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

Section 1

Theoretical Analysis
Fracture Mechanism
Correlations

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GERMANN INSTRUMENTS A/S

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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

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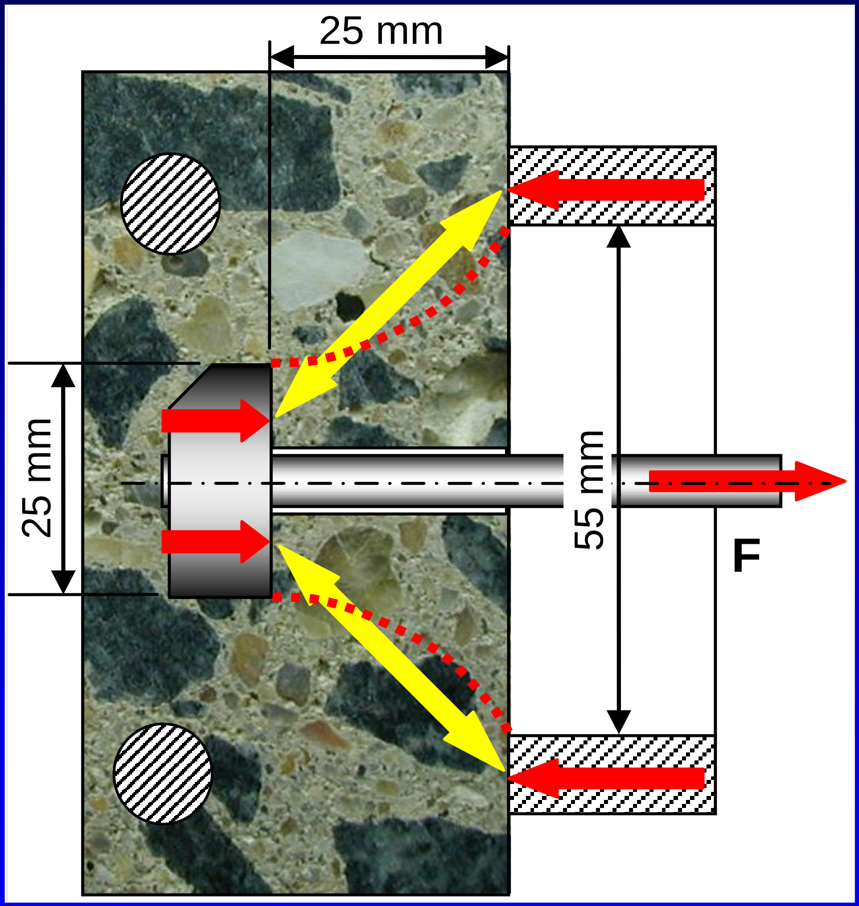
Sections

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

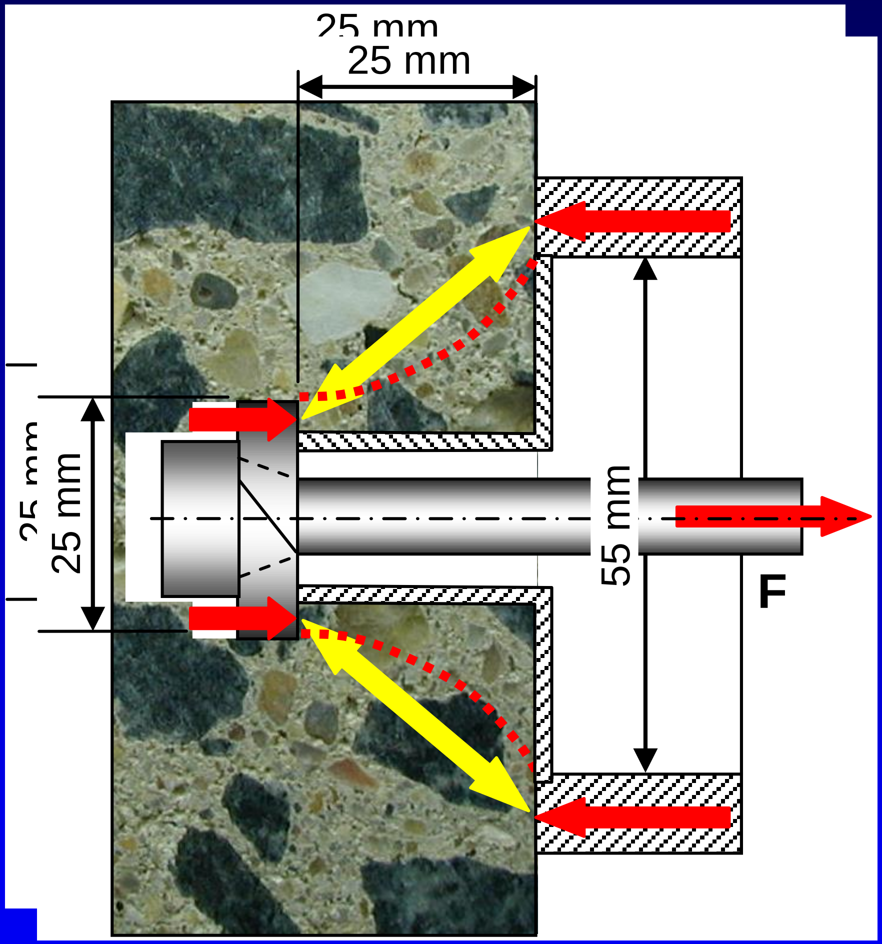
Section 1

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

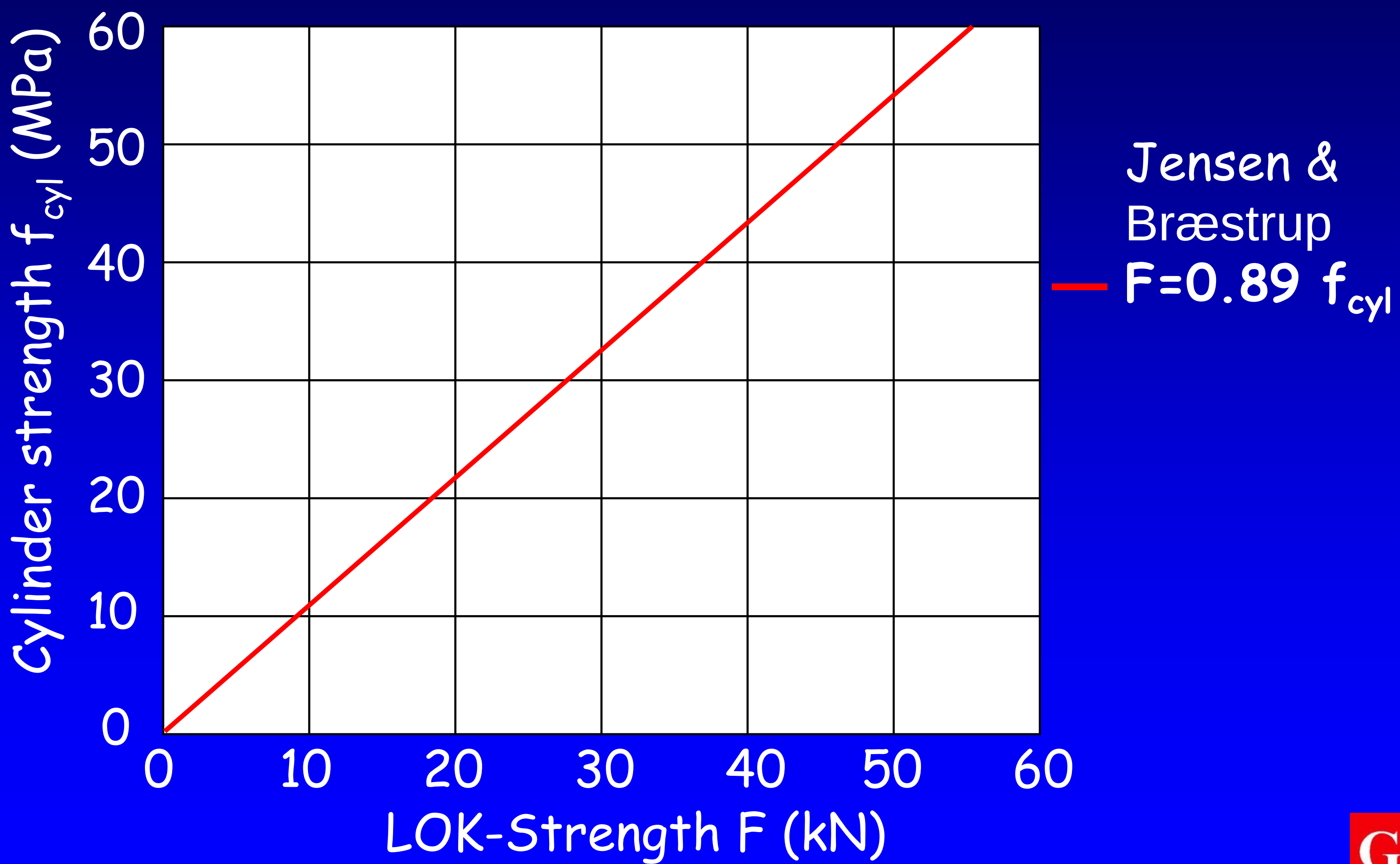
Analysis by Jensen & Bræstrup

Using Coulombs Criteria for Sliding Failure, the conclusion is:

"Plasticity analysis may be applied to determine the load-carrying 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_c and the tensile strength is 0.'

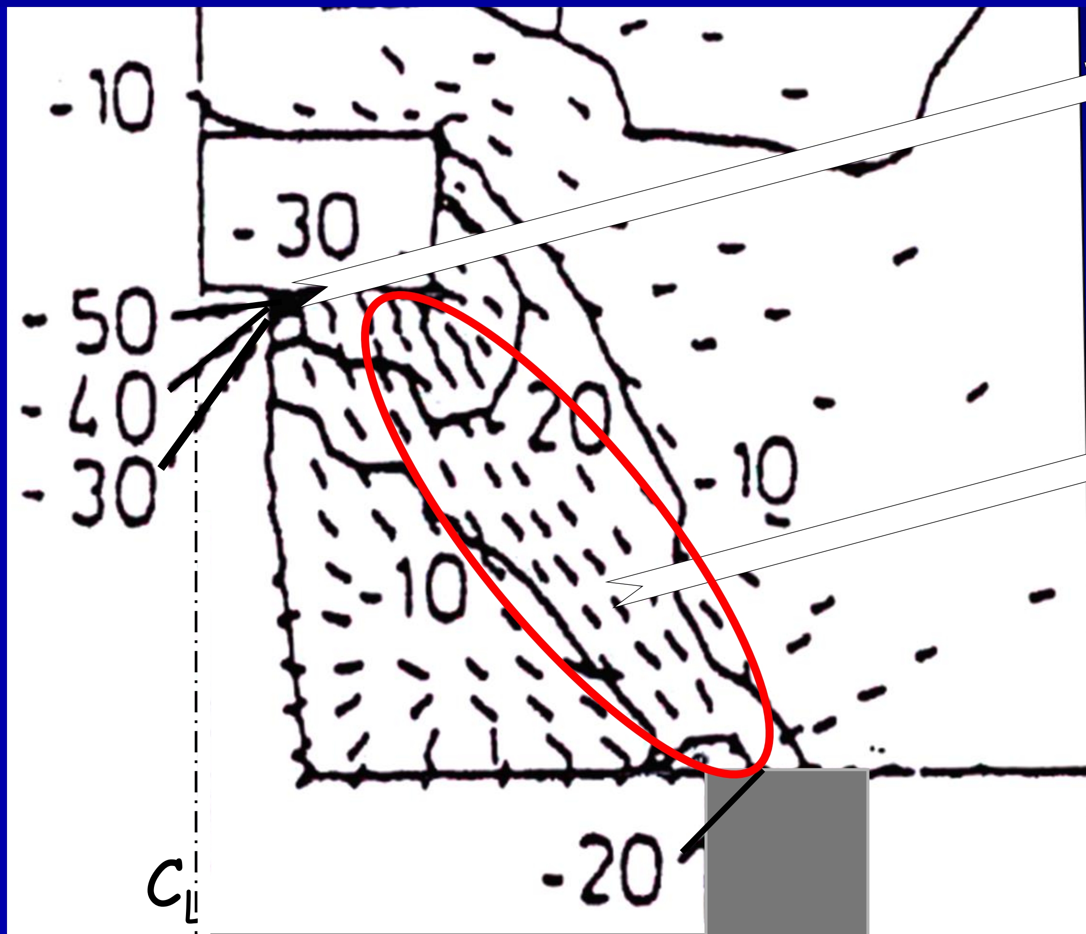
Analysis by Ottosen

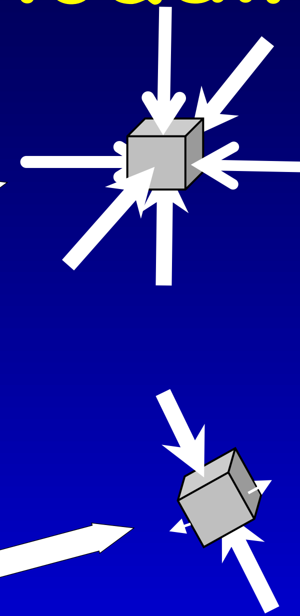
- Ottosen, N.S.: "Nonlinear Finite Element Analysis of Pull-Out Test", Journal of the Structural Division, ASCE, Vol. 107, No ST4, April 1981

Stress curves at 65% loading

Stresses in MPa are negative when stresses are compression

Ref Ottosen p. 597





“Strut” stress of 20 MPa

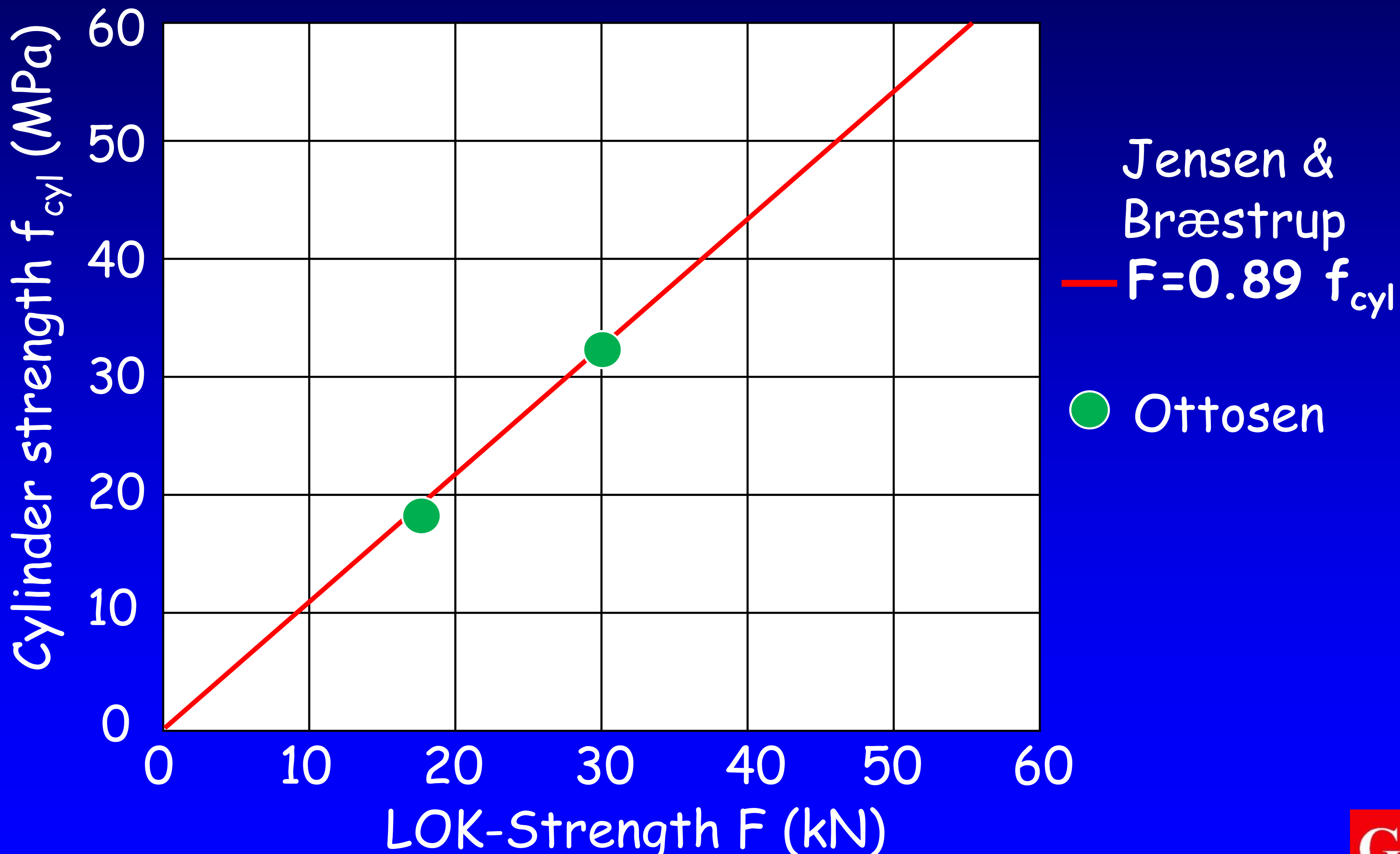
Large compressive forces run from the disc in a band (“strut”) towards the support. The stress state in this strut is biaxial compression superimposed by small tensile stresses

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.

