# 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
  www.NDTitans.com

# 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

# 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 in-place 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

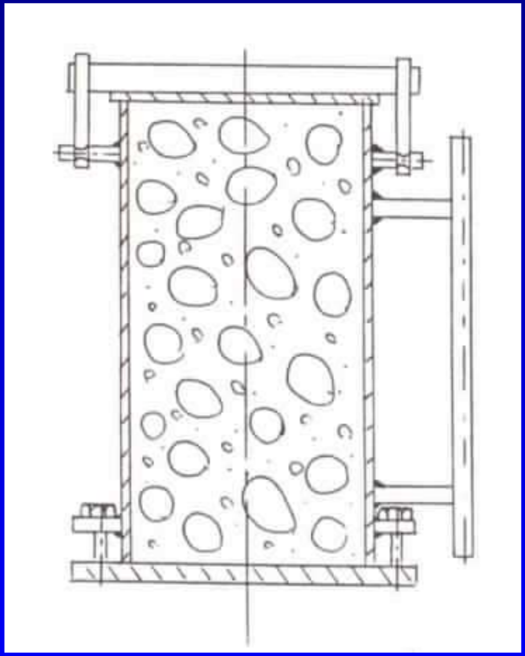
# Test Methods
# ACI 228.1R-19

- 1. Lab cylinders for potential strength

In-Situ Test Methods:

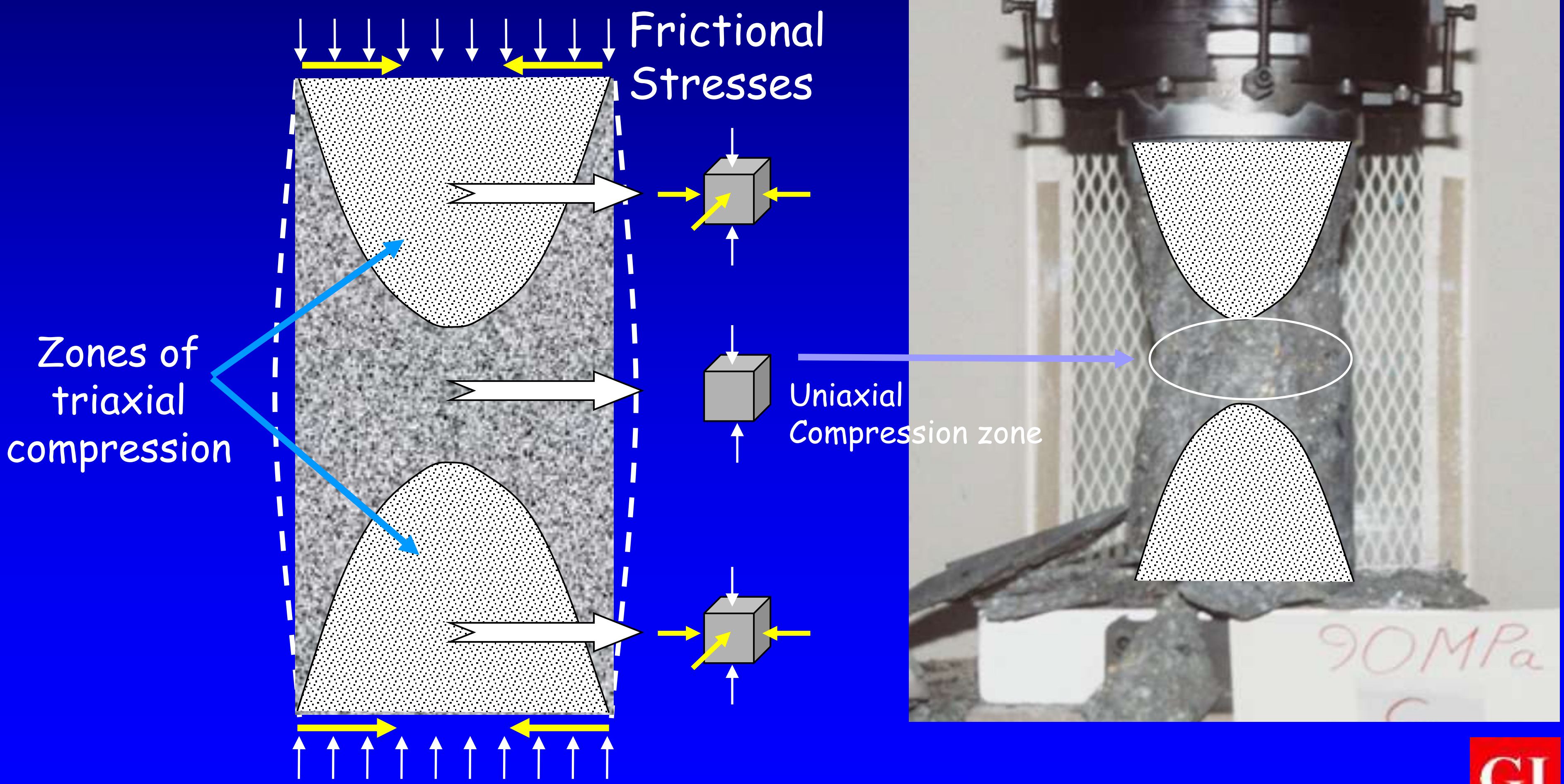
- 2. Cores
- 3. Pullout
- 4. Rebound hammer
- 5. UPV (Ultrasound)

# 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 $20^0$ C
- Tested in compression at 28 days (maturity days, $M_{20}$)

# Uniaxial compression, middle Triaxial Compression, end faces



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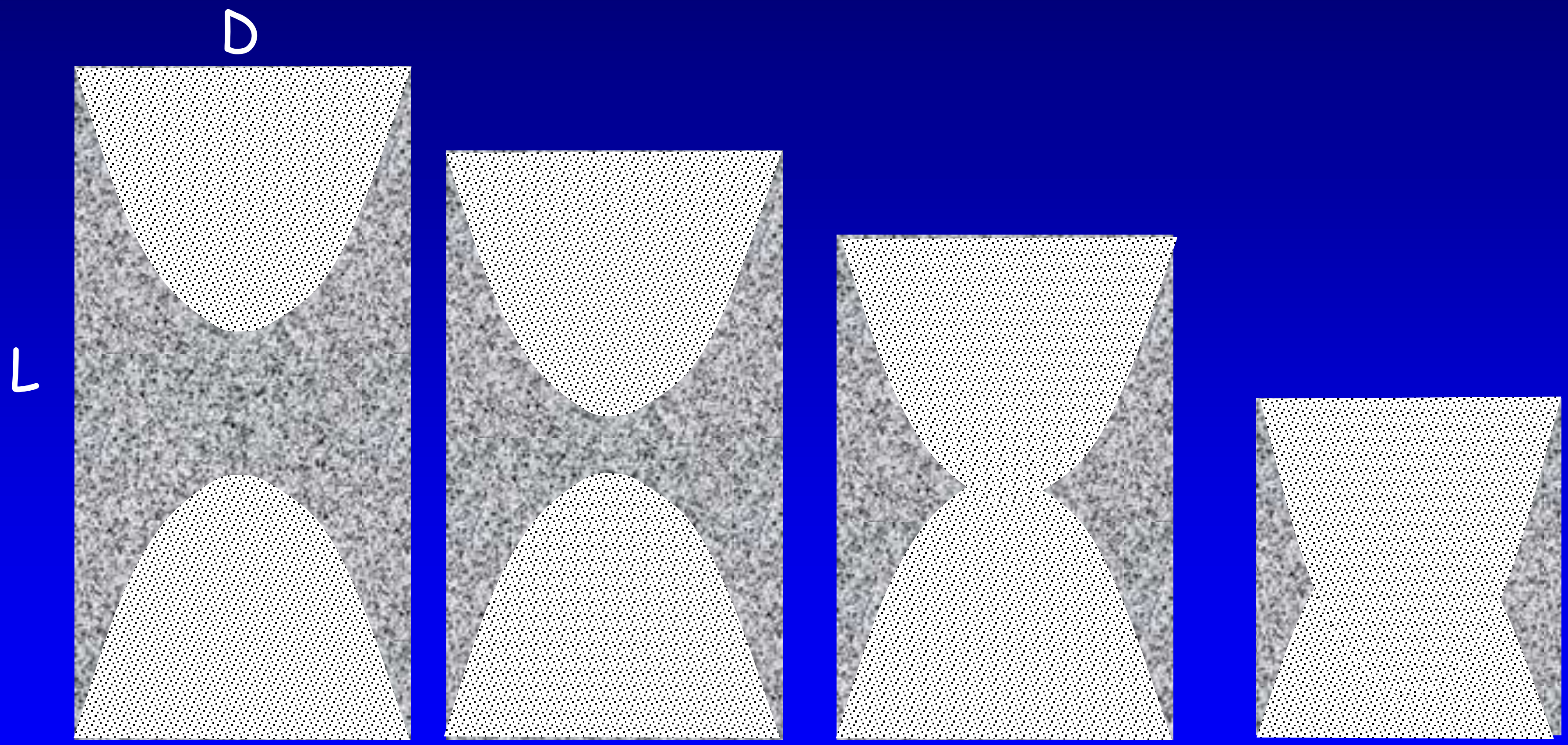
**Why is the strength from a 150 mm cube higher than a 150 mm x 300 mm cylinder ?**

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
(Reapproved 2016)

**Guide for Obtaining Cores and Interpreting Compressive Strength Results**

Reported by ACI Committee 214

American Concrete Institute®

In My **Judgment** by Adam Neville

## Core Tests: Easy to Perform, Not Easy to Interpret

Many 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 cross-sectional 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 parties, 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 suggest 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 quality of concrete corresponds to

Concrete international / NOVEMBER 2001

*Test smart – Build right*

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# Cores


# Some Factors Affecting Core Strengths

- 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

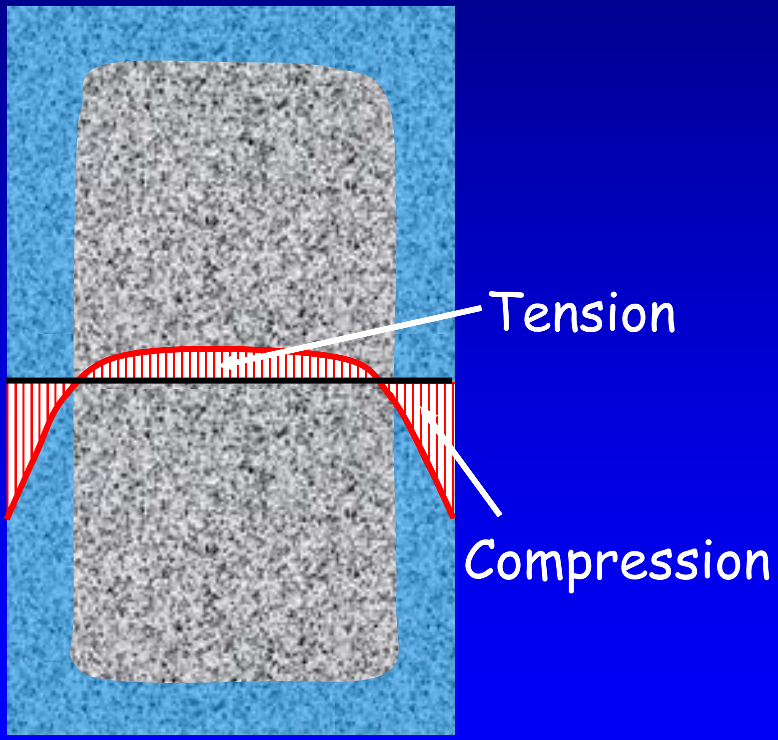
*In accordance with the provisions of ASTM C 42-90 and ACI 318-89, it is current practice to either dry concrete core specimens in air for 7 days or soak them in lime-saturated water for at least 40 hr before they are tested. In this paper, the effect of moisture condition on the strengths of mature 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*

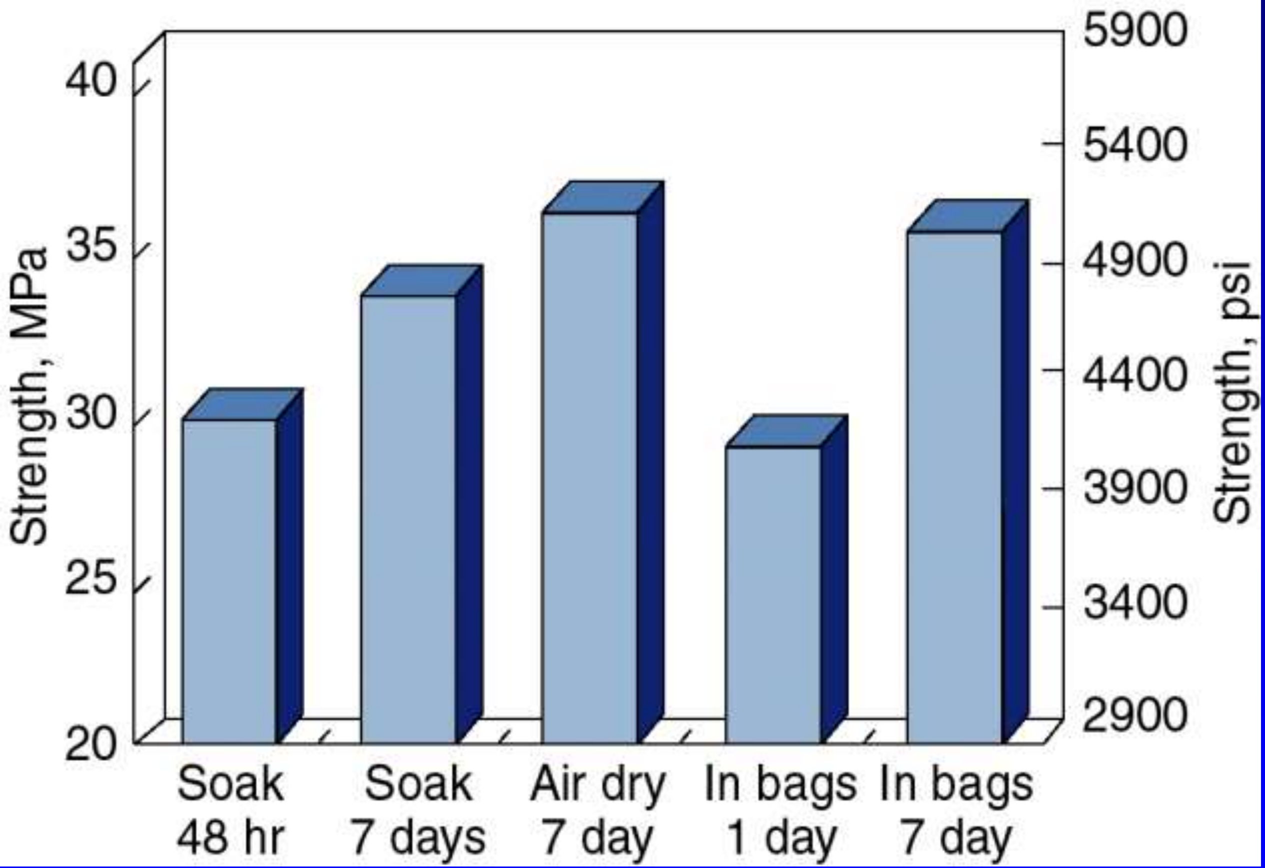
crete Society[6] recommends that cores be capped and then soaked for at least 2 days before testing. If the concrete in the structure is wet, the equivalent actual cube strength is taken to be 1.5 times the crushing strength of a core with length-to-diameter ratio equal to 1. If the concrete in the structure 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



# Effect of Core Conditioning on Strength

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# Moisture Conditioning ASTM C42/C42M

- Wipe off drilling water, surface dry
- Place in watertight containers
- Wait at least 5 days between wetting due to drilling or sawing and testing
- Other procedure permitted when required by the "specifier of tests"

# ACI 214.4R for coring

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

In-place strength

Correction for L/D

Correction for D

Correction for moisture content

Correction for "damage" due to coring

Core strength

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

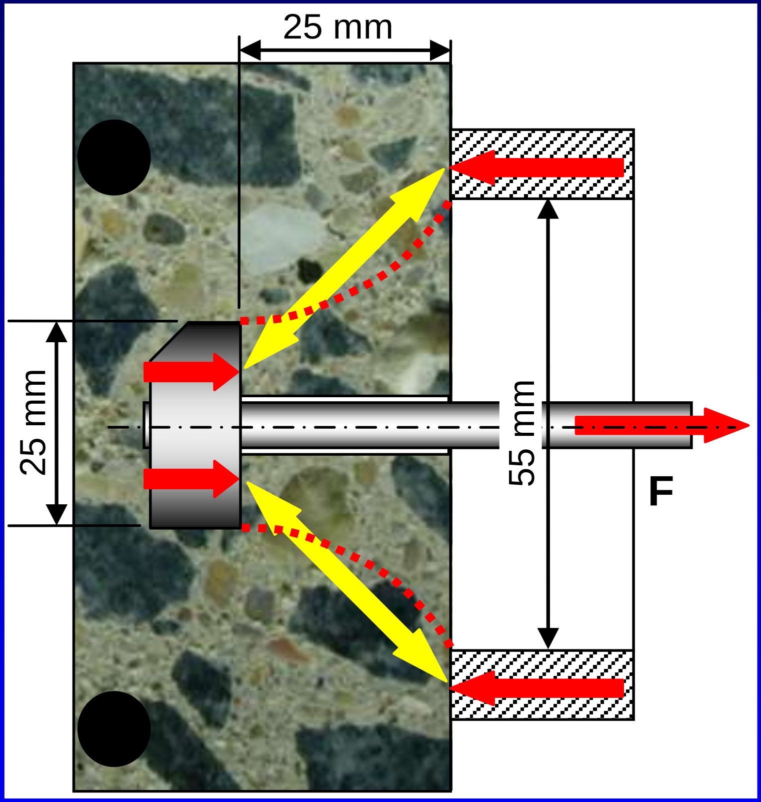
Equivalent specified strength

Statistical factor

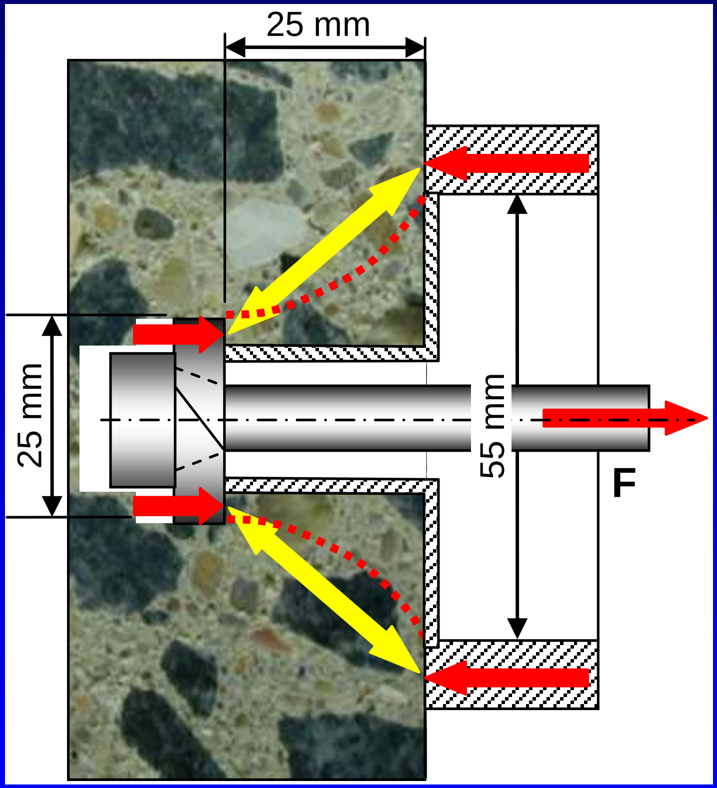
Average in-place strength

$$f_c \neq \frac{f_{core}}{0.85}$$

# 3. Pullout



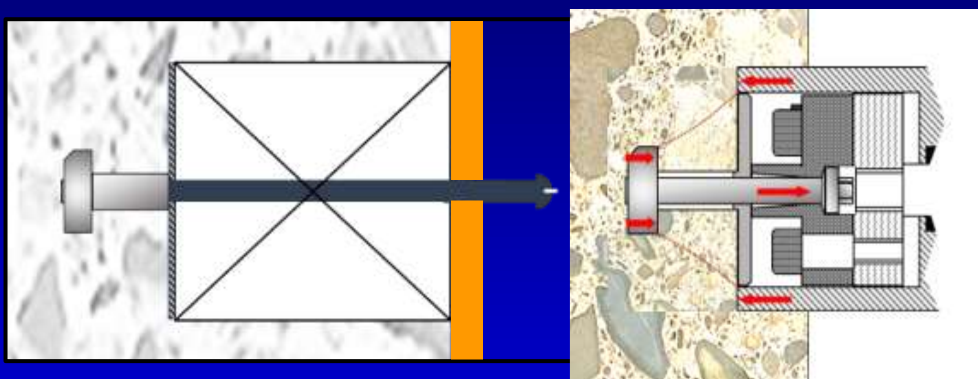

LOK-TEST




CAPO-TEST

# Testing the “interior” with pullout

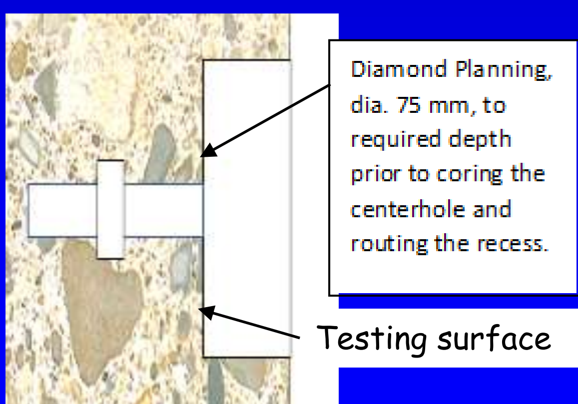
## LOK-TEST



Example:

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

## CAPO-TEST





testing surface 5 mm deep


testing surface 32 mm deep

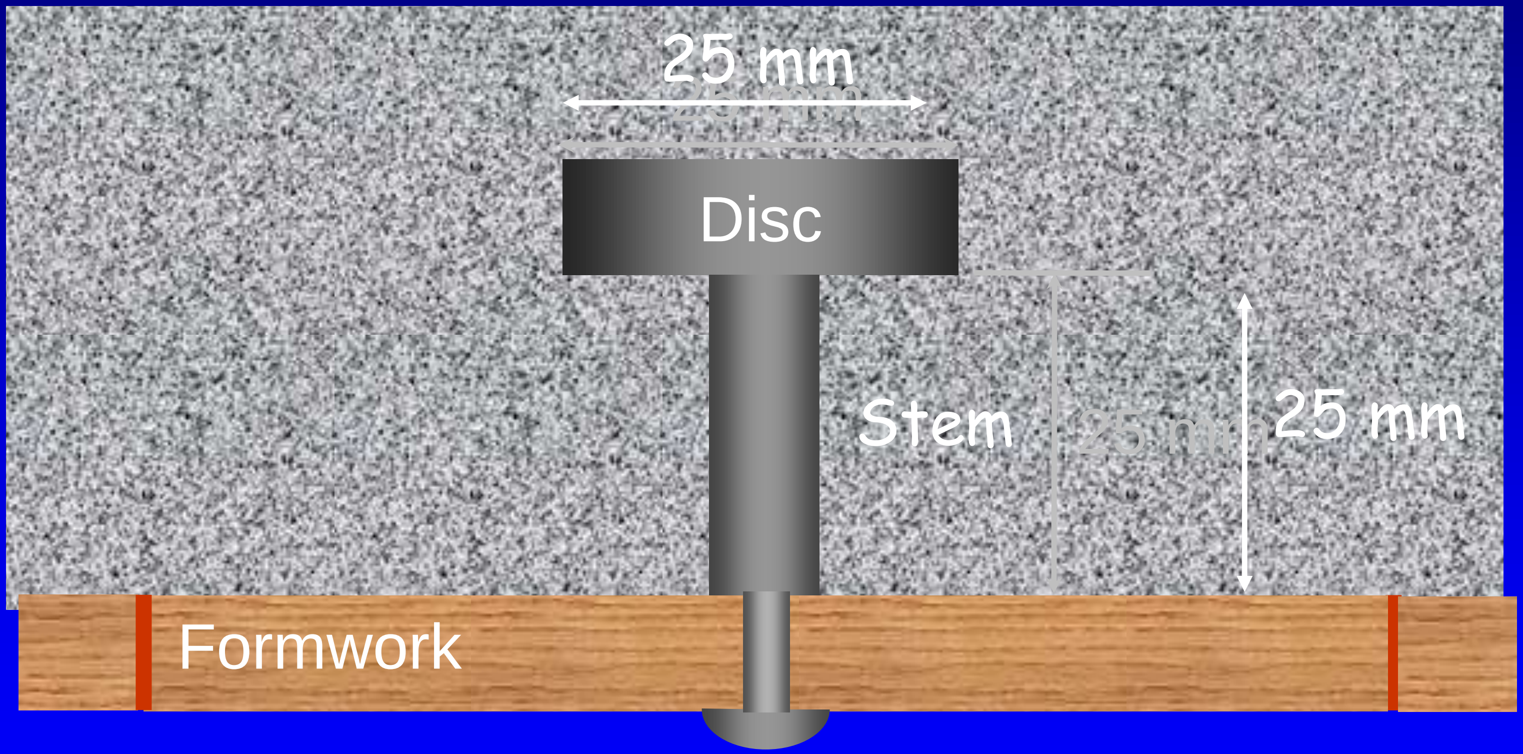
Example:

