Presentation on in-situ concrete strength evaluation systems

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Today's strength subjects 1. Lab specimens 2.Cores **3.Pullout 4.**Rebound hammer 5. Ultrasound 6. Windsor Probe

Overview

- Background
- Correlations
- Cases
- Pullout with LOK-TEST
- Pullout with CAPO-TEST
- Cores, Rebound Hammer, Ultrasound and Windsor Probe
- Conclusions
- Workshop information
- Implementation of the systems <u>www.NDTitans.com</u>

In-Situ Strength, why?

- Potential strength superimposed by effects of transportation, pumping, compaction, maturity and curing conditions, in-place
- Testing the final product, the structure itself, not only relying on laboratory testing
- Low strength of laboratory specimens
- Changed mixes, intentionally / not intentional
- Strength of existing structures for QA / QC, and calculation of load carrying capacity, e.g. for further loading
- Timing of safe and early loading operations
- Quality of the critical cover layer protecting the reinforcement in terms of penetrability



Examples of collapses that could have been prevented by testing reliably the compressive strength, in-situ



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Formwork Removal



- Multi-story building collapse in Boston, USA.
- Standard cylinders tested had passed the requirement.
- Subsequent investigation showed the in-place strength to be 50% of the cylinder strength at the time of formwork removal.

Willow Island, W.Va., USA Cooling Tower Collapse, April 1978

- Failure due to insufficient strength to support next "lift"
 51 deaths
 - Timing of next lift was determined by cylinders
 - LOK-TEST was subsequently used to estimate in-place strength before moving to the next lift





Courtesy of NIST

Beam collapse



- Beam collapse in a Russian grocery store
- 7 people killed
- Lab cylinders had passed the required strength 40 MPa
- Capo-Test showed 7-9 MPa strength inplace after collapse



Rana Plaza collapse, Bangladesh



RANA PLAZA COLLAPSE, textile factory, Dhaka, Bangladesh, 2016

Another 3 story's were build on top of the existing factory. Cracking in the walls happened prior to the collapse killing at 1,132 people and injured more than 2,500

- Lab testing unknown.
- Strength testing of the concrete quality months before collapse was made by rebound hammer, UPV and cores



Test Methods ACI 228.1R-19

- 1. Lab cylinders for potential strength
- In-Situ Test Methods:
- 2. Cores
- 3. Pullout
- 4. Rebound hammer
- 5. UPV (Ultrasound)

Report on Methods for Estimating In-Place Concrete Strength

American Concrete Institute

8.1R-19

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1. Lab cylinders for potential strength



- Mix is cast in the 150 mm x
 300 mm steel forms
- Compacted in three layers on vibration table
- Stripped after setting
- Cured in water at 20° C

 Tested in compression at 28 days (maturity days, M₂₀)

Uniaxial compression, middle Triaxial Compression, end faces



Why is the strength from a 150 mm cube higher than a 150 mm x 300 mm cylinder ?



Specimen strength increase for decreasing L/D due to change from uniaxial to triaxial compression state in the middle of the specimen



hence, the compression strength of a 150 mm cube is up to 30% higher than a 150 mm x 300 mm cylinder



2. Cores

ACI 214.4R-10 (Responsed 2016)

Guide for Obtaining Cores and Interpreting Compressive Strength Results

Reported by ACI Committee 214



American Concrete Institute®

Core Tests: Easy to Perform, Not Easy to Interpret



M any engineers have the experience of ordering the taking of cores. The operation is not difficult, usually undertaken by skilled specialist personnel. Once first place the value of the load in Newtons (or pounds), under which failure by crushing occurs, which is then to be divided by the crosssectional area of the core in square millimeters (or square inches). Dividing the first of these by the second gives a number in megapascals (or psi); but does this number represent the compressive strength of concrete in the structure from which the core was cut?

The answer is no. Not only must the number be processed, but the resulting value of strength also must be carefully interpreted. Because cores are generally taken when there is a problem, or suspected problem, with concrete, the situation usually involves two or more narties, and they may have than specified. But there may be other reasons: the cylinders may have been incorrectly consolidated (compacted); they may have been damaged in transit, subjected to freezing at a very early age, badly cured, or incorrectly tested; or the resulting compressive strength may have been incorrectly calculated or recorded.

The contractor has reasons to staggest that it is the cylinders that are unsatisfactory, while the concrete in the structure is as specified. On the other hand, the engineer has a professional responsibility to ensure the structural adequacy of the concrete, as well as a responsibility to the client (or owner) to ascertain that the multity of concrete corresponds to

Concrete international / NOVEMBER 2001











Test smart – Build right =

Some Factors Affecting Core Strengths

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- Core size
- Location of core
- Direction of coring
- Moisture conditioning
- Length-diameter ratio
- End preparation
- Embedded steel

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

Research Findings

ACI MATERIALS JOURNAL

TECHNICAL PAPER

Title no. 91-M21

ACI Materials Journal / May-June 1994

Effect of Moisture Condition on Concrete Core Strengths



by F. Michael Bartlett and James G. MacGregor

In accordance with the provisions of ASTM C 42-90 and ACI 318-89, it is current practice to either dry concrete core specimens in air for 7 days or soak them in lime-saturated water for at least 40 hr before they are tested. In this paper, the effect of moisture condition on the strengths of mature cores obtained from well-cured elements is investigated by reviewing available literature and performing regression analyses of data from tests of 727 core specimens.

It is shown that the compressive strength of a concrete specimen is

crete Society⁶ recommends that cores be capped and then soaked for at least 2 days before testing. If the concrete in the structure is wet, the equivalent actual cube strength is taken to be 1.5 times the crushing strength of a core with length-todiameter ratio equal to 1. If the concrete in the structure is dry, the equivalent actual cube strength is taken to be 1.65 times the core crushing strength.