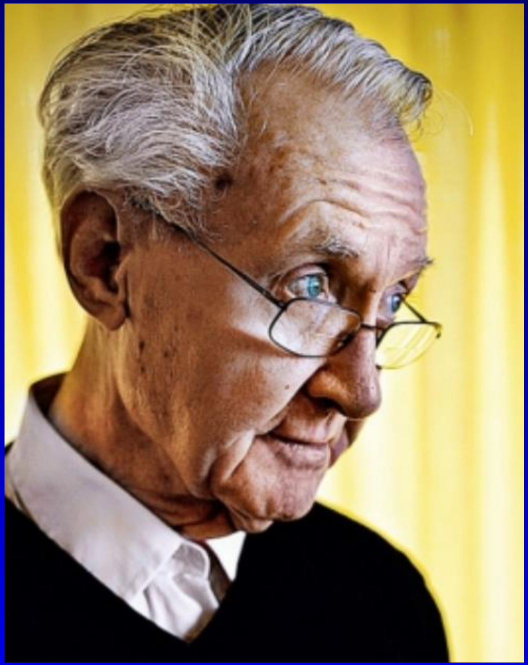
Conclusion by Ottosen

"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

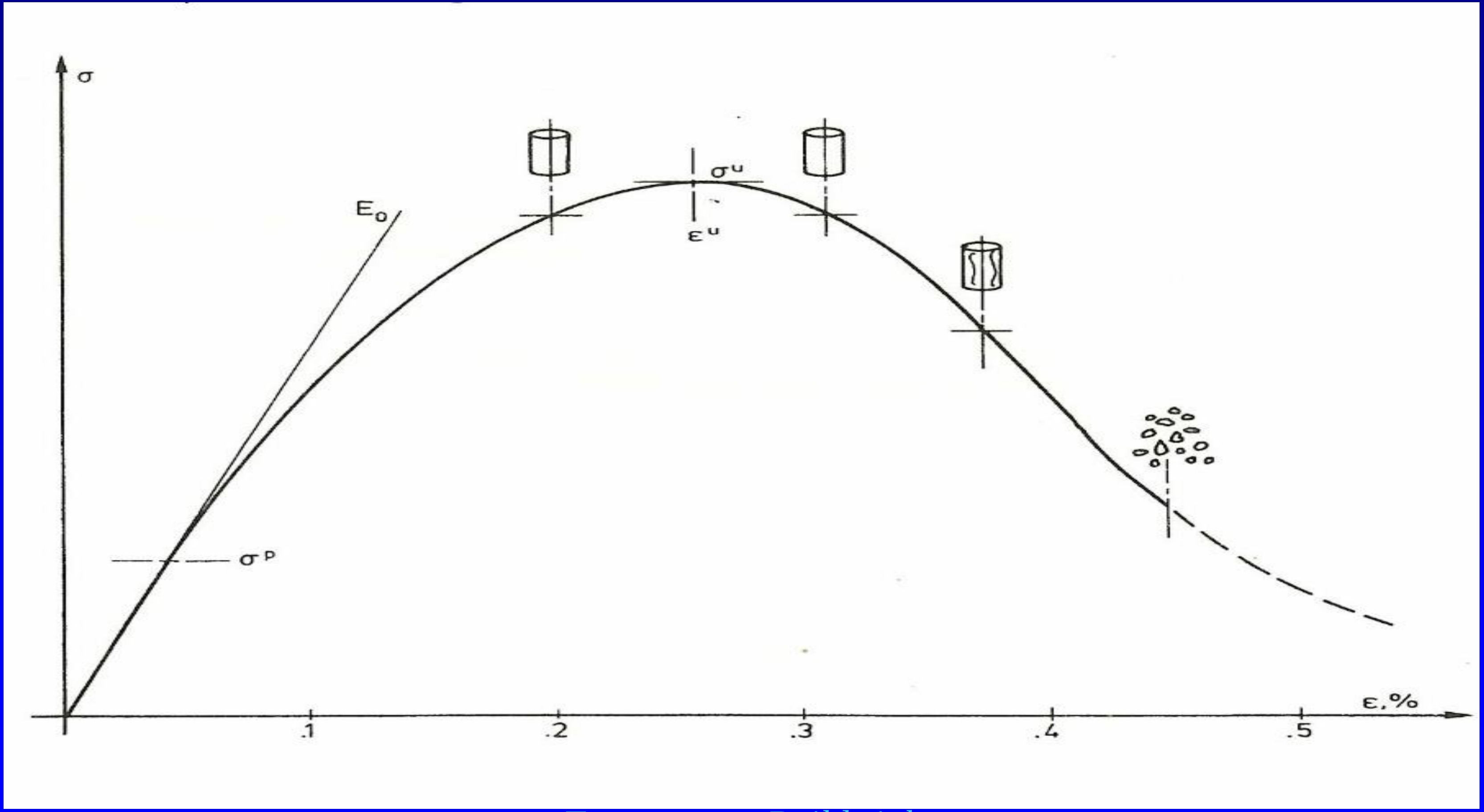
Krenchel, H. & Shah, S.P.: "Fracture analysis of the pullout test", Dept. of Structural Engineering, Technical University of Denmark, RILEM, Materials and Structures, Dunod, Nov-Dec. 1985 no 108

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

Linearity Compression Softening / Collapse



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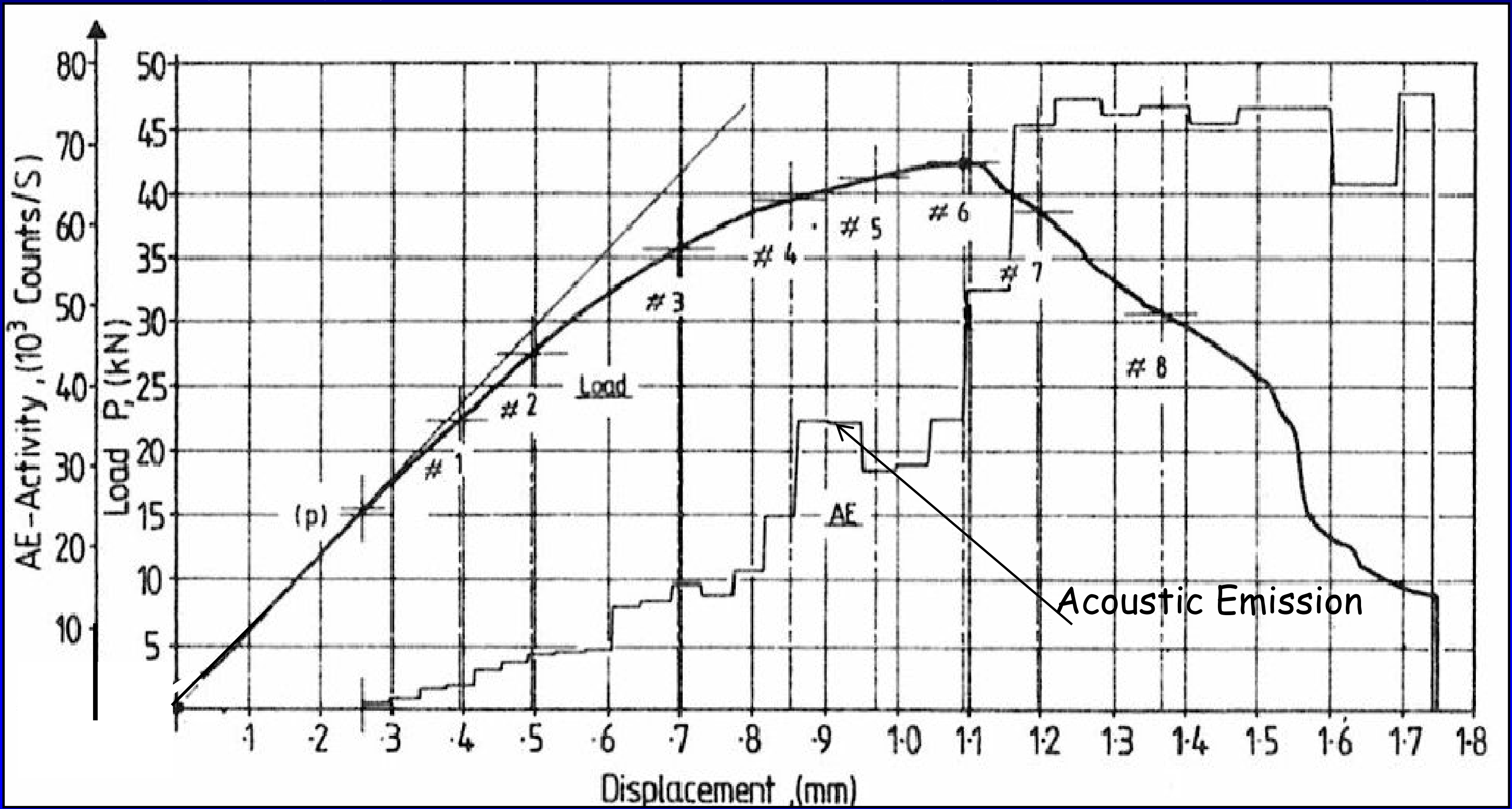
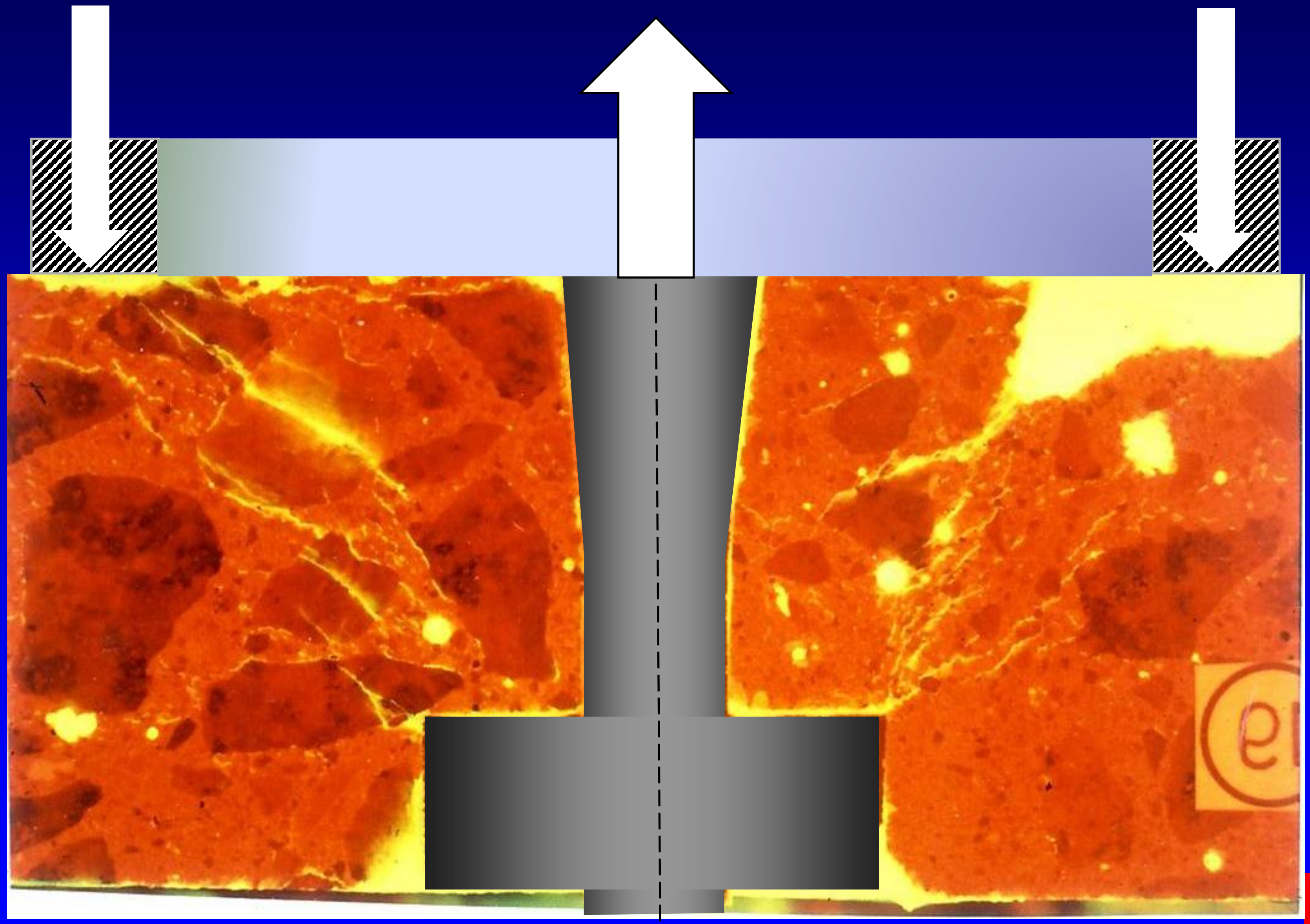
Load-displacement curve for LOK-TEST

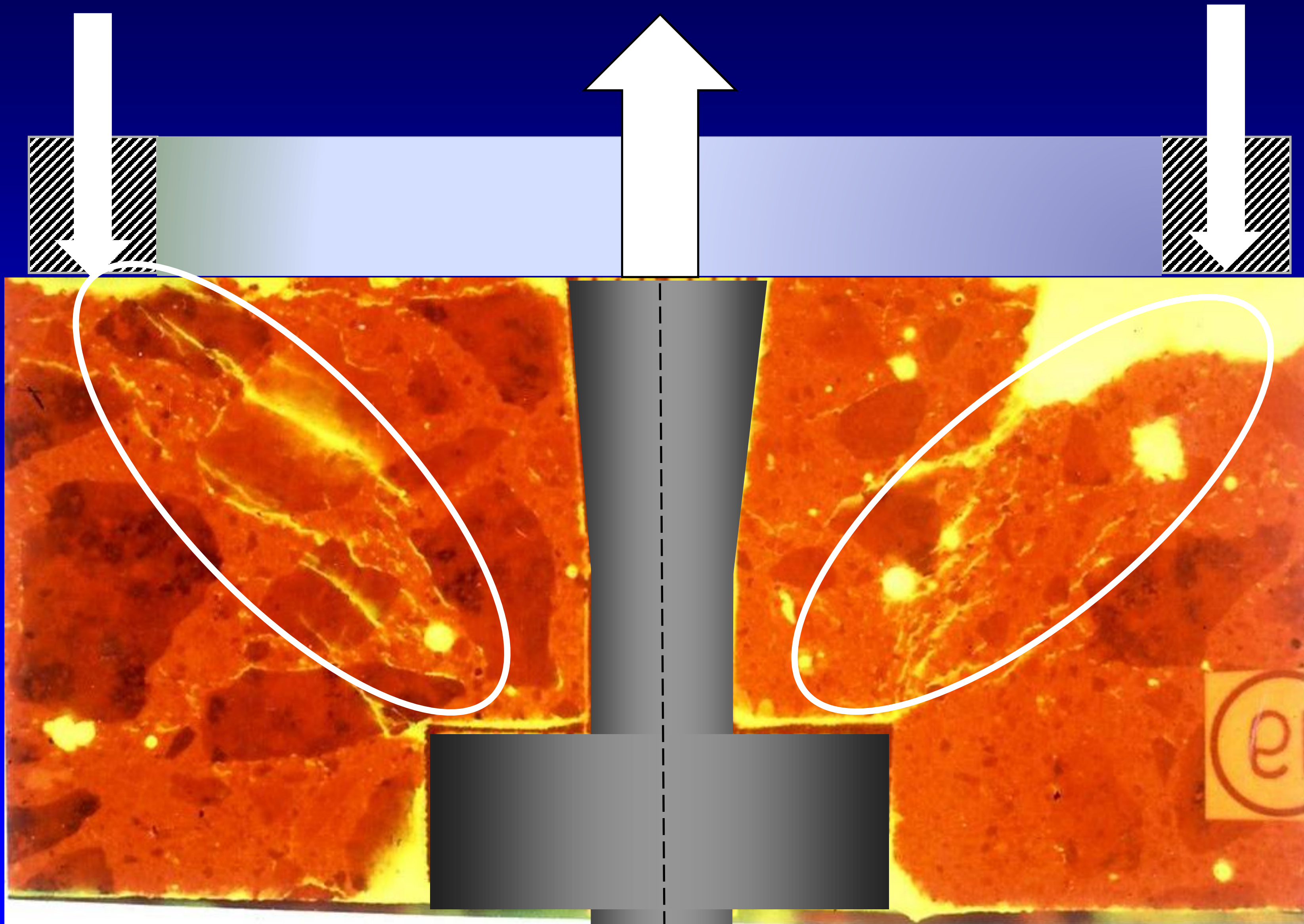
Linearity — Compression — Softening / collapse