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

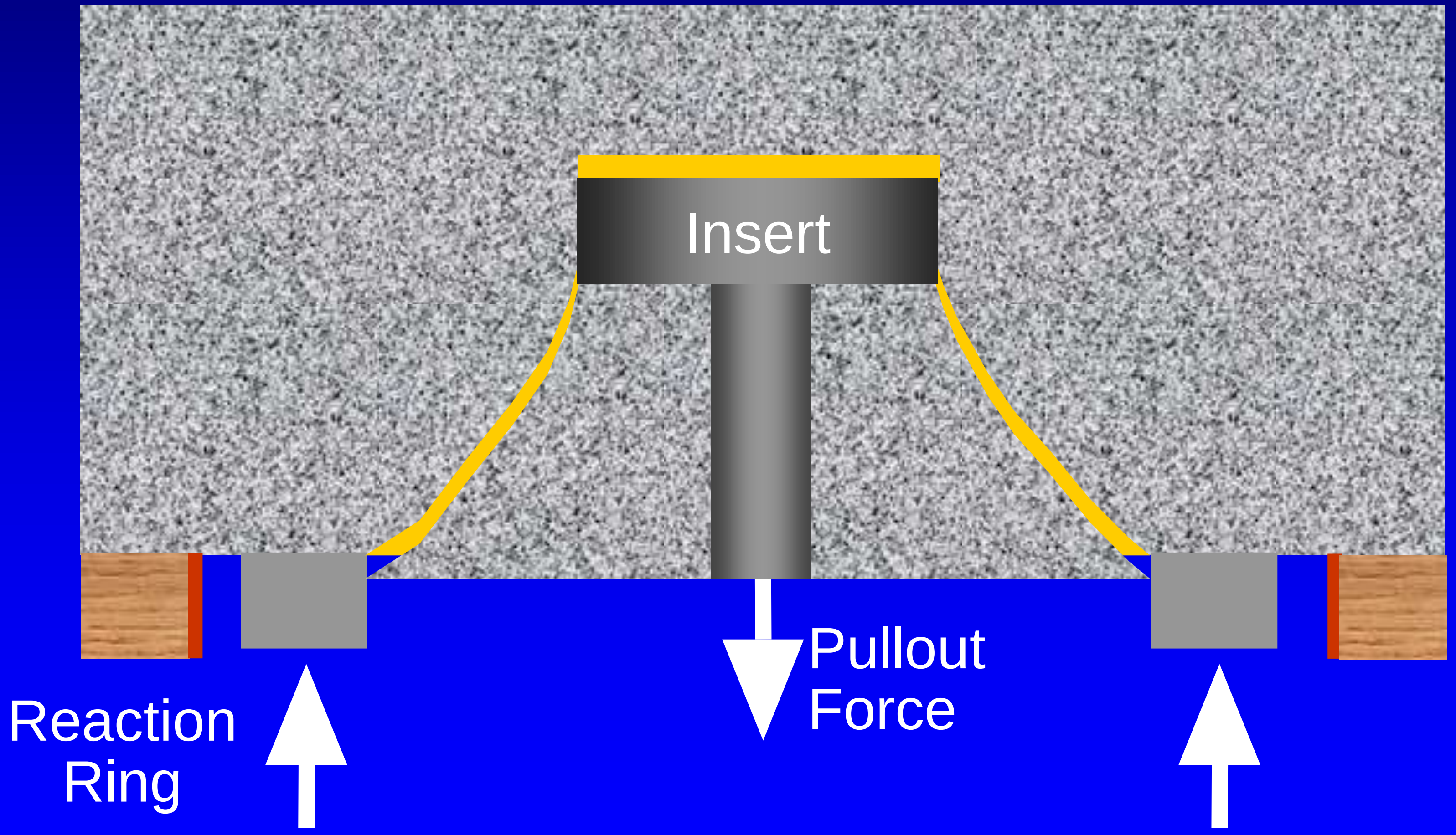
# LOK-TEST
# for new structures

- 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

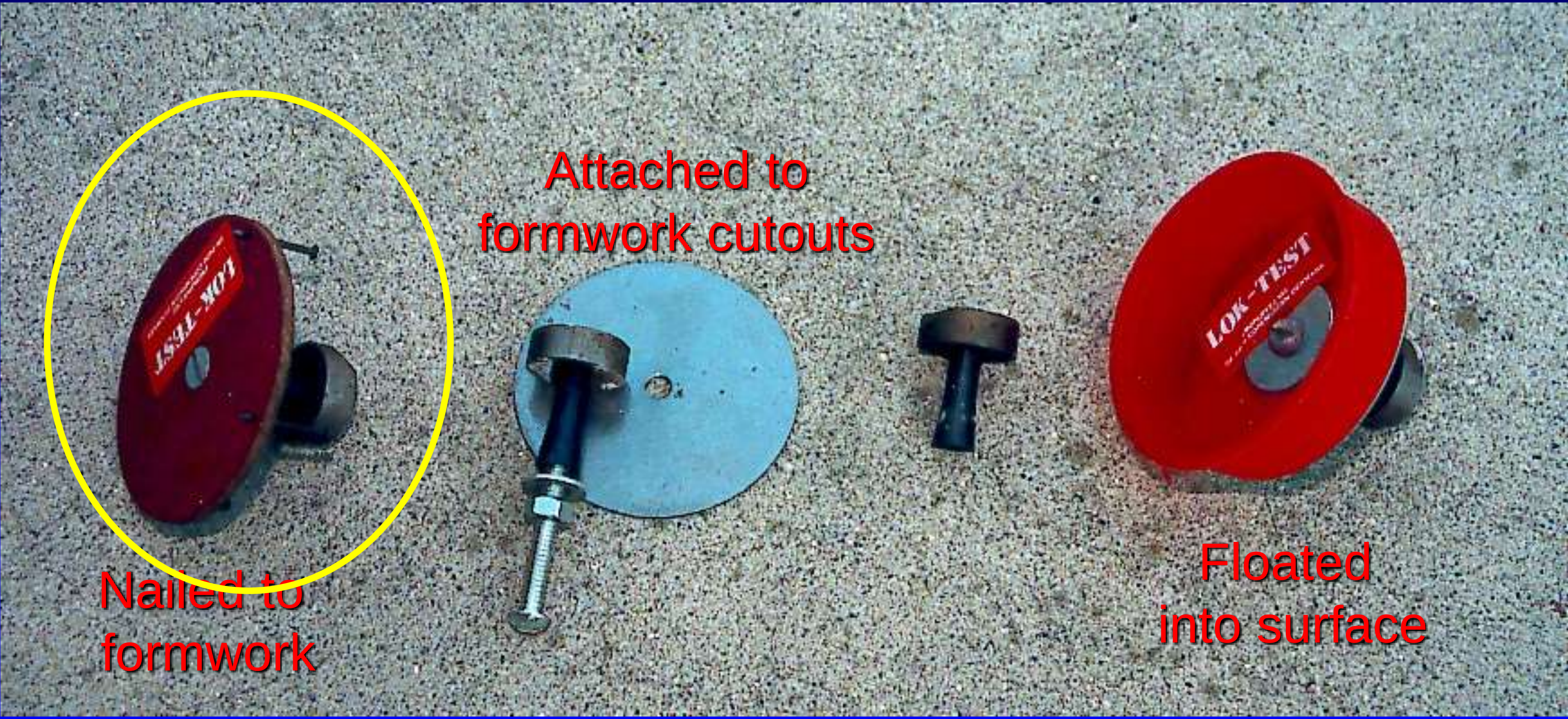
# LOK-TEST



# LOK-Test Pullout

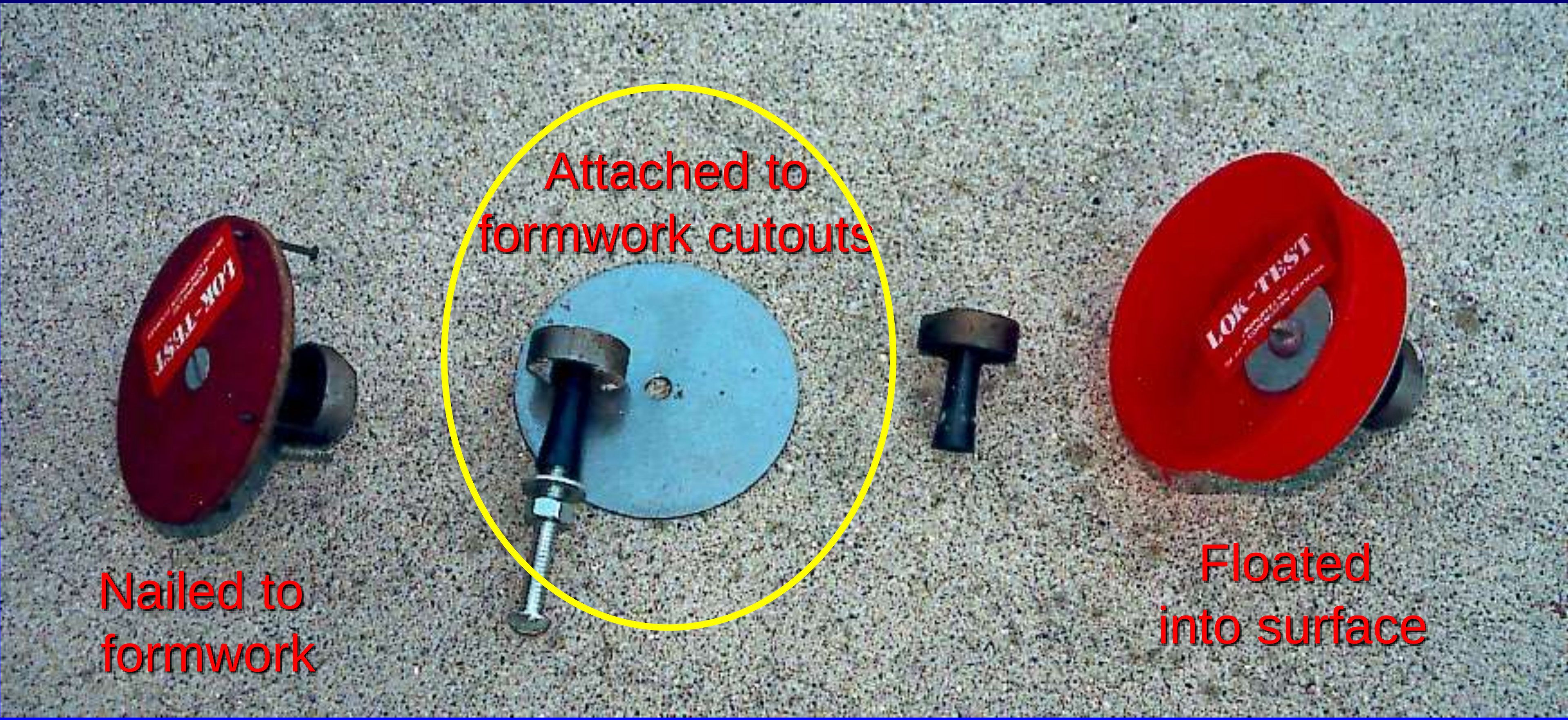


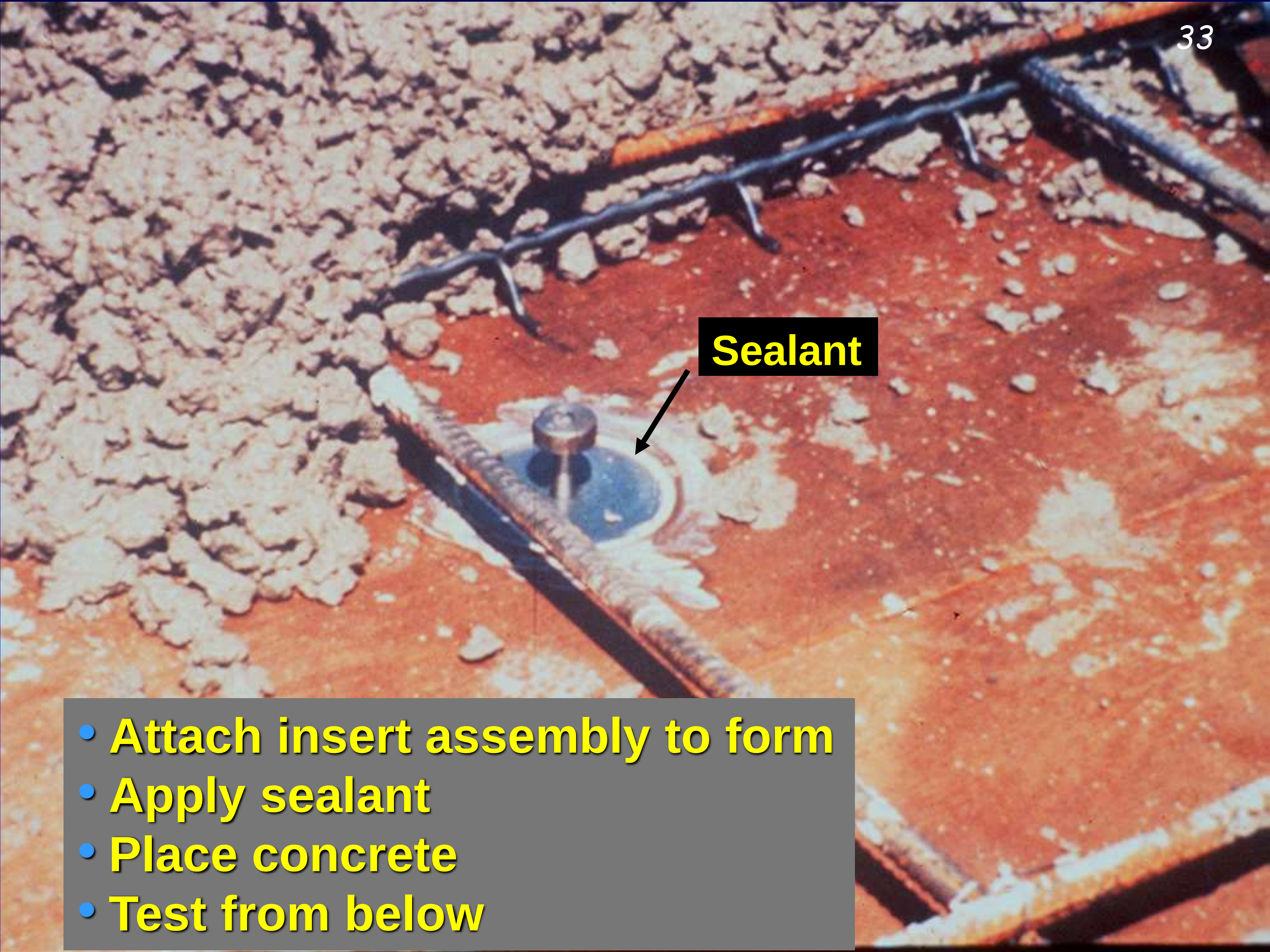
# Insert Hardware



# Nailing (L-40)

# Insert Hardware



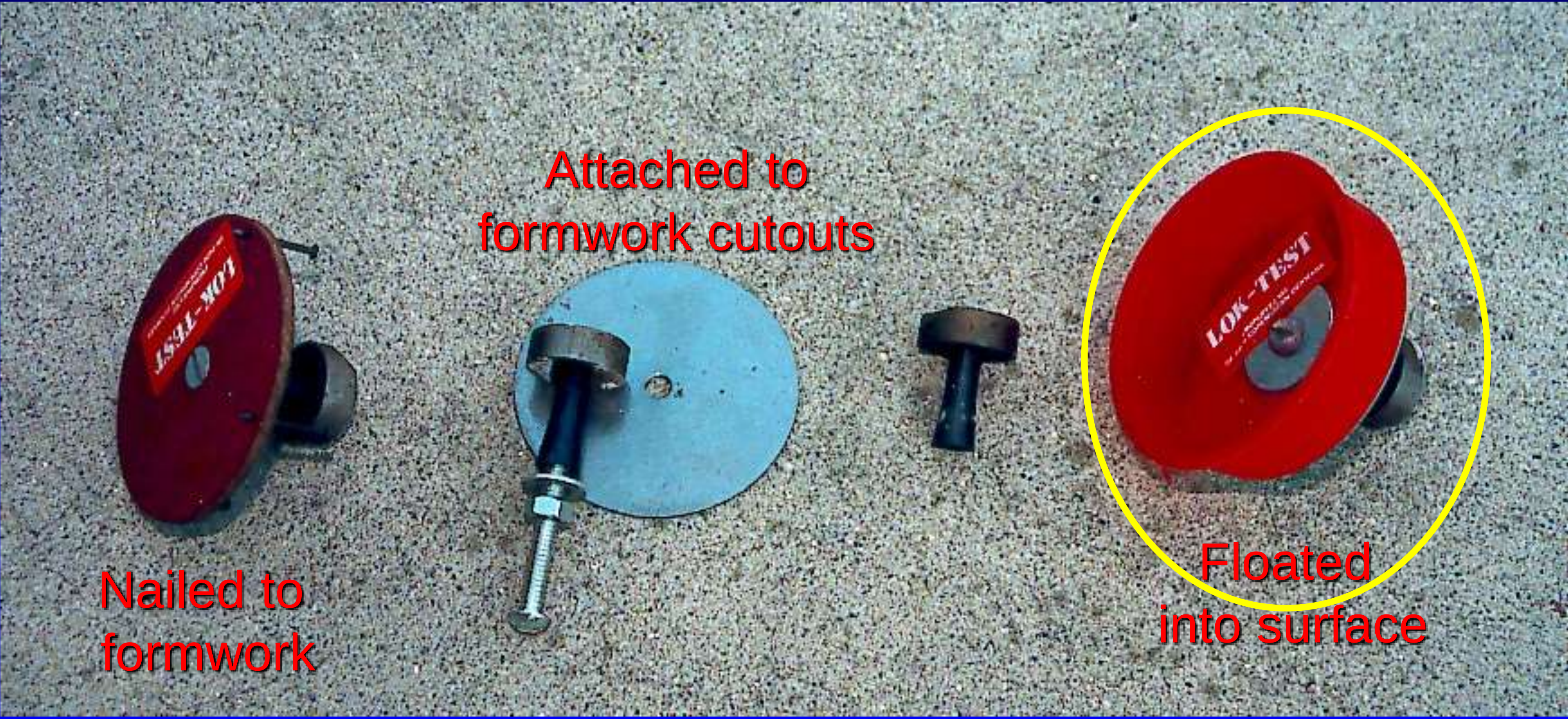



- **Attach insert assembly to form**
- **Apply sealant**
- **Place concrete**
- **Test from below**

# LOK-TEST for early and safe loading operation

10 inserts tested in less than 1 hour

# Insert Hardware



# Floating (L-49)



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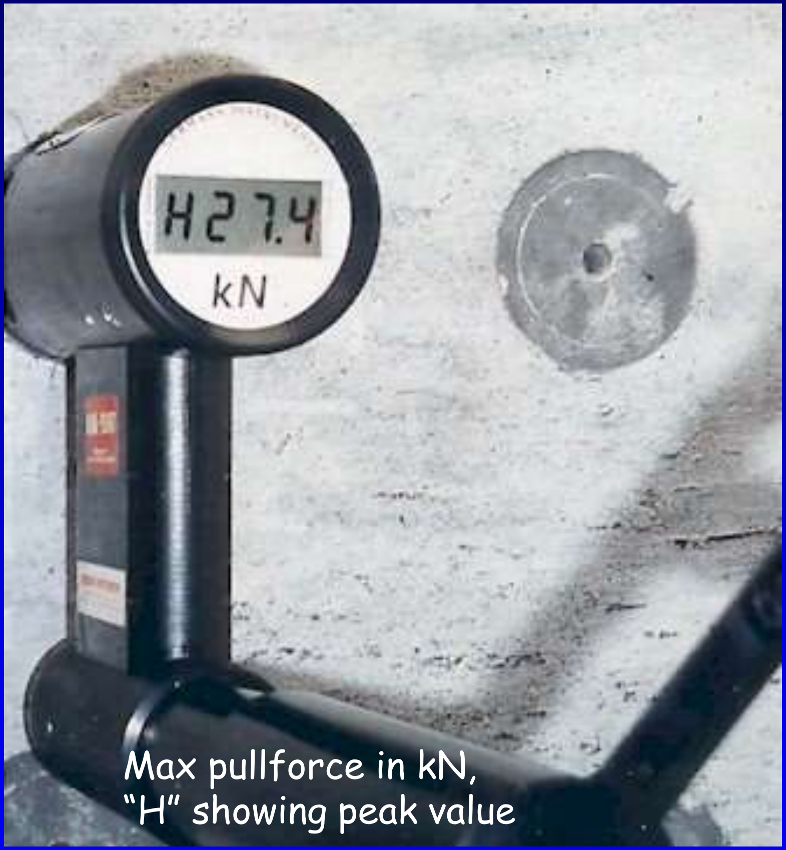
# LOK-TEST

## *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

For pre-installed LOK-TEST inserts, the test provides a reliable strength measurement in less than 5 minutes

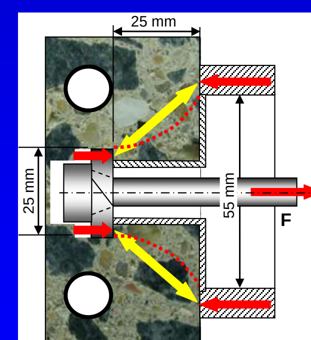
# CAPO-TEST for existing structures

## *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 conjested reinforcement areas after location of the reinforment




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

# Other Examples


London, UK
Strength of industrial floor


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


Great Belt Link, Denmark
Strength of cover layer

# Failure Mechanism

# 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"

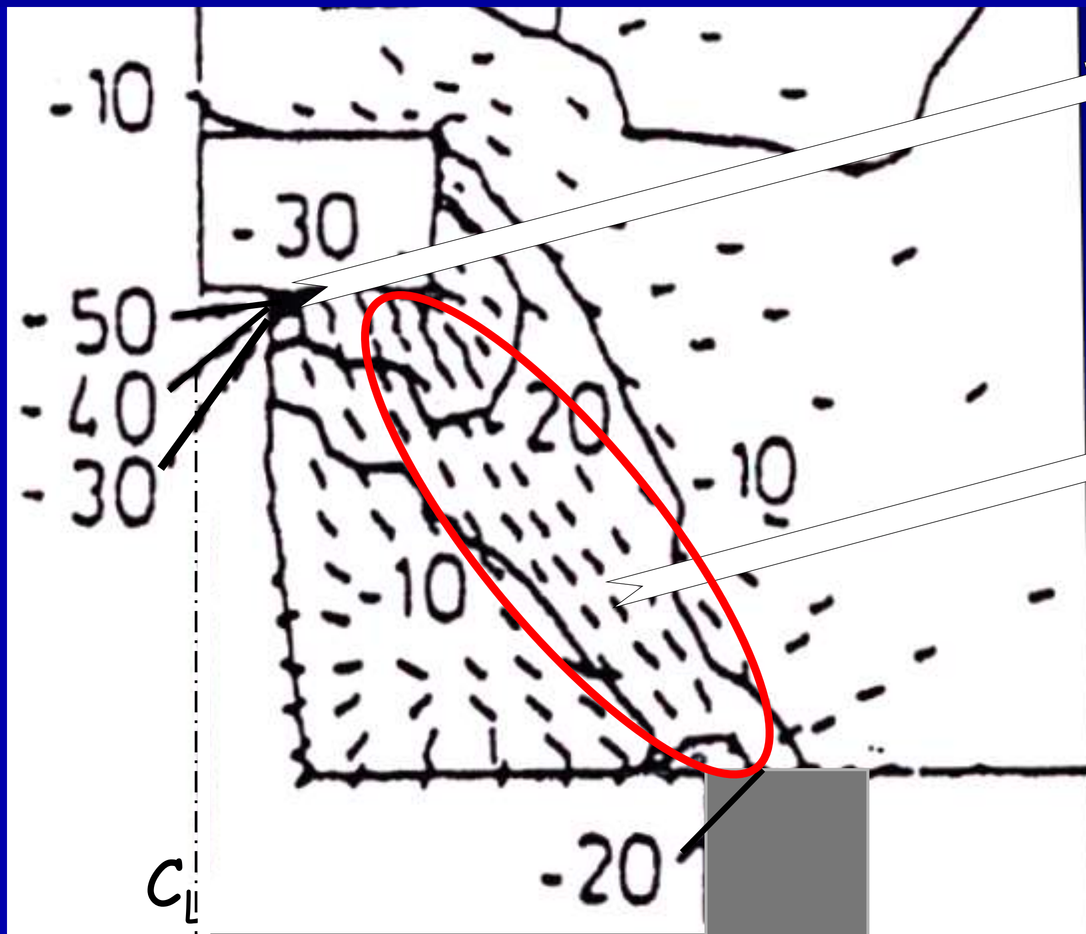
# Analysis by Ottosen

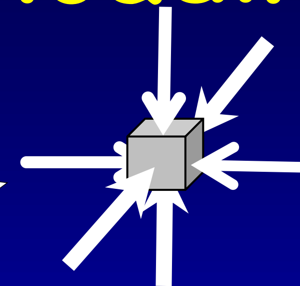
- Ottosen, N.S.: "Nonlinear Finite Element Analysis of Pull-Out Test", Journal of the Structural Division, ASCE, Vol. 107, No ST4, April 1981

# Stress curves at 65% loading

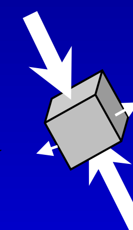
Stresses in MPa are negative when stresses are compression

Ref Ottosen p. 597



"Strut" stress of 20 MPa

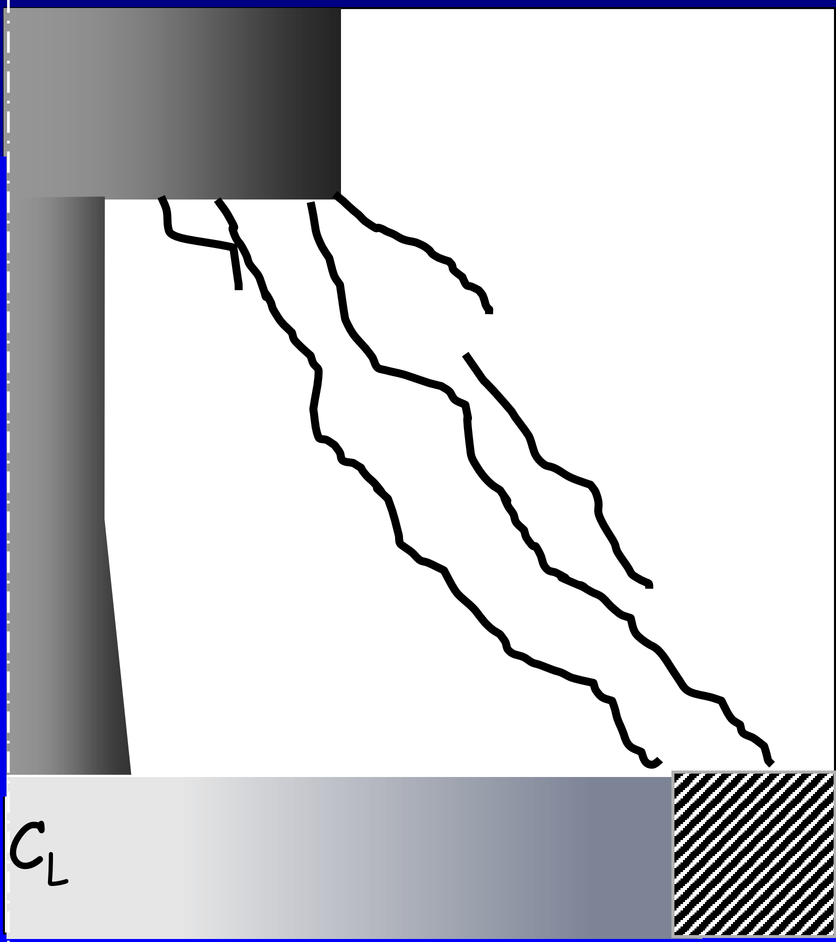


Large compressive forces run from the disc in a band ("strut") towards the support. The stress state in this strut is biaxial compression superimposed by small tensile stresses

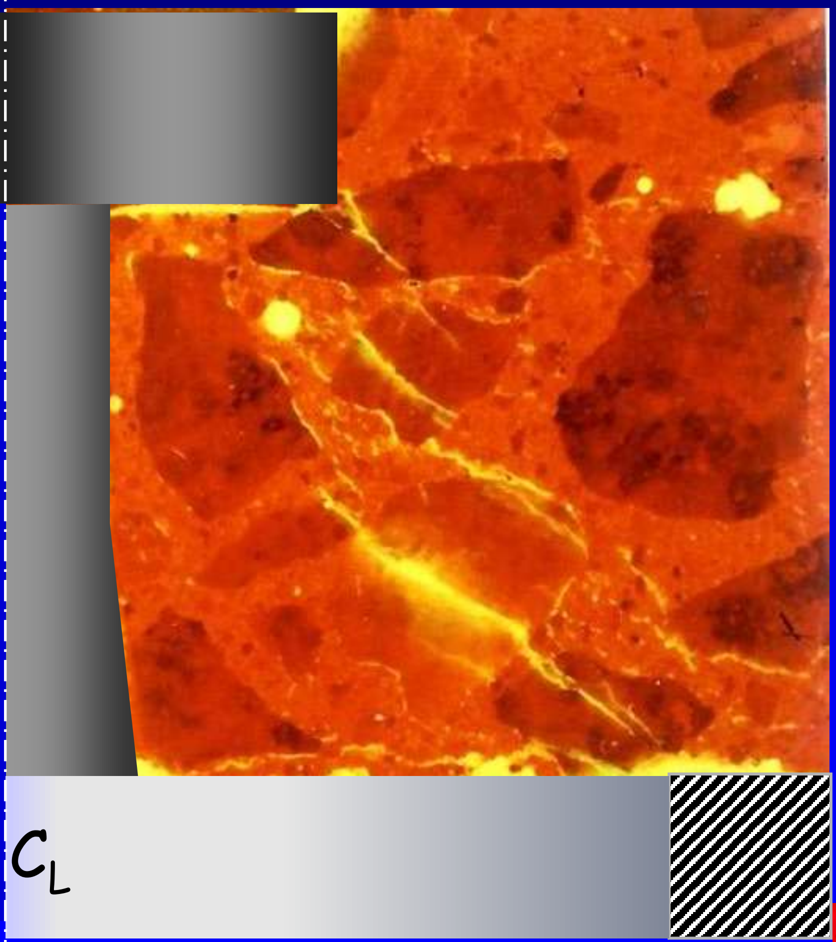
Calculations are made for a uniaxial compressive strength of 31.8 MPa. Note the much higher stresses (up to 50 MPa) are present right below the disc due to concentrated tri-axial loading in this area.