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





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Effect of Core Conditioning on Strength







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"

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ACI 214.4R for coring

$$f_c = F_{\ell/d} F_{dia} F_{mc} F_d f_{core}$$

In-place strength

Correction for L/D

Core strength

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Correction for "damage" due to coring

Correction for D

Correction for moisture content

Equivalent specified strength

$$f_{c,eq}' = K \overline{f_c}$$

Statistical factor



J core \vdash C 0.85

3. Pullout





LOK-TEST

CAPO-TEST



Testing the "interior" with pullout LOK-TEST







Example:

Testing surface 30 mm deep, pullout force 30.0 kN compared to 29.5 kN at 25 mm depth

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CAPO-TEST



Diamond Planning, dia. 75 mm, to required depth prior to coring the centerhole and routing the recess.

Testing surface



testing surface 5 mm deep



testing surface 32 mm deep

Example:

Testing surface 5 mm deep 39.0 kN and testing surface 32 mm deep 38.8 kN pullout force



LOK-TEST for new structures

- Install inserts
- Ready the testing
- Perform the LOK-TEST either to a required strength or to top-peak loading
- Transform the kN pullforce to compressive strength of lab cubes (or cores) or lab cylinders by general correlation



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LOK-TEST



LOK-Test Pullout



Insert Hardware

Attached to formwork cutouts

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5H.M

Nailed to

formwork

Floated into surface

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Nailing (L-40)



Insert Hardware

Attached to formwork cutouts

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Nailed to formwork

Floated into surface





• Attach insert assembly to form

- Apply sealant
- Place concrete
- Test from below

LOK-TEST for early and safe loading operation



10 inserts tested in less than 1 hour



Insert Hardware

Attached to formwork cutouts

Nailed to formwork

Floated into surface



Floating (L-49)




37 LOK-TEST Bring the compression machine to the structure



Loading Options:

- Loading to a required strength and no further (no visible damage to the surface)
- Loading exactly to failure (shown), minimal damage to the surface
- Loading to past failure and pullout, dislodging the failure cone



38 **CAPO-TEST for existing structures** Bring the compression machine to the structure





Capo Testing on columns to be further loaded. One observation is recommended to be the average of 2 or 3 Capo-Tests Terracon, Houston, USA

Capo giving immediate reliabel result, based on one correlation. If needed, to be used in highly conjected reinforcement areas after location of the reinforment

About 15 minutes per test for a trained operator Minimum damage, easy to patch



London, UK Strength of industrial floor

Other Examples



Translink, UK, Residual strength of tunnel segments



Trinity Square, Toronto, Canada Strength for early loading



Bridge Leznow, Poland Residual strength



Cigar Lake Uranium Mine, Canada Strength of gunite concrete Test smart – Build right ====



Great Belt Link, Denmark Strength of cover layer



Failure Mechanism

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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 disc 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

 Ottosen, N.S.: "Nonlinear Finite Element Analysis of Pull-Out Test", Journal of the Structural Division, ASCE, Vol. 107, No ST4, April 1981



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. *Test smart – Build right*



Compressive cracking, 98% loading, Finite element analysis and experimental analysis

IRef.: Ottosen, N.S.: Nonlinear Finite ElelementAnalysis of Pull-Out Test, JSD, ASCE, Vol. 107, No ST4, April 1981 Krenchel, H. & Shah, S.P.: "Fracture analysis of the pullout test", Dept. of Structural Engineering, Technical University of Denmark, RILEM, Materials and Structures, Dunod, Nov-Dec. 1985 no 108



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. & Shah, S.P.: "Fracture analysis of the pullout test", Dept. of Structural Engineering, Technical University of Denmark, RILEM, Materials and Structures, Dunod, Nov-Dec. 1985 no 108

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

Krenchel, H. & Mossing, P.: "LOK-Styrkebestemmelse af Beton, Brudmekanisk Analyse", Deprtment of Structural Engineering, Technical University of Denmark, Serie R, No 198, 1985

Stress-strain curve from uniaxial compressive test



Load displacement curve for pullout test



GI

98% load level



G

Situation at collaps into the softening regime



The three different stages of internal cracking in a pullout



Explanation

- 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 liniarity is lost.
- 2. From thereon multiple microcracks are developed in a compression strut between the disc and the counterpressure
- A collaps happens into the softening regime at increased loading, forming the final pullout cone



Note the higher stresses (up to 50 MPa) are present right below the disc due to concentrated tri -axial loading in this area while the stress in the "strut" (red area) is dominated by uniaxial stress <u>Test smart</u> Build right



LOK-TEST pullout failure



"Leaves" from the second crack pattern with the concrete in compession being intersected in the softening regime

Crushed material in the compression zone



CAPO-TEST pullout failure



"Leaves" from the second crack pattern with the concrete in compession being intersected in the softening regime

Crushed material in the compression zone



CAPO-TEST Failure



"Leaves" from the 2nd crack pattern with the concrete in compession being intersected in the softening regime



LOK-TEST to CAPO-TEST



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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), next slide



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



Conclusion: Stresses in the structure is not affecting the strength estimate with LOK-TEST Test smart – Build right

Clearance Requirements ASTM C900



Reinforcement clearance

Edge distance



Correlations

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Comparative testing, reported 1978, DTU, Denmark



- Columns 1000 mm high, 300 mm x 300 mm in square
- Five strength levels,10, 15, 20, 25 and 30 MPa
- Each batch consisting of 6 columns and 10 standard cylinders



5×6 columns



Program

Five batches, ea with 6 columns:

- 3 columns crushed in compression for in-situ strength
- 3 columns tested by cores 100 mm dia. x 300 mm (4 pcs), UPV, Rebound Hammer and LOK-TEST (4 pcs), at same location
 10 Cylinders in each batch

UPV, Rebound Hammer & LOK-TEST before coring

Results



Refs (1) Poulsen, E.P."Vurdering af betons styrke ved prøvning af udborede kerner, Del 1 og Del 2, DIAB, Nov 1975 (2) Kierkegaard-Hansen, P.: "LOK-TEST, Historical Background", DIAB, Oct 1978 Test smart – Build right

Lok-Test Correlations before 1978



Refs:

[1] Kierkegaard-Hansen, P., 1974, DIAB

[2] Rapport nr. 5 3/69 1974: Danish Technical University

[3] Jensen, O. & Leksø, S. 1976 / 1977, Danish Road and Bridge Lab & Danish State Railways

[4] Poulsen, P.E., Danish Institute of Technology & DIAB, 1978.