98% load level



Compression "Strut"



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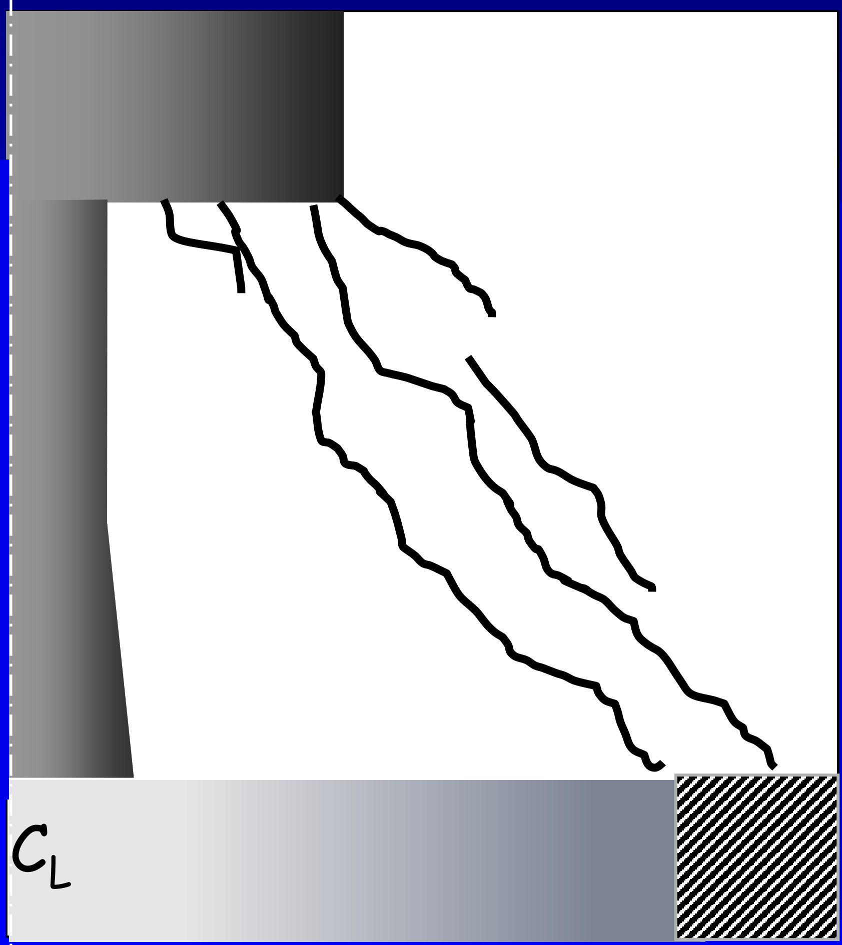
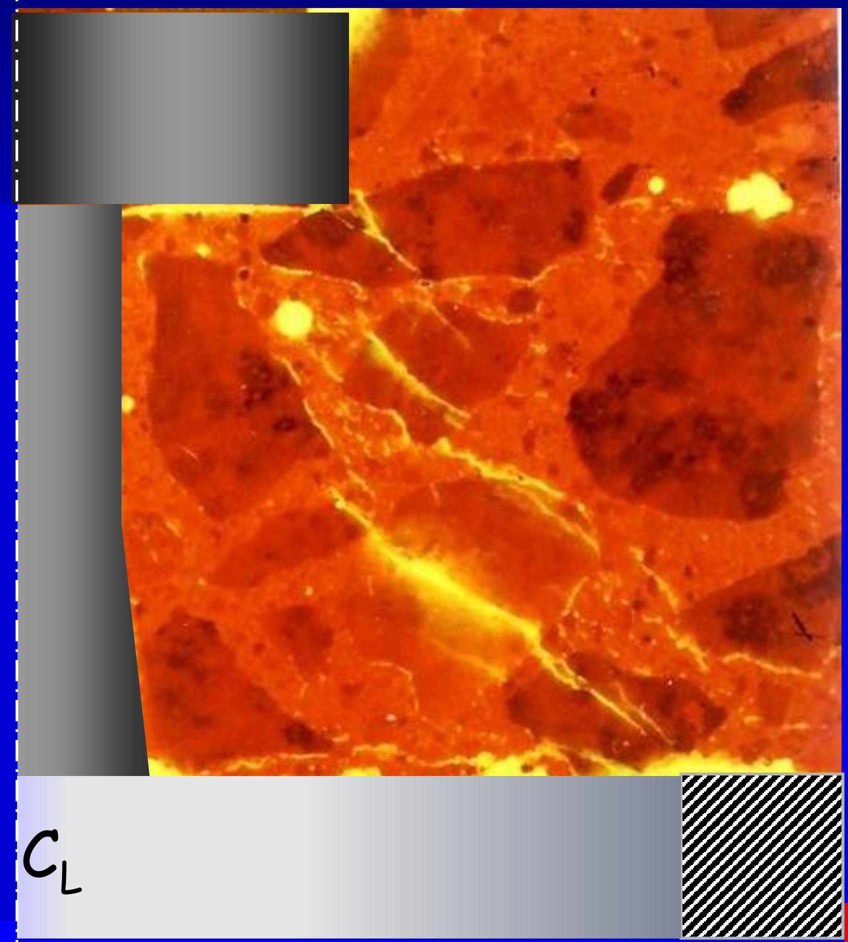
Compressive cracking, 98% loading, Finite element analysis and experimental analysis

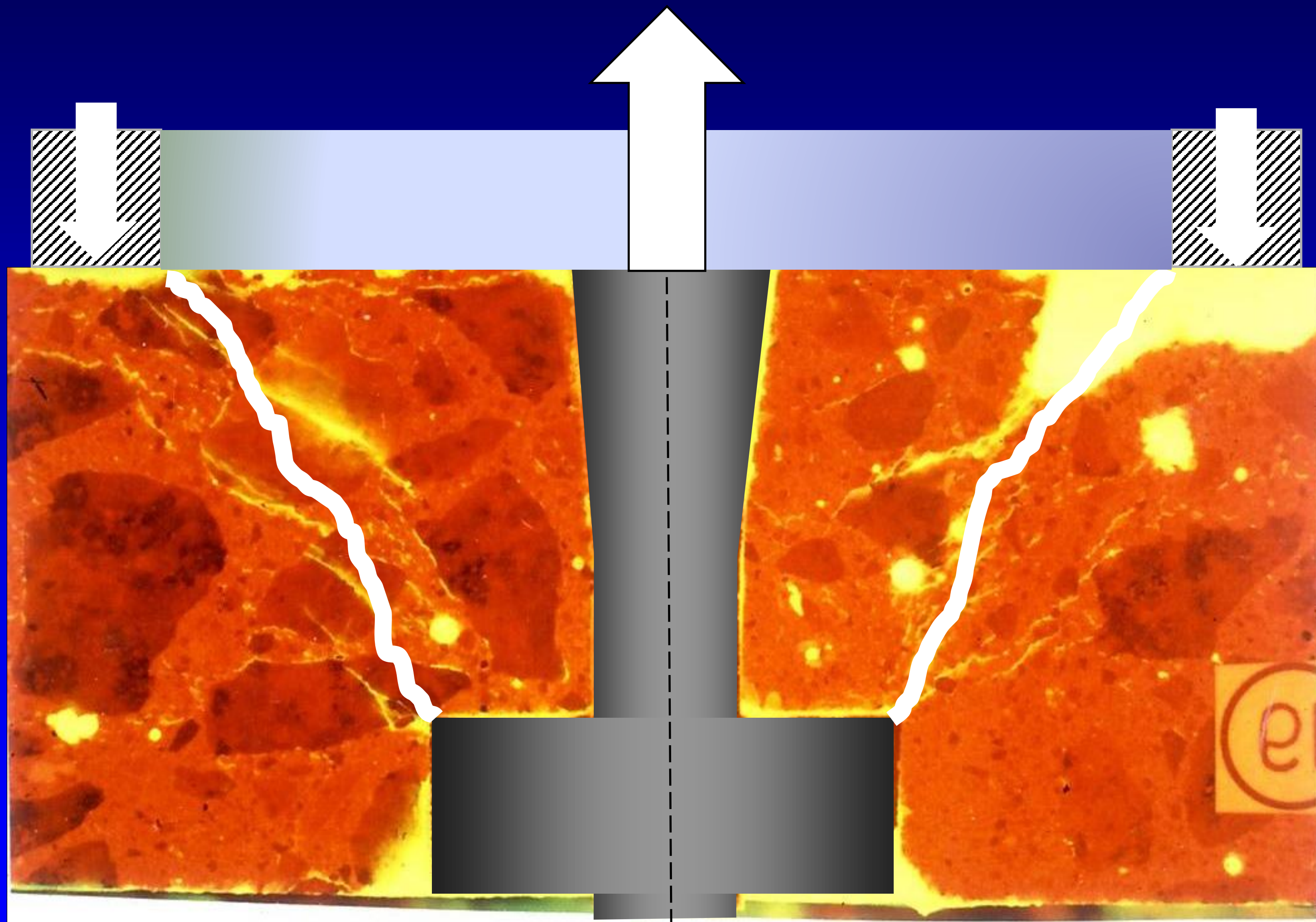
Ref.: Ottosen, N.S.: Nonlinear Finite ElelementAnalysis of Pull-Out Test, JSD, ASCE, Vol. 107, No ST4, April 1981



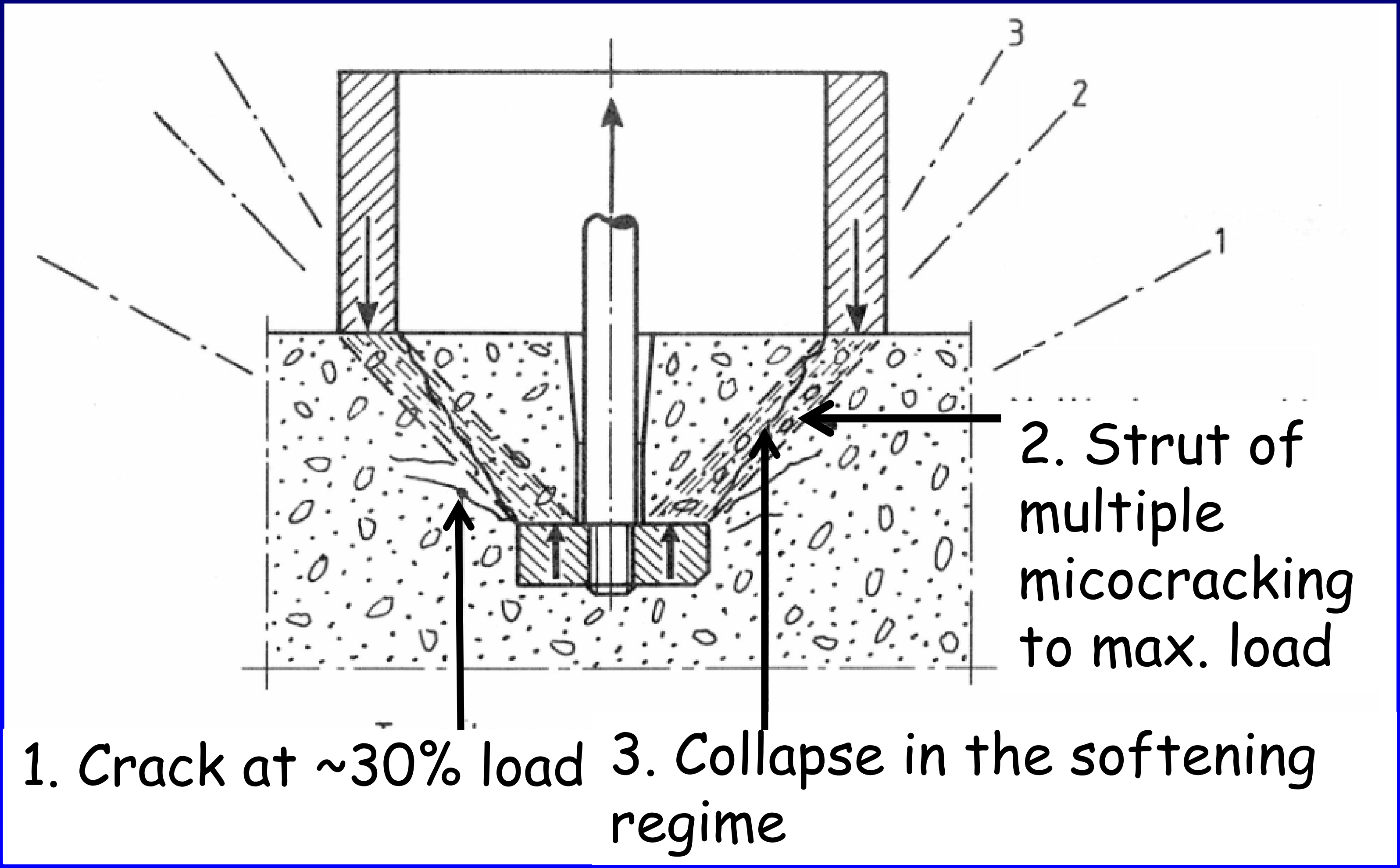
Krenchel, H. & Shah, S.P.: "Fracture analysis of the pullout test", Dept. of Structural Engineering, Technical University of Denmark, RILEM, Materials and Structures, Dunod, Nov-Dec. 1985 no 108



Collapse into the softening regime



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

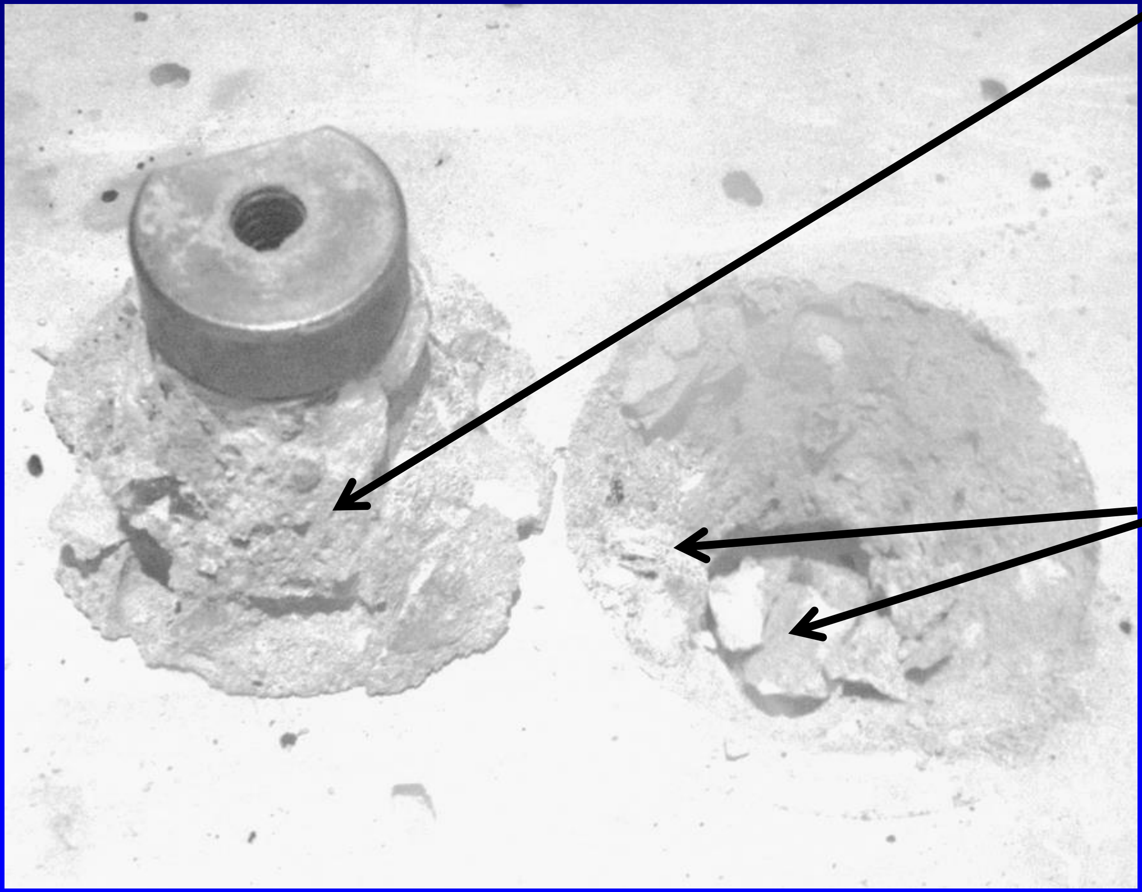


Ref: Krenchel, 1985

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 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**