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

Ref.: Ottosen, N.S.: Nonlinear Finite Elelement Analysis 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

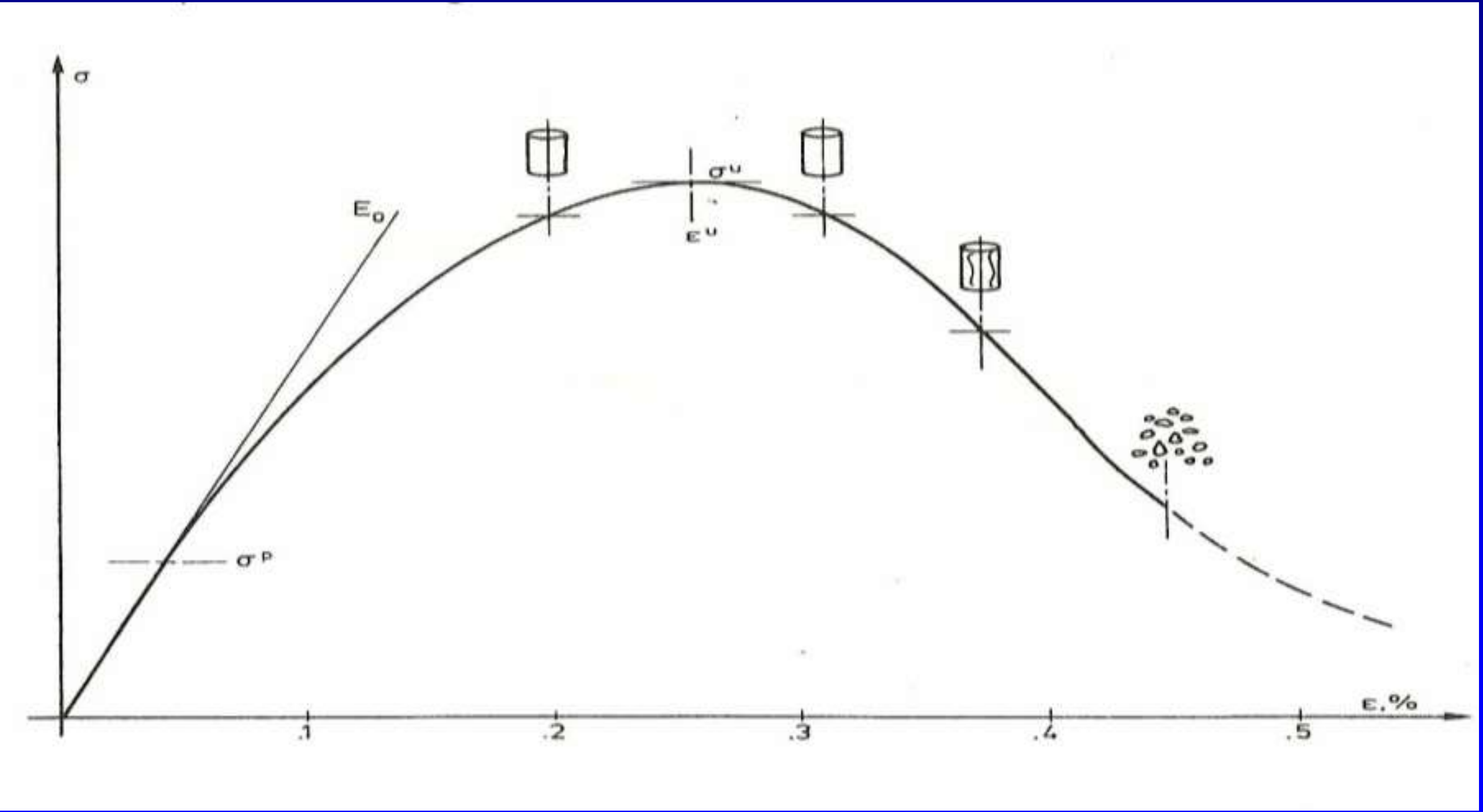
Krenchel, H. & Shah, S.P.: "Fracture analysis of the pullout test", Dept. of Structural Engineering, Technical University of Denmark, RILEM, Materials and Structures, Dunod, Nov-Dec. 1985 no 108

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

Linearity ⟷ Compression ⟷ Softening regime



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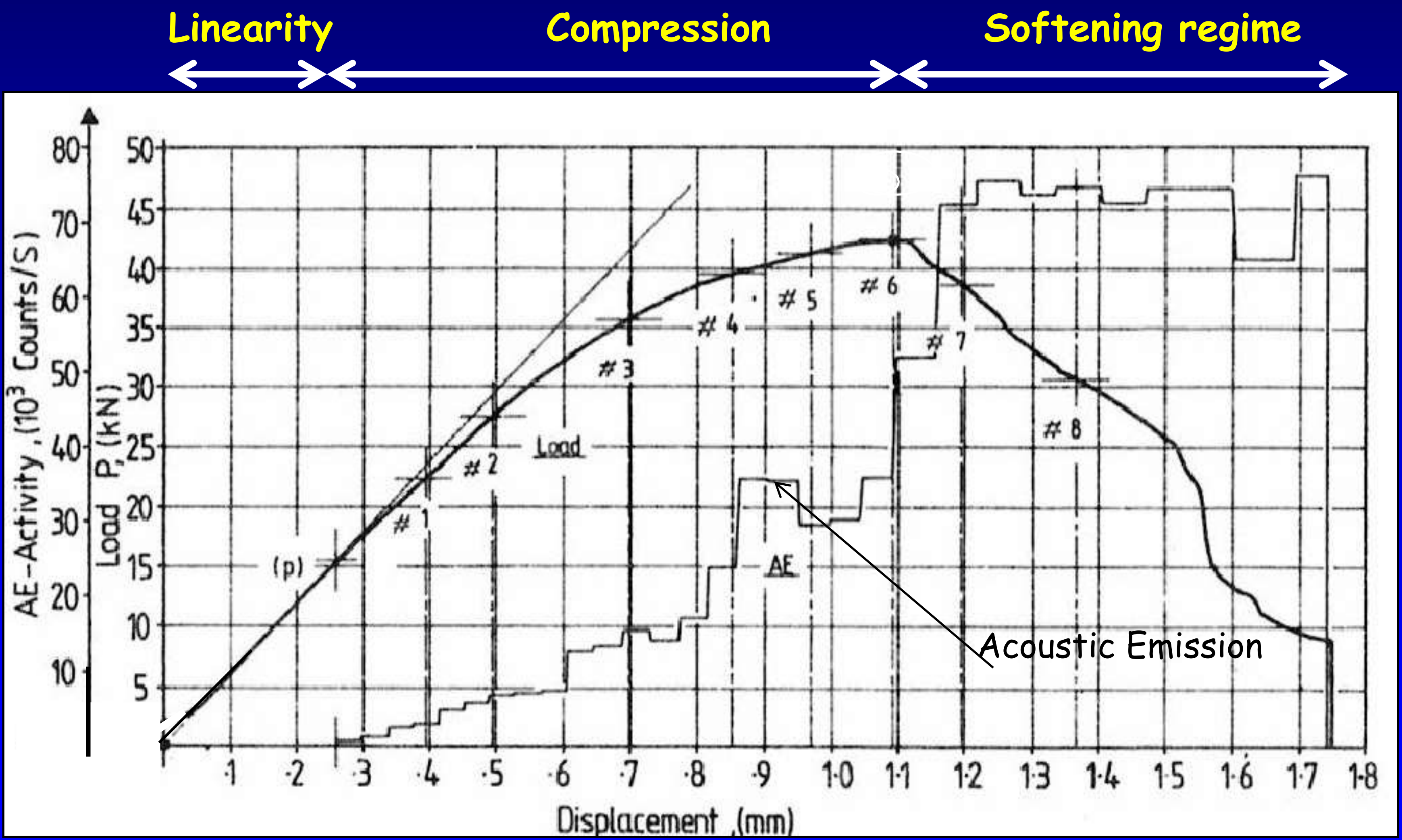
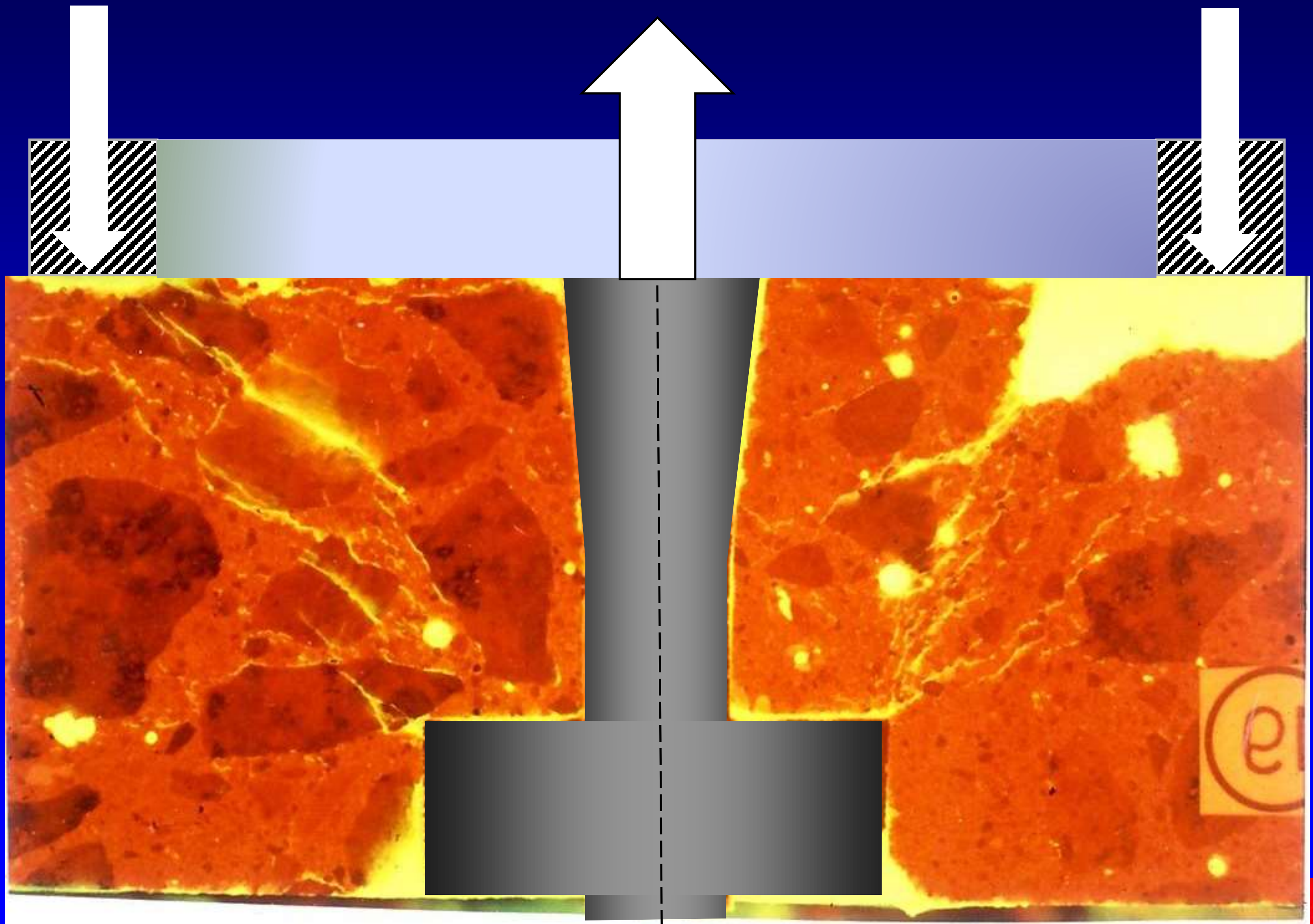
# Load displacement curve for pullout test



# 98% load level





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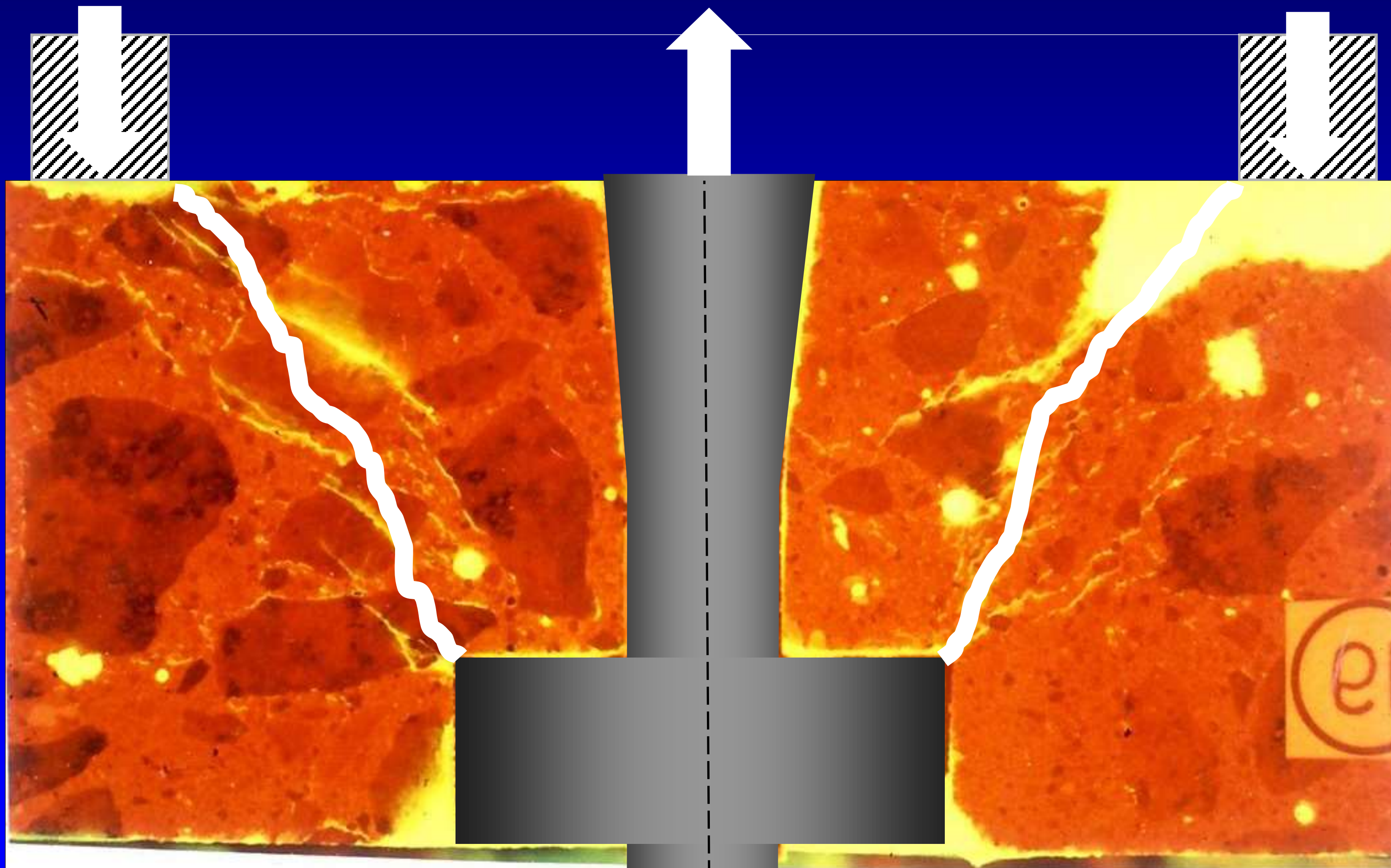
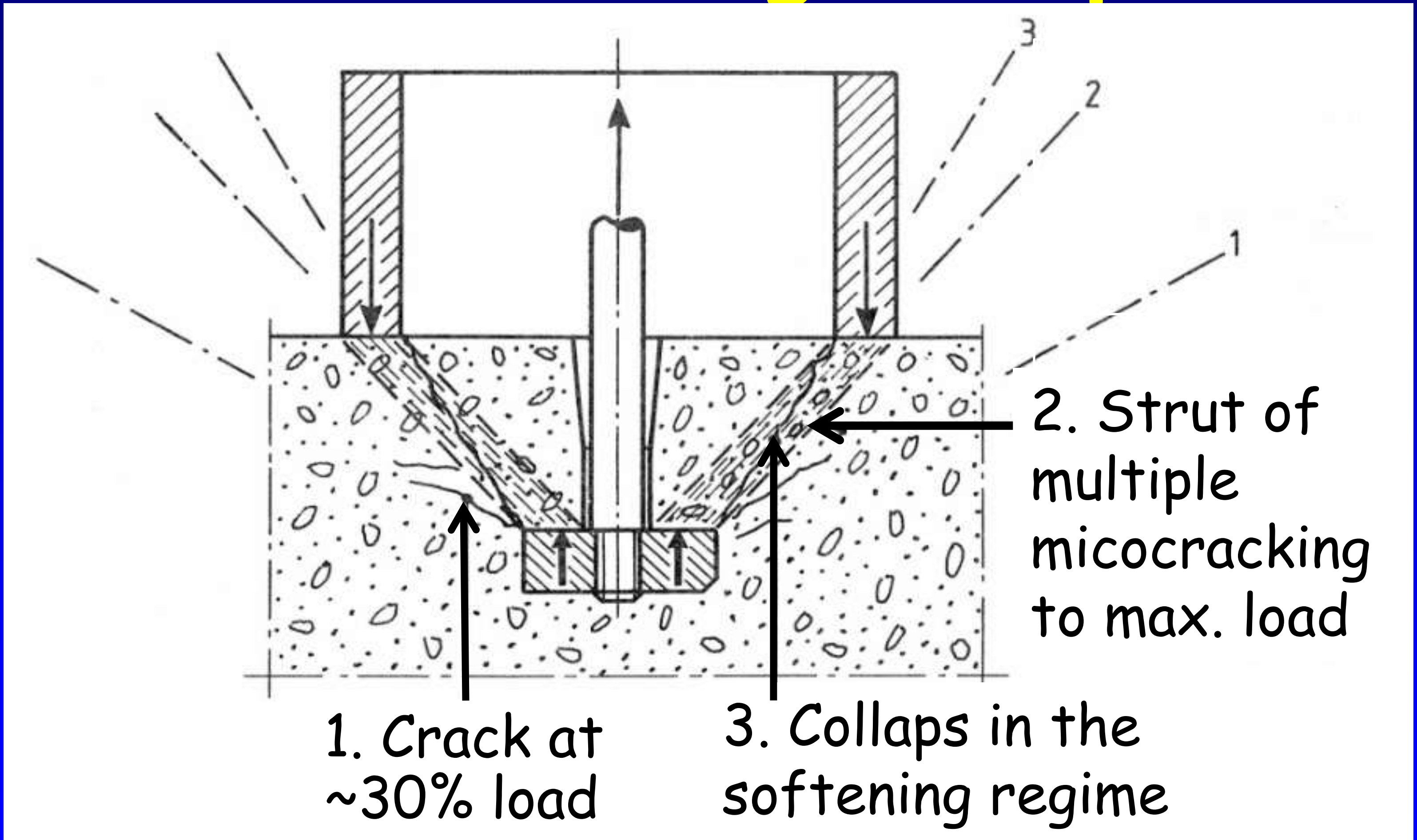
# Situation at collaps into the softening regime

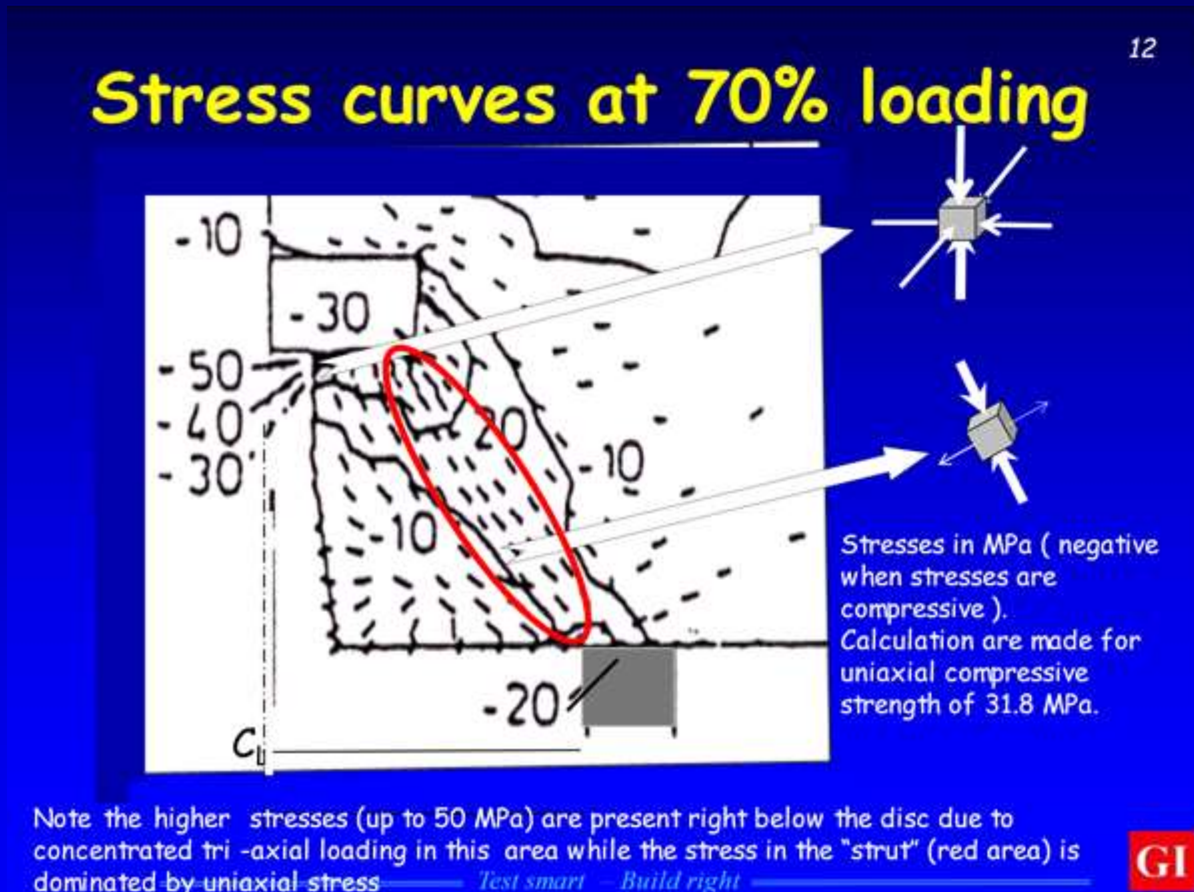


# The three different stages of internal cracking in a pullout

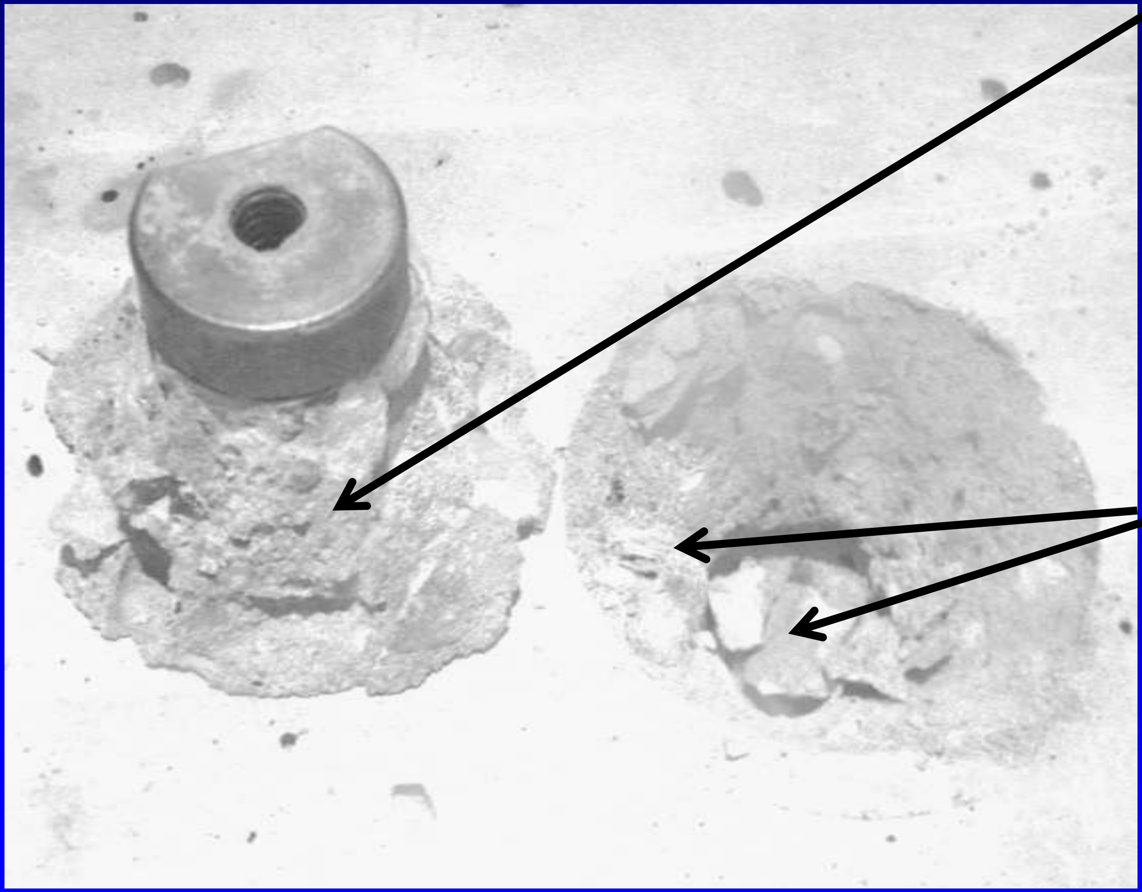


# Explanation

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


12
Stress curves at 70% loading
-10
-30
-50
-40
-30
20
-10
-10
-20
C
Stresses in MPa ( negative when stresses are compressive ). Calculation are made for uniaxial compressive strength of 31.8 MPa.
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
Test smart – Build right
GI