[5] Leksø, S., Danish Road and Bridge Lab. 1976.



Correlations before 1978



Refs:

[1] Kierkegaard-Hansen, P., 1974, DIAB

[2] Rapport nr. S 3/69 1974: Danish Technical University

[3] Jensen, O. & Leksø, S. 1976 / 1977, Danish Road and Bridge Lab & Danish State Railways

[4] Poulsen, P.E., Danish Institute of Technology & DIAB, 1978.

[5] Leksø, S., Danish Road and Bridge Lab. 1976.

Correlation Testing after 1978

- 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, DTU, Denmark



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

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CAPO-TEST to cylinder strength, 1st major correlation 1987, DTU, Denmark





Eighteen correlation between 150 mm dia \times 300 mm standard cylinder strength f_{cyl} and pullout (Lok or Capo) in kN

Methods

- 150 mm x 300 mm cylinders, LOK-TEST inserts in the bottom pulled exactly to failure, cylinders capped and tested in compression
- 2. 150 mm x 300 mm cylinders, pullout centrally placed on vertical faces of 200 mm cubes
- 3. 0.3 m \times 0.3 m \times 1 m columns crushed in compression, pullout on other matching columns
- 150 mm x 300 mm cylinders, pullout on structures in-situ, same maturity
- 5. 150 mm x 300 mm cylinders and cores, pullout on panels, same maturity

Eighteen correlations, standard cylinders to LOK-TEST or CAPO-TEST

	Author / ref.	Correlation	Range	Method	Country
1	Gay,G.	f _{cyl} = 1.08 Lok - 0.97	1-13 Mpa	1	USA
2	Bickley, J.	f _{cyl} = 1.10 Lok - 0.35	5-44 MPa	1	Canada
3	Krenchel, H.	f _{cyl} = 1.14 Lok - 2.16	3-33 MPa	2	Denmark
4	Krenchel, H.	f _{cyl} = 1.11 Capo – 1.02	3-33 MPa	2	Denmark
5	Krenchel, H.	f _{cyl} = 1.02 Lok - 0.54	5-50 MPa	2	Denmark
6	Jensen, J.	f _{cyl} = 1.09 Lok - 0.04	5-50 MPa	2	Denmark
7	Drake, K.D.	f _{cyl} = 0.96 Lok - 0.90	12-36 MPa	2	USA
8	Drake, K.D.	f _{cyl} = 1.47 Lok - 16.62	30-74 MPa	2	USA
9	Poulsen, E.	f _{cyl} = 1.20 Lok - 6.62	10-30 MPa	3	Denmark
10	Kierkegaard, P.	f _{cyl} = 1.24 Lok - 6.32	11-39 MPa	1	Denmark
11	Lekso, S.	f _{cyl} = 1.25 Lok - 7.40	20-55 MPa	5	Denmark
12	Lekso, S.	f _{cyl} = 1.41 Lok - 10.28	20-55 MPa	4	Denmark
13	Krenchel, H.	f _{cyl} = 1.32 Lok - 6.18	15-75 MPa	2	Denmark
14	Krenchel, H.	f _{cyl} = 1.33 Capo - 7.06	15-75 MPa	2	Denmark
15	McGee, R.L.	f _{cyl} = 0.95 Lok - 0.95	6-35 MPa	1 + 2	USA
16	Bickley, J.	f _{cyl} = 1.28 Lok - 4.51	3-45 MPa	1	Canada
17	AEC	f _{cyl} = 1.32 Lok - 11.53	40-110 MPa	2	Denmark
18	Bishr, H.A.M.	f _{cyl} = 1.25 Lok - 2.88	8-35 MPa	5	KSA


18 correlations to cylinder strength 1990-2013



Remember: Compression of the cylinders were made on different compression machine 73

Variations

Calibration Procedure,	Pullo	tu	Stand.specim.	
laboratory	SV	n	SV	n
Danish	9.4 %	2188	4.3%	1177
North American	7.5%	994	6.4%	994
Swedish/Dutch/English	6.8%	1180	6.2%	963

Structure,	LOK	-TEST	CAPO-TEST		
On-site testing	SV	n	SV	n	
Shotcrete			3.2%	310	
Slabs, bottom	10.5%	5320	7.1%	35	
Slabs, top	12.9%	955	9.3%	623	
Beams & Columns	8.1%	677	8.0%	434	
Walls & Foundations	10.1%	1020	10.4%	534	
Dubious Structures	14.7%	1225	15.3%	3334	

Ref.: Petersen (1994)



General cylinder relation to pullout strength by LOK/CAPO



Theoretical investigations relating LOK-TEST pullout force F in kN to cylinder compressive strength f_{cyl} in MPa, <u>compared to the General Correlation for cylinders f_{cyl} = 0.69 F^{1.12}</u>



 Ottosen. N.S.: "Nonlinear Finite Element Analysis of Pull-Out Test", Journal of the Structural Division, ASCE, Vol. 107, No.ST4, April 1981

