#### LOK-TEST & CAPO-TEST for in-situ strength

Section 1 Theoretical Analysis Fracture Mechanism Correlations

#### Claus Germann Petersen GERMANN INSTRUMENTS A/S April 15th, 2019

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## In-Situ Strength, why?

- Control of effects of transportation, compaction and curing providing a reliable indication of the condition of the finished structure
- Quality of the cover layer protecting the reinforcement against chloride ingress
- Eliminate shortcomings of cylinders, cubes and cores
- Low strength of laboratory specimens
- Changed mixes, intentionally / not intentional
- Strength of existing structures before further loading
- Timing of safe and early loading operations

## The "LOK" and "CAPO" names

- Both systems are on Danish origin invented / designed 1970-1990
- "LOK" is the Danish name for punching, hence the name LOK-TEST
- "CAPO" is an abbriviation of Cut And Pull Out test

#### Sections

- Section 1 Theoretical Analysis, Fracture Mechanism & Correlations
- Section 2
- Rationale, testing cases & standards
- Section 3 Hardware and Testing Procedures

Section 1 Theoretical Analysis Fracture Mechanism & Correlations

#### The two in place test systems presented





#### LOK-TEST

#### CAPO-TEST



#### **Theoretical Analysis**



Lich.Tech, M.W.Bræstrup



Professor N.S.Ottosen

- Jensen, B.C. & Bræstrup, M.W.: "LOK-Test Determine the Compressive Strength of Concrete", Nordisk Betong, 3-1976
- Ottosen, N.S.: "Nonlinear Finite Element Analysis of Pull-Out Test", Journal of the Structural Division, ASCE, Vol. 107, No ST4, April 1981





## Analysis by Jensen & Bræstrup

Using Coulombs Criteria for Sliding Failure, the conclusion is: "Plasticity analysis may be applied to determine the loadcarrying capacity of the 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"

#### Relationship between cylinder strength and LOK-Strength



#### Further explanation by Jensen & Bræstrup

'The equation P (kN) = 0.89  $f_c$  (MPa) is a plastic upper bound solution for the LOK/CAPO test ultimate load, assuming a failure mechanism comprising of concentrated deformations only in a conical surface between the outer edge of the imbedded disc and the inner edge of the counter pressure ring. The concrete is assumed to be a rigid, perfectly plastic material with the modified Coulomb failure criterion as yield condition, and the associated flow rule. In the 3-parameter modified Coulomb criterion the angle of internal friction is assumed to be arc tan 0.6, the compressive strength is f, and the tensile strength is 0.

## 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

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## 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".

#### Theoretical results, summary



#### Fracture Mechanism



Professor, dr.techn. Herbert Krenchel

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

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



#### Load-displacement curve for LOK-TEST







#### 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

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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





## The three different stages of internal cracking in a LOK-TEST



Ref: Krenchel, 1985

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



#### 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, the STRUT

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#### 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, the STRUT



#### **CAPO-TEST** Failure



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



## NOTE

- LOK-TEST and CAPO-TEST measure the compressive strength of concrete (2nd crack pattern, the STRUT). This constitutes the load-carrying mechanism
- The test is NOT a tensile, NOR a shear strength test, only the compressive strength is measured as the dominant material property
- The tensile crack developing at about 30% of the ultimate load release stesses in the area tested. Therefore, the pullout force is 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)

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



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#### Correlations



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#### **Correlations before 1978**

- Casting of 200 mm cubes or prisms with LOK-TEST inserts installed, accompanied by standard cylinders, compacted and cured equally
- Typical 20 cubes/prisms and 20 cylinders in each batch, w/c ratio between 0.80 and 0.36
- Tested in parallel at equal maturities



#### **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.



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#### Comparative testing, reported 1978



- Reinforced 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 x 6 columns For crushing Coré

#### 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

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#### Correlations obtained, with 90% conf. limits and $R_{xy}$



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

#### Cylinder relationships



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#### **Correlation** Testing

• Prepare cylinders (or cubes)

- Prepare 200 mm cubes with inserts
- Compact and cure under same conditions



#### **Correlation** Testing

- Test 2 cylinders and perform on 200 mm cubes 8 pullout tests at each test age:
  - > 1, 2, 3, 7, 14 and 28 days



#### Example NRMCA, 2008





#### LOK-TEST to cylinder strength, 1st major correlation 1987



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

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



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

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## Twenty correlations between 150 mm dia $\times$ 300 mm standard cylinder strength $f_{\rm cyl}$ in MPa and Lok or Capo in kN

#### Methods

- 1. 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 × 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
- 4. 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



