressive forces run from the disc in a rather narrow band towards the support, and this constitutes the load-carrying mechanism. Moreover, the failure in a LOK-TEST is caused by crushing of the concrete and not by cracking. Therefore, the force required to extract the embedded steel disc is directly dependent on the compressive strength of the concrete”.
Fracture analysis


Krenchel, H. & Bickley, J.A. : “Pullout Testing of Concrete, Historical Background and Scientific Level Today”, Dept. of Structural Engineering, Technical University of Denmark, Nordic Concrete Research, The Nordic Concrete Federation, 1987

Stress-strain curve from uniaxial compressive test

- Linearity
- Compression
- Softening regime
Load displacement curve for pullout test

Linearity

Compression

Softening regime

Acoustic Emission

AE-Activity, $10^3$ Counts/S

Load, P (kN)

Displacement (mm)
98% load level
Situation at collaps into the softening regime
Explanation

1. At about 30% of the load a circumferential crack is developed at a open angle running from the outer edge of the disc. This is where the linearity is lost.

2. From thereon multiple microcracks are developed in a compression band between the disc and the counterpressure.

3. A collapse happens into the softening regime at increased loading, forming the final pullout cone.
The three different stages of internal cracking in a pullout

1. Crack at ~30% load
2. Band of multiple micocracking to max. load
3. Collaps in the softening regime
LOK-TEST pullout failure

“Leave” from the second crack pattern with the concrete in compression being intersected in the softening regime

Crushed material in the compression zone
CAPO-TEST pullout failure

“Leave” from the second crack pattern with the concrete in compression being intersected in the softening regime

Crushed material in the compression zone
NOTE

- LOK-TEST and CAPO-TEST measure the compressive strength of concrete (2nd crack pattern). This constitute the load-carrying mechanism.
- The tests are NOT testing the tensile, NOR the shear strength, only the compressive strength.
- The tensile crack develops at about 30% of the ultimate load. This crack release stesses in the pullout area. Therefore, pullout values are not affected by inherent stresses in the structure (ref.: Jehrbo Jensen, J.K.: “Influences of Stresses in a Structure on the LOK-TEST Pullout Force”, AUC, Deptm. of Building Technology and Structural Engineering, Aalborg, Denmark, 1990)
Clearance Requirements
ASTM C900

Insert clearance

25 mm

\( d_b \) ≥ \( d_b \) or NMSA

>150 mm

>100 mm

Reinforcement clearance

Edge distance
Correlations in the laboratory

- To 150 mm x 300 mm cylinder strength
- To 150 mm cube strength

Pullout (LOK-TEST or CAPO-TEST) performed on specimens with exactly the same concrete quality as the standard specimens (same concrete mix, same compaction and same curing)
Correlation Testing

- Prepare cylinders (or cubes)
- Prepare 200 mm cubes with inserts
- Compact and cure under same conditions
Cylinder relationships
LOK-TEST to cylinder strength, 1st major correlation 1987

Krenchel&Bickley1987

- Max aggr size (8 mm)
- Max aggr size (16 mm)
- Max aggr size (32 mm)

Linear fit
95% confidence intervals

150 mm x 300 mm cylinder (MPa)

\[ f_{\text{cylinder}} = 1.20 \text{ LOK} - 4.1 \]
\[ R_{xy} = 0.99 \]
\[ \text{SD} = 0.9 \text{ MPa} \]

Aggregate type: Sea Gravel and Granite (for strength > 70 MPa)
CAPO-TEST to cylinder strength, 1st major correlation 1987

Aggregate type: Sea Gravel and Granite (for strength > 70 MPa)

Test smart – Build right
18 correlations to cylinder strength 1990-2013

18 correlations between cylinder strength and pullout force compared to the general correlation for cylinders:

\[ f_{cyl} = 0.69 F^{1.12} \]

Compressive strength, \( f_{cyl} \) (MPa)

LOK-TEST/CAPO-TEST pullout force \( F \) (kN)