> Jensen, B.J. & Bræstrup, M.W.: "Lok-Tests determine the compressive strength of concrete", Nordisk Betong 2-1976 (F = 0.89 f_{cul})

Cube relationships



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LOK-TEST to cube strength, 1st major correlation 1983, CBI, Sweden



CAPO-TEST to cube strength, 1st major correlation 1983, Sweden



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13 Correlations between 150 mm cube strength $\rm f_{cube}$ and/or cores (100 mm dia \times 100 mm long) $\rm f_{core}$ in MPa and pullout load (Lok or Capo) in kN

Methods:

- 150 mm cubes for compression test, pullout on vertical faces of 150 mm cubes (or 200 mm cubes for high strength)
- 150 mm cubes for compression test, pullout on vertical faces of 150 mm cubes (for high strength kept in steel frame or kept in the steel mold)
- 3. 150 mm cubes and 100 mm dia x 100 mm cores for compression, pullout on panels in the top
- 4. 100 mm dia. cores × 100 mm on vertical panels for compression, pullouts on panels in-situ
- 5. 100 mm dia. cores × 100 mm on vertical panels for compression, pullouts on panels in the lab
- 6. 100 mm dia. Cores x 100 mm in-situ, Capo-Test in-situ

Assumption:

The 150 mm x 150 mm x 150 mm cube strength has the same compressive strength as drilled-out cores, 100 mm diameter, 100 mm long <u>Test smart – Build right</u>



13 Correlations between 150 mm cube strength f_{cube} and/or cores (100 mm dia x 100 mm long) f_{core} in MPa and pullout load (Lok or Capo) in kN

	Author / ref.	Correlation	Range	Method
1	Johansen, R	$f_{cube/core} = 1.28 \text{ Lok} - 2.18$	8-35 Mpa	3
2	Gelhard, R.	f _{cub} = 1.23 Lok - 2.46	12-64 MPa	1
3	Winden, N.	f _{cube} = 1.26 Lok - 1.89	3-48 MPa	1
4	Winden, N.	f _{cube} = 1.32 Lok - 3.07	18-50 MPa	1
5	Bellander, U.	$f_{cube/core} = 1.34 \text{ Lok} - 3.70$	10-60 M Pa	4 + 1
6	Bellander, U.	f _{core} = 1.37 Lok - 4.57	10-60 MPa	5
7	Bellander, U.	f _{cube} = 1.56 Lok - 2.80	3-85 MPa	2
8	Bellander, U.	f _{cube} = 1.58 Capo - 2.66	3-85 MPa	1
9	Worthers, P.	f _{cube} = 1.42 Capo - 1.00	50-98 MPa	2
10	Moczko, A.	f _{core} = 1.42 Capo - 4.20	20-50 MPa	6
11	Thun.U	f _{core} = 0.98 Capo ^{1.12}	11-105 MPa	6
12	Price, W. F.	f _{cube} = 1.52 Lok - 1.49	42-92 MPa	1
13	Price, W. F.	f _{cube} =1.54 Lok - 5.00	35-108 MPa	1

13 correlations to cube strength



Remember: Compression of the cores / cubes were made on different compression machine



General cube / core relation to pullout strength by LOK/CAPO



The two general correlations

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Precision Data for calculation



Precision



Precision curves for LOK/CAPO test, calculated with the average of the standard deviation and with the pooled standard deviation. LOK-TEST and CAPO-TEST has a precision of ±3 MPa for one test and ±2 MPa for two tests, based on the general correlations.

Robust Correlations

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

Conclusions

- The failure mechanism in LOK-TEST/CAPO-TEST is well understod. Compression occur in the strut between the 25 mm disc/ring, 25 mm deep, and the 55 mm inner dia. counter pressure on the surface, hence the pullout force is a direct measure of the compressive strength
- LOK-TEST and CAPO-TEST gives the same pullout force on the same concrete quality
- Correlations between laboratory specimens and LOK-TEST or CAPO-TEST show robust general correlations to standard cylinders or to standard cubes / drilled out cores no matter what parameter is considered. The correlations have been investigated up to 40 mm maximmum aggregate size. Only for lightweight aggregates another correlation has been found



Conclusions, cont'd

- The most comprehensive and reliable physical correlations made until today are the ones by Krenchel and Bickley, slide 67-68 for cylinders and for cubes the ones by Bellander, slide 76-77
- They are reflected in the general correlations, slide 82
- For these correlations the precision of the strength estimate by LOK-TEST or CAPO-TEST is within ±3 MPa for one test and ±2 MPa for two tests, slide 83

LOK-TEST and CAPO-TEST examples and procedure





London, UK Strength of industrial floor

Other Examples



Translink, UK, Residual strength of tunnel segments



Trinity Square, Toronto, Canada Strength for early loading



Bridge Leznow, Poland Residual strength



Cigar Lake Uranium Mine, Canada Strength of gunite concrete Test smart – Build right ====

CAPO-TEST

Great Belt Link, Denmark Strength of cover layer



Pullout on the Great Belt Link, Denmark ⁹² for QC of the cover layer



COMA-Meter used for maturity. The LOK-TEST or CAPO-TEST values, corrected for maturity, had to be minimum 90% of the lab cylinder strength

CAPO-TEST in progress Note: insufficient curing protection by a thin, loose plastic sheet



⁹³ **Great Belt Link** Example, 6 CAPO-TEST performed in a control section of one of the westbridge's pillars for QC of the cover layer

	CAPO test readings, kN	Compressive strength cylinders, Mpa
A CARLEN AND A CARLEN AND AND AND AND AND AND AND AND AND AN		0.69*F ^{1.12}
and the second	41	44.2
1 2 3	36	38.2
	40	43.0
a la serie a la serie de la	42	45.4
	40	43.0
The second secon	41	44.2
- In the state of the Calman		
	Average, MPa	43.0
6 5 4	Std dev, MPa	2.51
and the second	K (natrella)	1.86
- A MARTINE CONTRACTOR OF THE CONTRACTOR OF THE		
	Lower 10th percentile, MPa (Danish method)	38.30

Ref: Pullout testing by LOK-test and CAPO-TEST with particular reference to the in-place concrete of the Great Belt Link, p.69



LOK-TEST for early and safe loading operation



10 inserts tested in less than 1 hour





John Aubrey Bickley D.Sc (Honoris Causa), P.Eng., FICE, FCSCE Canada

LOK-TEST, the "HOLY GRAIL"

Strength for Formwork Removal



Scotia Plaza – Toronto, Canada.