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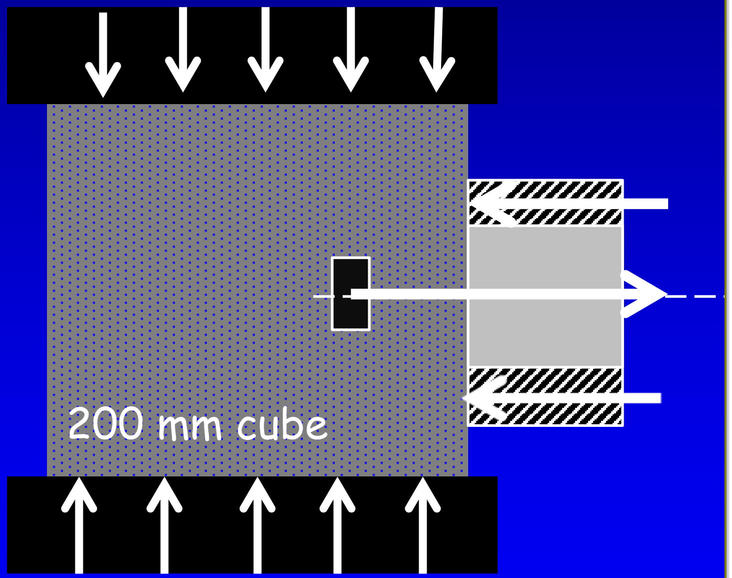
CAPO-TEST Failure

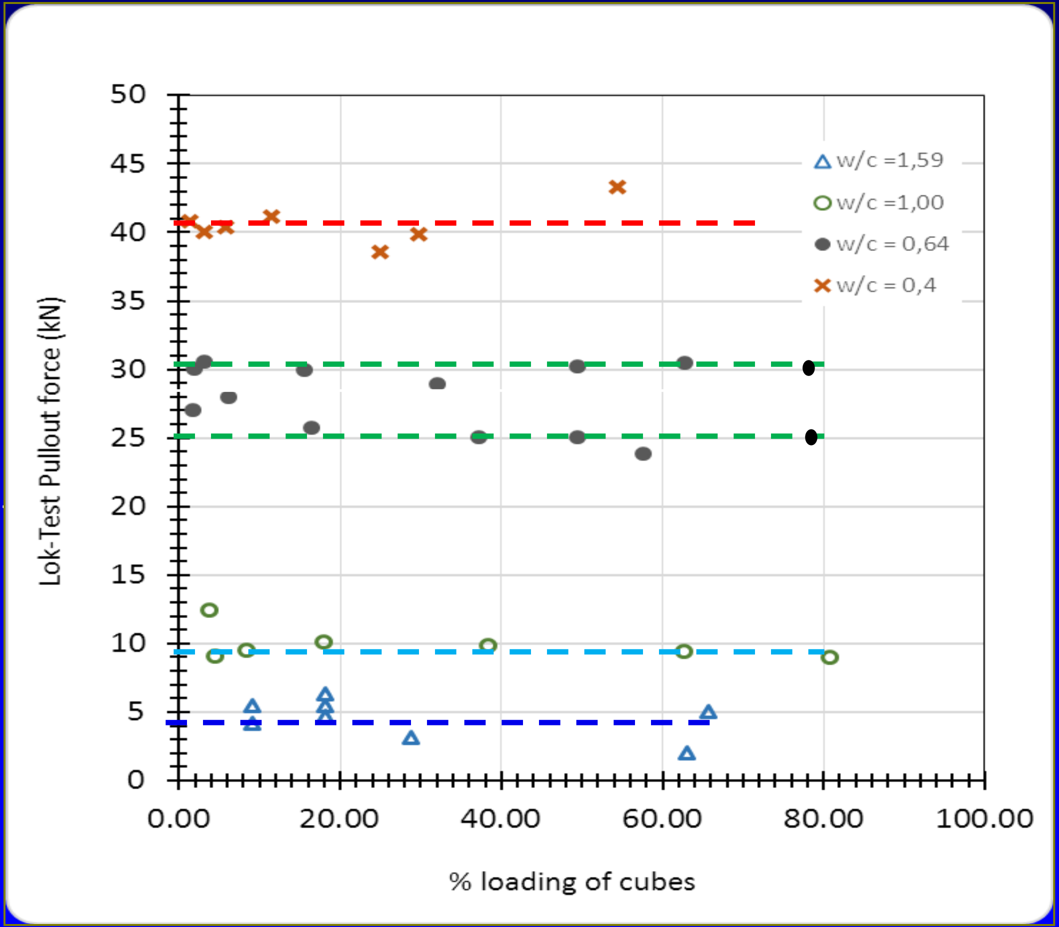
"Leaves" from the 2nd crack pattern with the concrete in compression **STRUT** being intersected in the softening regime

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



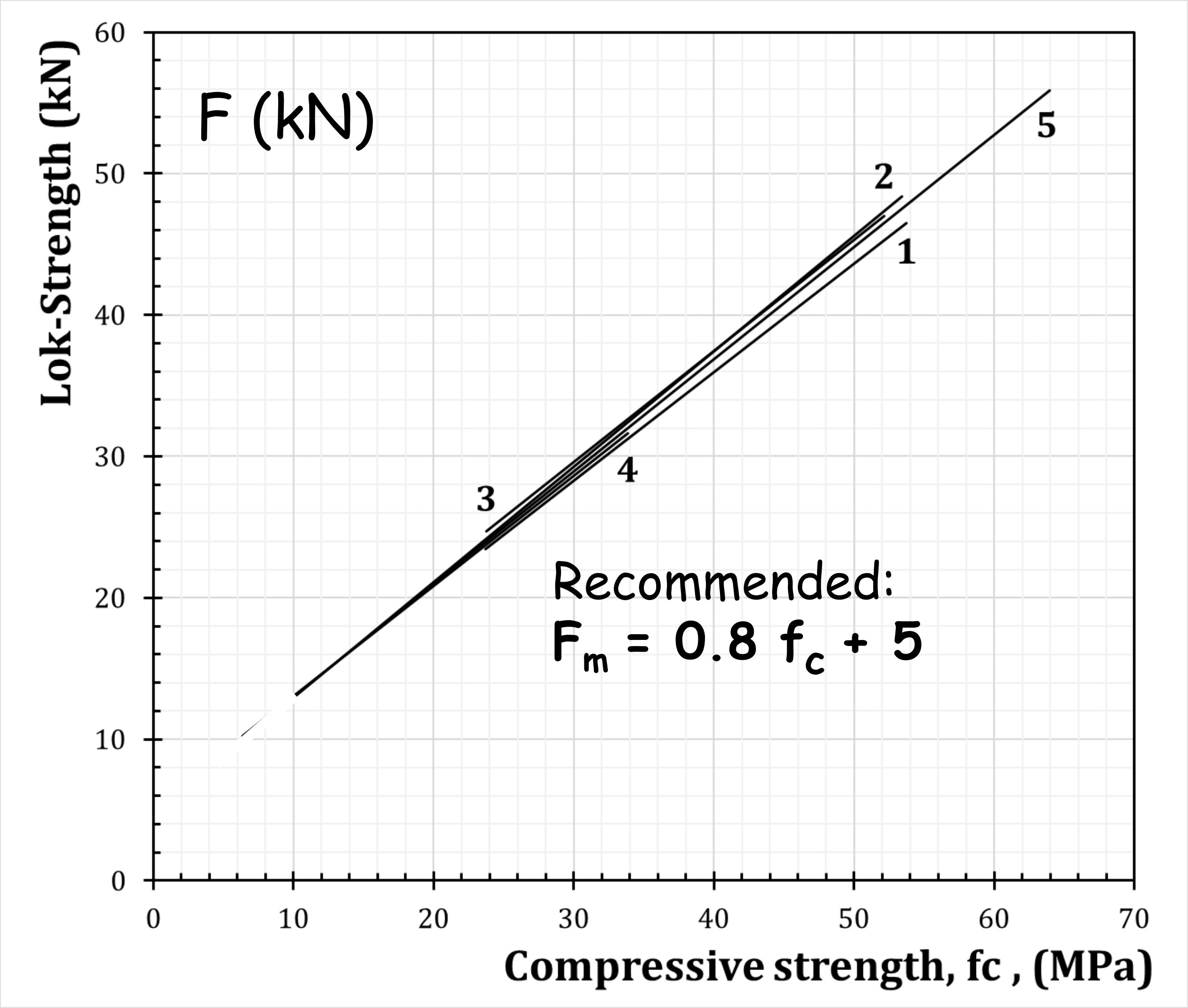


Correlations

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

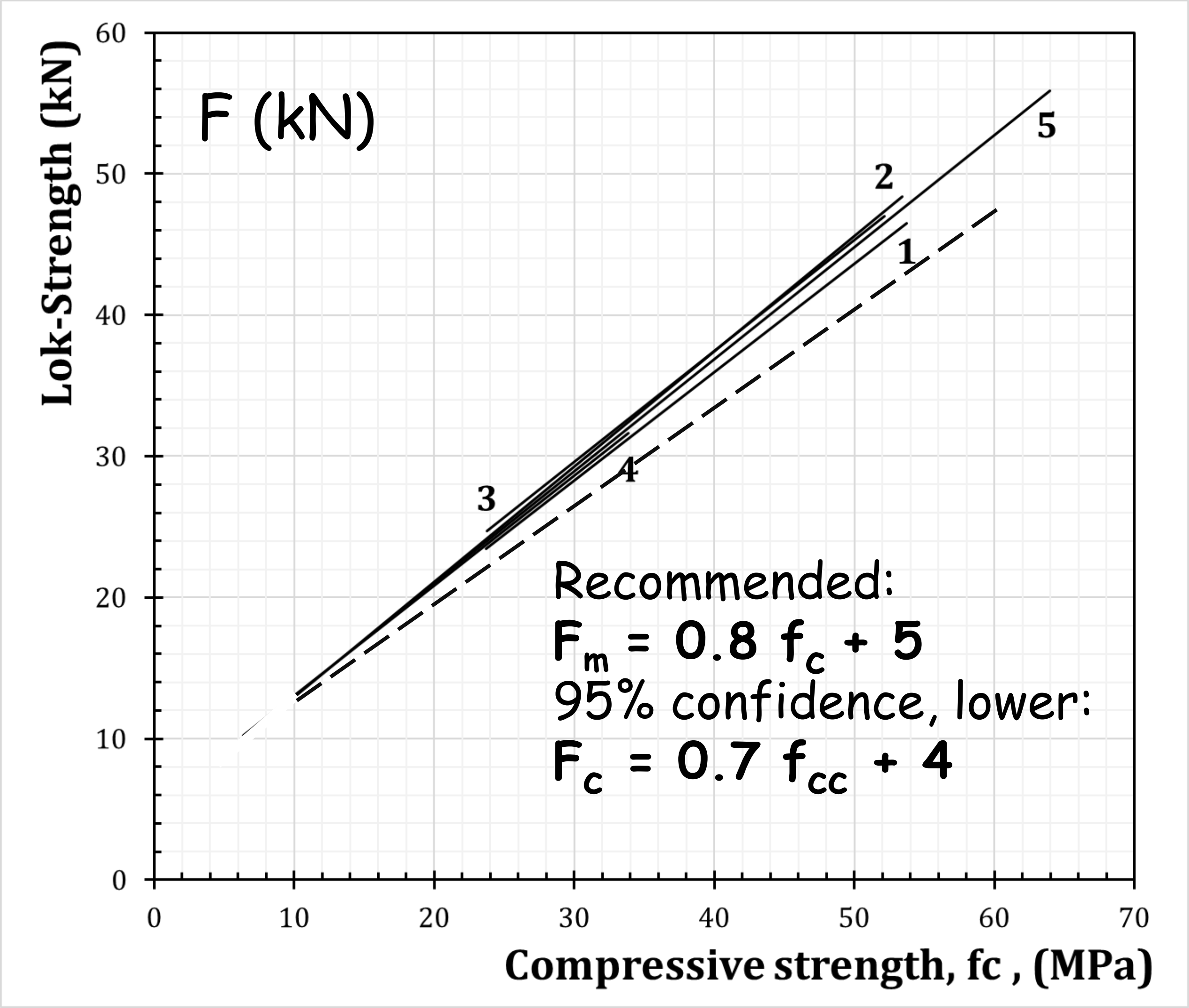
[2] Rapport nr. S 3/69 1974: Danish Technical University

[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.

Correlations before 1978



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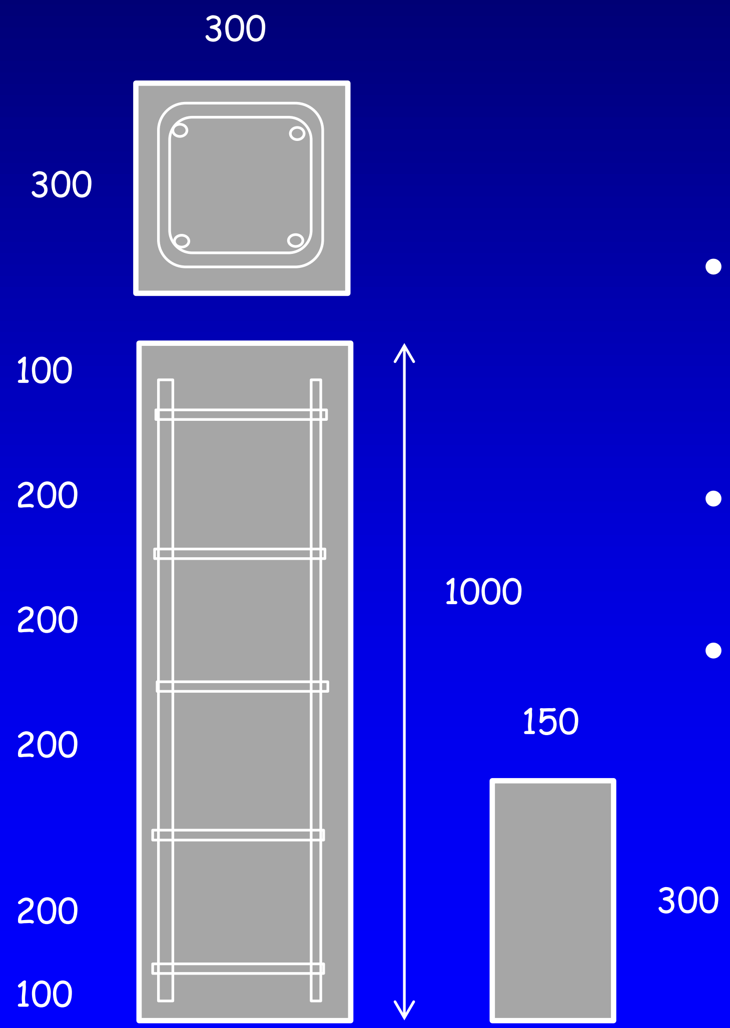
[3] Jensen, O. & Leksø, S. 1976 / 1977, Danish Road and Bridge Lab & Danish State Railways