Gay, G. LOK 1-13 MPa
Bickley, J. LOK 5-44 MPa
Krenchel, H. LOK 3-33 MPa
Krenchel, H. LOK 3-33 MPa
Krenchel, H. LOK 5-50 MPa
Jensen, J. LOK 5-50 MPa
Drake, K.D. CAPO 12-36 MPa
Drake, K.D. LOK 30-74 MPa
Poulsen, E. LOK 10-30 MPa
Kierkegaard, P. LOK 11-39 MPa
Lekso, S. LOK 20-55 MPa
Lekso, S. LOK 20-55 MPa
Krenchel, H. CAPO 15-75 MPa
Krenchel, H. LOK 15-75 MPa
McGee, R.L. LOK 6-35 MPa
Bickley, J. LOK 3-45 MPa
AEC LOK 40-110 MPa
Karthikeyan, H. LOK 8-32 MPa
Cube relationships
LOK-TEST to cube strength, 1st major correlation 1983

Bellander1983

- 150 mm cubes (MPa) max. aggregate size 16 mm
- 150 mm cubes (MPa) max. aggregate size 32 mm

Linear fit
95% confidence intervals

\[ f_{\text{cube}} = 1.55 \text{ LOK} - 2.58 \]

\[ R_{xy} = 0.97 \]

SD = 0.9 MPa
CAPO-TEST to cube strength, 1st major correlation 1983

\( f_{\text{cube}} = 1.56 \text{ CAPO} - 3.17 \)

\( R_{xy} = 0.99 \)

SD = 1.2 MPa
13 correlations to cube strength

13 correlations between cube strength and pullout force compared to the general correlation for cubes:

\[ f_{\text{cub}} = 0.76 F^{1.16} \]
CAPO-TEST to LOK-TEST

Line of equality

General Correlations

General Correlations for Cylinder and Cube Strength

\[ f_{\text{cube}} = 0.76 \cdot F^{1.16} \]

\[ f_{\text{cyl}} = 0.69 \cdot F^{1.12} \]
Robust Correlation

Not affected by:

- Cementitious materials
- Water-cement ratio
- SCC mixtures
- Fibers
- Age
- Air entrainment
- Admixtures
- Curing conditions
- Age and depth of carbonation
- Stresses in the structure
- Shape, type or size of aggregate < 38 mm
  - Lightweight aggregate, however, produce a significantly different correlation
# Variations

### Calibration Procedure, laboratory

<table>
<thead>
<tr>
<th></th>
<th>Pullout V</th>
<th>Pullout n</th>
<th>Standard spec. V</th>
<th>Standard spec. n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danish</td>
<td>9.4%</td>
<td>2188</td>
<td>4.3%</td>
<td>1177</td>
</tr>
<tr>
<td>North American</td>
<td>7.5%</td>
<td>994</td>
<td>6.4%</td>
<td>994</td>
</tr>
<tr>
<td>Swedish/Dutch/English</td>
<td>6.8%</td>
<td>1180</td>
<td>6.2%</td>
<td>963</td>
</tr>
</tbody>
</table>

### Structure, On-site testing

<table>
<thead>
<tr>
<th></th>
<th>LOK-TEST V</th>
<th>LOK-TEST n</th>
<th>CAPO-TEST V</th>
<th>CAPO-TEST n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shotcrete</td>
<td></td>
<td></td>
<td>3.2%</td>
<td>310</td>
</tr>
<tr>
<td>Slabs, bottom</td>
<td>10.5%</td>
<td>5320</td>
<td>7.1%</td>
<td>35</td>
</tr>
<tr>
<td>Slabs, top</td>
<td>12.9%</td>
<td>955</td>
<td>9.3%</td>
<td>623</td>
</tr>
<tr>
<td>Beams &amp; Columns</td>
<td>8.1%</td>
<td>677</td>
<td>8.0%</td>
<td>434</td>
</tr>
<tr>
<td>Walls &amp; Foundations</td>
<td>10.1%</td>
<td>1020</td>
<td>10.4%</td>
<td>534</td>
</tr>
<tr>
<td>Dubious Structures</td>
<td>14.7%</td>
<td>1225</td>
<td>15.3%</td>
<td>3334</td>
</tr>
</tbody>
</table>