- SAFE and EARLY stripping of forms using LOK-TEST for estimating in-place strength has been done in North America on about 400 major structures
- Earnings due to speeding up construction schedule reported to be about 0.2 to 1.5 M Dollars

Source: Bickley, J.A.: "How to Build Faster for Less – The Role of In-Place Testing in Fast Track Construction", ACI, Spring Convention, Sap Francisco, 1994



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	20 Storey	15 Storey	30 Storey	Twin	14Storey	3Storey	9Storey
	Building	Headquar	Building	Towers	Building ⁵	Centre	Condom.
		te					
Savings	(All Numbers are \$/1000)						
Interest	600	1750	188	NC	NC	533	43
Earlier	200	NC	25	NC	NC	466	40
Rental							
Formwork	120	254	NC	75	NC	NC	NC
Reshoring	NC	NC	NC	NC	NC	NC	NC
Winter	NC	NC	114	(0.3/pour/	NC	NC	NC
Heating				day)			
f_c^1 at 91	NA	50	38	62	23	NA	NA
days							
Design	120	NA	NA	NA	NA	NA	NA
Overhead	NC	NC	20	NC	NC	NC	NC
Sub-Total	1040	1825	385	137	NC	999	83
Costs							
Concrete	20 ¹	320	152	56	93	20	0
Testing	15 ²	38	24	10	14	10	4
Sub-total	35	358	176	66	107	30	4
Net Saving	1005 ³	1467	209	71	NC	969	79

OF

Accelerated construction, Savings to Owners

LOK-TEST equipment



Plus inserts

John A.Bickley, Canada: "The Holy Grail"



CAPO-TEST for existing strucures





Test smart – Build right



Prepare Concrete



Core Hole





Plane surface





Test





Cut Slot





Insert Expansion Cone and Coiled Split-Ring


Ring Expansion Hardware

Nut with base pullbolt

Sliding disc.

Coiled ring

Cone ~

When assembling, make sure the inner sharp edge of the coiled ring is against the cone surface

Coupling

Expand Ring



Test smart – Build right



Expand Ring



Pullout the Expanded Ring against a 55 mm counterpressure





Couple and Apply Pullout Force



Acceptable Test

Sharp 55 mm diameter edge from counterpressure 112

Criteria for correct CAPO testing





CAPO-TEST





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CAPO-TEST failure











Capo-Test on shotcrete, Note the failure zone is unaffected by water needed during coring / recessing

Test smart – Build right

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. The "Aging Factor" is not substatiated or explained by the manufacturer of the Schmidt Hammer



CAPO-TESTing on Polish bridges









= Test smart – Build right

Comparative Strength Estimates from 50 Polish Bridges, examples

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Average	Co	res	CAPO	-TEST	Schmidt / S	Structure	Schmidt /	Cores
	(MPa)	V (%)	(MPa)	V (%)	(MPa)	V (%)	(MPa)	V (%)
Strength	32.8	9.5	33.5	11.7	55.9	16.4	44.5	15.1

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

Bridge No.	Cores from structure		Capo-Test on structure		Schmidt Hammer on structure		Schmidt Hamher on cores	
	MPa	Av. of	MPa	% dif	MPa	% dif	MPa	% dif
1	19.6	б	20.3	+3.4%	36.9	+88.3%	28.4	+44.9%
2	24.7	3	26.9	+8.9%	37.4	+51.4%	28.8	+16.6%
3	29.7	4	31.8	+7.1%	49.5	+66.7%	38.2	+28.6%
4	34.2	3	36.8	+7.6%	56.8	+66.1%	43.1	+26.0%
5	33.3	4	32.3	-3.0%	61.6	+85.0%	49.3	+48.0%
6	34.2	3	37.6	+9.9%	54.5	+59.4%	36.5	+6.7%
7	35.4	4	37.1	+4.8%	66.3	+87.3%	57.0	+61.0%
8	37.1	3	35.9	-3.2%	56.9	+53.4%	46.1	+24.3%
9	37.5	4	36.8	-1.9%	70.9	+89.1%	61.0	+62.7%
10	42.0	3	39.7	-5.5%	68.4	+62.9%	57.4	+36.7%
Avg.	<i>32.8</i>		33.5	+2.1	55.8	+70.0%	<i>44.6</i>	+36.0%

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 Test smart – Build right



Cores compared to CAPO



Comparison to the general correlation for cubes

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

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: $C_{cube} = 0.79 Capo^{1.14}$

Core, CAPO and Schmidt Hammer strength estimates, 15 bridges

1	2	3	4	5	
Bridge	Name	Average core	CAPO, Estimated	Schmidt	
No.		strength, MPa	compressive	Hammer on	
		(C_{core})	strength, MPa	Structure	
			(Гсаро)	(MPa)	
1	Zyrow	34.2	36.4	57.9	
2	Dobrut	24.7	26.6	51.5	
3	Wizna	46.4	50.6	73.5	
4	Jablonica	34.2	37.3	57.1	
5	Kamion	37.1	35.5	60.1	
6	Modlin	42.0	39.4	71.8	
7	Modlin	37.5	38.1	71.6	
8	Jablonica	35.4	36.7	69.6	
9	Leszno	42.4	40.2	74.6	
10	Wierzbica	33.3	31.7	59.9	
11	Zyrow	29.7	31.2	52.4	
12	Zofka	28.5	30.8	53.2	
13	Zglobice	31.7	33.4	71.8	
14	Terespol	31.7	34.0	62.5	
15	Minsk	19.6	19.5	38.8	