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

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

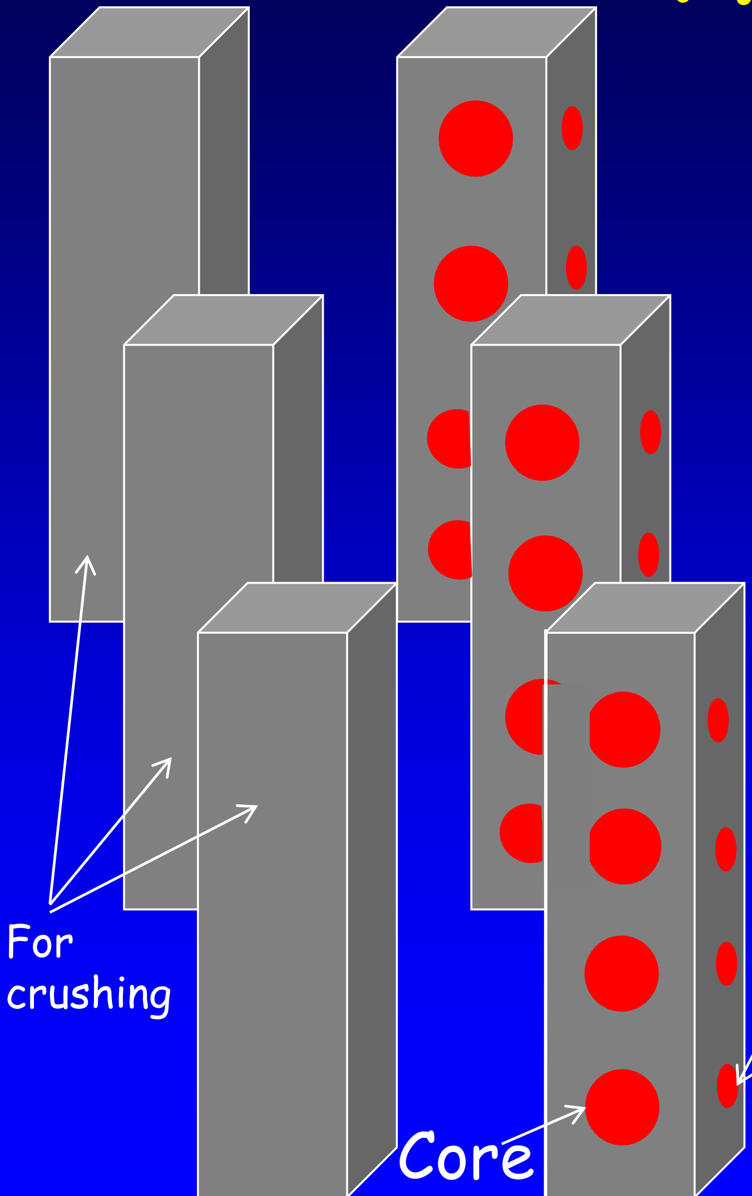
Comparative testing, reported 1978



- 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

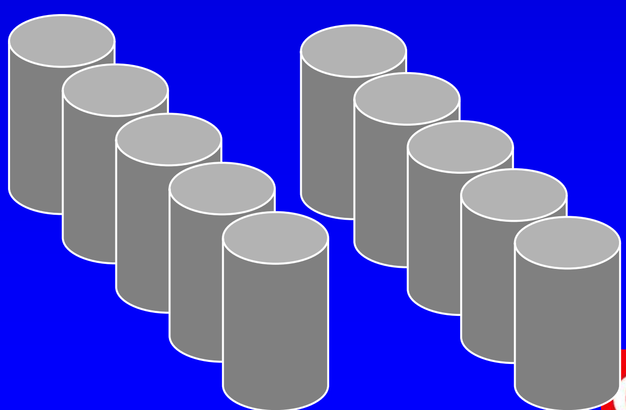
Program

5 x 6 columns



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



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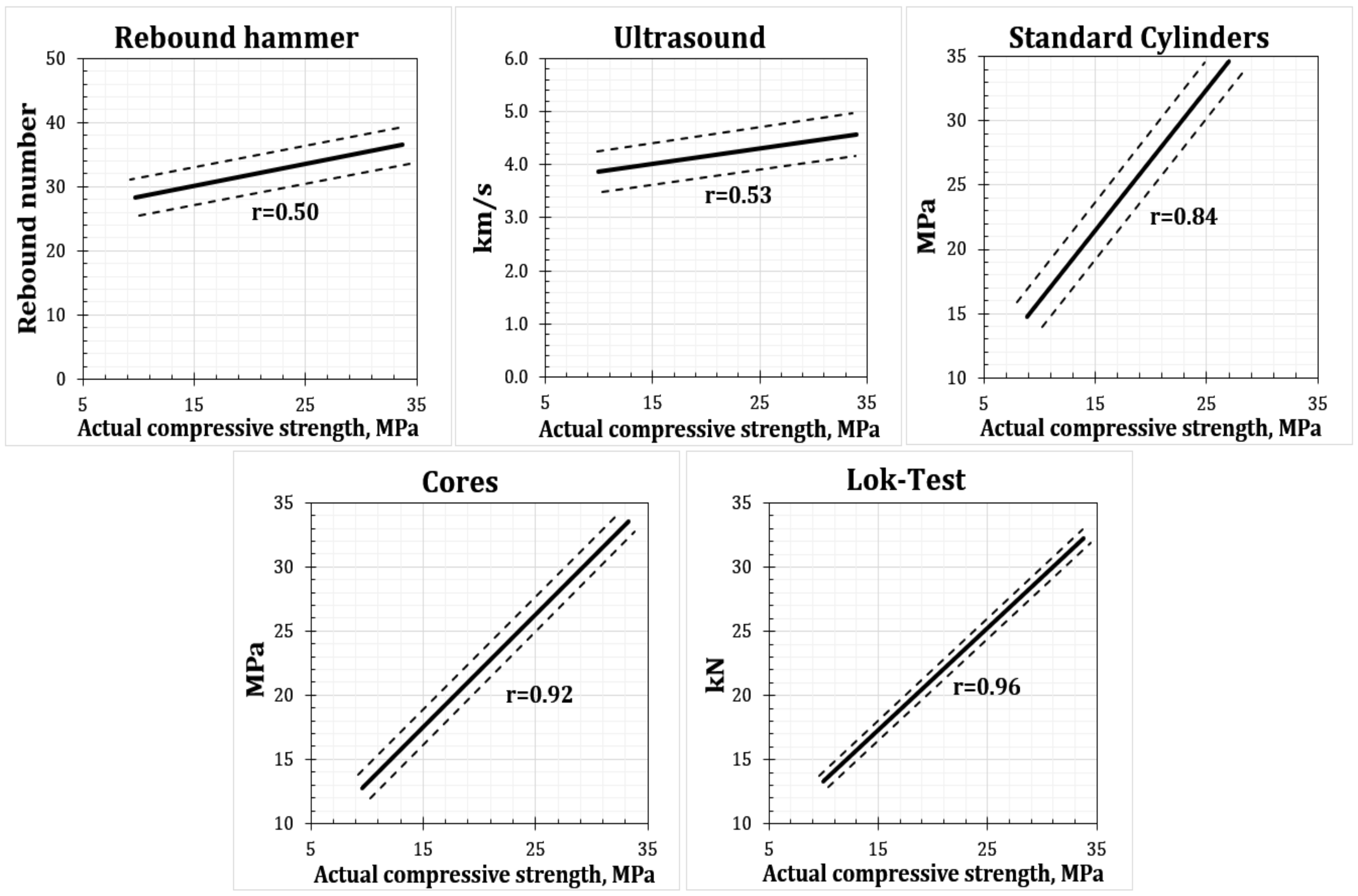
Correlations obtained, with 90% conf. limits and R_{xy}



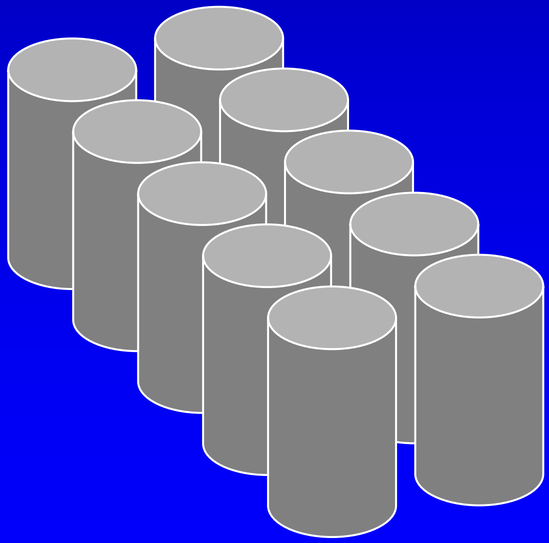
Refs (1) Poulsen, E.P."Vurdering af betons styrke ved prøvning af udborede kerner, Del 1 og Del 2, DIAB, Nov 1975

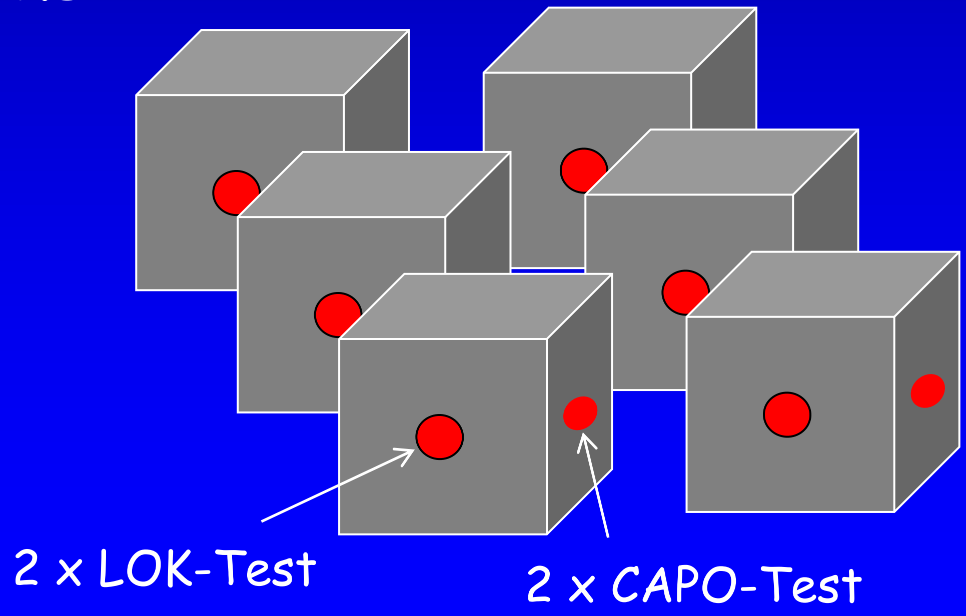
(2) Kierkegaard-Hansen, P.: "LOK-TEST, Historical Background", DIAB, Oct 1978

Cylinder relationships

Correlation Testing

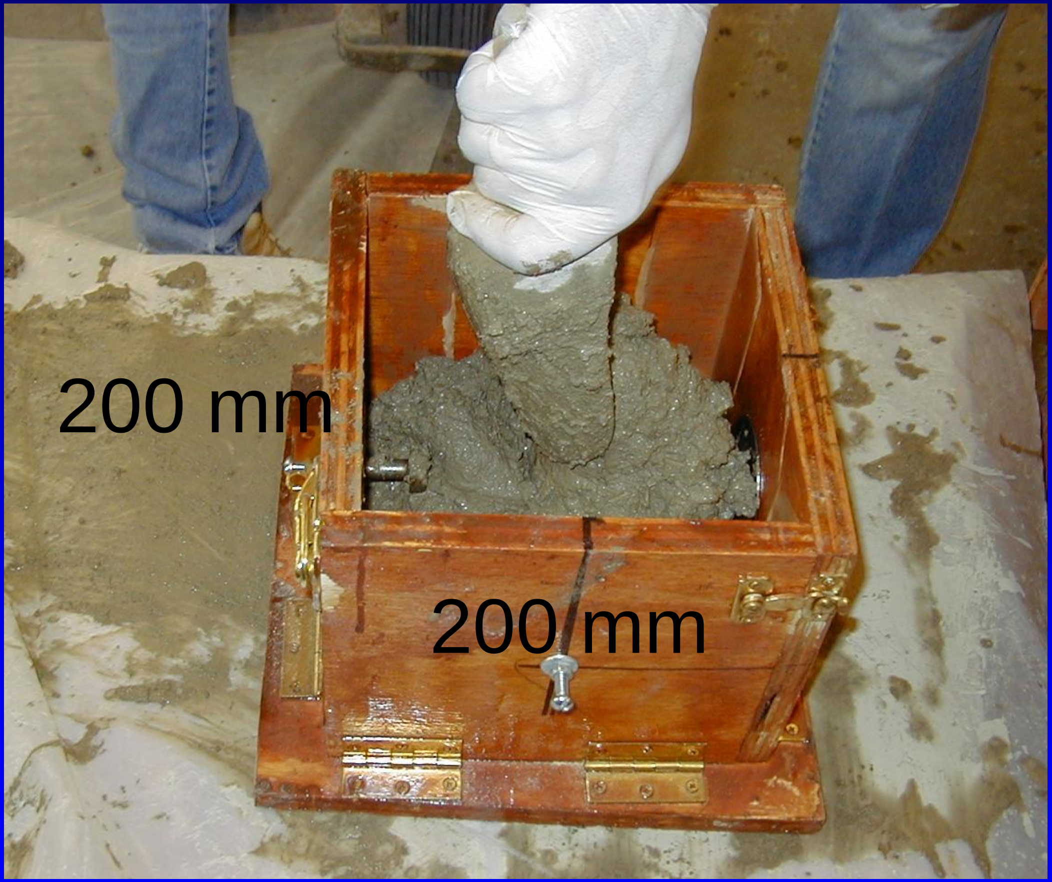
- Prepare cylinders (or cubes)
- Prepare 200 mm cubes with inserts
- Compact and cure under same conditions





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



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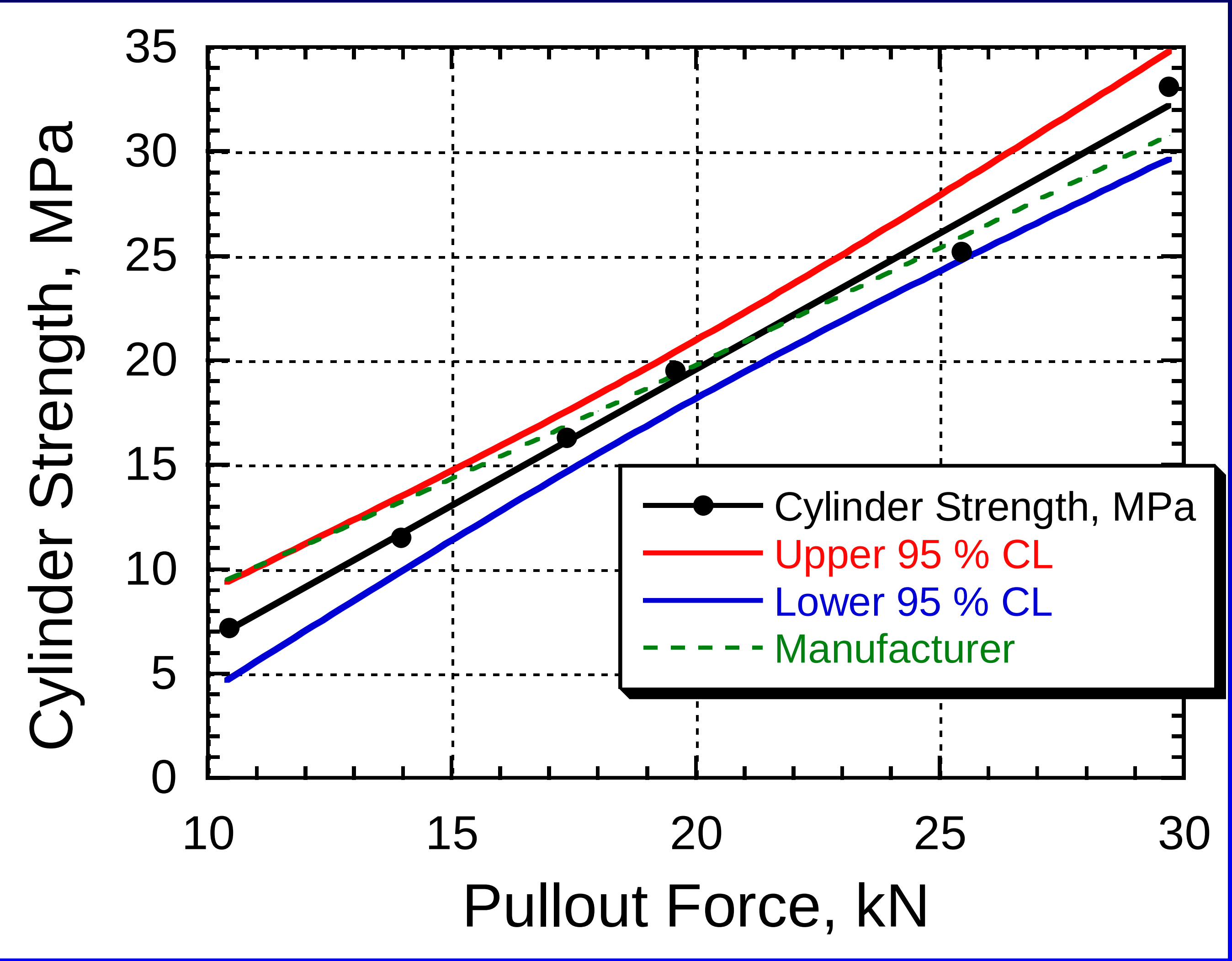
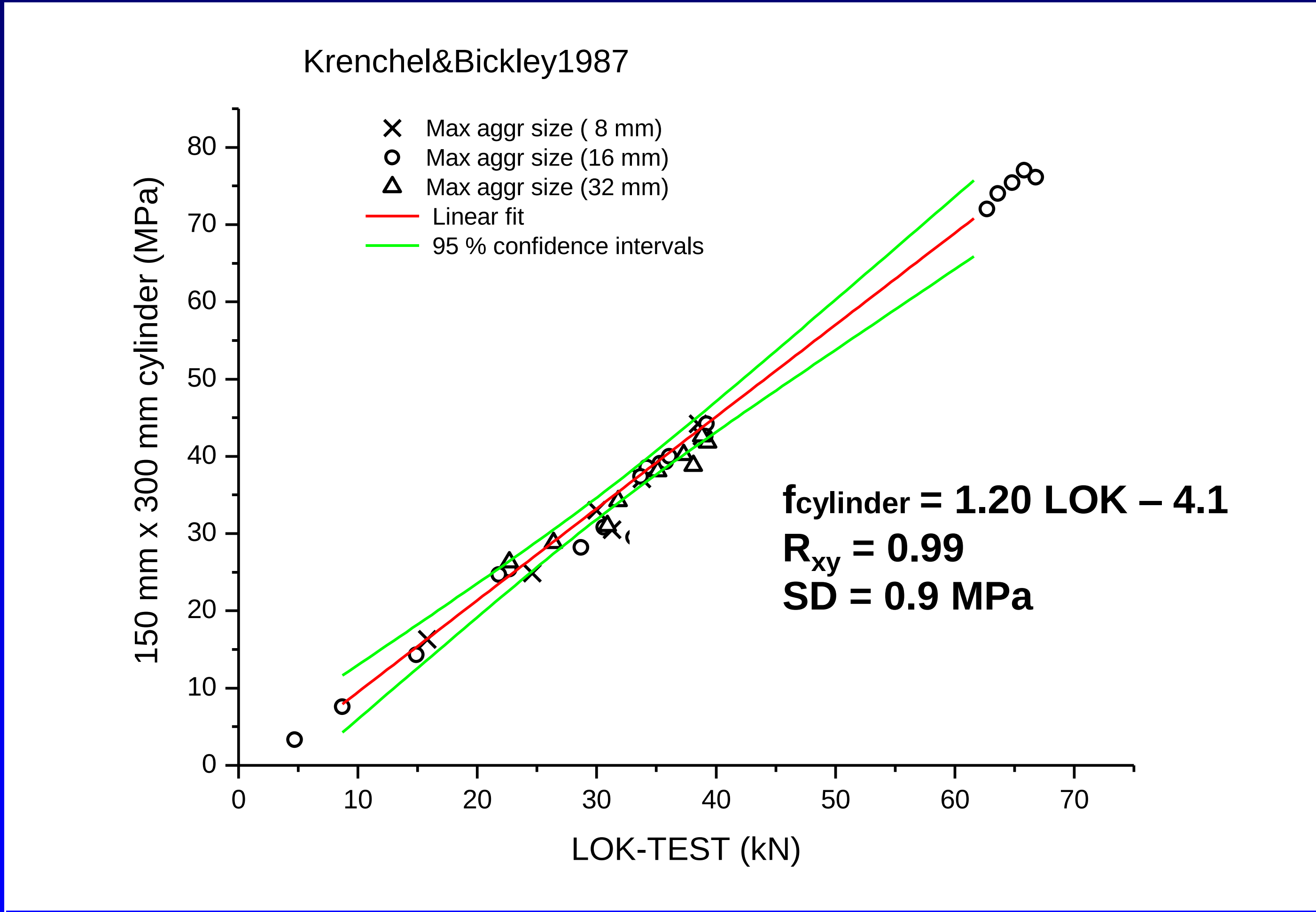
Example NRMCA, 2008