Ref.: Petersen (1994)
Why is the strength from a 150 mm cube higher than a 150 mm x 300 mm cylinder?
Effect of End Friction – Triaxial Compression

Zones of triaxial compression

Frictional Stresses

Test smart – Build right
As L/D Decreases
Strength Increases
CORES

• The ratio of the maximum aggregate size in the concrete to the diameter of the core has a significant influence on the measured strength when it is greater than about 1:3.

• 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.

• 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 comparable to a 150 mm by 300 mm cylinder manufactured and cured under the same conditions.

Preferred diameter of core is 100 mm
Cores
Moisture Gradients Immediately After Wet Drilling

- Moistened concrete tends to swell
- Swelling is restrained by dry interior
- Results in internal stresses; outer region in compression
- Measured strength is reduced
Effect of Core Conditioning on Strength

- Soak 48 hr
- Soak 7 days
- Air dry 7 day
- In bags 1 day
- In bags 7 day

Strength, MPa

Strength, psi

Values:
- Soak 48 hr: 20 MPa, 2900 psi
- Soak 7 days: 30 MPa, 4000 psi
- Air dry 7 day: 35 MPa, 4400 psi
- In bags 1 day: 35 MPa, 4900 psi
- In bags 7 day: 40 MPa, 5400 psi

CT003
Moisture Conditioning
ASTM C42/C42M

• Wipe off drilling water, surface dry
• Place in watertight containers
• Wait at least 5 days between wetting due to drilling or sawing and testing
• Other procedure permitted when required by the “specifier of tests”
ACI 214.4R for coring

\[ f_c = F_{\text{L/D}} F_{\text{dia}} F_{\text{moi}} F_{\text{core}} \]

- In-place strength
- Core strength
- Correction for L/D
- Correction for D
- Correction for "damage" due to coring
- Correction for moisture content

Equivalent specified strength:

\[ f_{c,eq} = K f_c \]

- Average in-place strength
- Statistical factor

Test smart – Build right
Capo-Test on shotcrete,
Note the failure zone is unaffected by water needed during coring / recessing
Comparative study Polish bridges for increased loading

- Cores, sawcut, capped, tested after 5 days drying in lab conditions (100 mm dia x 100 mm cores)
- CAPO-Test in-situ, double amount of cores
- Schmidt Hammer in-situ, up to 20 locations, each 6 tests
- Schmidt Hammer on side of cores prior to compression tests

NOTE: All Schmidt Hammer results have been reduced by an “Aging Factor” of 1.4 recommended by manufacturer
CAPO-TESTing on Polish bridges