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Schmidt Hammer and CAPO strength estimates, 15 bridges



In average, the Schmidt Hammer is overestimating the strength by 71%



Effect of carbonation on CAPO



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Considerations using LOK-TEST / CAPO-TEST

- Testing depth is 25 mm, samples for coring are taken deeper in the structure
- If needed, inserts may be placed deeper than 25 mm from the surface, slide 26, the "interior"
- LOK-TEST / CAPO-TEST will never give higher strength estimates than lab testing
- LOK-TEST on slabs have shown up to ~10-15% higher strength of the bottom compared to the top surface, partly due to better compaction, and partly better curing at the bottom



Considerations, cont'ed

- Capo-Test is 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
- Relationships have not been investigated for max. aggregate size > 40 mm



Considerations

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

Experience has shown that badly cured cover layer tested with pullout may give up to 20% 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 craking, insufficient compaction and/or bad 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, slide 28.

CAPO-Test vs. Cores

- Instant results alternatively to cores
- Cause only a small fracture cone hole compared to a 100 mm coring hole.
- Does not require pre-planning of test locations
- Can perform test at any accessible location
- Permits testing of existing structures,
- ~15 minutes per test.
- Portable equipment (electricity and water is needed)

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Summary

- LOK-TEST and CAPO-TEST are reliable methods for estimating in-situ compressive strength
- Can be used for new construction and existing construction
- General correlations according to EN 12505-3: 2005 and CS A23.2-15
- Following ASTM C 900-19 confirm general correlations for LOK-Test
- For CAPO-Test cores can be drilled out for comparison to the general correlation



Standards mentioning the correlations

EN 12505-3: 2005:

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 900-19:

"For a given concrete and a given test apparatus, pullout strengths can be related to compressive strength test results"

CSA Group 2014, A23.2-15

"Pullout strength is correlated to compressive strength of standard cylinders. For a given configuration of insert, bearing system and depth of insert, there is a correlation between pullout strength and standard cylinder's compressive strength"

Recent published papers on CAPO-TEST



Journal of Testing and Evaluation

Thereps LL¹ Jigar Dasal,² and Wesley Bullock²

DOI: 10.1820/JTE20170697

In-Place Estimation of Concrete Compressive Strength Using Postinstalled Pullout Test – A Case Study

Darrain to ARM Industry and resemants that the Unit of Darray of Case Paral Concern Income Concern Classes Agences: "A Sofie operations attended

ACI MATERIALS JOURNAL

TECHNICAL PAPER

Title No. 113-MPE

CAPO-TEST to Estimate Concrete Strength in Bridges

by Andrzej T. Moczko, Nicholas J. Carino, and Claus Germann Petersen

The paper addresses valuelier, cardinantee or scatting une structural affect the compressive strength extended using the COPONERT is protoutable pulled are conferring in APPW CONtractEV (2004 4 Filters bridge, surging that 25 years of age or the time of technic, while investigated. For each tradies, escape when of over everythe and CAPIP pulline re planned. Darbumation physics which samed from 2 m Fl and (#30% to (.14 inc), true measured using adomical stations well-ado it was anticipated idea, as the signth of parlowation starsauld, the suffers' prompti modili terrene pio die pase probeining concerstronget. Plan: the re-plane compressive enough automatic on the later of the manufactures 5 primeral consistence would be expected in comparingly stored the stored measured by the same. If and Posed that, we everyge the compression energy? automized from the CAPO-TEIT and the general convolution wat only 2.0% generation stee de nouvel oue ricept. Mire represents due un m carcolation between depth of uniformation and the total or over of the carbon and arranged based on the COPO TEET.

Revealed CARS 1981 colonadas, one strength, conductor, mining the much prime as

INTRODUCTION.

The aging of concerns bridges to combination with manual any ice loads and high replacement costs terresses the need for associated maintenance, and if resided strengthening of door sources structures. One of the key consisten in any situation assument is for mythod compression strength of the concession

Trubinely, the in-place compressive energie has been estimated by taking and torting cones. With the method, cones are defined out, any pool carefully to the independence, new out to the many much, woodaw combined, such samed for ground. and second to the laboratory unity a suffreed compression noting random. The enough obtained depends on many Pactors such as core size, aggregate tite, focular of core, direc-tion of vering, resistant coredition at time of mating, length-tipreservation, and preservation, and parameter of designified used The taking of own leaves holes to the singence that even he equival and the entire process of delibeg, specimen prepara tion, and thering is this canimentar and confly

Abstrative ratheds for assuming the in-piece comproand showed out include the retained furnities, meaning alesande paixe relacity or the CAPO/TEST' These are indirect methods that require the use of an empirical correlation to universe the in-place compressive strangily from the other researced by the test method.