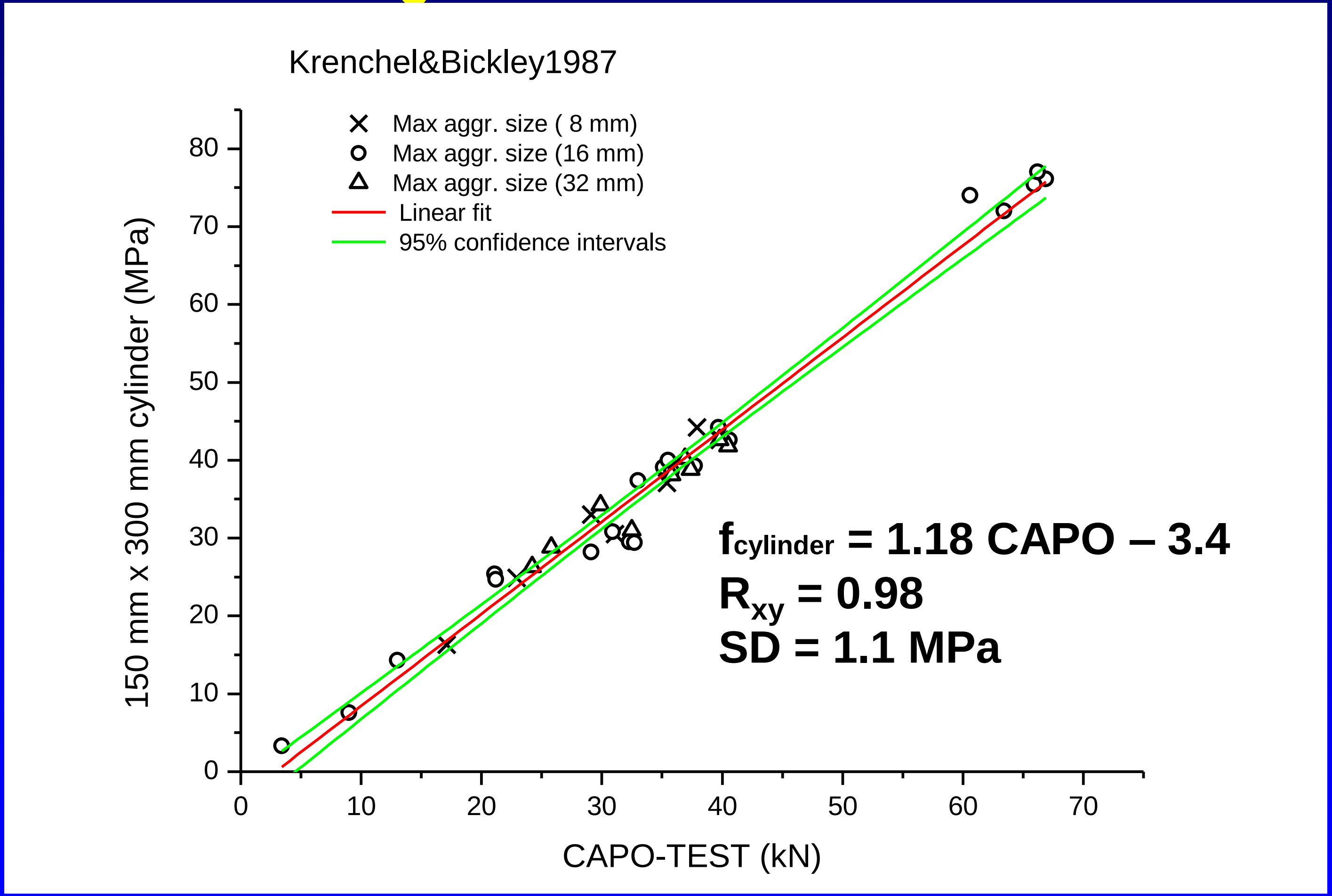
http://www.nrmca.org/research/HVFAC_Final_Report_final.pdf

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



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)

Twenty correlations between 150 mm dia x 300 mm standard cylinder strength f_{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 x 300 mm cylinders, pullout centrally placed on vertical faces of 200 mm cubes
3. 0.3 m x 0.3 m x 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

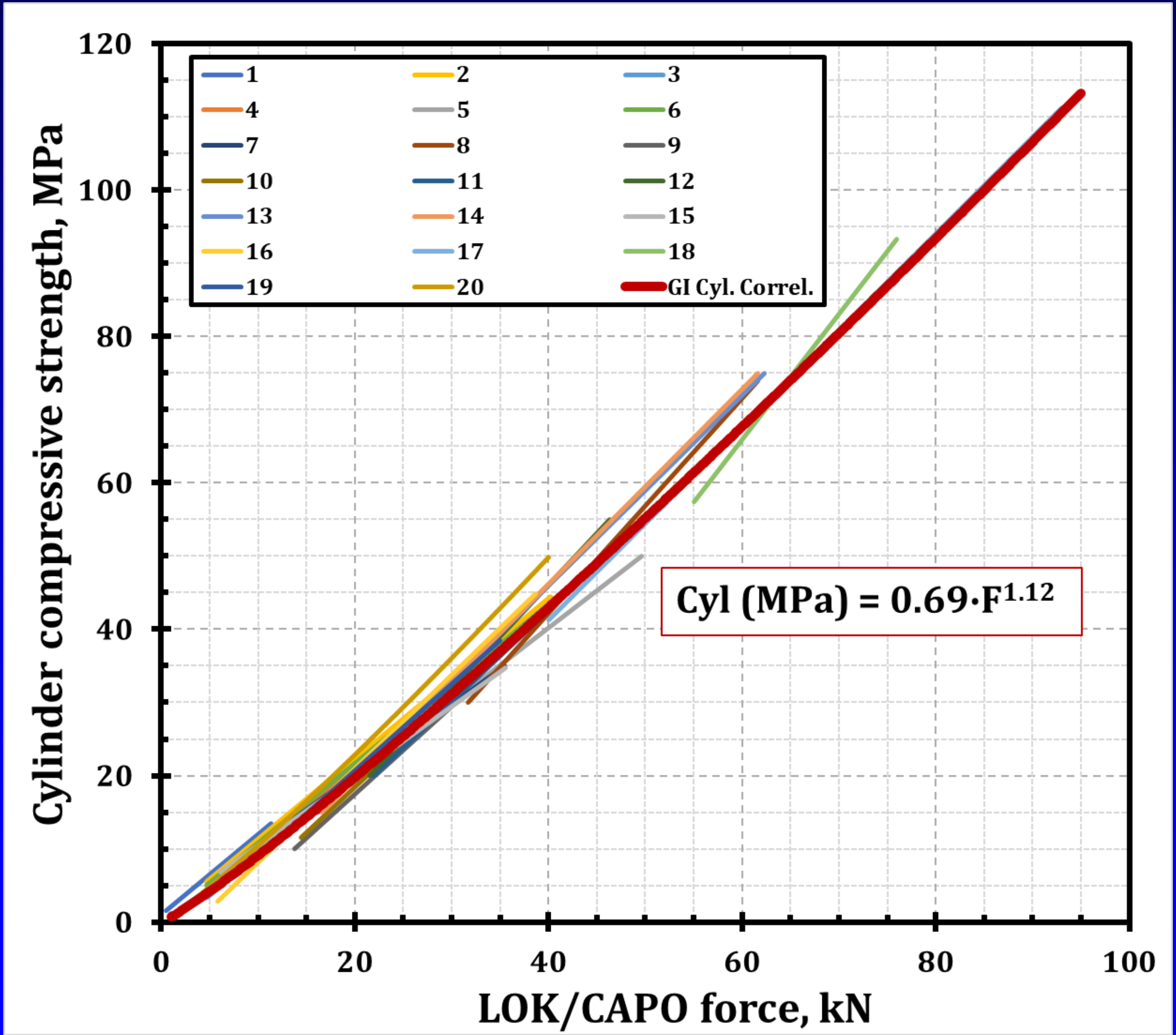
Parameters investigated

- 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

20 correlations, Cylinders to LOK/CAPO -TEST

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

Summary



120
100
80
60
40
20
0
Cylinder compressive strength, MPa
0
20
40
60
80
100
LOK/CAPO force, kN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
GI Cyl. Correl.
Cyl (MPa) = 0.69·F1.12

GI

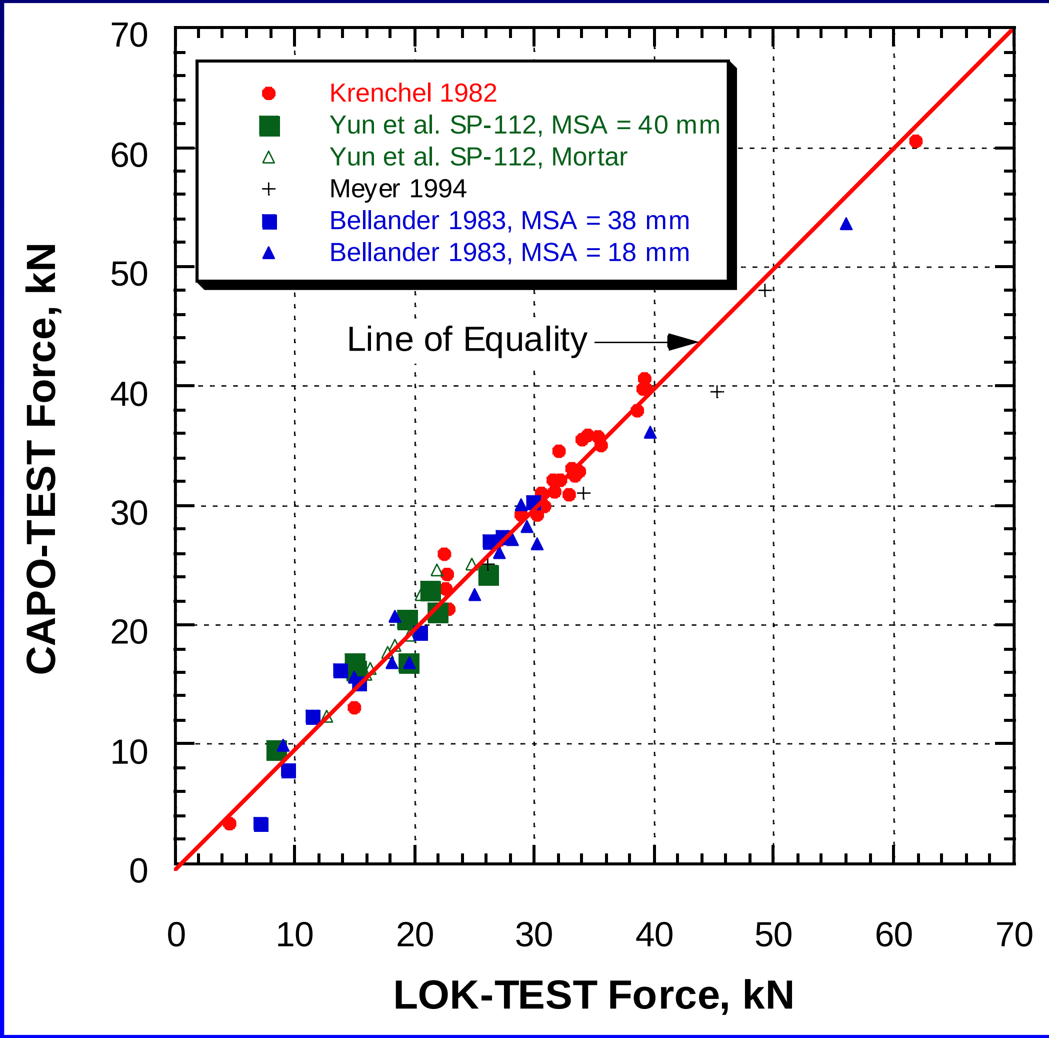
Summary

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		Cylinders		Rxy
S (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

$\bar{x}$ = Weighted mean of the data sets

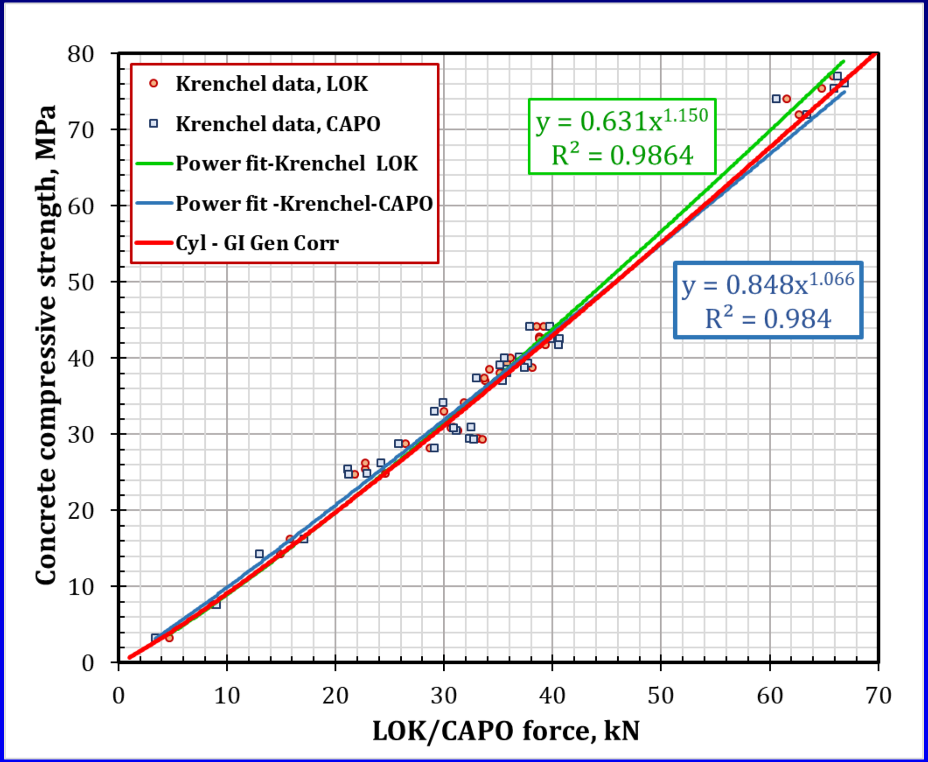
$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + \cdots + (n_m - 1)s_m^2}{n_1 + n_2 + \cdots + n_m - m}}$$