#### Parameters investigated

- 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 < 40 mm</li>



## 20 correlations, Cylinders to LOK/CAPO -TEST

	Author	Correlation	Range	Nos Cyl / PO	Rxy	Method
1	Gay, USA	f <sub>cyl</sub> = 1.08 Lok - 0.97	1-13 Mpa	46 /46	0.91	1
2	Bickley, Canada	f <sub>cyl</sub> = 1.10 Lok - 0.35	5-44 MPa	340 / 340	0.94	1
3	Krenchel, Denmark	f <sub>cyl</sub> = 1.14 Lok - 2.16	3-33 MPa	75 / 150	0.93	2
4	Krenchel, Denmark	f <sub>cyl</sub> = 1.11 Capo - 1.02	3-33 MPa	75 / 146	0.93	2
5	Krenchel, Denmark	f <sub>cyl</sub> = 1.02 Lok - 0.54	5-50 MPa	250 / 500	0.93	2
6	Jensen, Denmark	f <sub>cyl</sub> = 1.09 Lok - 0.04	5-50 MPa	96 / 96	0.94	2
7	Drake, USA	f <sub>cyl</sub> = 0.96 Lok - 0.90	12-36 MPa	69 / 69	0.99	2
8	Drake, USA	f <sub>cyl</sub> = 1.47 Lok - 16.62	30-74 MPa	20 / 20	0.99	2
9	Poulsen, Denmark	f <sub>cyl</sub> = 1.20 Lok - 6.62	10-30 MPa	36 / 216	0.96	3
10	Kierkegaard, Denmark	f <sub>cyl</sub> = 1.24 Lok - 6.32	11-39 MPa	100 / 100	0.99	1
11	Leksoe, Denmark	f <sub>cyl</sub> = 1.25 Lok - 7.40	20-55 MPa	240 / 360	0.93	5
12	Leksoe, Denmark	f <sub>cyl</sub> = 1.41 Lok - 10.28	20-55 MPa	240 / 360	0.91	4
13	Krenchel, Denmark	f <sub>cyl</sub> = 1.32 Lok - 6.18	15-75 MPa	116 / 216	0.95	2
14	Krenchel, Denmark	f <sub>cyl</sub> = 1.33 Capo - 7.06	15-75 MPa	116 / 214	0.95	2
15	McGee, USA	f <sub>cyl</sub> = 0.95 Lok - 0.95	6-35 MPa	36 / 36	0.94	1+2
16	Bickley, Canada	f <sub>cyl</sub> = 1.28 Lok - 4.51	3-45 MPa	472 / 472	0.92	1
17	AEC, Denmark	f <sub>cyl</sub> = 1.32 Lok - 11.53	40-110 MPa	40 / 80	0.96	2
18	Trow, Canada	f <sub>cyl</sub> = 1.7 Lok - 36.8	60-90 MPa	88 / 88	0.97	2
19	Bishr, KSA	f <sub>cyl</sub> = 1.25 Lok - 2.88	8-35 MPa	168 / 168	0.96	5
20	DTU, Denmark	f <sub>cyl</sub> = 0.8Lok <sup>1.12</sup>	3-40 MPa	46 / 92	0.99	2

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#### Summary



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#### Summary

Testing range: 1.5 MPa – 110 MPa Nos of cylinders: 2642 Nos of LOK / CAPO-TEST: 3824

#### Average variations and correlation coefficient

LOK / CAPO-TEST		Cylin	Rxy	
5 (kN)	V (%)	S (MPa)	V (%)	
2.6	8.8	2.1	5.3	0.95



#### LOK-TEST to CAPO-TEST







#### Precision

$$P = \frac{z \cdot C_v}{\sqrt{n}} \qquad C_v = \frac{S_p}{\bar{x}}$$

P = Precision: The maximum error between the in-situ obtained sample average of pull-out force and the true average under a certain confidence level (ACI 437R, ASTM E122).

Z = z-factor of the normal distribution = 1.96 for a 95% confidence level n = sample size, number of in-situ Lok/Capo tests

 $C_v$  = Coefficient of variation of the data sets  $\overline{x}$  = Weighted mean of the data sets

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + \dots + (n_m - 1)s_m^2}{n_1 + n_2 + \dots + n_m - m}}$$

 $s_p$  = Pooled standard deviation of the data sets  $n_{i \dots m}$  = number of tests per set m = number of sets



#### Data for calculating the Precision



Krenchel (13 and 14)

Bishr (19)



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#### Precision obtained for LOK and CAPO



Krenchel (13 + 14), 116 cyl and 216 LOK, 214 CAPO-Test Bishr, (19), 168 cyl and 168 LOK-Test Test smart – Build right

#### General correlation for cylinder strength to LOK-TEST or CAPO-TEST



Theoretical investigations relating LOK-TEST pullout force F in kN to cylinder compressive strength f<sub>cyl</sub> in MPa, compared to the General Correlation for cylinders f<sub>cyl</sub> = 0.69 F<sup>1.12</sup>



## Cube relationships



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



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



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## 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

#### Methods:

- 1. 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 x 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 \_\_\_\_\_\_ Test\_smart – Build right \_\_\_\_\_\_



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

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#### 13 correlations to cube strength



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#### General cube - LOK/CAPO relationship



#### The two general correlations



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#### 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
- Carbonation
- Shape, type or size of aggregate < 38 mm</li>
  - Lightweight aggregate, however, produce a significantly different correlation <u>significantly</u> - <u>Build right</u>



## Variation from testing on-site

- The variation on LOK-TEST and CAPO-TEST is ~8% on concrete in the lab
- Testing on-site the variation is:

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



#### Conclusion

- 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 diameter counter pressure on the surface, hence the LOK-TEST and CAPO-TEST measures directly the compressive strength on the concrete

#### Conclusion

- Correlations show stable, robust and sensitive general correlations to standard lab specimens or cores for all types of normal concrete.
- Due to this stability of correlations the LOK-TEST and the CAPO-TEST will not need correlation to cores, as all other methods do (ACI 228.1) and (EN-13791)
- The precision for two adjacent tests is ~8% on the strength estimate, for 4 tests ~6%
- Testing range from 1.5 MPa to 100 MPa (cylinders) and from 1.5 MPa to 120 MPa (cubes) has been investigated