Robinsed humany measurements on old, carbonated strutarts have shown increases of urbrani numbers of up in 10% compared with new-carbonated concrete of the paint mangels 10 The same planeters in has been observed by one

ACI Materials Journal/November Department 2016

of the automation a comparison of arrought automatic by released harmer compared with mastated cure strengths. Despite the use of a recommended "sping relation factor" of 0.7 to account the surfacements, the command compression strongth fram minuted values was found to be, an everyout approximately 20% higher than the story storogite." Without applying dia "aging reduction factor," the strength estimate wanted have been, on average, approximately MPG higher that the cost arongha. There is no general cortel between obcassil another and compressive strength. Threetime, each simulate has to be evaluated based on a consilation Armshaned with come these that selection. Another popular industrys: is economic the speed of a

pulse of administrative stress waves, trateally called the altramust puter vehicity AIPVS. For a given concerns example. there are strend factors that will affect the UPV of the concrete, much as appreprint tayle, appreprint conducts, and more products." In manage preservity, small differences in UPV nay compared to long differences to compression storigh, the is, UPV is relatively exemptive to charges courses murgh is additor, in ministered organic the presence of reinforcement can built in inscratate values of DPV. While UPV is not prove to be influenced by surface carbonation, the UPV method is not a good choice for alcoholy which contrasts of in-place comprise strength: the multish is case appropriate for instanting for aschematy of the sources in a senation The CAPO-TEST' is a pestimulable pollout war

conferming to the requirements of ANTM CHOR' and EN (2934-).4 The serie "post-testafled" means that the CAPG-TEST dues not measing graphaling, begats of Wesh concepts; The test care he performed on an atoming strainers at any accessible location, In the CAPO TEST, concerns strength is assessed within a 24 mm (1 is) ring organ. The CAPO TITT - it to described in detail. This suppr Econom on the correlation between CAPO-

TERT made and the comprision strength of computer core takes from 15 existing concerns bridges with sarying carbonariae depth. This succession is savigated to the game condution matched previously beaution a series of indureadest statist for suscerimented converts. For practical field tooling, it will be interesting to examine if the general constances is colubly for estimation in place constants circuiti in and amazura will a tarbonated surface layer.

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Test smart – Build right =

Practical cases in the application of the pullout method (LOK-TEST and CAPO-TEST) for in-place compressive strength

Claus Germann Petersen'

MATHC Wab of Conferences 361, 07006 (2022)

Concret e Solutions 2022

Oermann Instruments A/S, Copenhagen, Denmark. www.germanninstruments.com

Abstract. The pullout methods LOK- TEST and CAPO-TEST for in-place compressive strength are presented with their theoretical analysis' hackground and correlations from 30 major statics, made worldwide, showing robust general correlations between palloat force and steerigh by cylinders or cubes' witzensis, atomig strate general ortenations tensore pratos are not artegia to y curinas to cuesto cores. The coefficient of vension of the systems are shown, nyrotefal in 1984. Practical cases long the systems are described. Case 1. In-Sita compressive intraght testing of quantitated protocol context larged limiting segments using CAPO-17871. (Xi, Cae 2. Strength testing with CAPO-18781) with the spectral context larged limiting segments using CAPO-17871. (Xi, Cae 2. Strength testing with CAPO-18781) with the spectral context larged limiting expension and careful firms attripping with LOK-17837, Canada, Case 4. Curing of the cover larger evolution 1991 and and the foreshifty. Detrumts.

1 Introduction

Reliable and quick testing of existing structures for strength may be important for purposes such as documentation of unknown strength, for upgrading, for further loading or for documentation of doubtful structures in cases where questions are mised in relation to compliance with code specifications. Pullout offers such advantages. Testing of cores from the structure is doubtful, depends on many factors such as moisture, planeness, aggregate size, L/D ratio and presence of reinforcement. Coring is also time consuming, expensive and causes large holes in the structure. The use of indirect methods such as the rebound hammer and/or ultrasound (UPV) requires for every structure many cores for establishing the correlation, and the relationships obtained are not sensitive.

On new structures, production control of the in place actual strength of the structure is essential, not only trusting laboratory strength, but also considering the effects on in-site strength of the actual mix delivered, the transportation, the pumping, the casting, the compaction, and the curing of the cover layer, especially in aggressive environments. Again, rebound hammer and ultrasound pulse velocity require correlation testing for each mixture, involving lab testing. Estimation of strength by manurity requires a pre-established maturity-strength relationship for the mixture used and does not consider the effects of transportation, pumping, casting, consolidation and

curing Pallour produces reliable estimates of strength in place, based on one correlation, the test systems are rapid and economical, only minor damage cause to the structure, and can be used without testing of cores, [10]. A special feature is testing of the cover layer, the "peel" of the structure protecting the reinforcement. The curing of this "Peel" is essential on new structures in

*Composing autor genam-culturnam org

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terms of durability, not at least if chlorides are present from de-icing salts, the sea or airbome. Pullout can be used for this purpose for production control.

https://doi.org/10.1051/mataccom/202236107006

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2 The pullout systems

Invented at the Danish Technical University (DTU) in the late 1960's and 1970's, [1, 2], the LOK-TEST (the Danish name for "Punch-Test") uses a disc cast into the free concrete, and the CAPO-TEST (Cut And Pull Out- Test) uses a ring expanded in an undercut recess in existing concrete, [3, 4]. Pullout is made through a counterpressure with dimensions as shown in Figure 1 and Figure 2, producting compression forces between the expanded ring and the counterpressure, hence the pullout force is a direct



Fig. L.LOX-TEST

NOTE

In-Place Strength Without Testing Cores: The Pullout Test

Nicholas J. Carino, PhD Consultant, Chagrin Falls, OH, USA

6th International Seminar on Advances in Cement & Concrete Technology for Sustainable Development

In-Place Strength Without testing cores.





Costs CAPO-TEST vs. Cores

Test smart – Build right

CAPO-TEST		
Coring	5 minutes	
Planing	2 minutes	
Recess routing	2 minutes	
Expansion of ring	3 minutes	
Pullout	5 minutes	
Repair of cone hole	5 minutes	
	~20 minutes	

Based on an hourly rate of 150 USD the costs of one Capo-Test is ~50 USD /test Test result immidiately available on-site Two well-trained technicians can perform 30-50 Capo-Test per day

CORES			
Coring	20 minutes		
Specimen preparation			
Freight to lab	30 minutes		
End preparation	40 minutes		
Curing in lab	3 days		
Testing	30 minutes		
Repair of core hole	30 minutes		

Total excluding curing in the lab ~2 hours

Based on an hourly rate of 150 USD the costs of one core is minimum 300 USD Test result available of about 1-2 weeks





User comment

First, thanks for creating this wonderful test method!