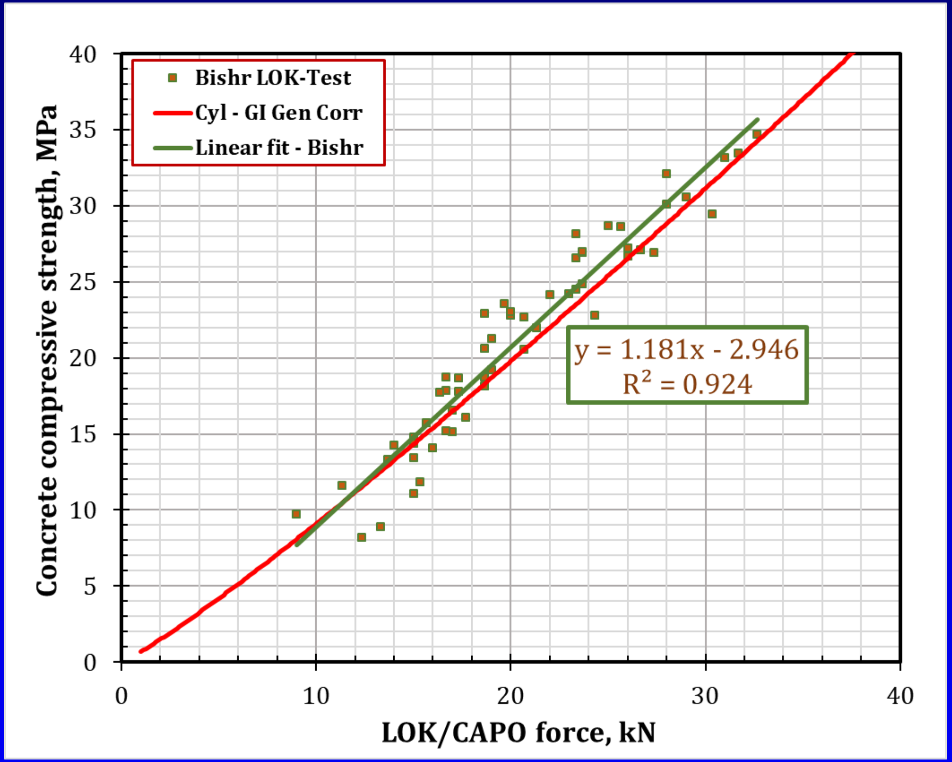
s_p = Pooled standard deviation of the data sets

$n_{i \cdots m}$ = number of tests per set

m = number of sets

Data for calculating the Precision

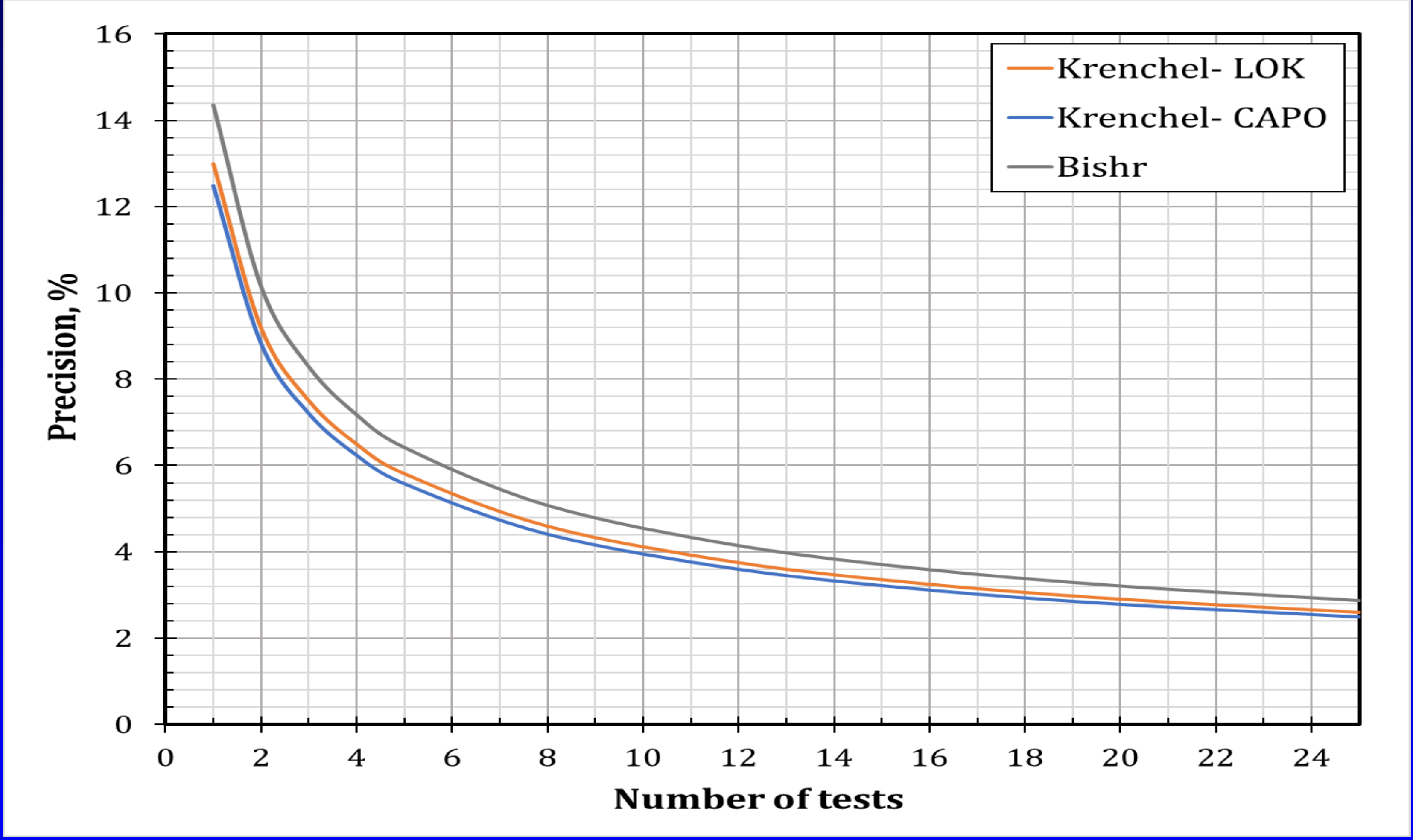




Krenchel (13 and 14)

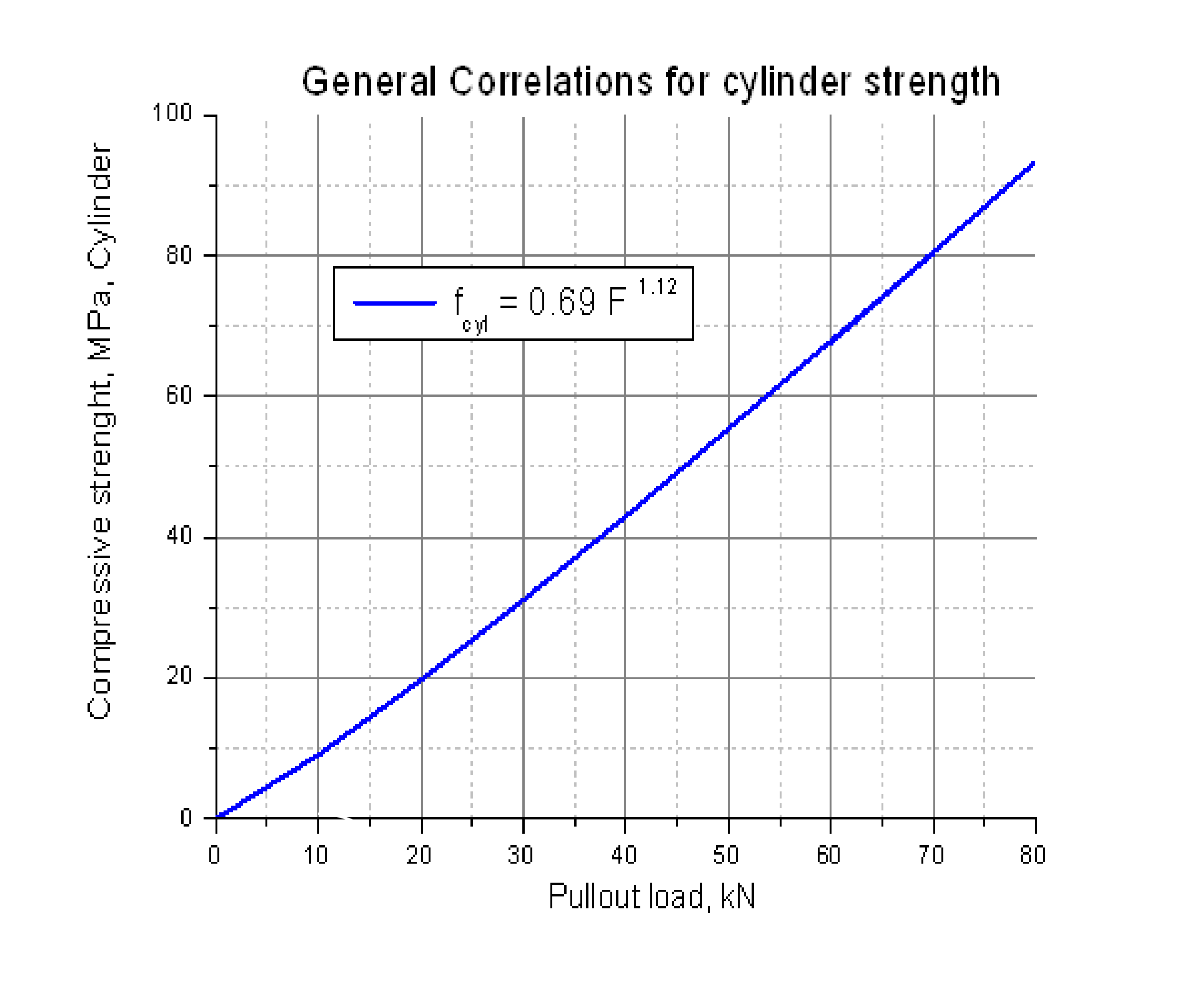
Bishr (19)

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

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



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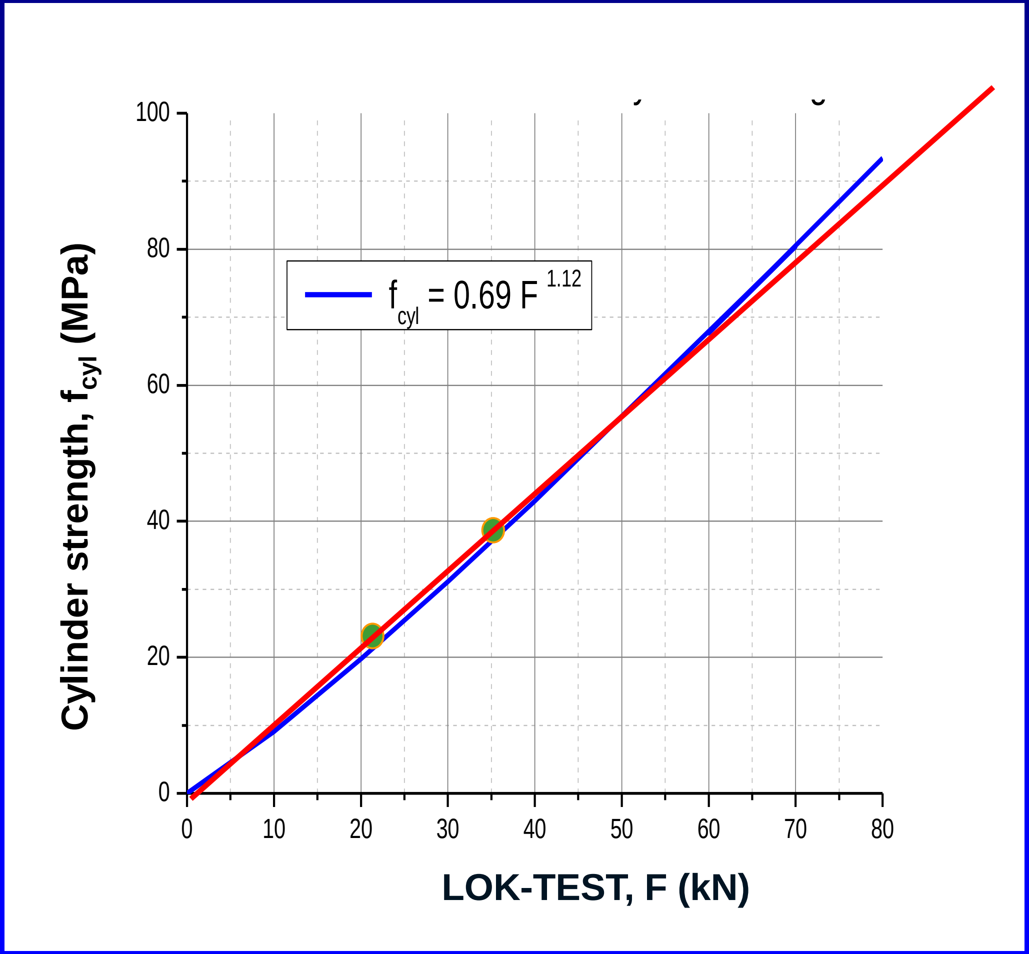
Theoretical investigations relating LOK-TEST pullout force F in kN to cylinder compressive strength f_{cyl} in MPa, compared to the General Correlation for cylinders $f_{cyl} = 0.69\ F^{1.12}$

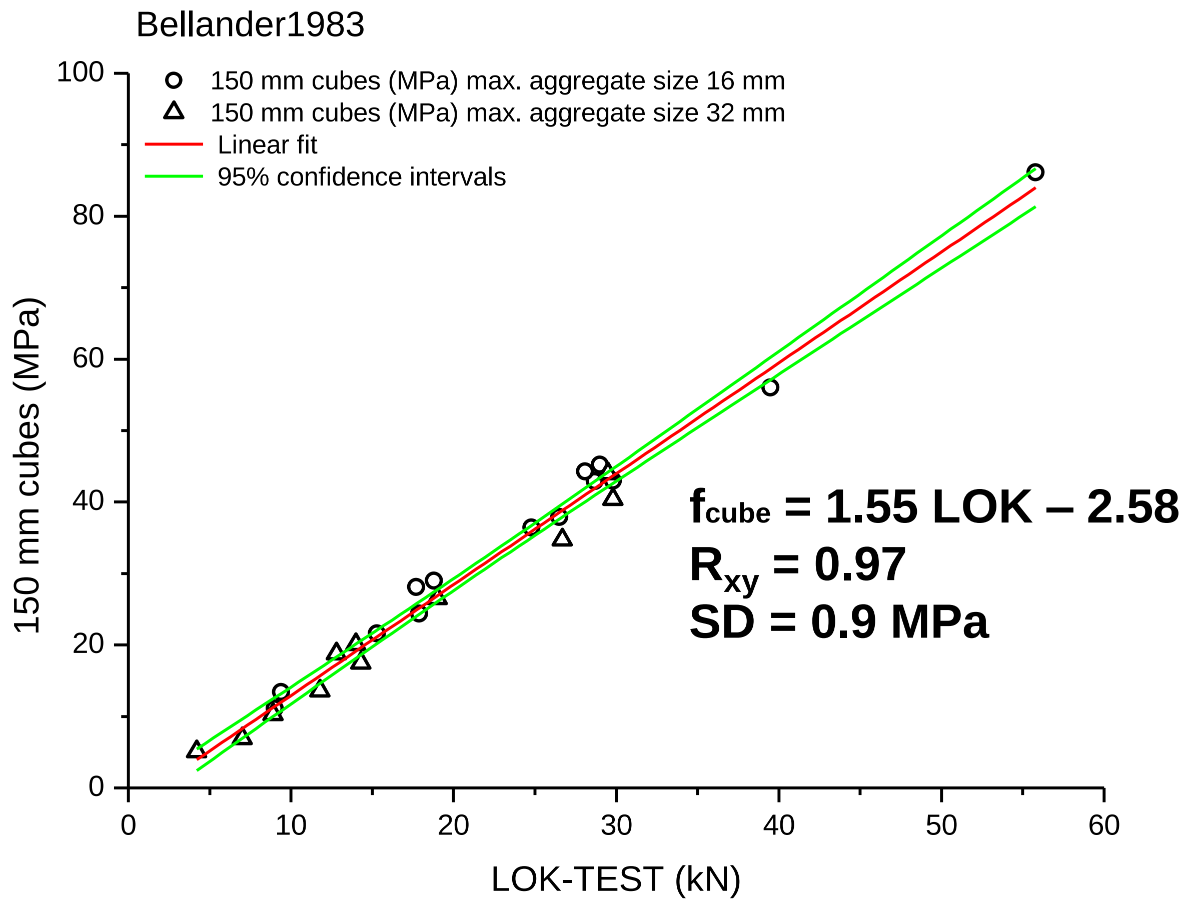


● Ottosen. N.S.: ”Nonlinear Finite Element Analysis of Pull-Out Test”, Journal of the Structural Division, ASCE, Vol. 107, No.ST4, April 1981