# 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



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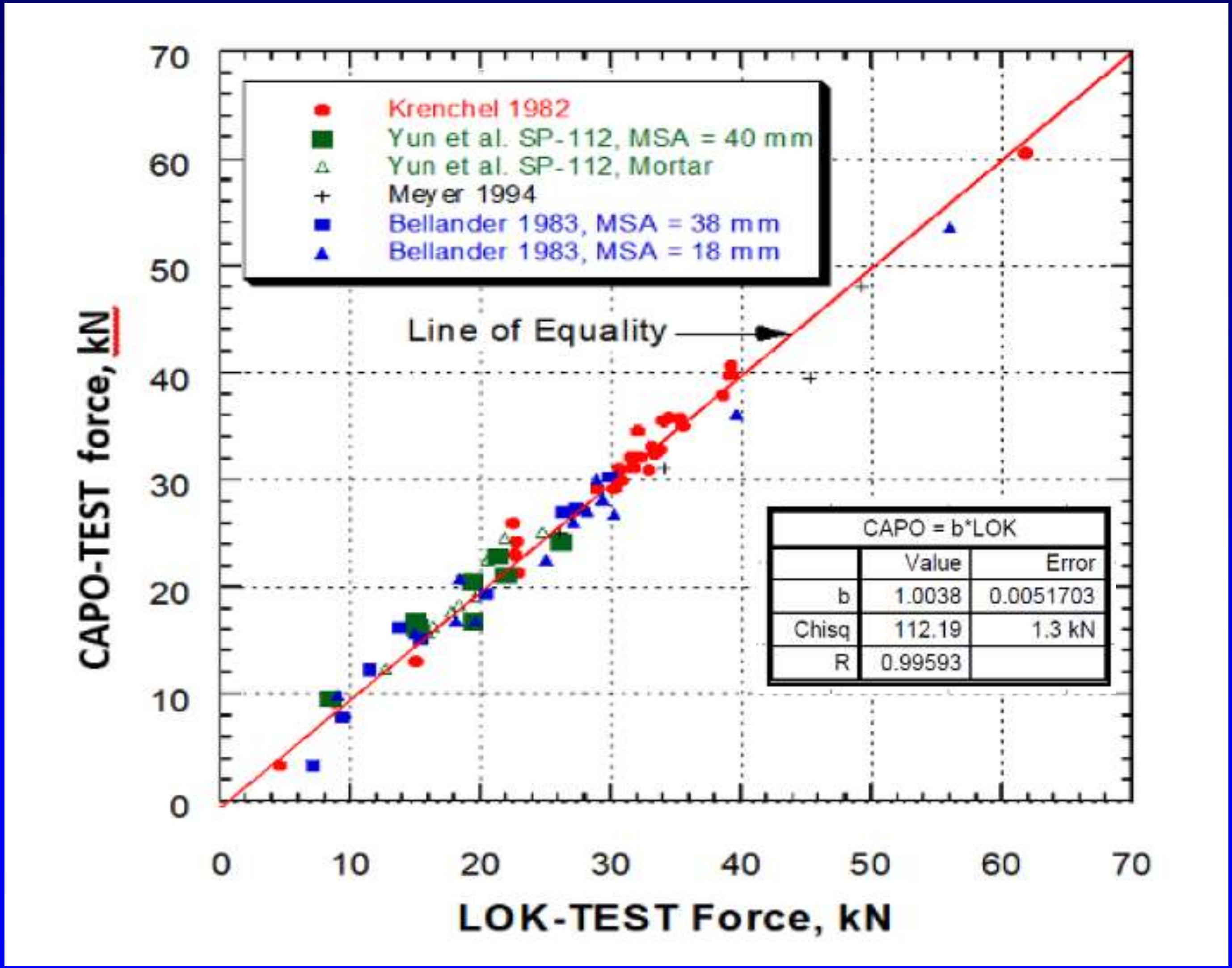
# CAPO-TEST Failure

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

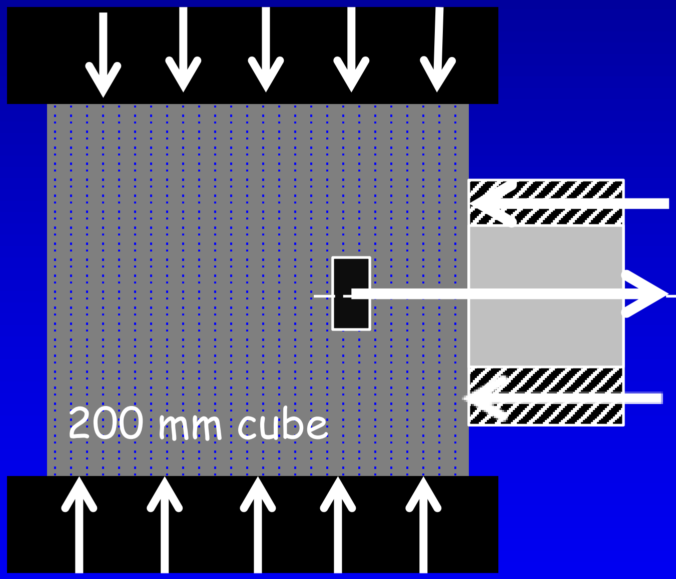
# LOK-TEST to CAPO-TEST

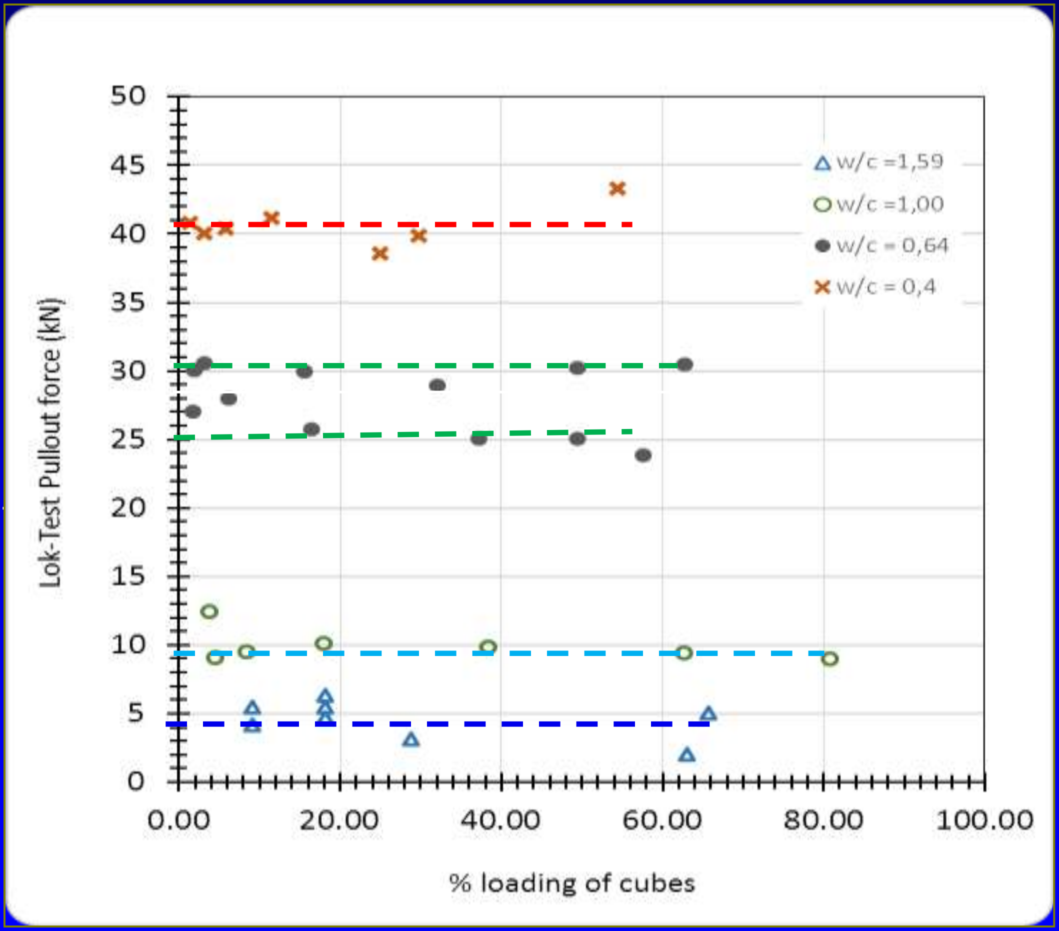


# NOTE

- 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

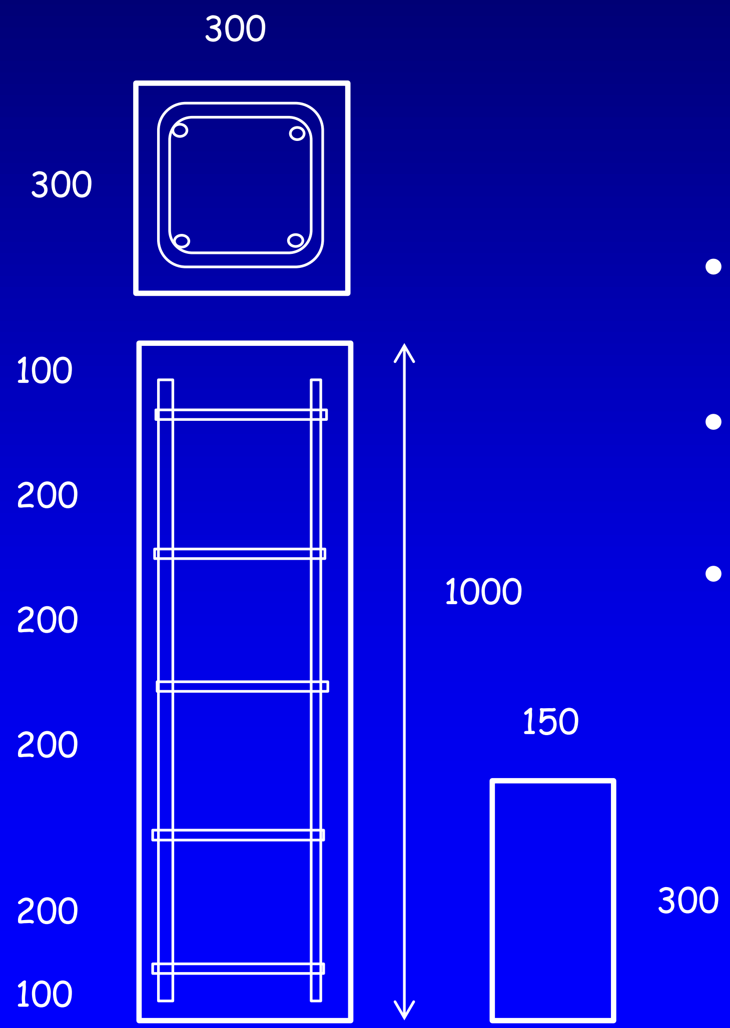
# Clearance Requirements ASTM C900


Reinforcement clearance

Edge distance

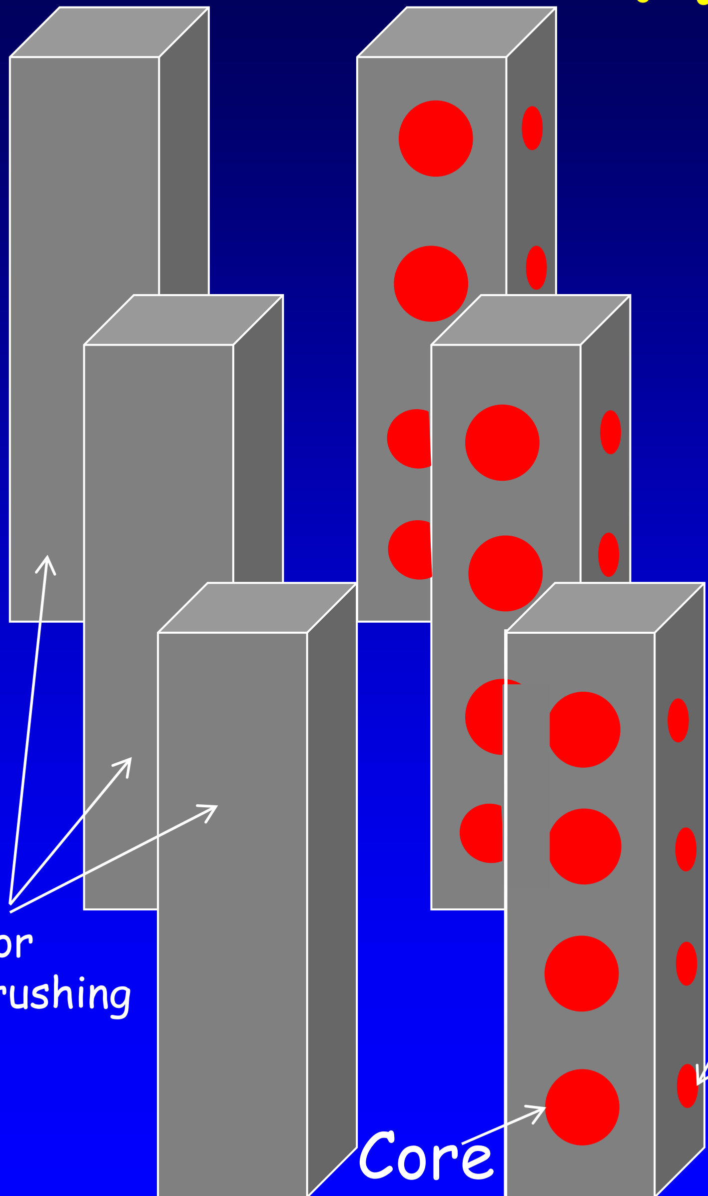
# Correlations

# Comparative testing, reported 1978, DTU, Denmark



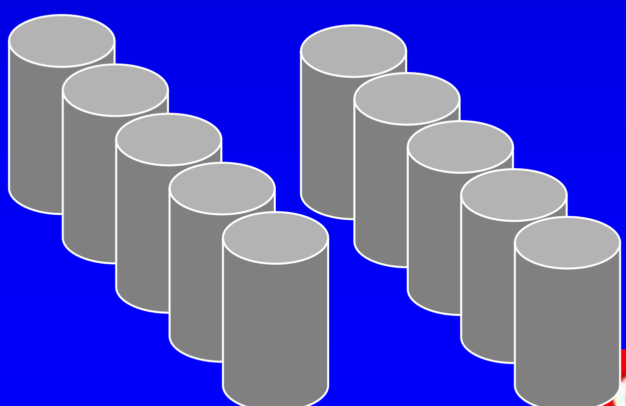

- Columns 1000 mm high, 300 mm x 300 mm in square
- Five strength levels,10, 15, 20, 25 and 30 MPa
- Each batch consisting of 6 columns and 10 standard cylinders

# Program

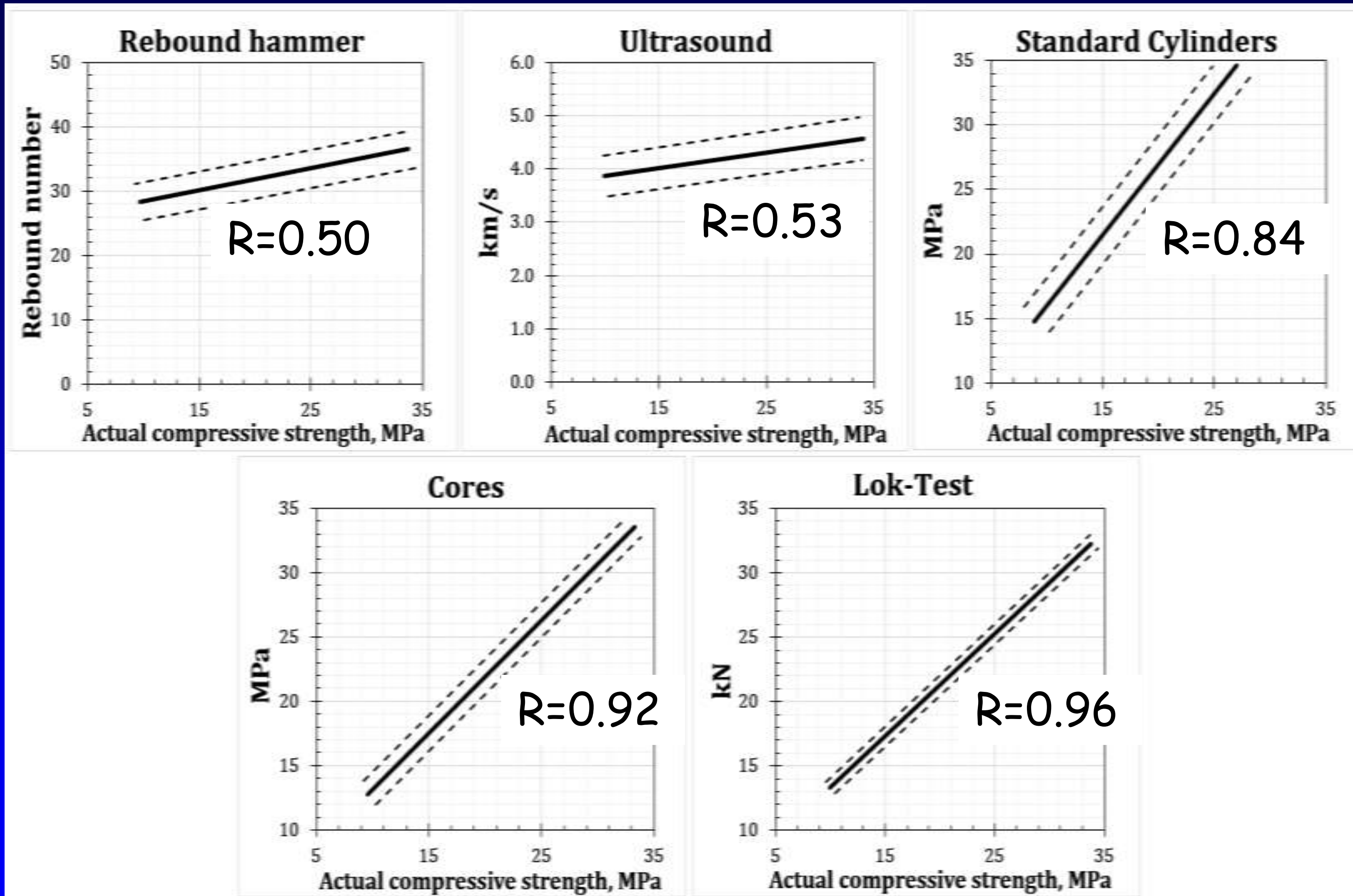



Five batches, ea with 6 columns:

- 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

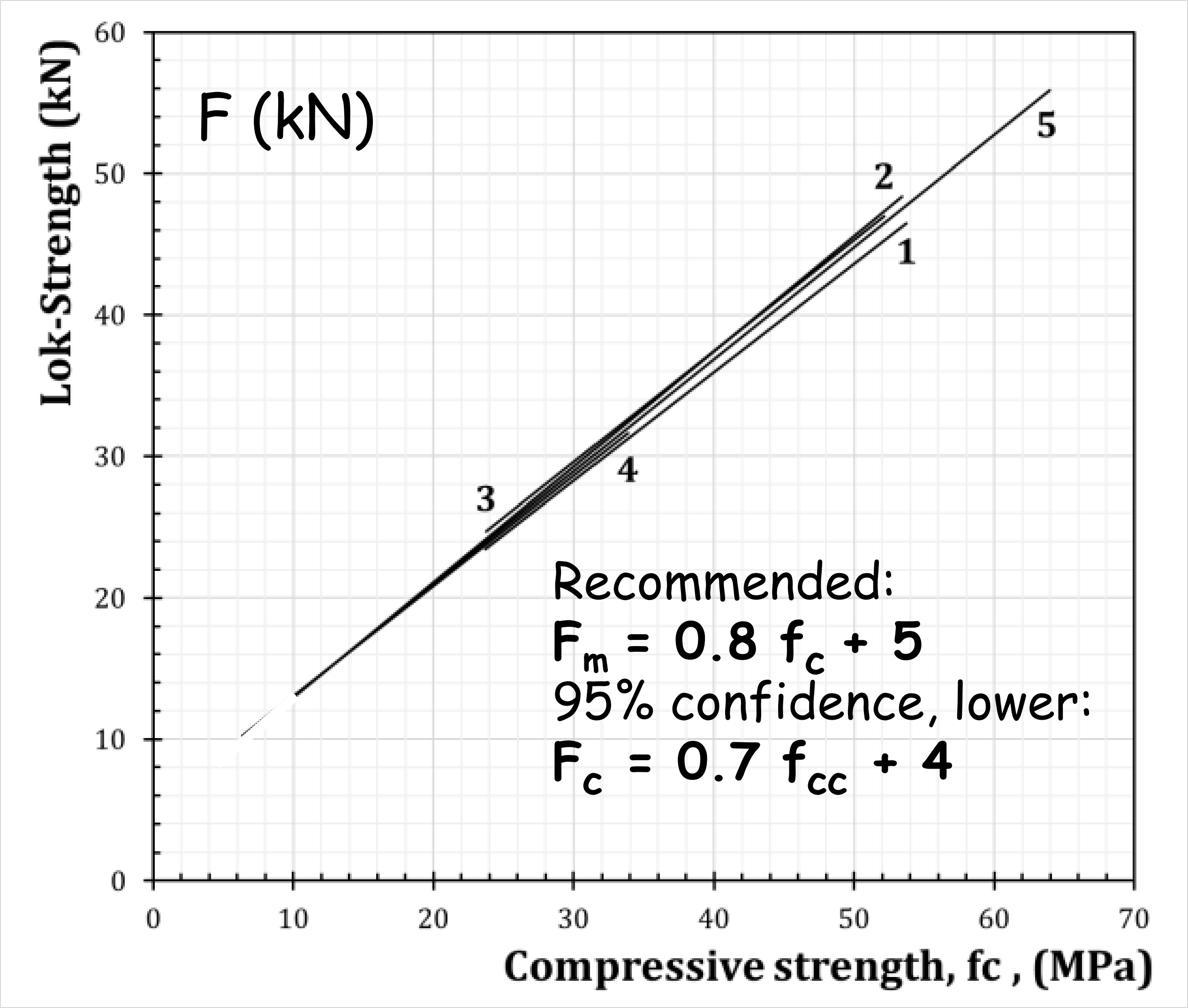


# Results




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

# Lok-Test Correlations before 1978




Refs:

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

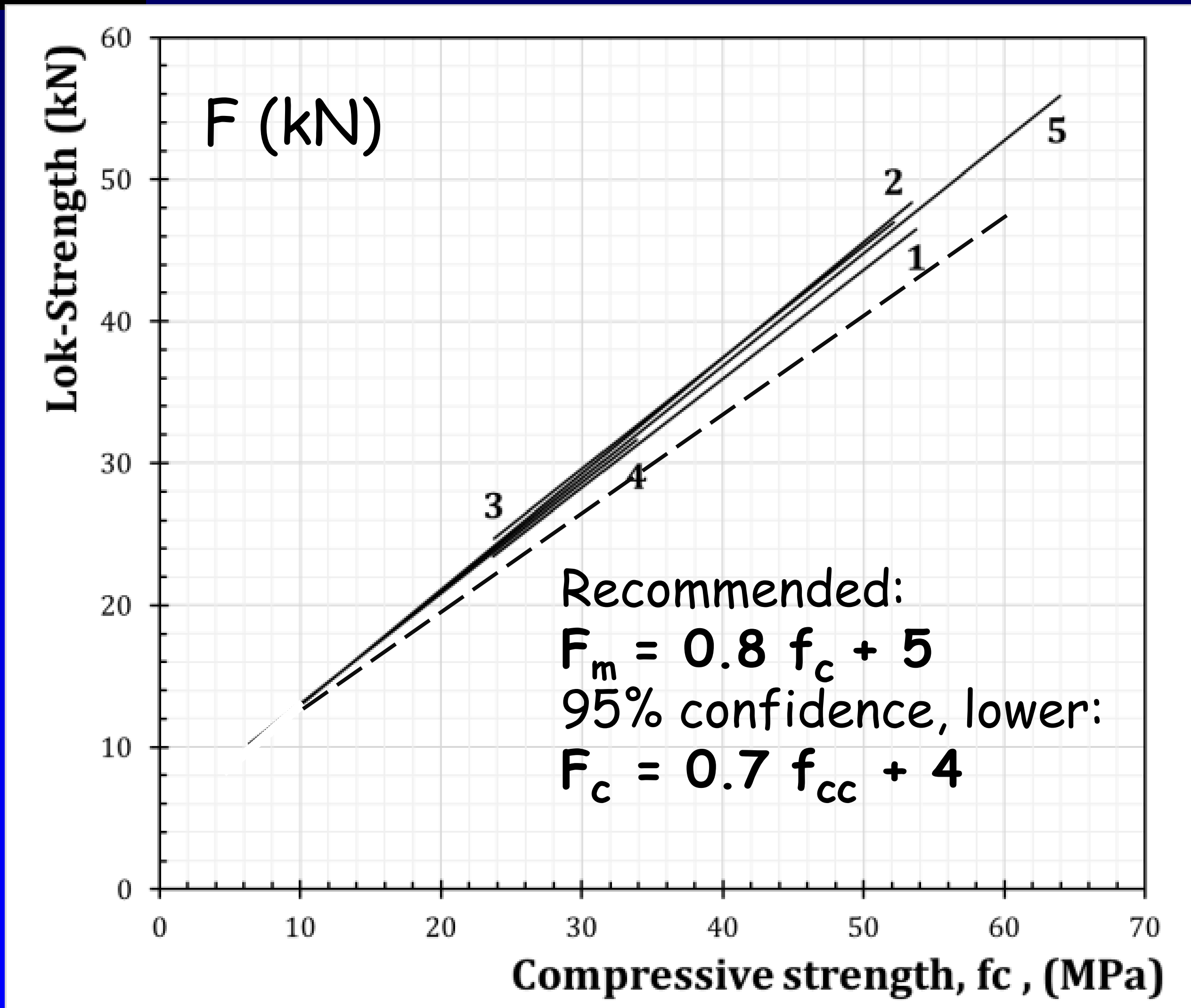
[2] Rapport nr. S 3/69 1974: Danish Technical University

[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




Refs:

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

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

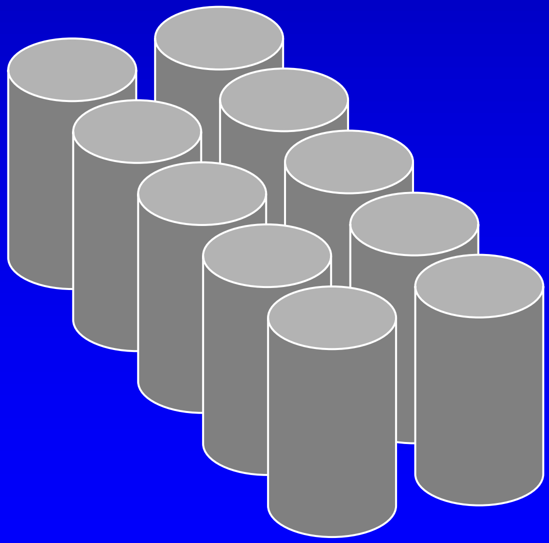
[3] Jensen, O. & Leksø, S. 1976 / 1977, Danish Road and Bridge Lab & Danish State Railways

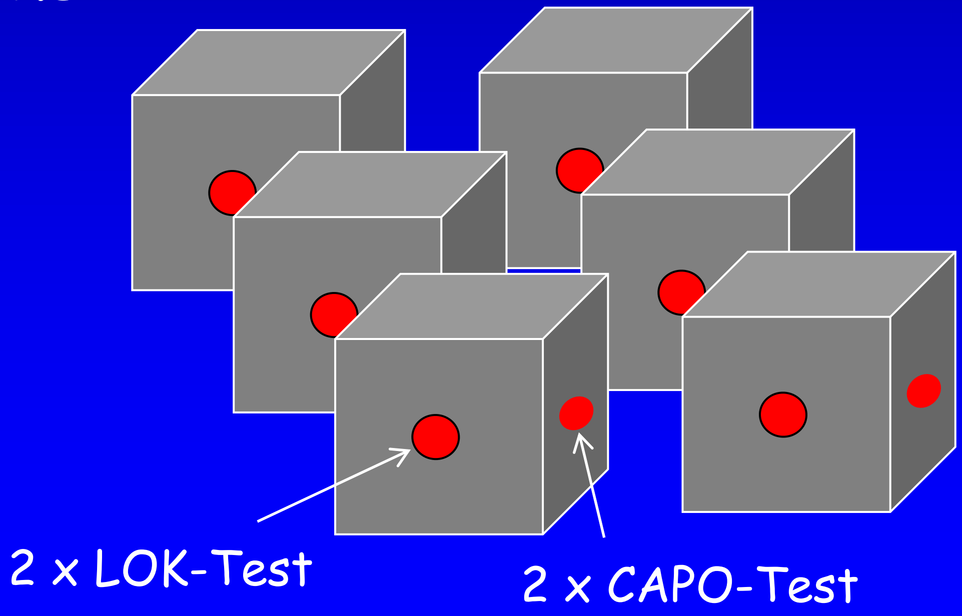
[4] Poulsen, P.E., Danish Institute of Technology & DIAB, 1978.