COMA-Meter
<table>
<thead>
<tr>
<th>Bridge No.</th>
<th>Cores from structure</th>
<th>Capo-Test on structure</th>
<th>Schmidt Hammer on structure</th>
<th>Schmidt Hammer on cores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPa</td>
<td>Av. of</td>
<td>MPa</td>
<td>α(CT)</td>
</tr>
<tr>
<td>1</td>
<td>19.6</td>
<td>6</td>
<td>20.3</td>
<td>+3.4%</td>
</tr>
<tr>
<td>2</td>
<td>24.7</td>
<td>3</td>
<td>26.9</td>
<td>+8.9%</td>
</tr>
<tr>
<td>3</td>
<td>29.7</td>
<td>4</td>
<td>31.8</td>
<td>+7.1%</td>
</tr>
<tr>
<td>4</td>
<td>34.2</td>
<td>3</td>
<td>36.8</td>
<td>+7.6%</td>
</tr>
<tr>
<td>5</td>
<td>33.3</td>
<td>4</td>
<td>32.3</td>
<td>-3.0%</td>
</tr>
<tr>
<td>6</td>
<td>34.2</td>
<td>3</td>
<td>37.6</td>
<td>+9.9%</td>
</tr>
<tr>
<td>7</td>
<td>35.4</td>
<td>4</td>
<td>37.1</td>
<td>+4.8%</td>
</tr>
<tr>
<td>8</td>
<td>37.1</td>
<td>3</td>
<td>35.9</td>
<td>-3.2%</td>
</tr>
<tr>
<td>9</td>
<td>37.5</td>
<td>4</td>
<td>36.8</td>
<td>-1.9%</td>
</tr>
<tr>
<td>10</td>
<td>42.0</td>
<td>3</td>
<td>39.7</td>
<td>-5.5%</td>
</tr>
<tr>
<td>Avg.</td>
<td>32.8</td>
<td>33.5</td>
<td>33.5</td>
<td>+2.1%</td>
</tr>
</tbody>
</table>

Comparative testing, Polish experience, bridges 20-30 years old, ref. A. Mozcko, Wroclaw University

Note: The Schmidt Hammer results have been reduced by 1.4, the "aging" factor recommended by the manufacturer.
## Comparative Strength Estimates from Polish Bridges, summary

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Cores (MPa)</th>
<th>V (%)</th>
<th>CAPO-TEST (MPa)</th>
<th>V (%)</th>
<th>Schmidt on Structure (MPa)</th>
<th>V (%)</th>
<th>Schmidt on Cores (MPa)</th>
<th>V (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strength</strong></td>
<td></td>
<td>32.8</td>
<td>9.5</td>
<td>33.5</td>
<td>11.7</td>
<td>55.9</td>
<td>16.4</td>
<td>44.5</td>
<td>15.1</td>
</tr>
</tbody>
</table>

**Carbonation depth: 2 mm - 35 mm**

**Source:** Moczko, A.: “Comparative Study of In-Situ Strength Measurements on 50 Polish Bridges”, University of Wroclaw, Poland, 2007
Correlation from Polish bridges

100 mm dia x 100 mm core strength (MPa) equiv. to 150 mm cube strength (MPa)

$C_{core} = 0.79 \text{ Capo}^{1.14}$

$R_{xy} = 0.97$

Standard deviation = 2.2 MPa
Comparison to the general correlation for cubes

Note that the correlation found
\[ C_{\text{core}} = 0.79 \text{ Capo}^{1.14} \]
match closely the general correlation for cubes
\[ C_{\text{cube}} = 0.76 \text{ Capo}^{1.16} \]

As a 100 mm dia. core, 100 mm long gives a strength equivalent to the strength value of a 150 mm cube, the following general relationship may be applied:
\[ C_{\text{cube}} = 0.79 \text{ Capo}^{1.14} \]
Effect of carbonation

Avg. Core 33.9 MPa, Avg.CAPO 33.7 MPa, Diff -0.6%
Avg. Carbonation Depth 13.1 mm

Ref: Moczko, (2010)
Considerations using CAPO-TEST

- Capo-Test depth is 25 mm, samples for coring is taken deeper in the structure
- Relationships have not been investigated for max. aggregate size > 40 mm
- Capo-Test seems to be unaffected by depth of carbonation (Polish data)
- Minimum distance to edges and corners of 100 mm has to be observed
- Minimum distance from the “strut” to reinforcement ~ 10 mm
Consideration

Quality of the cover layer protecting the reinforcement on new structures using modern concrete mixes:

Experience has shown that cover layer testing with pullout may give up to 20% - 30% reduction of the strength compared to cores or standard laboratory specimens.

Experience has also shown that the electrical conductivity of the cover layer is increased 40%-50%, indicating a negative effect on the cover layer from insufficient compaction and/or curing conditions on-site, increasing the chloride permeability.