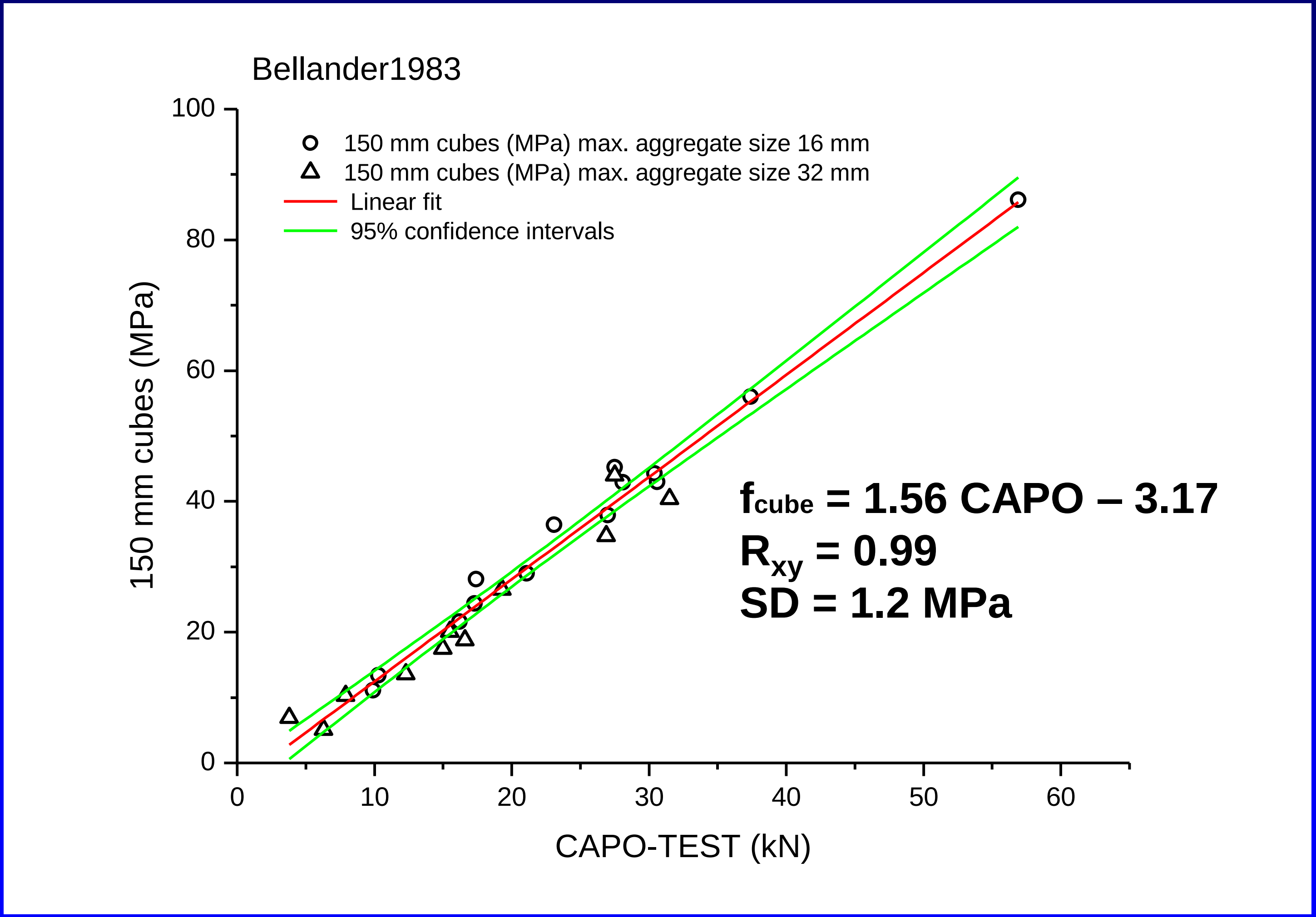
— Jensen, B.J. & Bræstrup, M.W.: ”Lok-Tests determine the compressive strength of concrete”, Nordisk Betong 2-1976
($F = 0.89\ f_{cyl}$)

Cube relationships

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



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



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)
2. 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 x 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

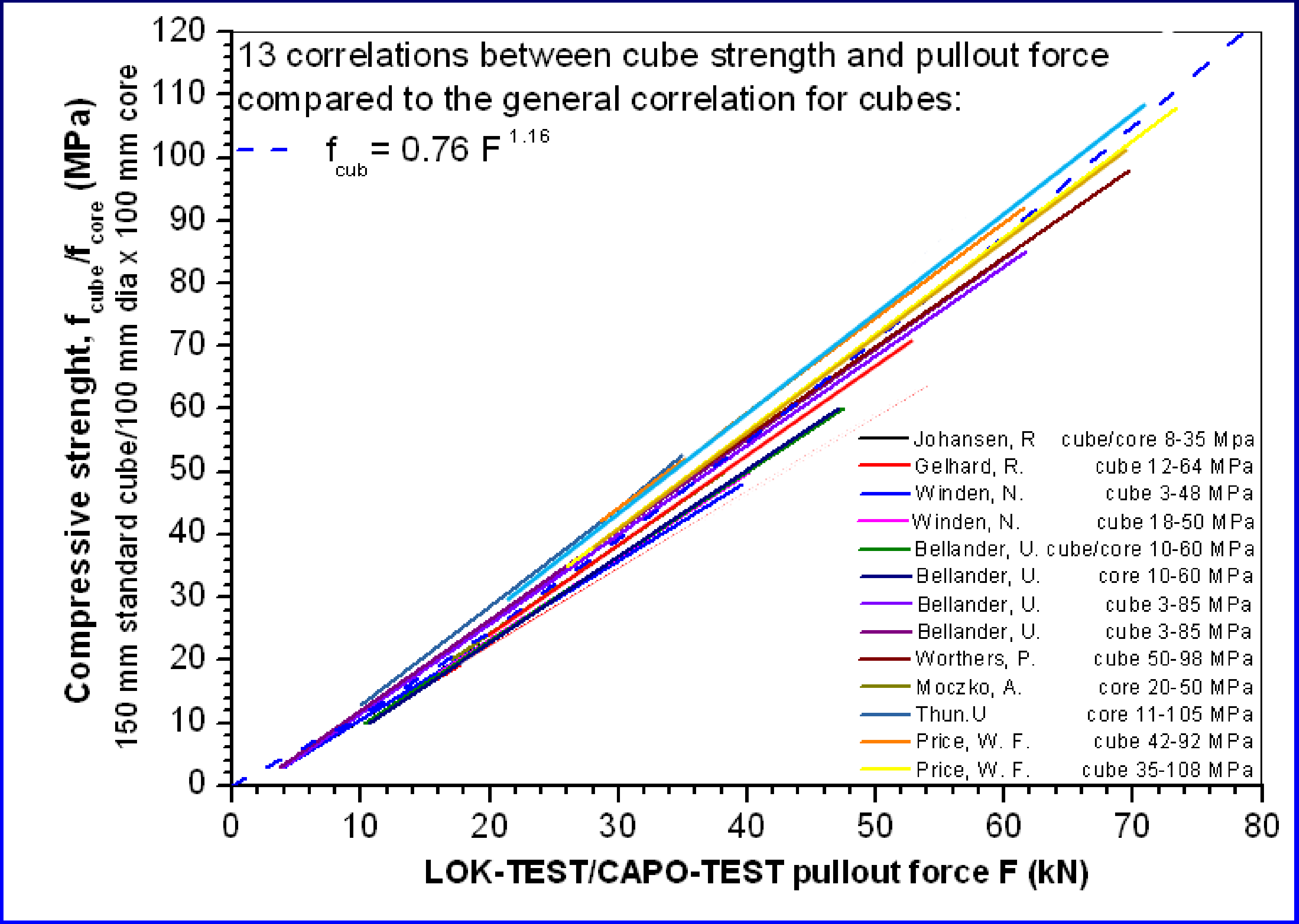
Assumption:

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

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

13 correlations to cube strength



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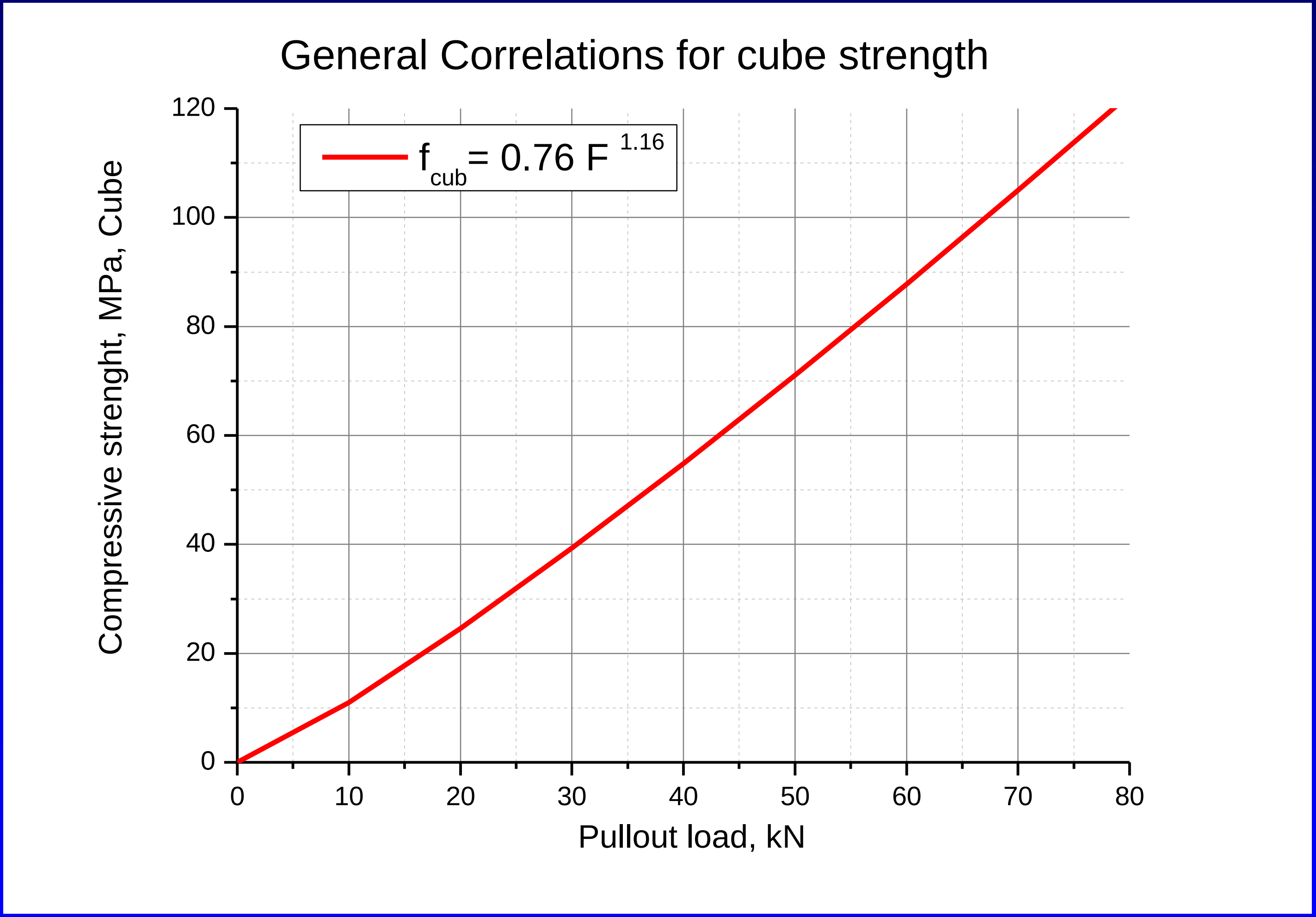
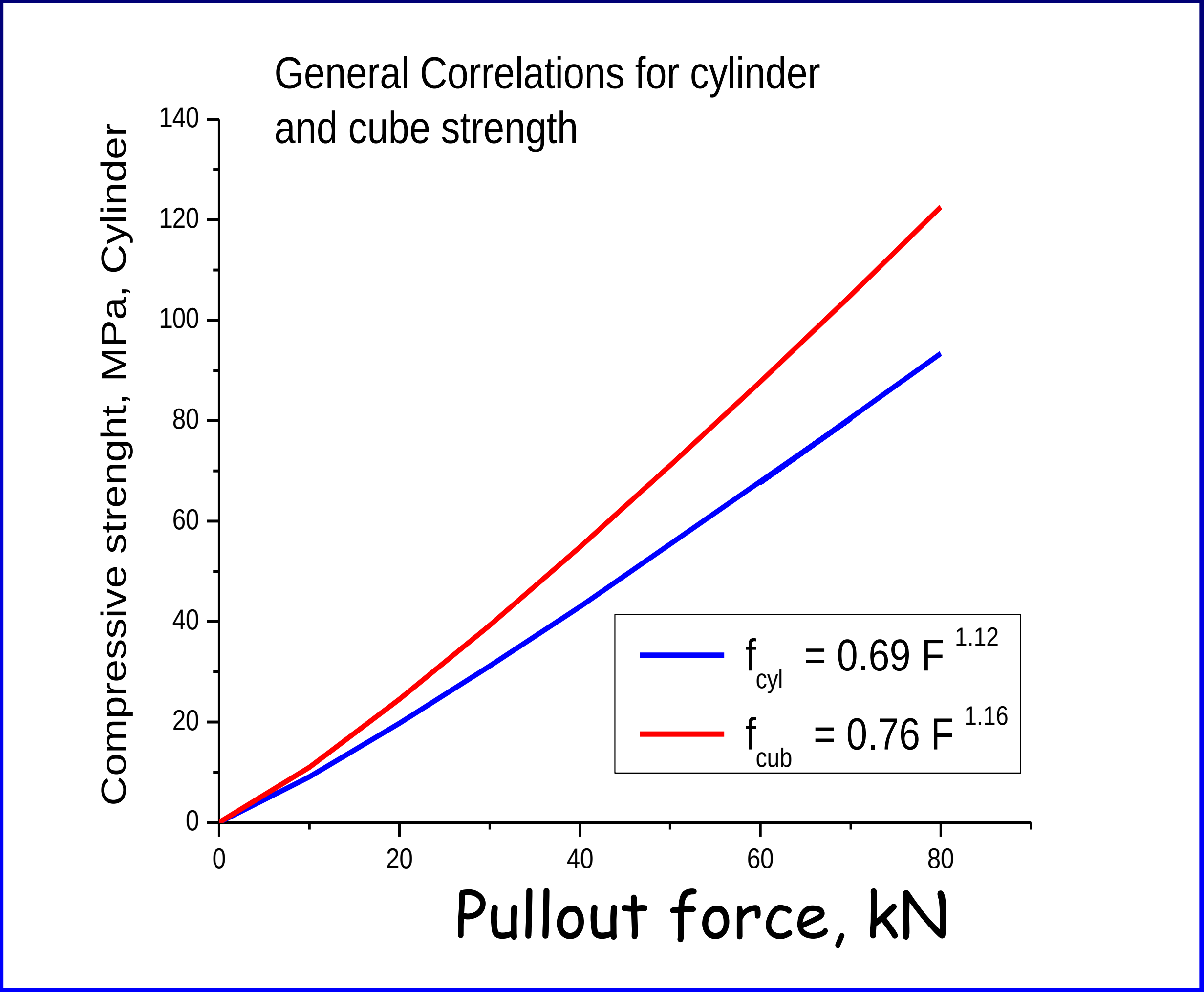
General cube – LOK/CAPO relationship



The two 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
- Carbonation
- Shape, type or size of aggregate < 38 mm
  - Lightweight aggregate, however, produce a significantly different correlation

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, On-site testing	LOK-TEST SV	n	CAPO-TEST 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

GI

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