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

# Correlation Testing after 1978

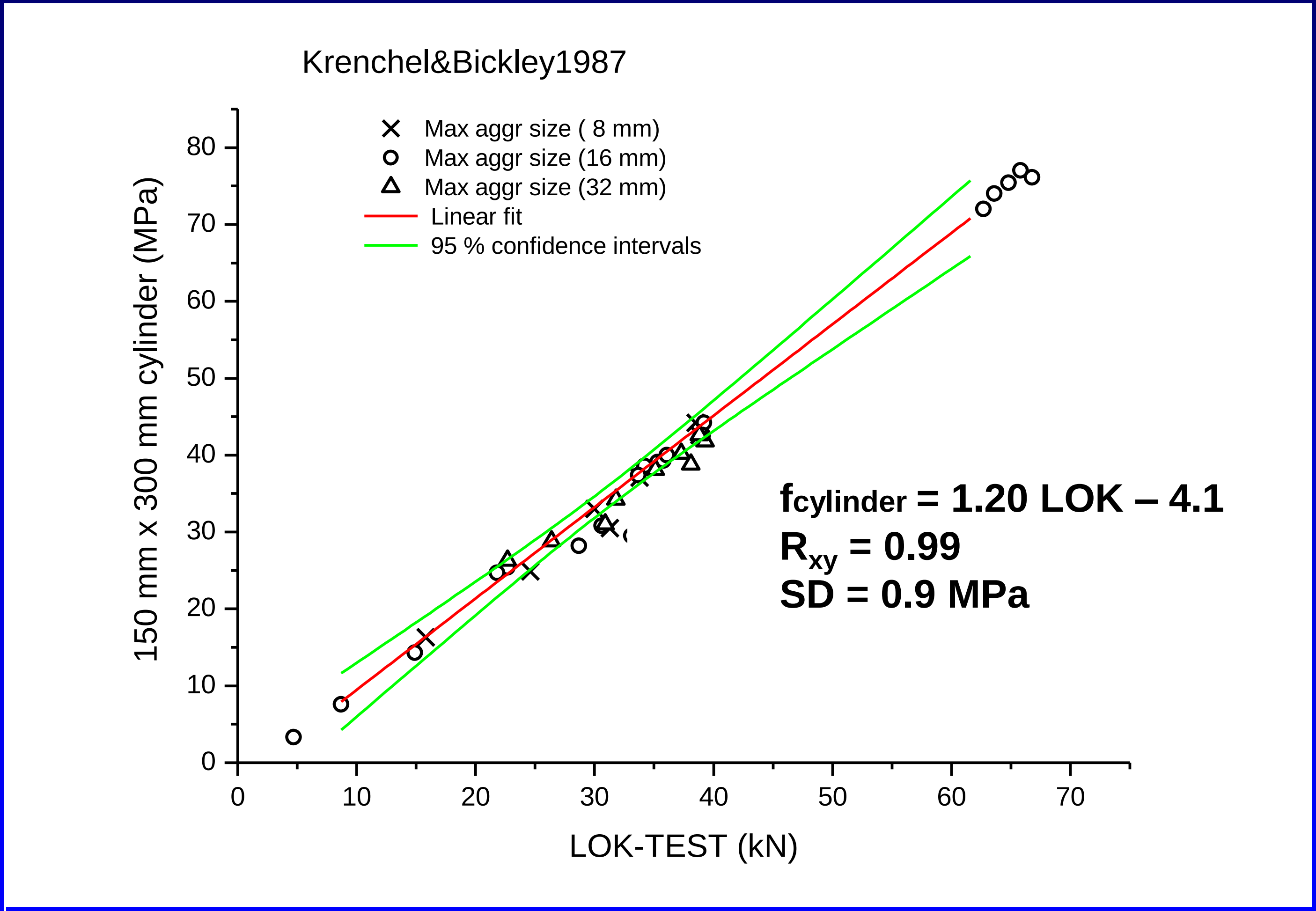
- Prepare cylinders (or cubes)
- Prepare 200 mm cubes with inserts
- Compact and cure under same conditions





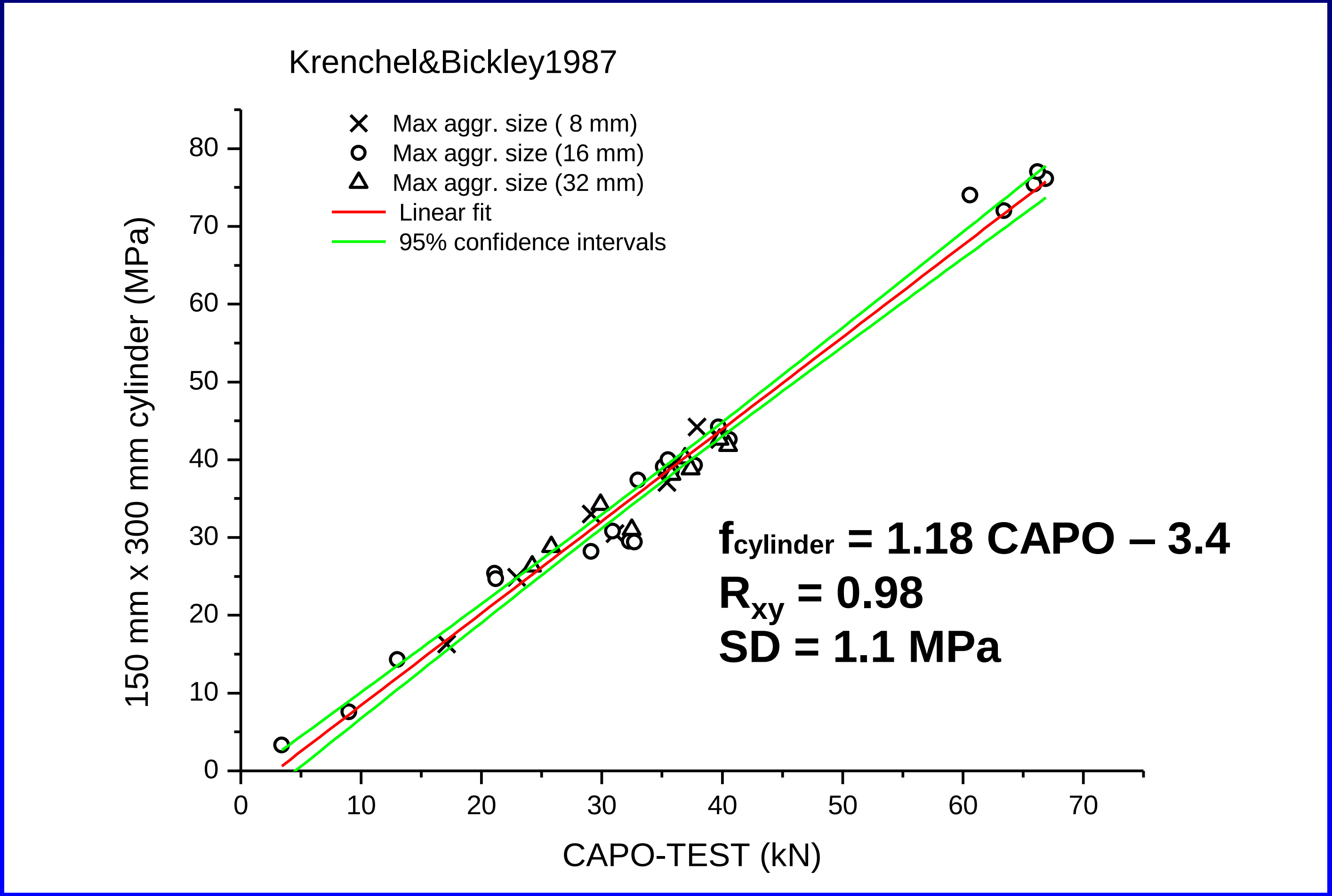
# Cylinder relationships

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




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

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




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

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

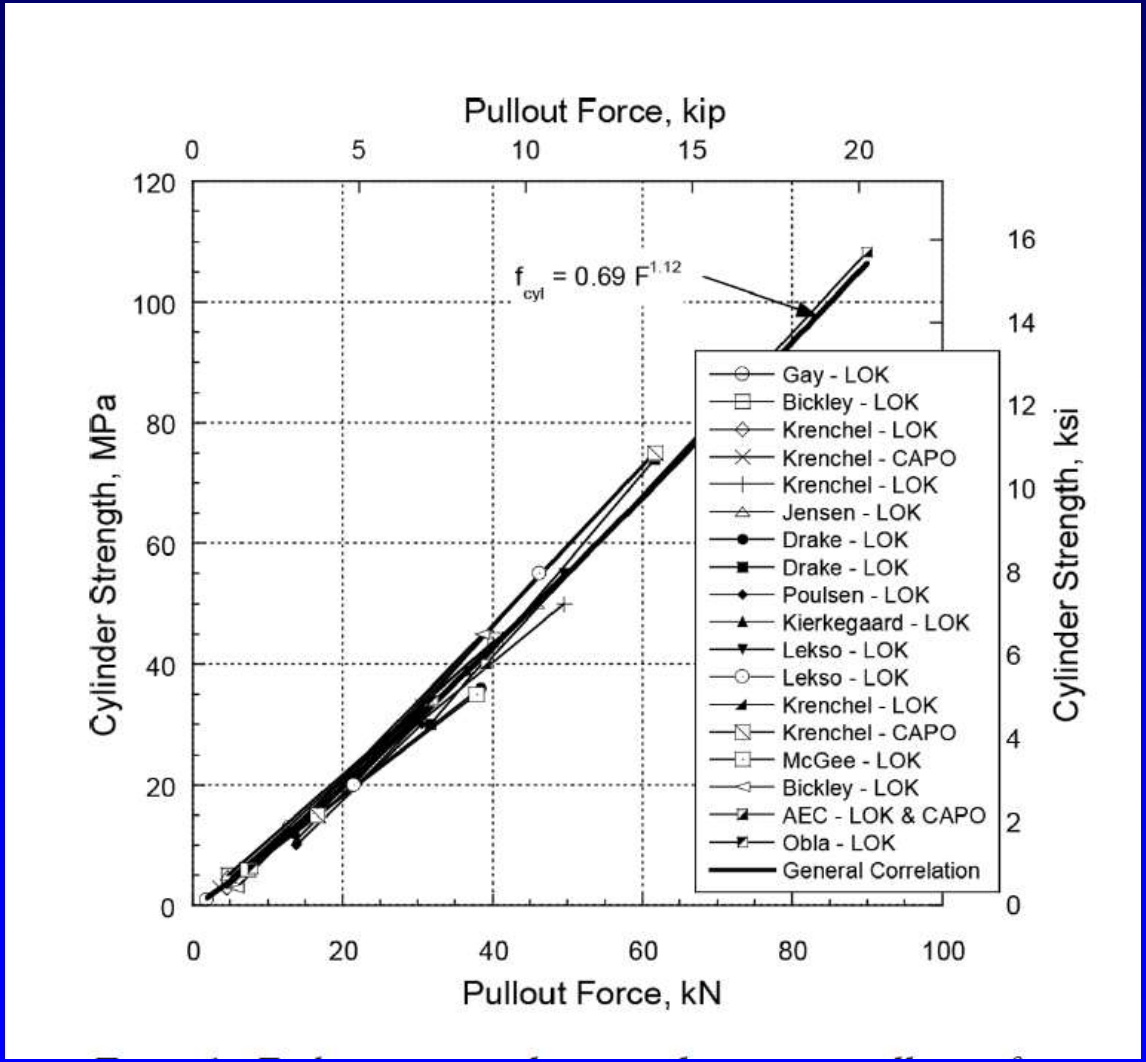
Methods

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

# 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

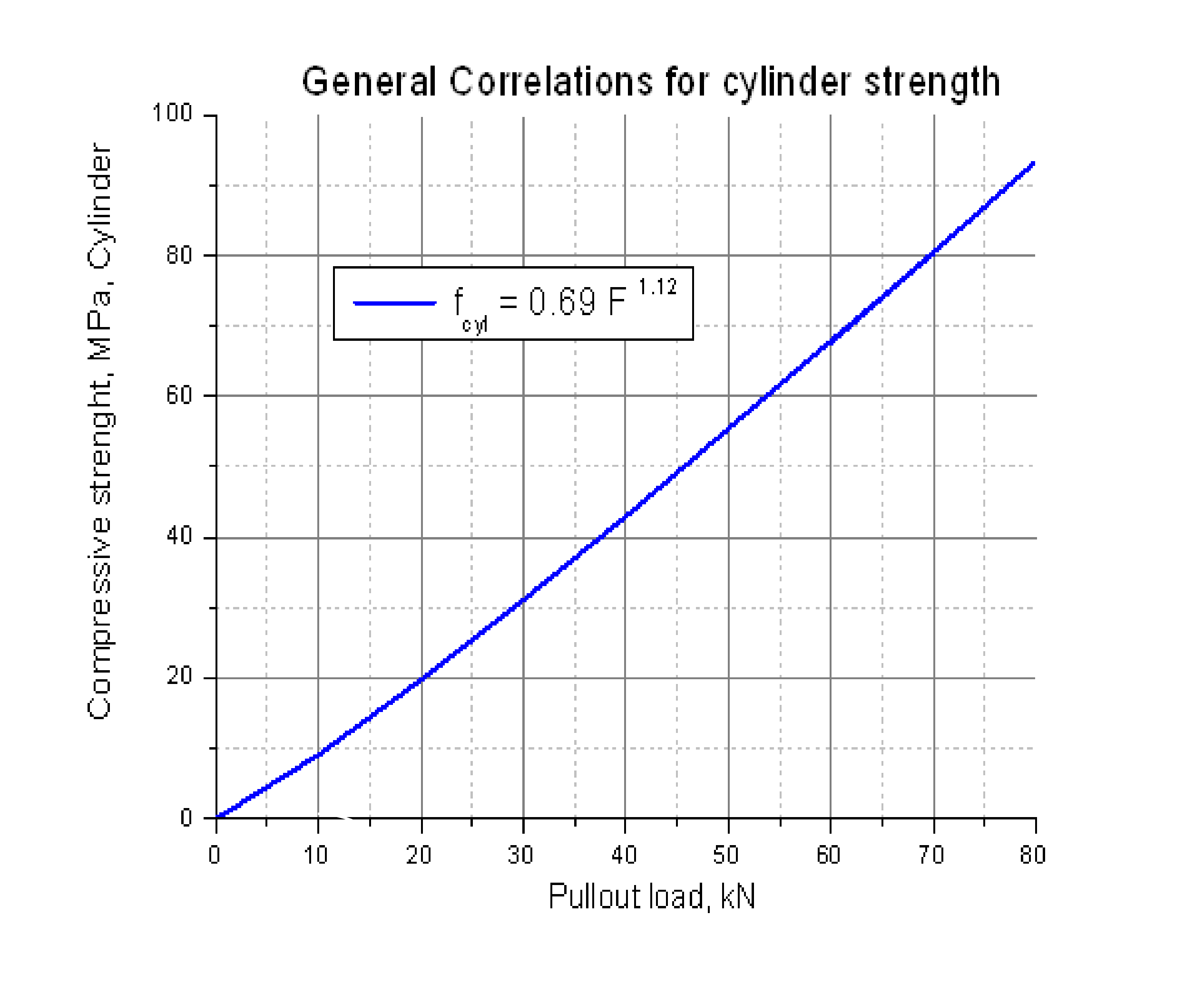
# Variations

| Calibration Procedure, laboratory | Pullout SV | Pullout n | Stand.specim. SV | Stand.specim. 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 |

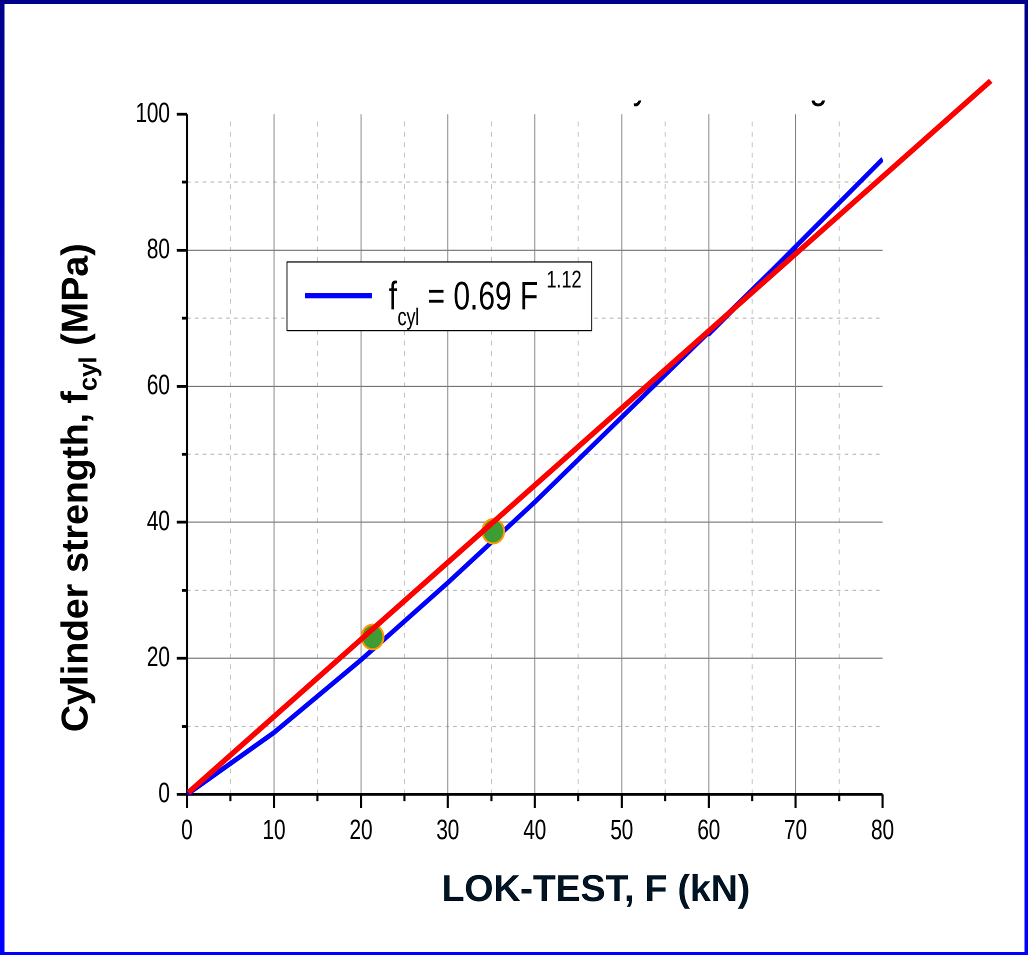
| Structure, On-site testing | LOK-TEST SV | LOK-TEST n | CAPO-TEST SV | CAPO-TEST n |
|---|---|---|---|---|
| Shotcrete | | | 3.2% | 310 |
| Slabs, bottom | 10.5% | 5320 | 7.1% | 35 |
| Slabs, top | 12.9% | 955 | 9.3% | 623 |
| Beams & Columns | 8.1% | 677 | 8.0% | 434 |
| Walls & Foundations | 10.1% | 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, compared to the General Correlation for cylinders $f_{cyl} = 0.69\ F^{1.12}$



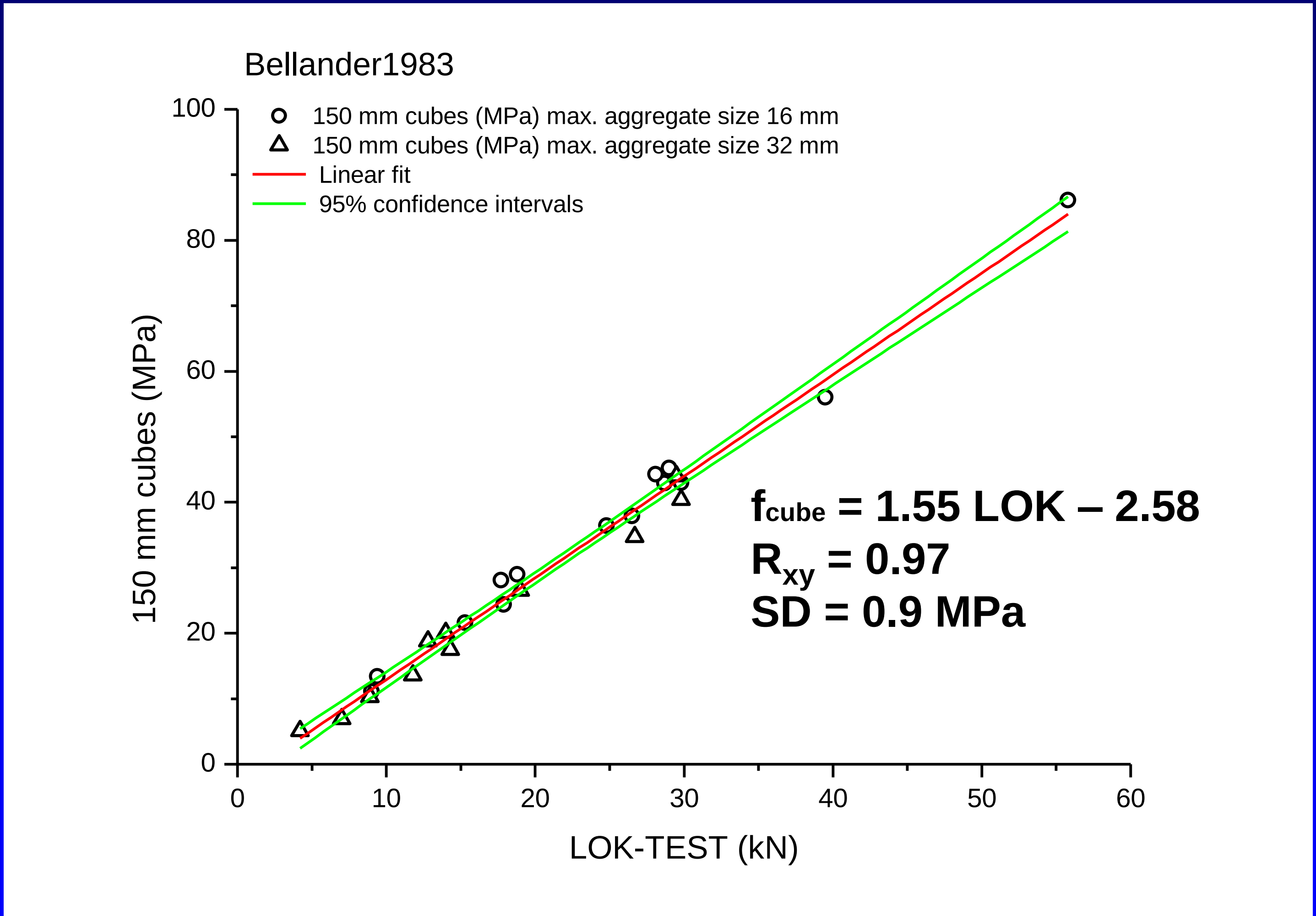

Ottosen. N.S.: ”Nonlinear Finite Element Analysis of Pull-Out Test”, Journal of the Structural Division, ASCE, Vol. 107, No.ST4, April 1981

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

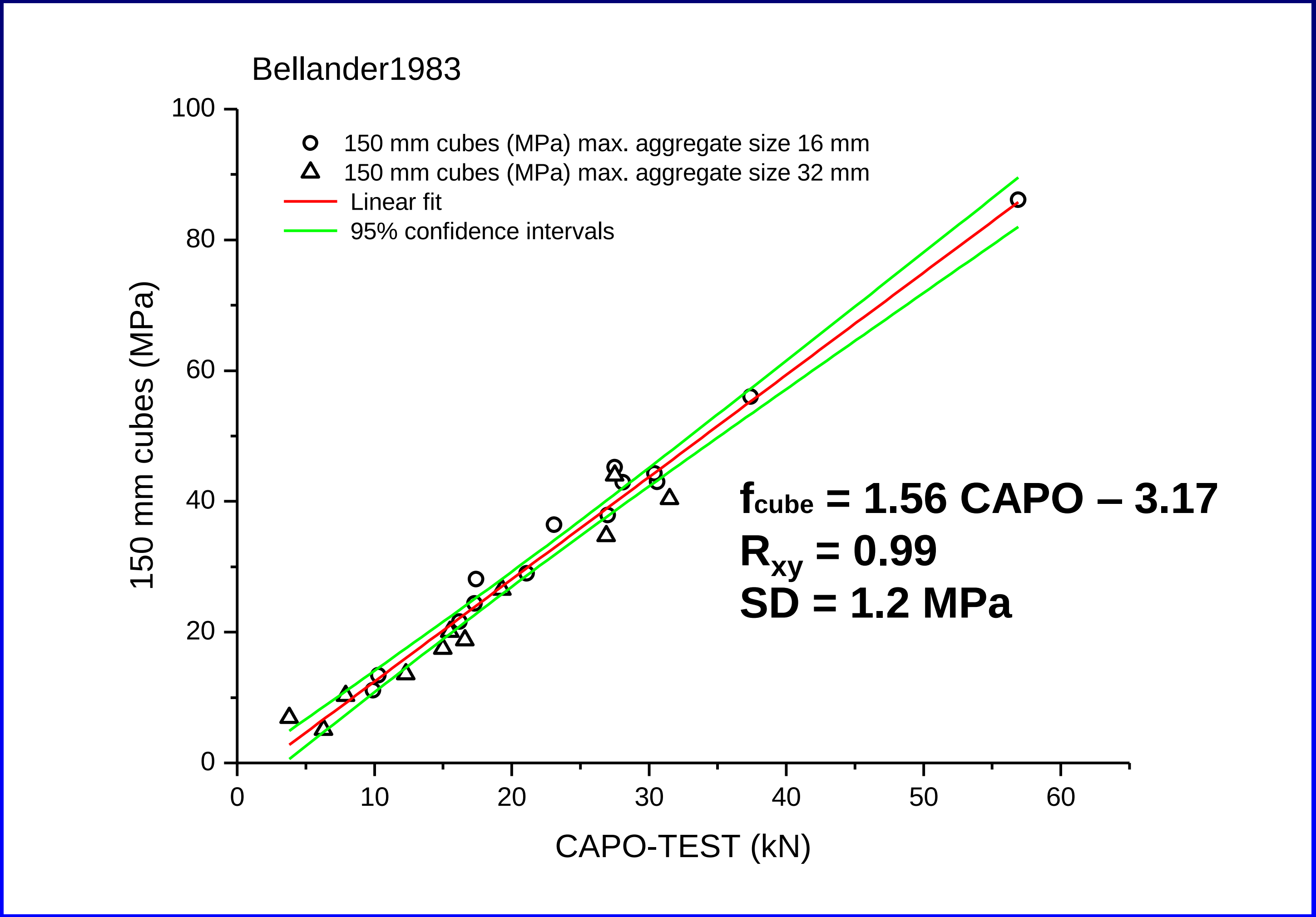
# LOK-TEST to cube strength, 1st major correlation 1983, CBI, Sweden