I would like to point out that for performing CAPO test we charge \$250 per sample for typical existing structures where strength information is needed. We are generally testing minimum 3 or 4 locations. For a project where many tests were needed, we would discount the pricing to about 50 percent off. On average it takes us 20 min per location depending on surface conditions

Why charge this much? Repairs and replacement parts are a little pricy at times and there is a considerable investment upfront.

\$250 is still less than core sample extraction, patching, conditioning, capping and testing. Extraction and patching alone is close to \$250 these days. Plus \$100-120 for testing.

Charging this much makes it more attractive for service providers. Client reaction has been very positive.

Todd Allan, Radarview, USA



Equipment CAPO-TEST, C-1000





C-101 Prep. – Kit + tray

C-102 SV-Kit

C-104 Pullmachine



C-112 Inserts

Test smart – Build right



CAPO-TEST, C-2000 alternative, without suction plate







Other systems for homogeneousness







Rebound Hammer

Ultrasound (UPV)



= Test smart – Build right

Factors Affecting Rebound Number

- Elastic modulus of concrete
- Aggregate type
- Air voids
- Carbonation
- Surface texture
- Surface moisture condition
- Rigidity of test object
- Mix specific



Elasticity and compressive strength



Elasticity has a weak relationship to compressive strength with a large scatter

Ref DTU, Denmark, 1987, Prof. K.V.Johansen: "coffee grounds"

Test smart – Build right

Rebound to cores, case 1



Rebound to cores, case 2


Comparison of Relationships



Rebound Hammer related to cube strength

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

Ref: Tam, C.T.: "Application of NDT in Appraisal of Buildings", 4th Int.' I Conf. On Inspection, Appraisal, Repair and Maintenance of Buildings & Structures, 28-30 March, 1995, Hong Kong

Series	Aggregate		Aggregate-cement
	coerse	fine	retio
GR(4.5)	granite	river sand	4,5
GR(6)	granite	river sand	6.0
GM(6)	granice	mining sand	6.0
LM(6)	limestone	mining sand	6.0



Schmidt Hammer and CAPO strength estimates, 15 bridges



In average, the Schmidt Hammer is overestimating the strength by 71%, even with the recommended deduction of an "aging factor" of 1.4 recommended by Proceq Without the "aging" factor reduction the estimate of the compression strength by the Schmidt Hammer would have been 99.4%, in average



Schmidt Rebound Hammer

- Strength is not measured physically as it is with cores or LOK-TEST / CAPO-TEST pullout
- A rebound value is obtained, related not only to the Elasticity of the material, but also Aggregate type, Air voids, Carbonation, Surface texture Surface moisture condition and Rigidity of the test object
- Correlation to strength can only be made by comparing the rebound numbers to cores for every structure
- Such correlations have great variations, and the relationship(s) obtained are not sensitive as they have no 45° slopes, with large scatter of results

Strength Relationship UPV

Physics:
$$V \propto \sqrt{E}$$

Empirically: $E \propto \sqrt{f_c}$ f_c
 $\therefore f_c \propto (V)^4$
For mature concrete, large increases in strength is accompanied by



crease y small increase in velocity, mix specific.

Velocity



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Elasticity and compressive strength



Elasticity has a weak relationship to compressive strength with a large scatter

Ref DTU, Denmark, 1987, Prof. K.V.Johansen: "coffee grounds"

Lab relationship for a specific mix



Test smart – Build right



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UPV (Ultrasound Pulse Velocity) related to cube strength

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

Ref: Tam, C.T.: "Application of NDT in Appraisal of Buildings", 4th Int. 1 Conf. On Inspection, Appraisal, Repair and Maintenance of Buildings & Structures, 28-30 March, 1995, Hong Kong



Example Aggregate Type



Ref: Bungey, 1982

Factors Affecting UPV for Given Concrete Mix

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



Windsor Probe Penetration Resistance of Hardened Concrete by shooting a probe into the concrete and measure the pentartion depth



Correlations



Malhotra, 1974



Test smart – Build right





Bungey, 2002



Bungey, 2002



Precision



Precision of Windsor Probe based on one mix specific correlation CBI Report 7869 compared to LOK/CAPO precision, general correlation, slide 83-84



ACI Committee 228

Report on Methods for Estimating In-Place Concrete Strength

Reported by ACI Committee 228



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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.



In-Place Strength Without Testing Cores: The Pullout Test

Nicholas J. Carino, PhD Consultant, Chagrin Falls, OH, USA

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In-Place Strength Without testing cores.





CONCLUSIONS Current Practice for Acceptance Testing of Concrete

- Standardized testing of specimens made from concrete delivered to the project
 - > Standard consolidation
 - Standard curing
- Provides assurance that correct concrete was delivered
- Indicates potential strength
 - Does not account for actual consolidation and curing

Future Performance-Based Specifications

- Measure in-place properties of concrete to ensure structure will perform as intended
- Methods for estimating in-place strength
 - > Testing drilled cores ----- High cost
 - Rebound number method
 - > Probe penetration test
 - > Ultrasonic pulse velocity
 - Pullout test

Requires correlation – testing for each concrete mixture

Reliable estimates

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Evaluation techniques by Pullout, LOK-TEST / CAPO-TEST Cores **Rebound hammer** UPV Pull-off test Maturity method are dealt with in detail in workshops www.ndtitans.com as well as advanced methods www.germanninstruments.com

Thank you for your attention

www.germanninstruments.com

www.NDTitans.com



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