To check this effect, LOK-TEST inserts may be embedded deeper in the structure, and surface planing prior to CAPO-TEST may be done at a required depth.
CAPO-Test advantages

• Does not require pre-planning test locations
• Can perform test at any accessible location
• Permits testing of existing structures
• 20-30 minutes per test
• Test results immediately available
• Cause only a small fracture cone hole compared to a 100 mm coring hole.
• Portable equipment (electricity and water is needed)
CAPO-TEST Procedure
Prepare Concrete

1. Core hole
   18.4 mm dia.

2. Plane surface
   100 mm dia.

3. Cut slot
   Dia 25 mm

25 mm

10 mm
Core Hole
Plane surface
Cut Slot

25 mm
Cut Slot
Cut Slot
Insert Expansion Cone and Coiled Split-Ring

Coiled ring

Cone
Ring Expansion Hardware

- Nut
- Coiled ring
- Cone
Expand Ring

Nut
Expand Ring
Pullout the Expanded Ring against a 55 mm counterpressure
Apply Pullout Force
Acceptable Test

Sharp 55 mm diameter edge from counterpressure
Criteria for correct CAPO testing

- Fully expanded ring, 25 mm dia.
- Plane surface
- 25 mm depth
- Sharp edge 55 mm dia.
CAPO Equipment

Prep. Kit

DSV Kit with Surface Planner

Pullmachine

Inserts
EN 12505-3: 2005:
“The correlation between strength and pullout force for the apparatus being used should be established experimentally. It has been shown that for a given type of apparatus the relationship between pullout force and compressive strength is similar over a wide range of concretes and that a general correlation can be used with reasonable accuracy”

ASTM C 900-06:
“For a given concrete and a given test apparatus, pullout strengths can be related to compressive strength test results.....Before use, these relationships must be established for each test system and each new concrete mixture”
Summary

• Pullout test is a reliable method for estimating in-situ compressive strength of the cover layer

• Can be used for new construction and existing construction

• General correlations according to EN 12505-3: 2005

• Following ASTM C 900-06 confirm general correlations for LOK-Test

• For CAPO-Test cores can be drilled out for comparison to the general correlation
Other systems intending to estimate compressive strength in-situ

Rebound Hammer

Ultrasound (UPV)
Rebound number to cores, mix specific

Core Strength, MPa vs. Rebound Number

Ward, M.A. and Langan, B.W., Cement Concrete and Aggregates, 16(2), Dec. 1994, 181-185

n = 13
Factors Affecting Rebound Number

- Strength and elastic modulus of concrete near to surface
  - Aggregate type dependence
- Thickness of carbonation zone
- Surface texture
- Surface moisture condition
- Rigidity of test object
Comparison of Relationships

![Graph showing comparison of relationships between core strength (MPa) and rebound number for Case 1 and Case 2.](Image)
Rebound Hammer related to cube strength

Average relationships shown for granite and limestone aggregates and curing conditions (water and air)

Strength Relationship UPV

Physics: \[ V \propto \sqrt{E} \]

Empirically: \[ E \propto \sqrt{f_c} \]

\[ \therefore f_c \propto \sqrt[4]{E} \]

For mature concrete, large increase in strength is accompanied by small increase in velocity, mix specific.
Relationship for a specific mix
Factors Affecting UPV for Given Concrete Strength

• Aggregate type
• Aggregate content
• Moisture content
  ➢ Saturated concrete 5% greater UPV than dry
• Presence of reinforcement
  ➢ Perpendicular to pulse path
  ➢ Parallel to pulse path
Example
Aggregate Type

Ref: Bungey, 1982
UPV (Ultrasound Pulse Velocity) related to cube strength

Average relationships shown for granite and limestone aggregates and curing conditions (water and air)

Evaluation techniques by

Pullout test
Testing cores
Rebound hammer
UPV
Pull-off test
Maturity method

are dealt with in detail at our NDT Workshops
as well as other advanced NDT Methods
www.germann.org
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