GI

# 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

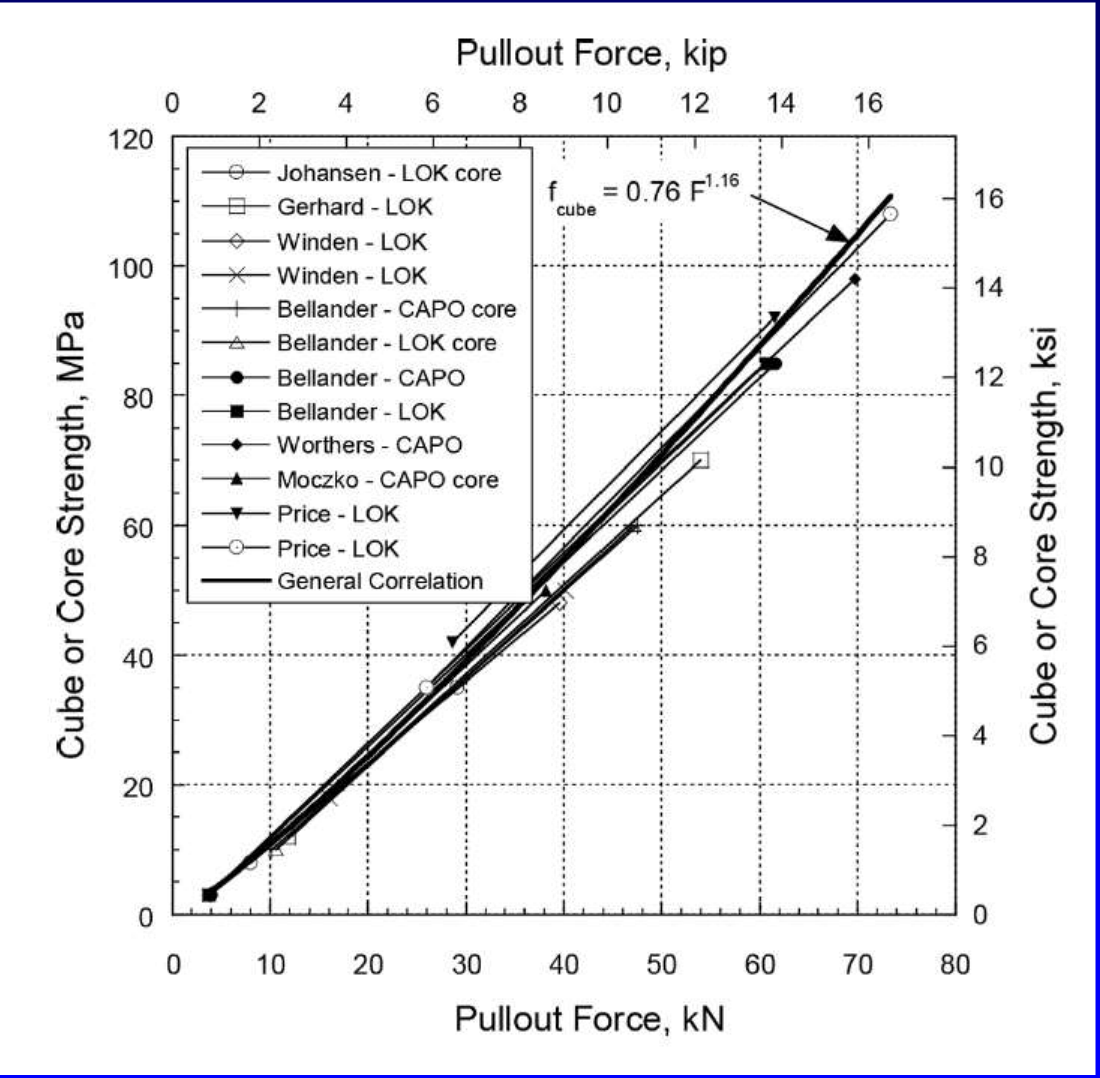
Assumption:

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

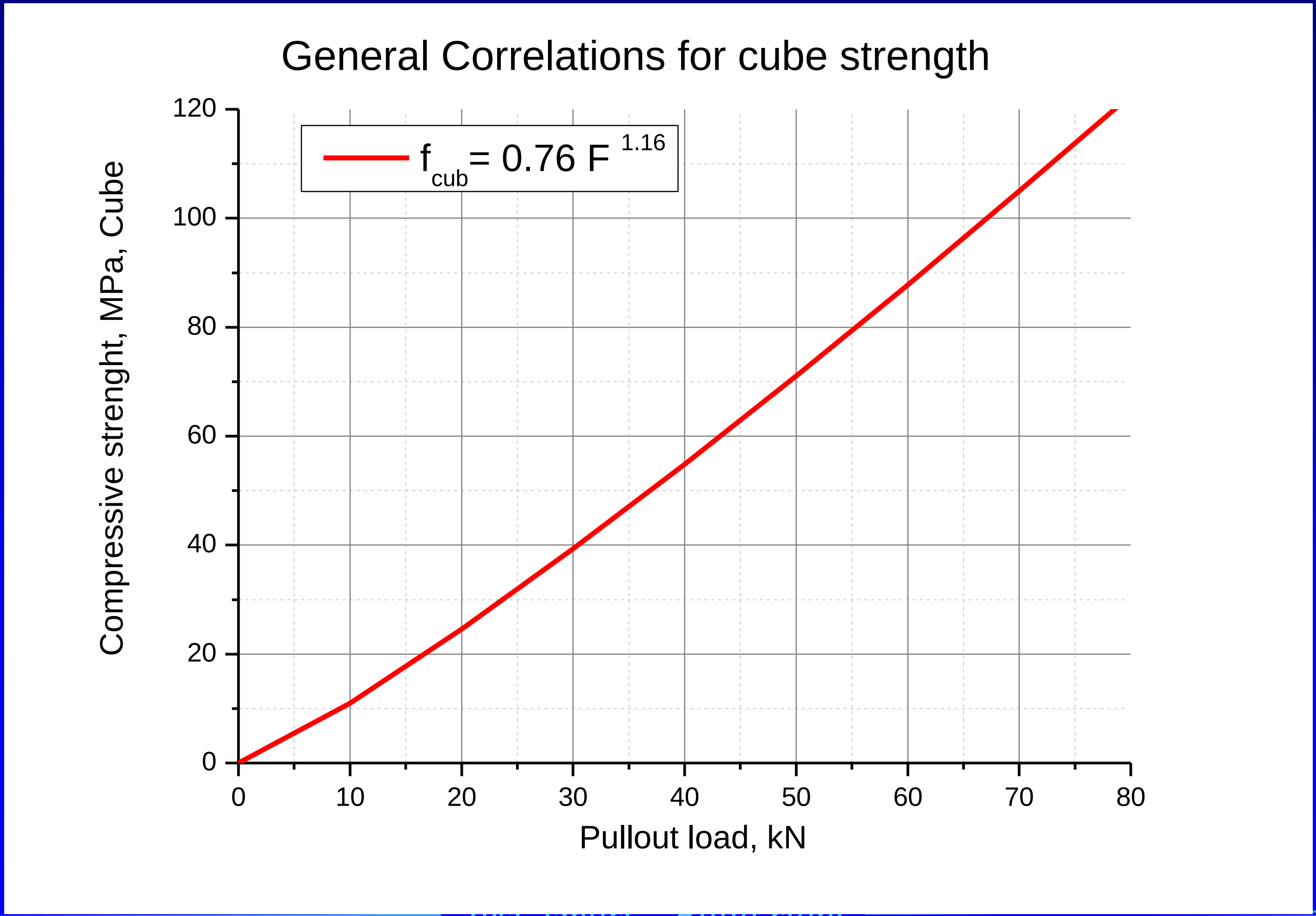
| | Author / ref. | Correlation | Range | Method |
|---|---|---|---|---|
| 1 | Johansen, R | $f_{cube/core}$ = 1.28 Lok – 2.18 | 8-35 Mpa | 3 |
| 2 | Gelhard, R. | $f_{cub}$ = 1.23 Lok – 2.46 | 12-64 MPa | 1 |
| 3 | Winden, N. | $f_{cube}$ = 1.26 Lok – 1.89 | 3-48 MPa | 1 |
| 4 | Winden, N. | $f_{cube}$ = 1.32 Lok – 3.07 | 18-50 MPa | 1 |
| 5 | Bellander, U. | $f_{cube/core}$ = 1.34 Lok – 3.70 | 10-60 MPa | 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

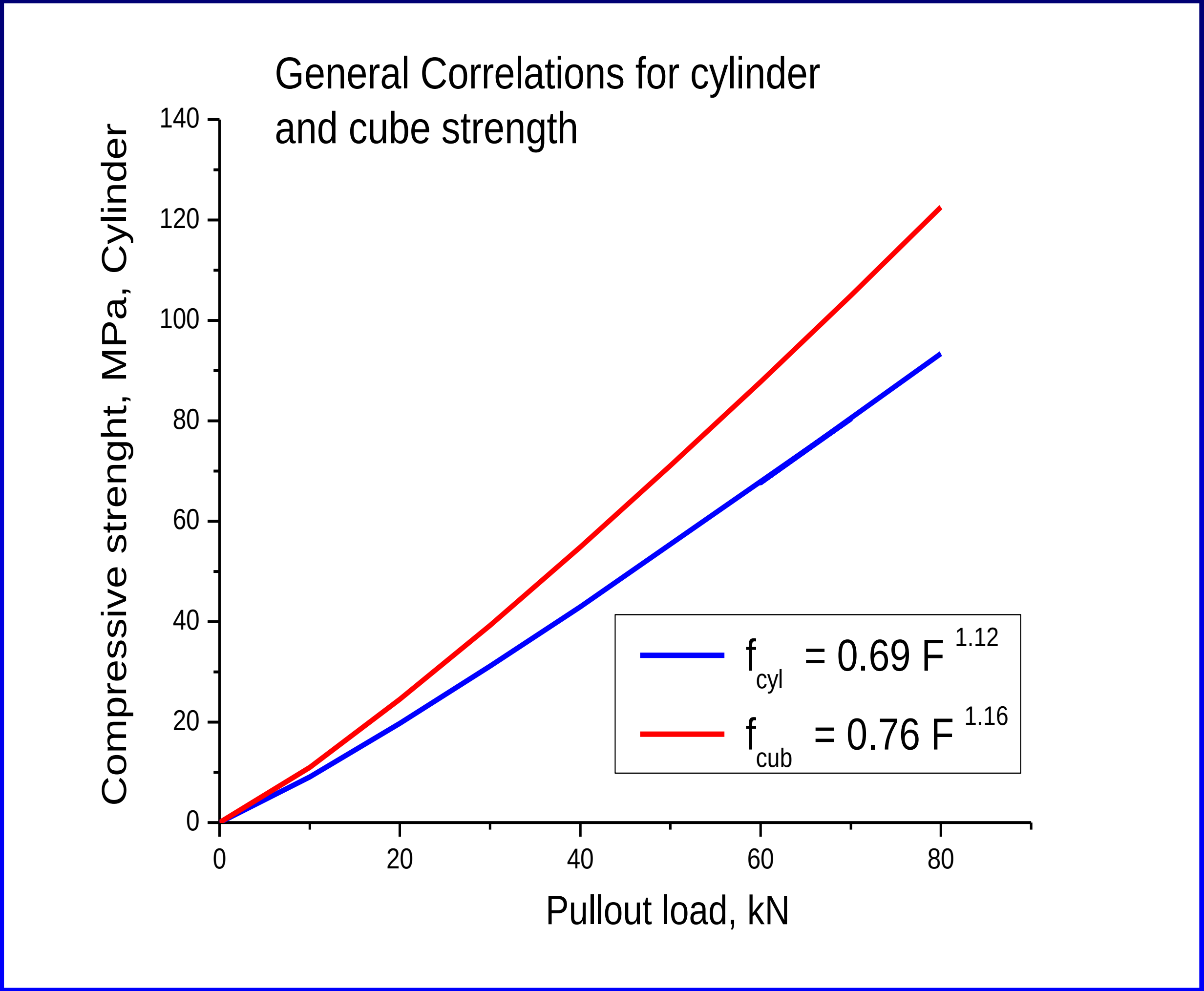
# General cube / core relation to pullout strength by LOK/CAPO



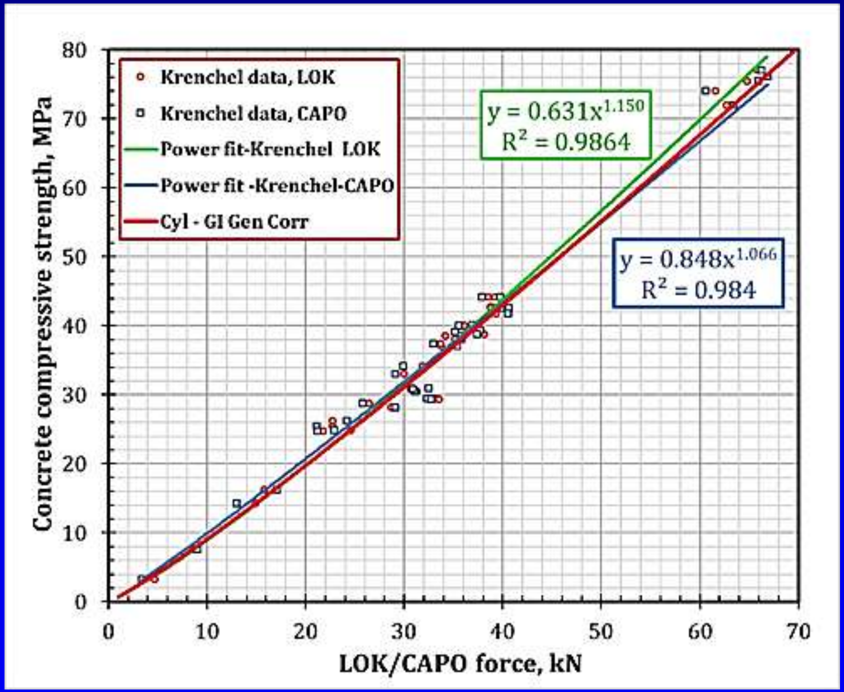


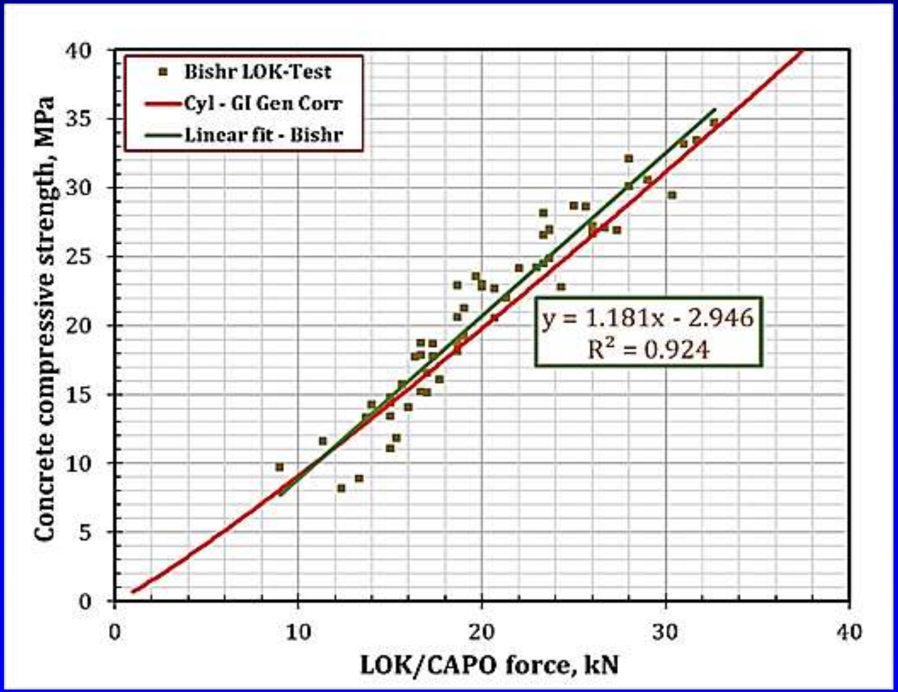

GI

# The two general correlations



# Precision
# Data for calculation



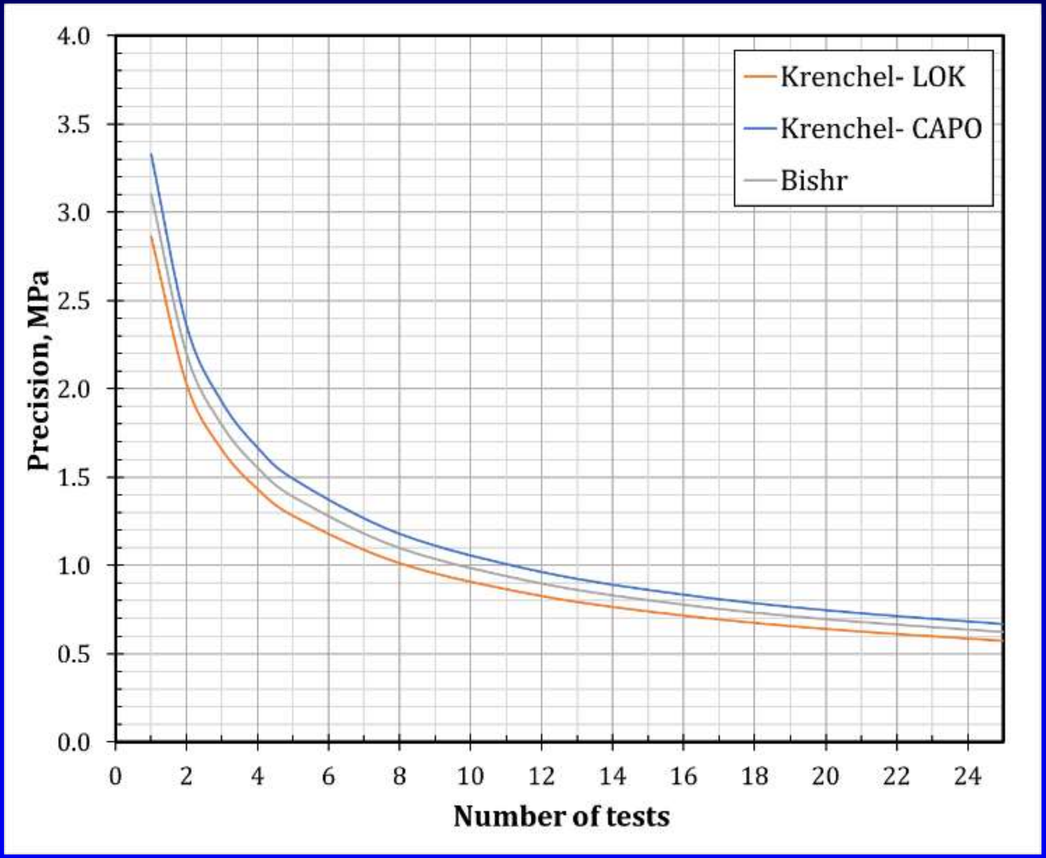




$$P = \frac{z \cdot C_v}{\sqrt{n}}$$

$$C_v = \frac{s_p}{\bar{x}}$$

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

# 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

# Other Examples


London, UK
Strength of industrial floor


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


Great Belt Link, Denmark
Strength of cover layer

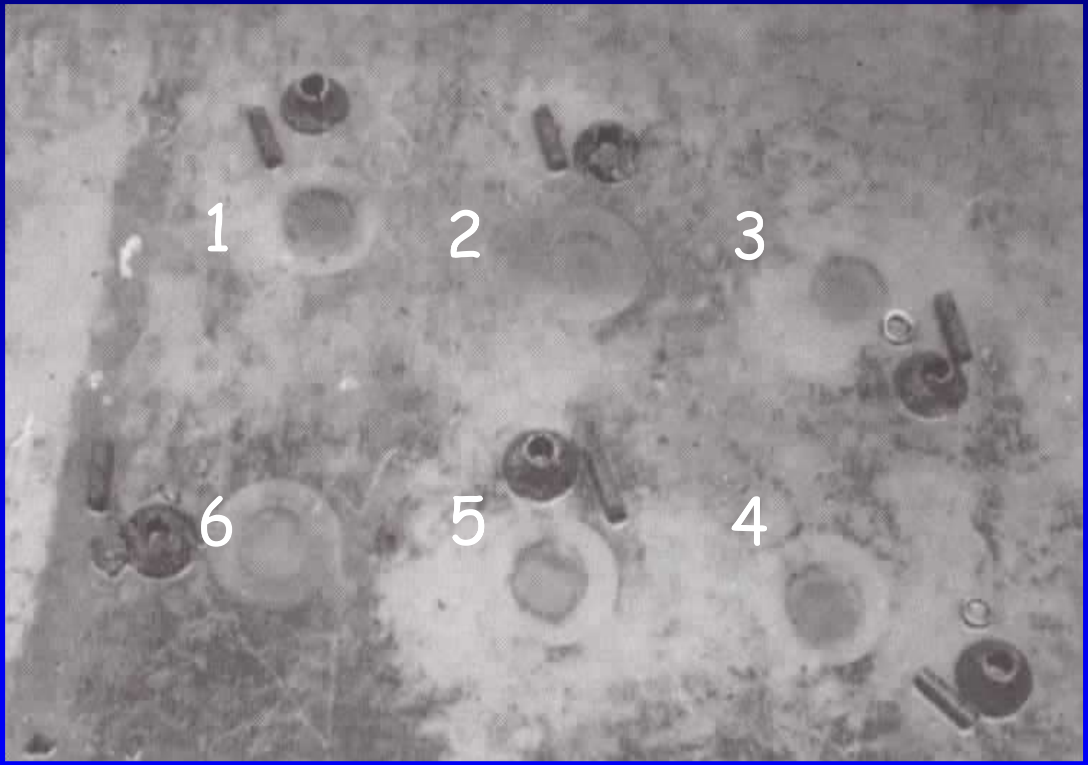
# Pullout on the Great Belt Link, Denmark for QC of the cover layer


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

# 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

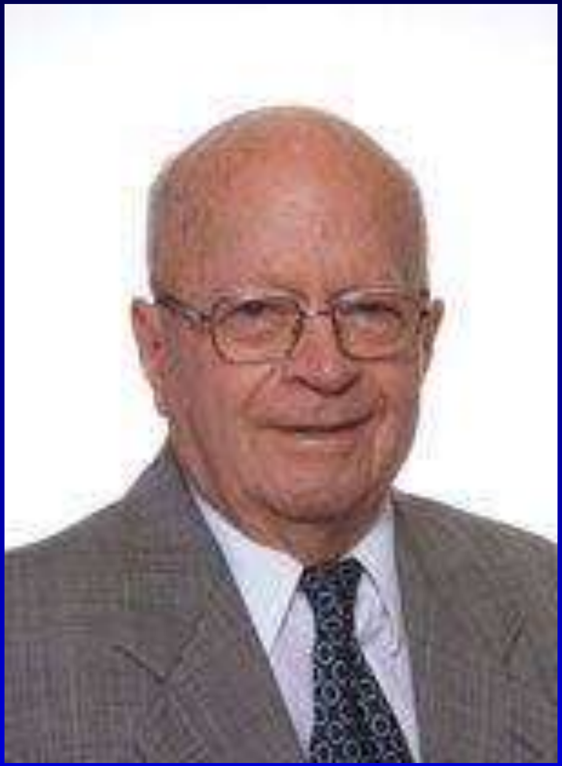



| CAPO test readings, kN | Compressive strength cylinders, Mpa<br>$0.69*F^{1.12}$ |
|---|---|
| **41** | 44.2 |
| **36** | 38.2 |
| **40** | 43.0 |
| **42** | 45.4 |
| **40** | 43.0 |
| **41** | 44.2 |
| | |
| Average, MPa | 43.0 |
| Std dev, MPa | 2.51 |
| K (natrella) | 1.86 |
| | |
| Lower 10th percentile, 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, San Francisco, 1994*



GI

| | 20 Storey Building | 15 Storey Headquarte | 30 Storey Building | Twin Towers | 14Storey Building[5] | 3Storey Centre | 9Storey Condom. |
|---|---|---|---|---|---|---|---|
| Savings | (All Numbers are $/1000) | | | | | | |
| Interest | 600 | 1750 | 188 | NC | NC | 533 | 43 |
| Earlier Rental | 200 | NC | 25 | NC | NC | 466 | 40 |
| Formwork | 120 | 25[4] | NC | 75 | NC | NC | NC |
| Reshoring | NC | NC | NC | NC | NC | NC | NC |
| Winter Heating | NC | NC | 114 | (0.3/pour/ day) | NC | NC | NC |
| $f^1_c$ at 91 days | NA | 50 | 38 | 62 | 23 | NA | NA |
| 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 |

# Accelerated construction, Savings to Owners

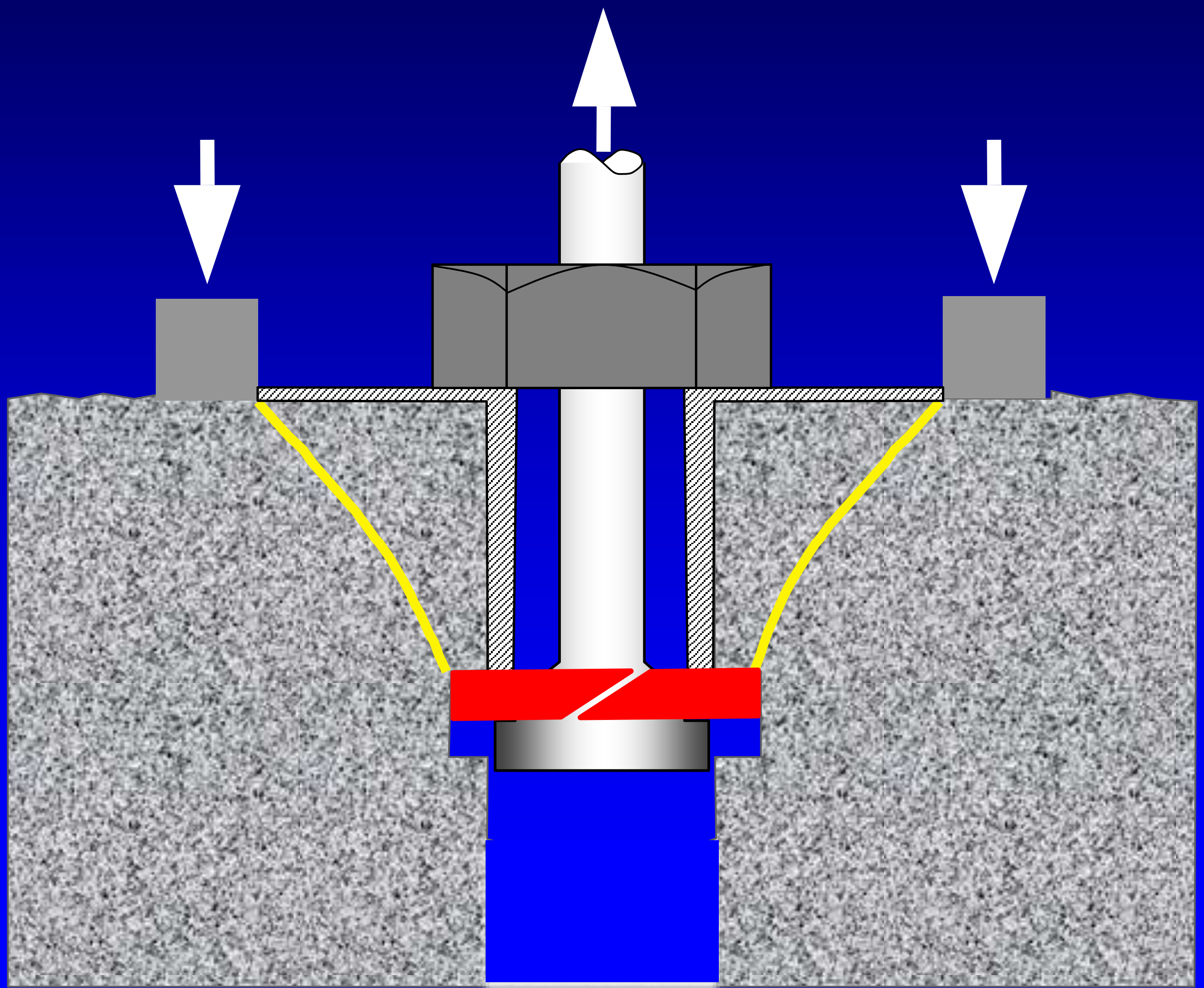
# LOK-TEST equipmemt

Plus inserts

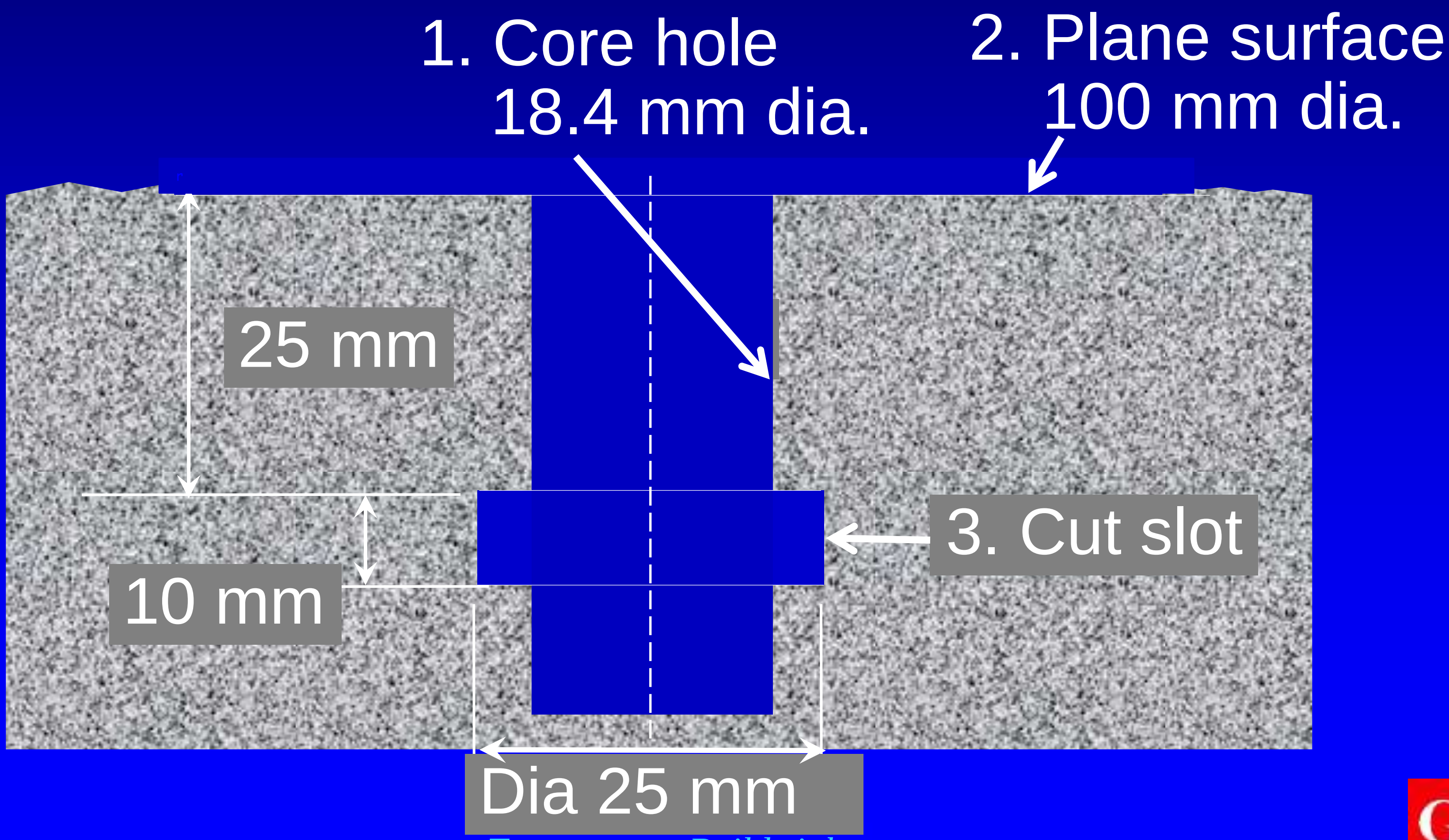
John A.Bickley, Canada: "The Holy Grail"

# CAPO-TEST
# for existing strucures

# CAPO-TEST Pullout



# Prepare Concrete



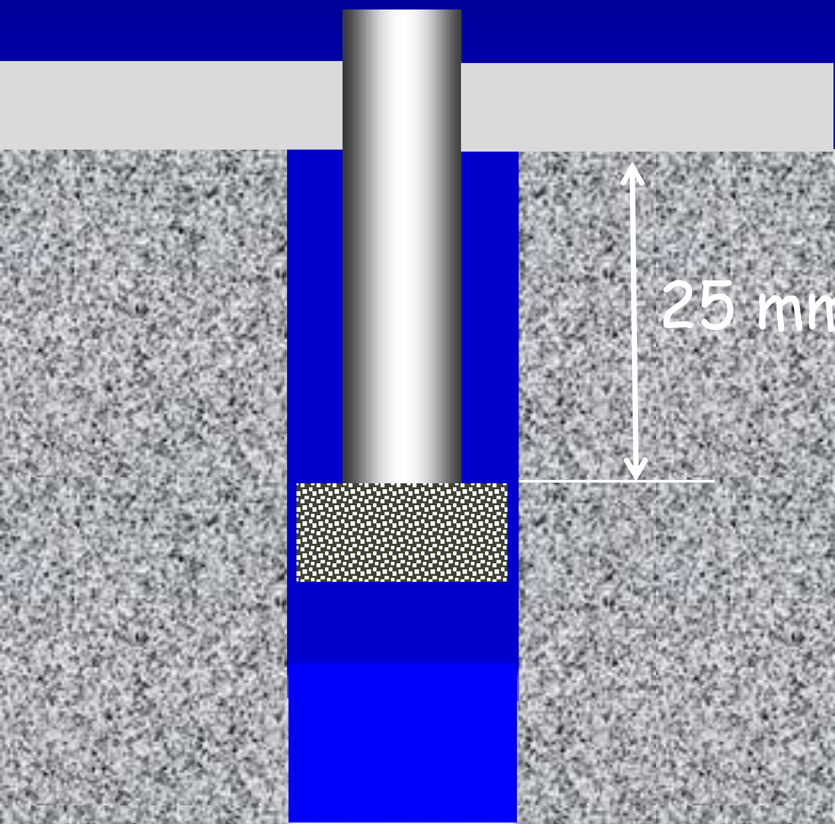



GI

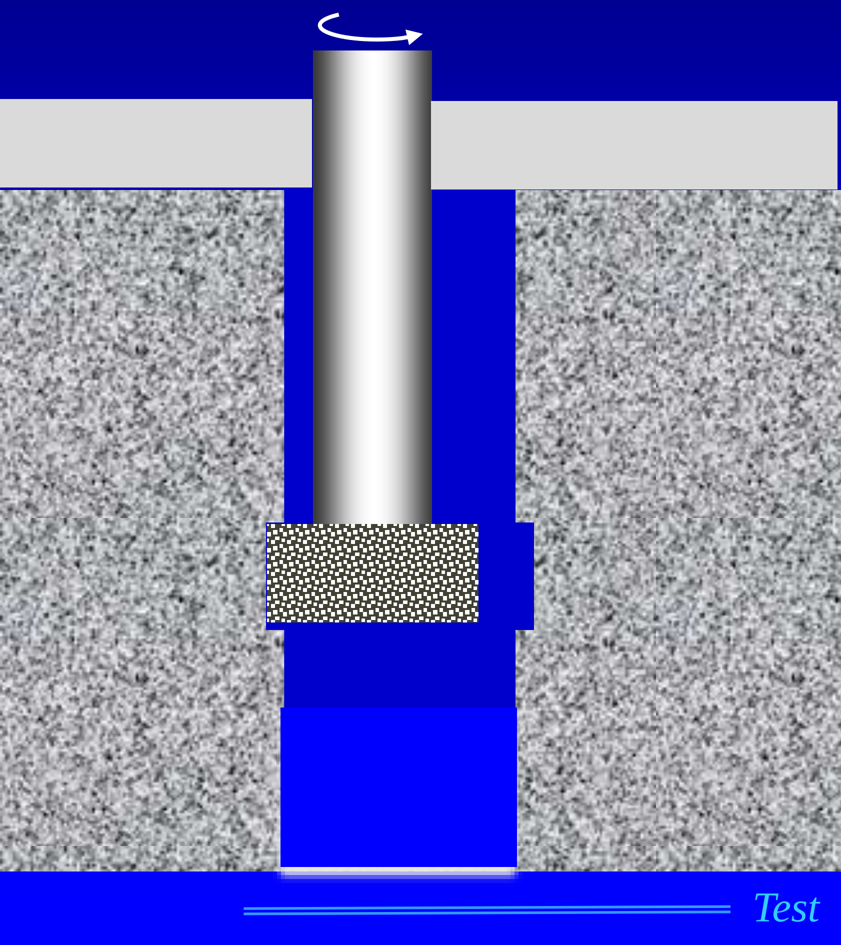
# Core Hole

# Plane surface

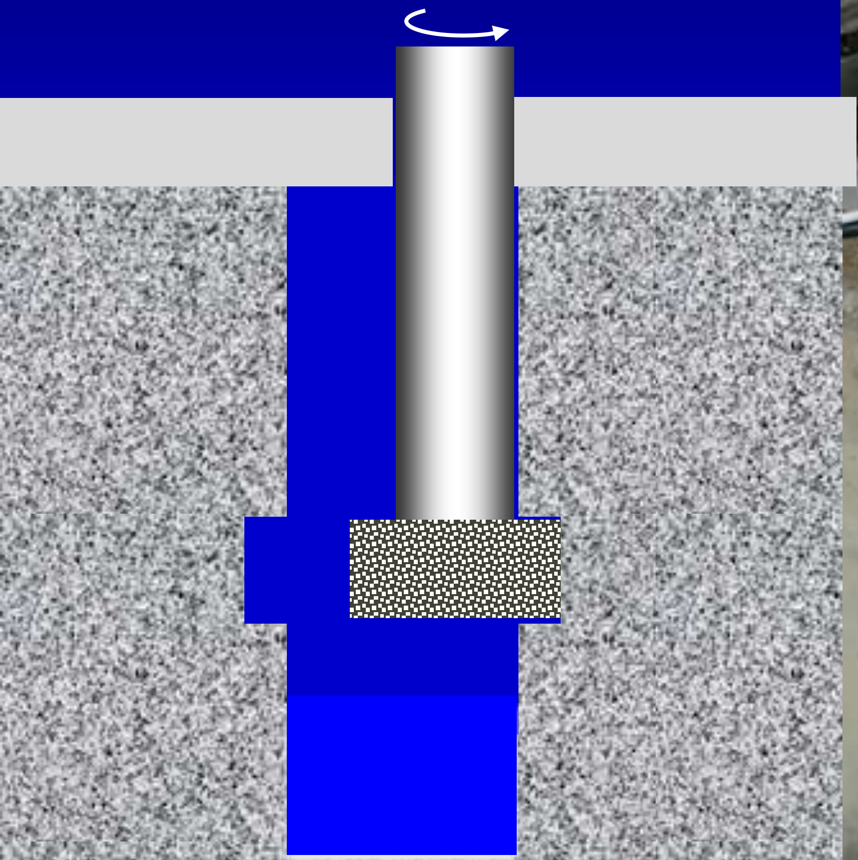
# Cut Slot



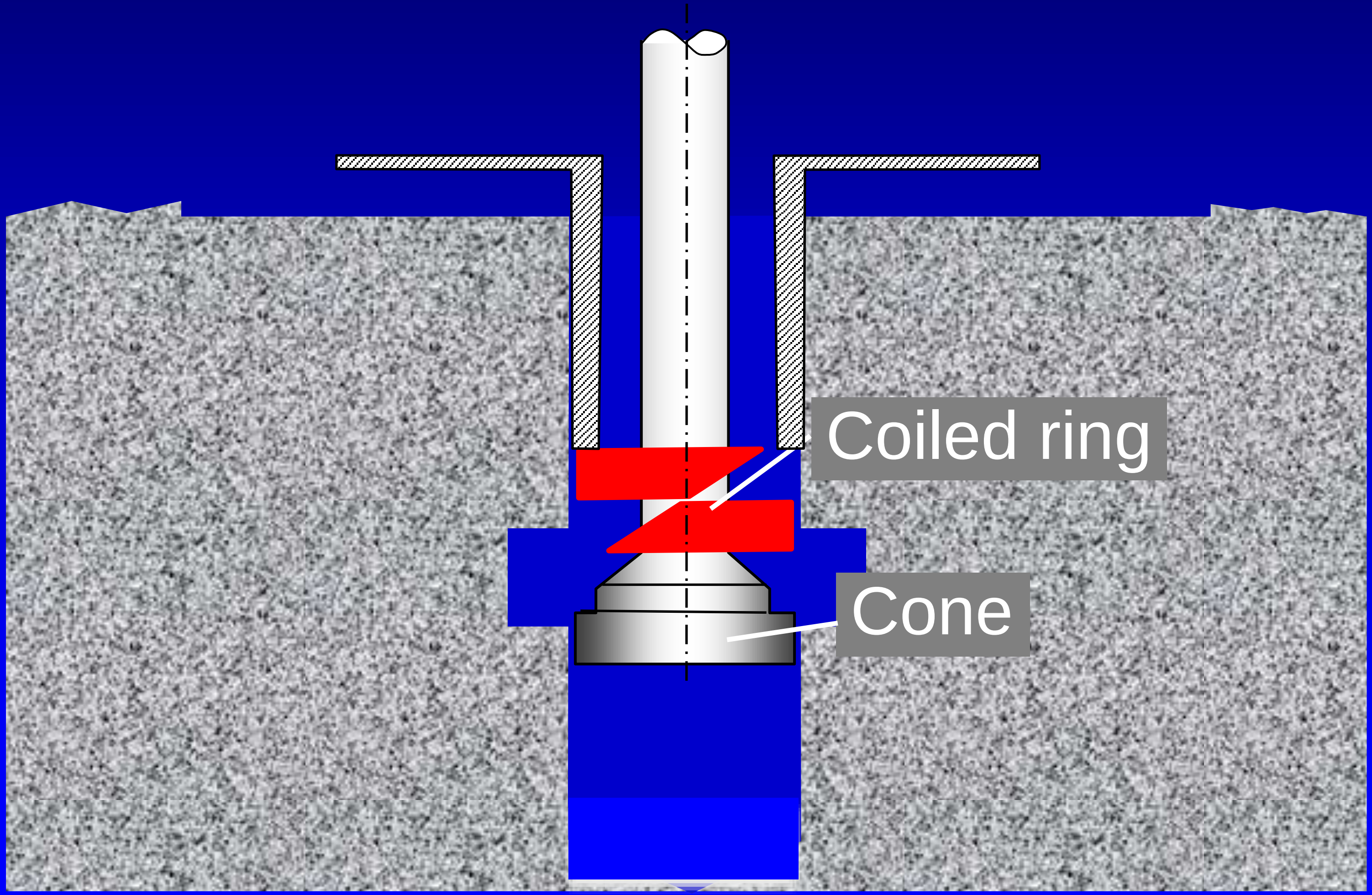

# Cut Slot



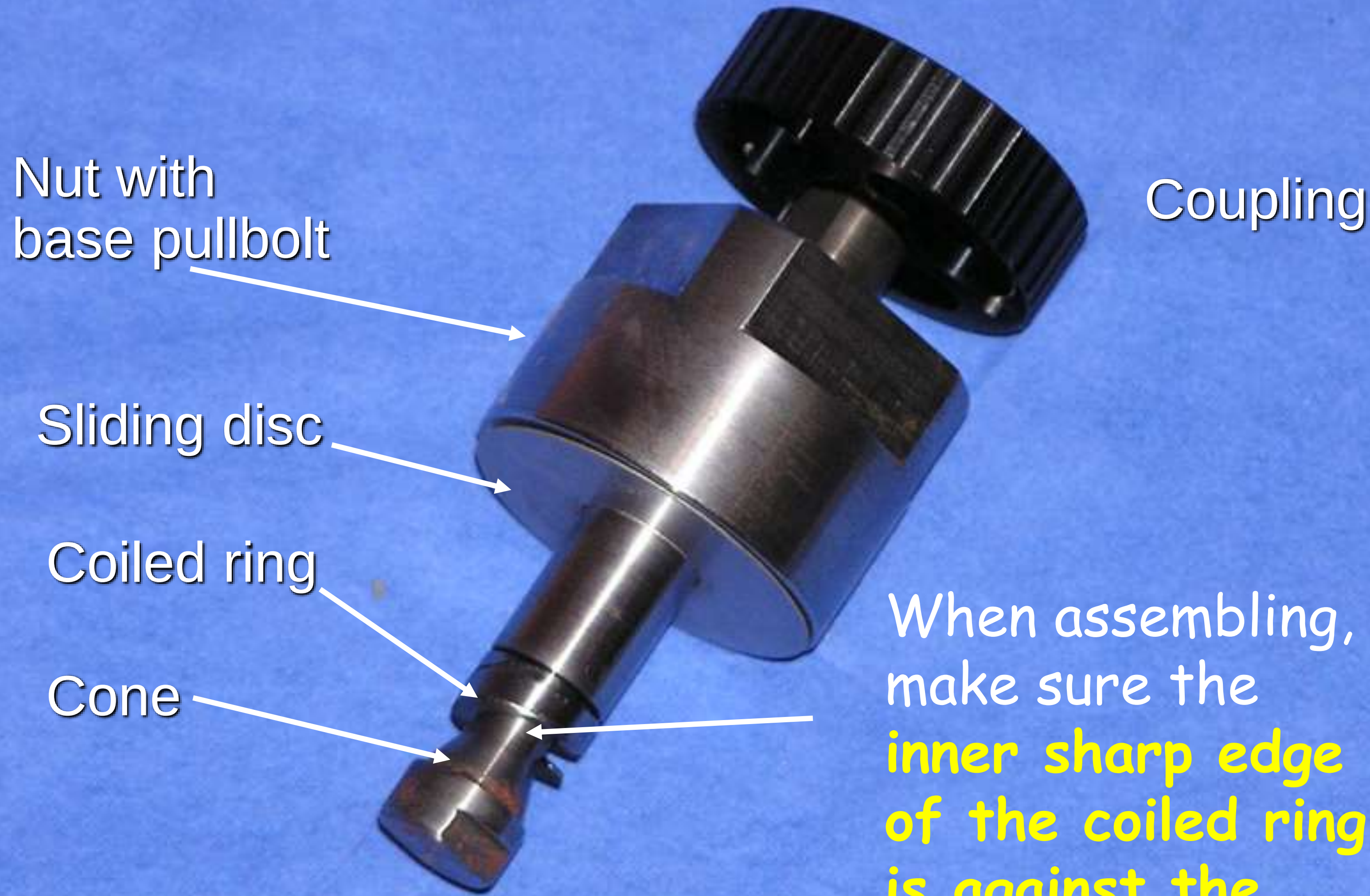

# Cut Slot



# Insert Expansion Cone and Coiled Split-Ring

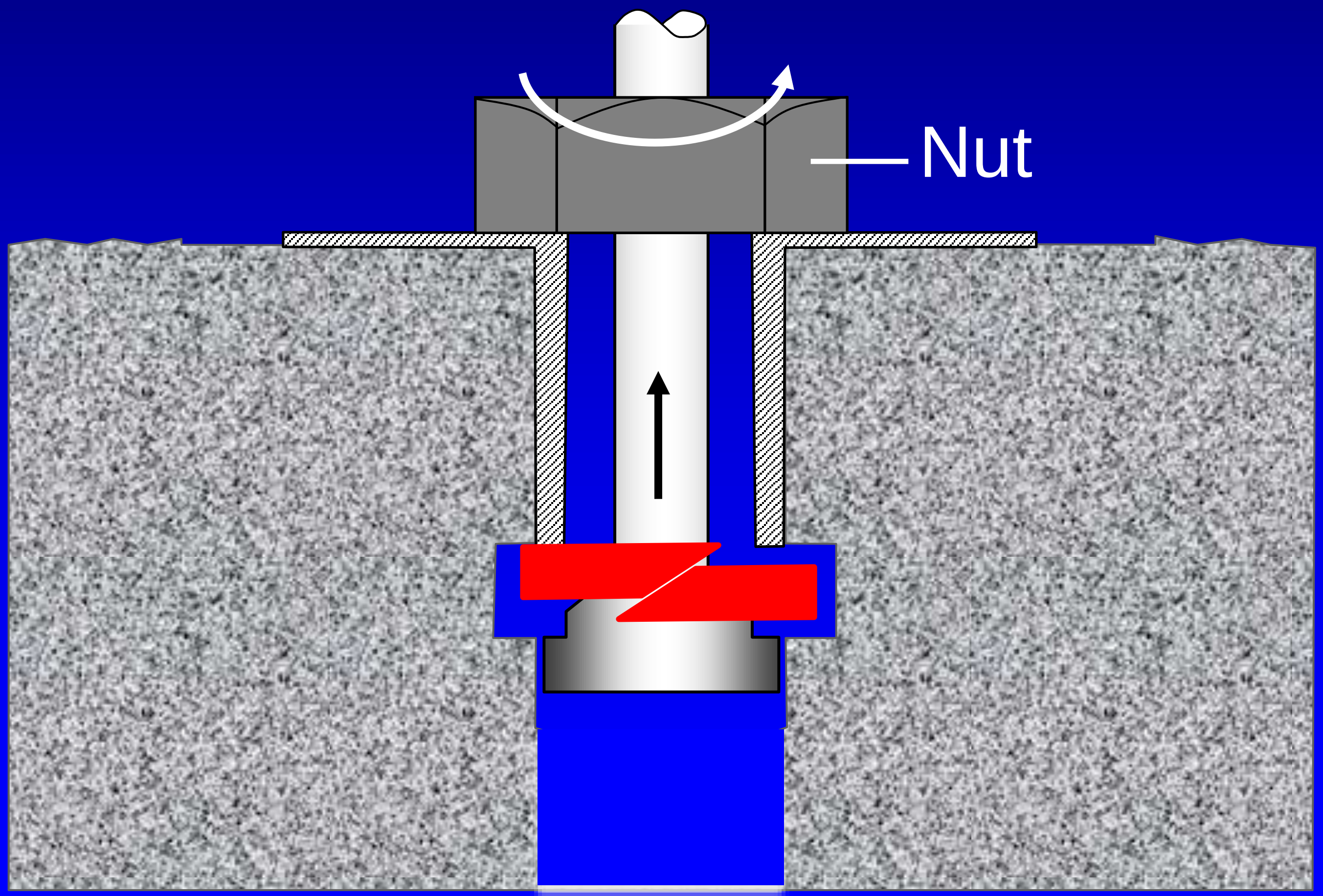


# Ring Expansion Hardware



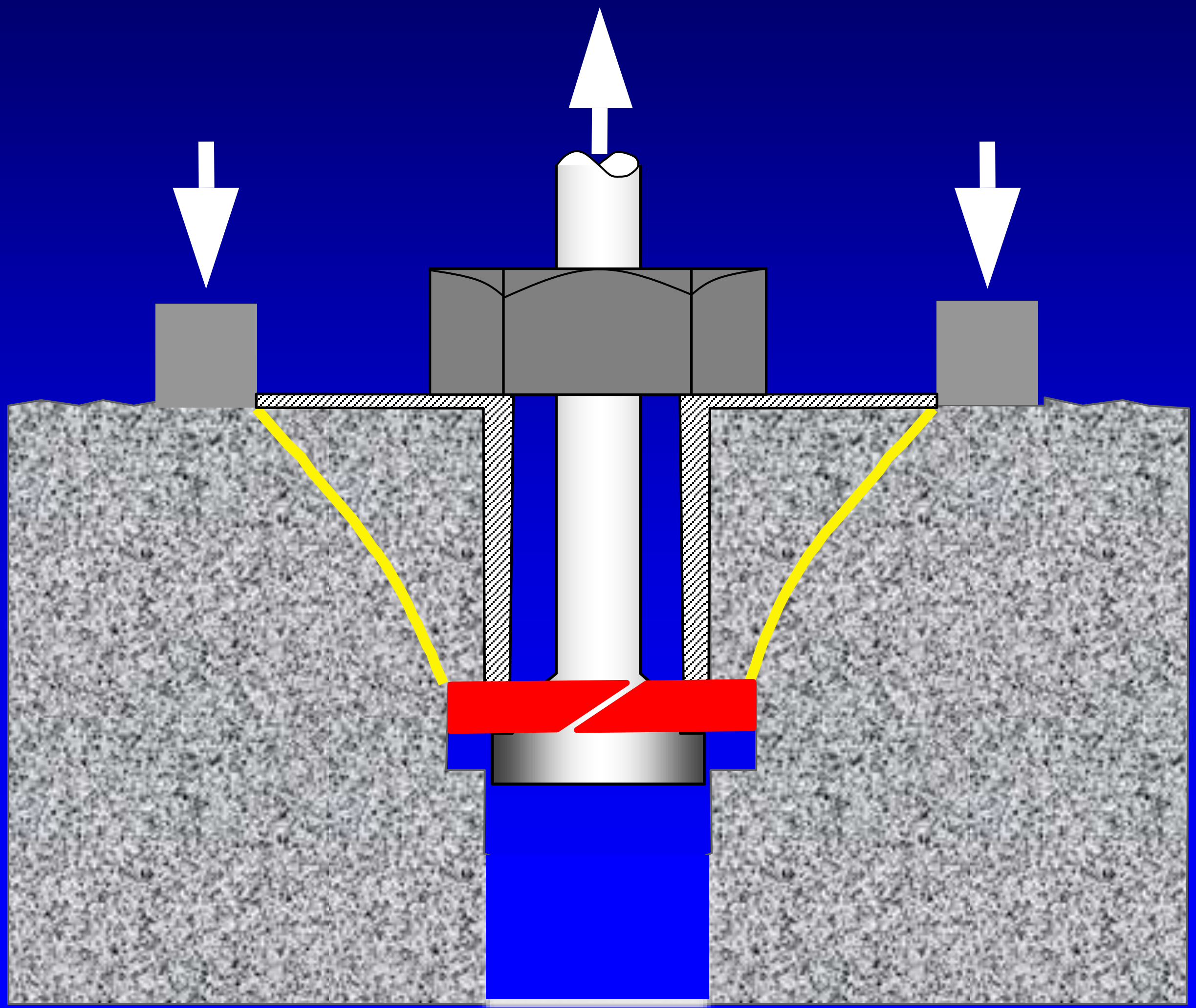

When assembling, make sure the **inner sharp edge of the coiled ring is against the cone surface**

# Expand Ring



# 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

# Criteria for correct CAPO testing

# CAPO-TEST



GI

# CAPO-TEST failure

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

# Comparative study Polish bridges for increased loading

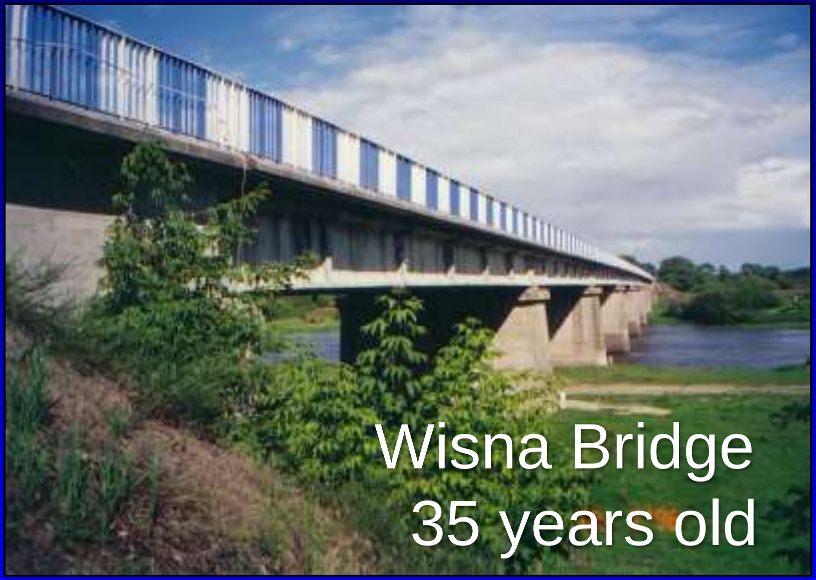
- Cores, sawcut, capped, tested after 5 days drying in lab conditions (100 mm dia x 100 mm cores)
- CAPO-Test in-situ, double amount of cores
- Schmidt Hammer in-situ, up to 20 locations, each 6 tests
- Schmidt Hammer on side of cores prior to compression tests

NOTE: All Schmidt Hammer results have been reduced by an "Aging Factor" of 1.4 recommended by manufacturer. The "Aging Factor" is not substatiated or explained by the manufacturer of the Schmidt Hammer

# CAPO-TESTing on Polish bridges

COMA-Meter

# Comparative Strength Estimates from 50 Polish Bridges, examples


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

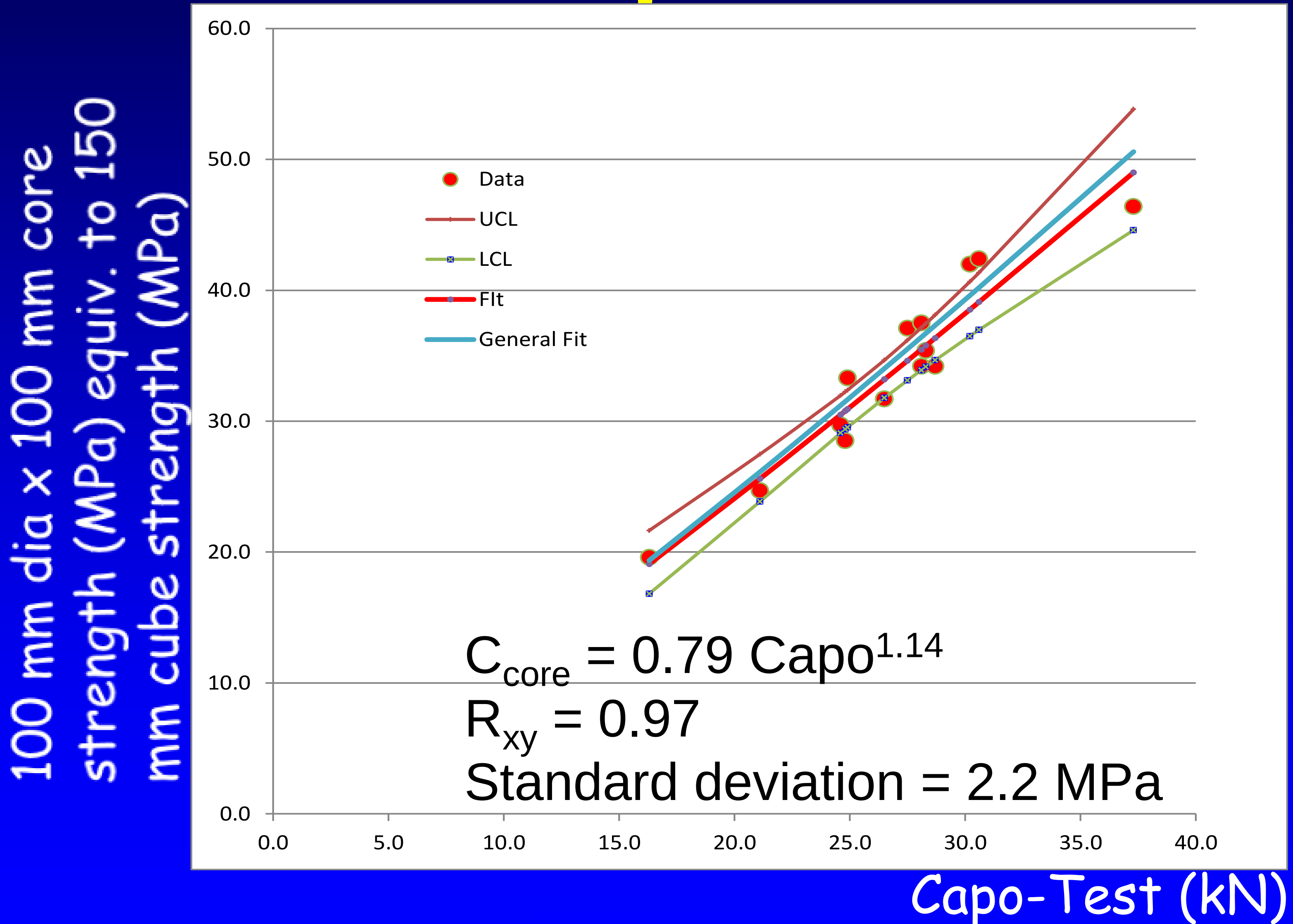
***Carbonation depth: 2 mm - 35 mm***

***Sour**ce: 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 Hammer on cores* | |
|---|---|---|---|---|---|---|---|---|
| | **MPa** | Av. of | **MPa** | **% dif** | **MPa** | **% dif** | **MPa** | **% dif** |
| 1 | 19.6 | 6 | 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.*** | ***32.8*** | | ***33.5*** | ***+2.1*** | ***55.8*** | ***+70.0%*** | ***44.6*** | ***+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

# 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 $C_{cube} = 0.76\ Capo^{1.16}$

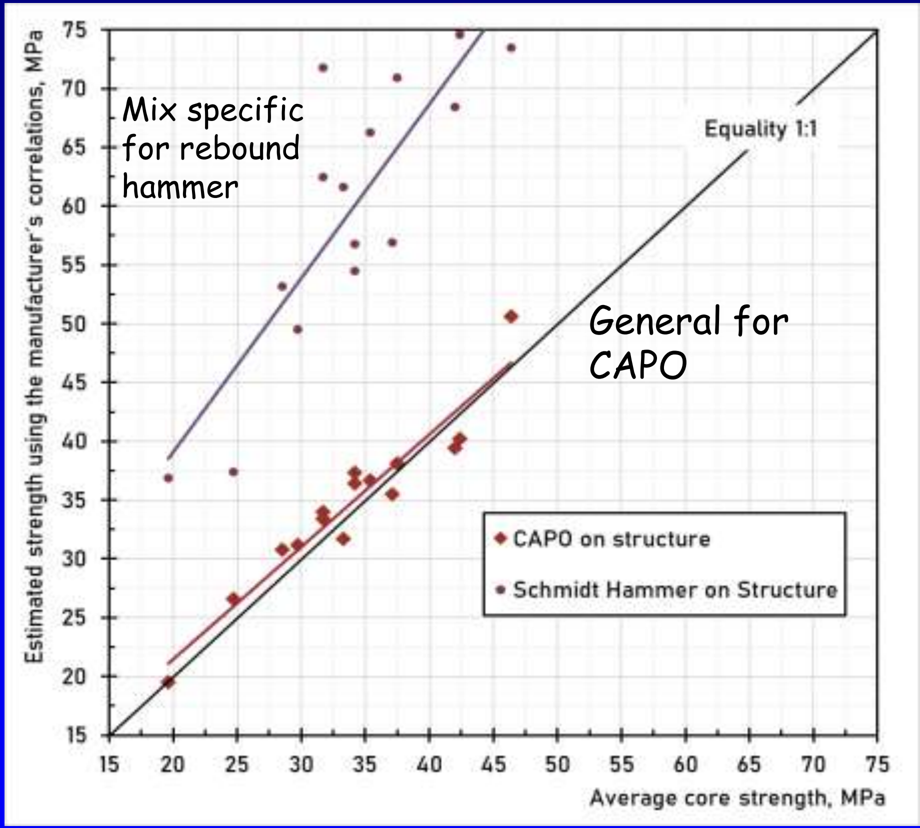
As a 100 mm dia. core, 100 mm long gives a strength equivalent to the strength value of a 150 mm cube, the following general relationship may be applied:

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

# Core, CAPO and Schmidt Hammer strength estimates, 15 bridges

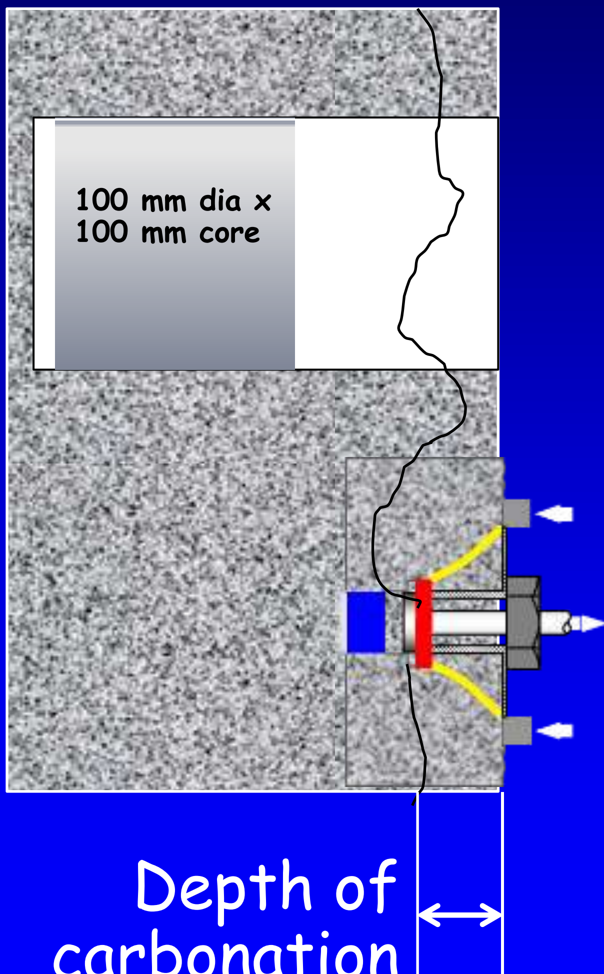
| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Bridge No. | Name | Average core strength, MPa ($C_{core}$) | CAPO, Estimated compressive strength, MPa ($f_{CAPO}$) | Schmidt Hammer on Structure (MPa) |
| 1 | Zyrow | 34.2 | 36.4 | 57.9 |
| 2 | Dobrut | 24.7 | 26.6 | 51.5 |
| 3 | Wizna | 46.4 | 50.6 | 73.5 |
| 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 |

# Schmidt Hammer and CAPO strength estimates, 15 bridges

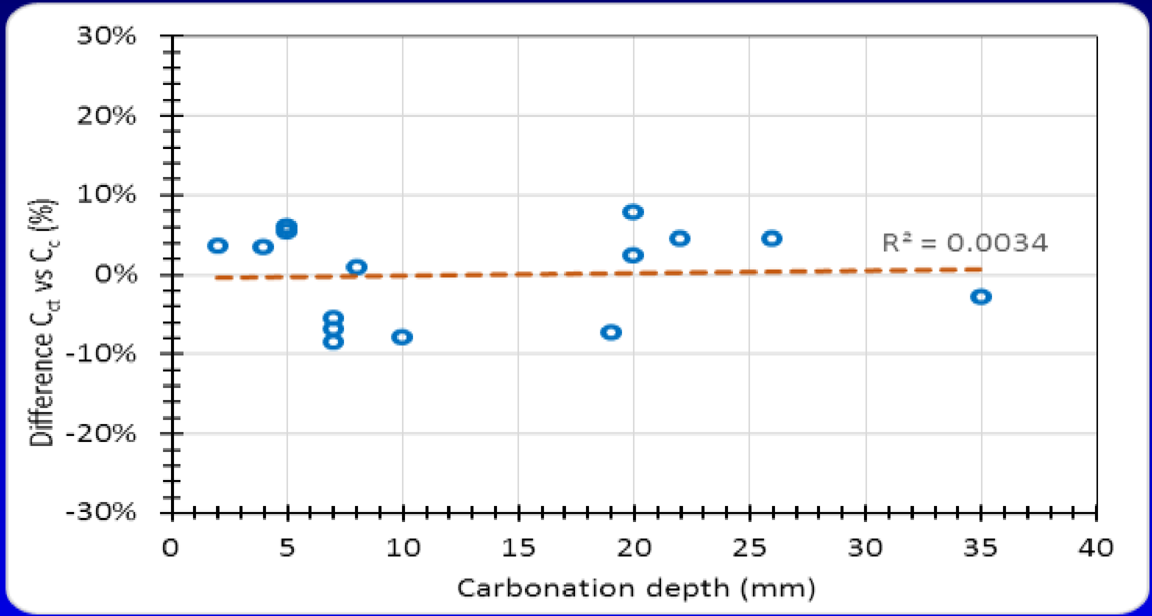



In average, the Schmidt Hammer is overestimating the strength by 71%

# Effect of carbonation on CAPO




Depth of carbonation




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

Ref: Moczko, (2016)

Conclusion:
Neglectable effect
from carbonation



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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'd

- 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)

# 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

Zhengo Li, Jigar Desai, and Wesley Bullock

DOI: 10.1520/JTE20170687

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

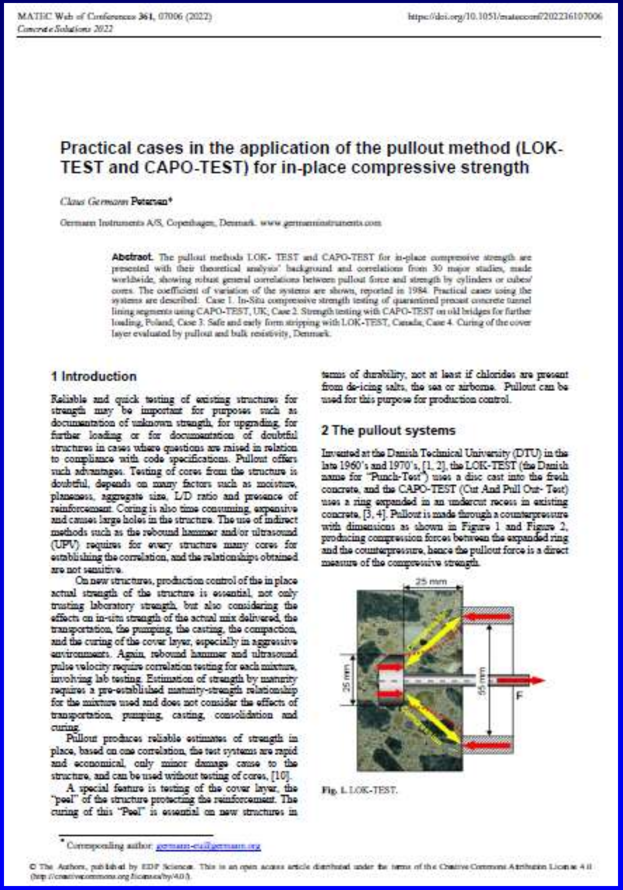

ACI MATERIALS JOURNAL TECHNICAL PAPER

CAPO-TEST to Estimate Concrete Strength in Bridges

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

INTRODUCTION

ACI Materials Journal/November-December 2016


MATEC Web of Conferences 361, 07006 (2022)

Concrete Solutions 2022

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

Claus Germann Petersen*

Germann Instruments A/S, Copenhagen, Denmark

1 Introduction

2 The pullout systems



Fig. 1. LOK-TEST.

In-Place Estimation of Concrete Compressive Strength Using Postinstalled Pullout Test – A Case Study", Journal of Testing and Evaluation, ASTM, August 31, 2018

ACI publication: CAPO-TEST to Estimate Concrete Strength in Bridges.

MATEC Web of Conferences **361**, 0 (2022) *Concrete Solutions 2022* 7006 *Concrete Solutions 2022* 7006

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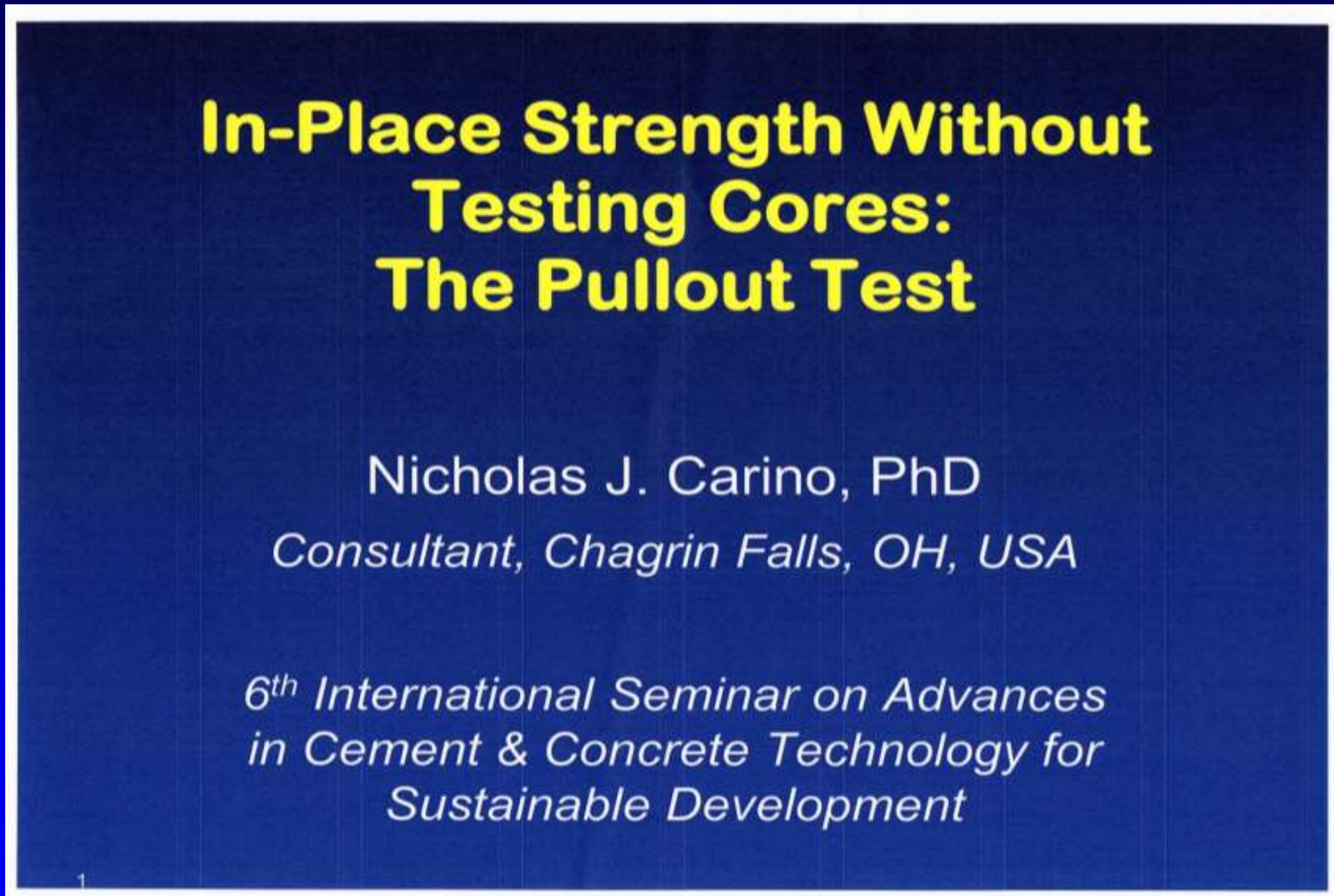
*Test smart – Build right*

# NOTE




In-Place Strength Without testing cores.

# Costs CAPO-TEST vs. Cores

| 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

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

# Other systems for homogeneousness



Rebound Hammer

Ultrasound (UPV)

# Factors Affecting Rebound Number

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



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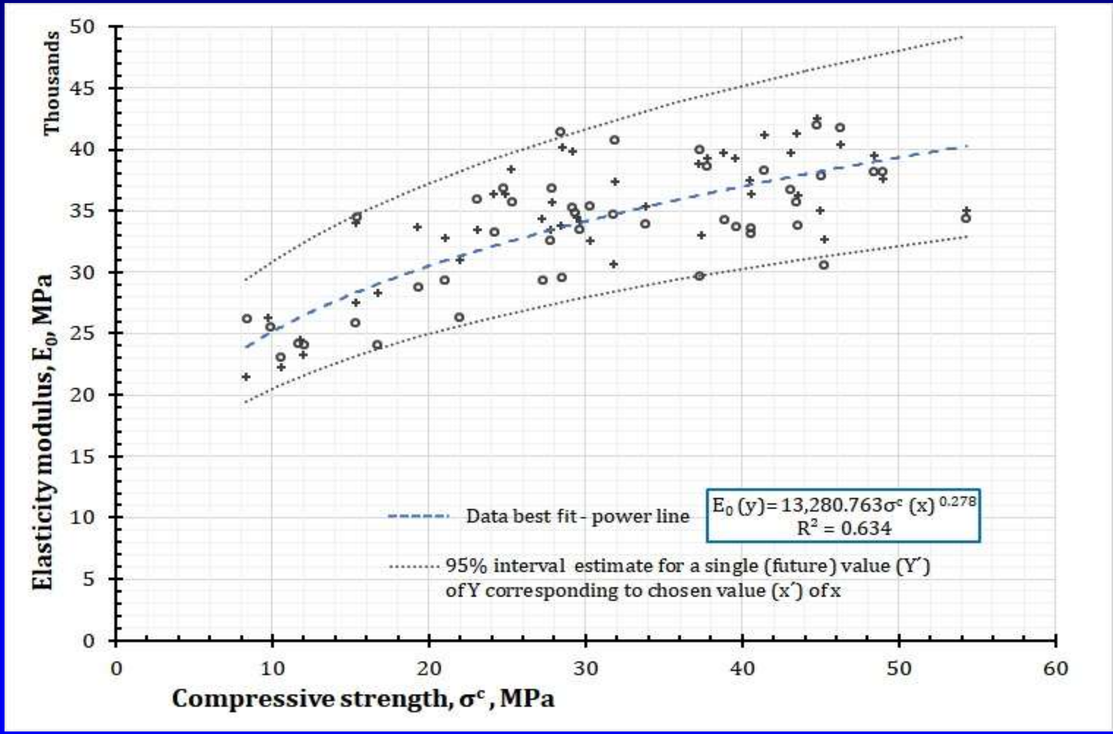
# Elasticity and compressive strength

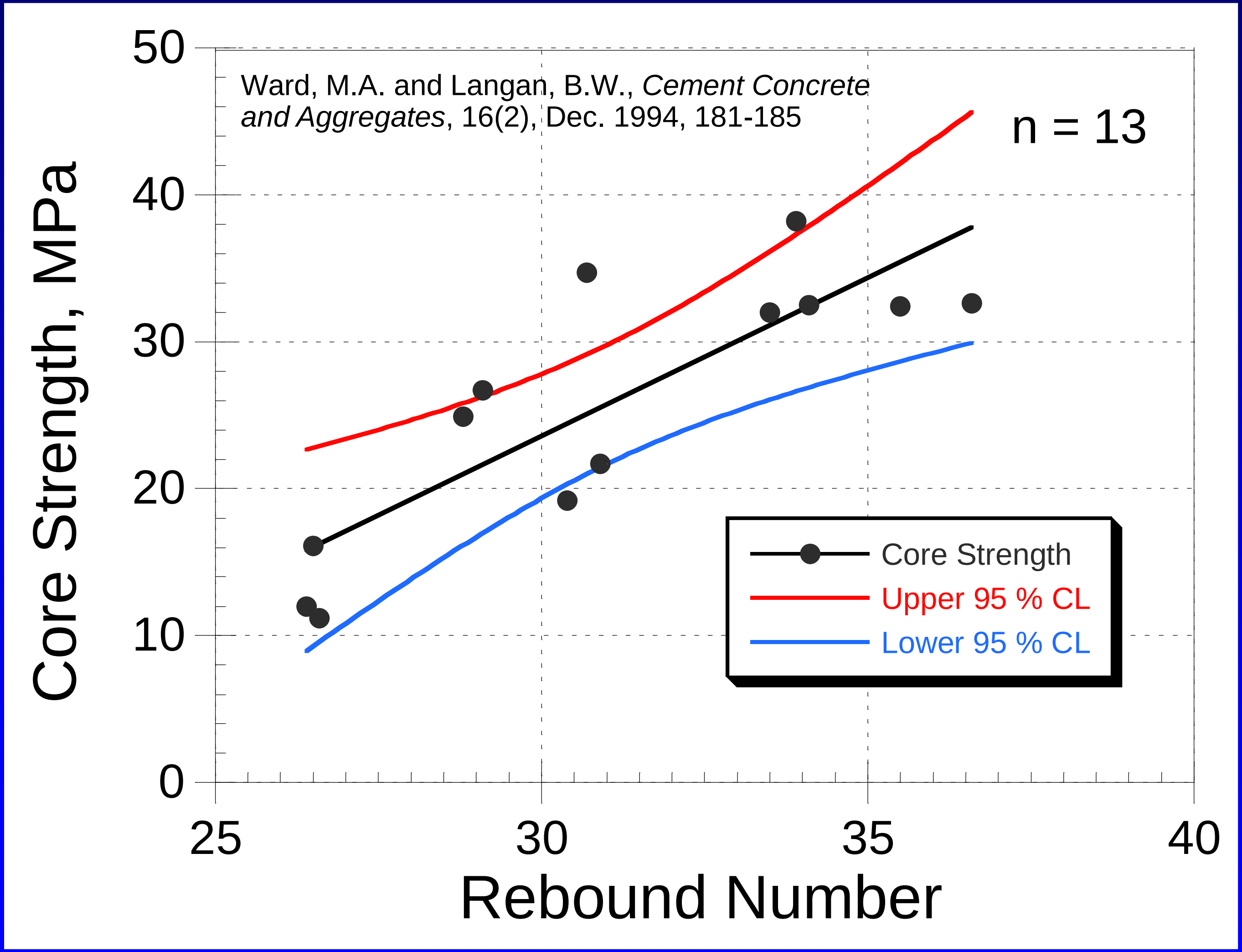
$$E \propto \sqrt{f_c}$$



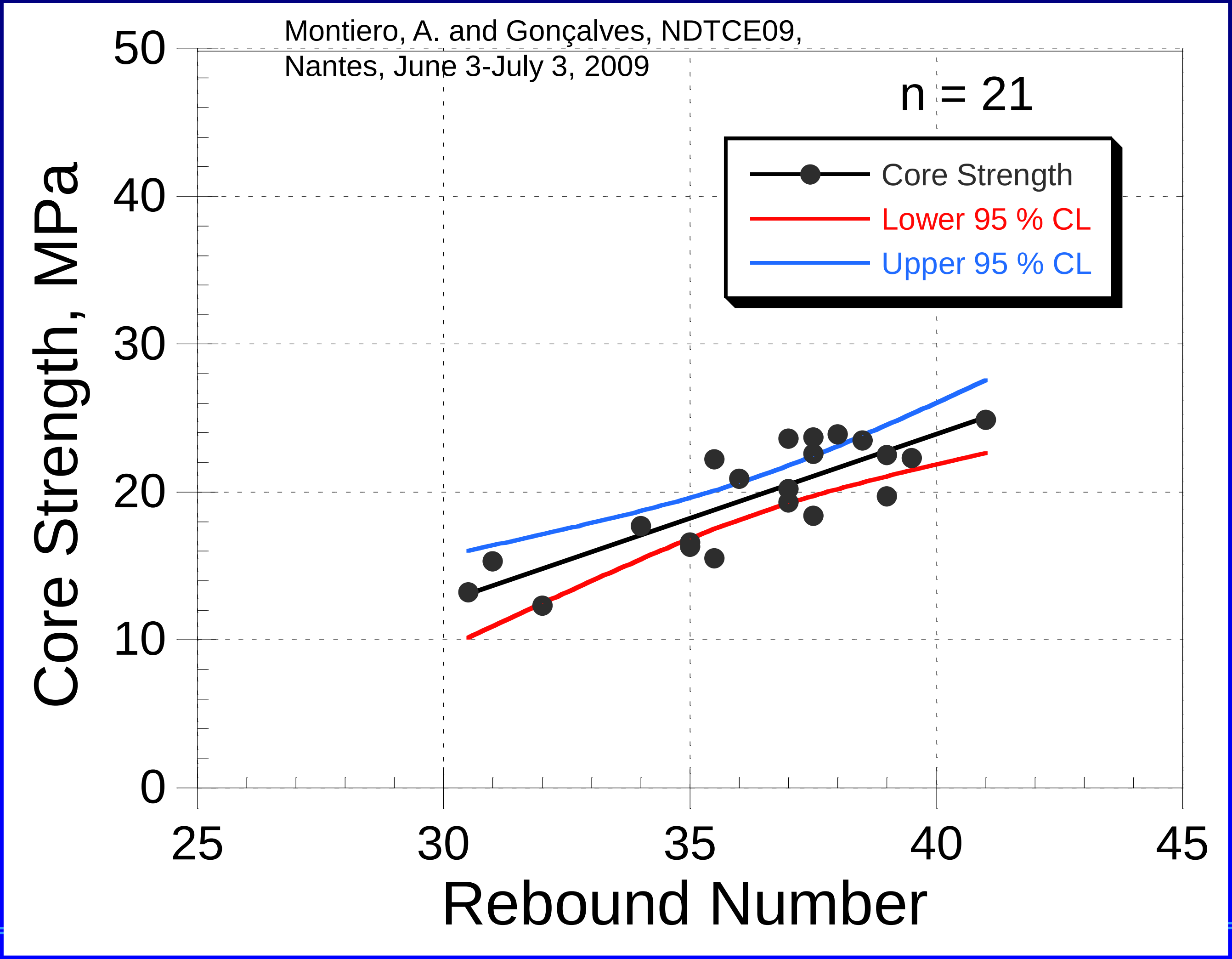

Elasticity has a weak relationship to compressive strength with a large scatter

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

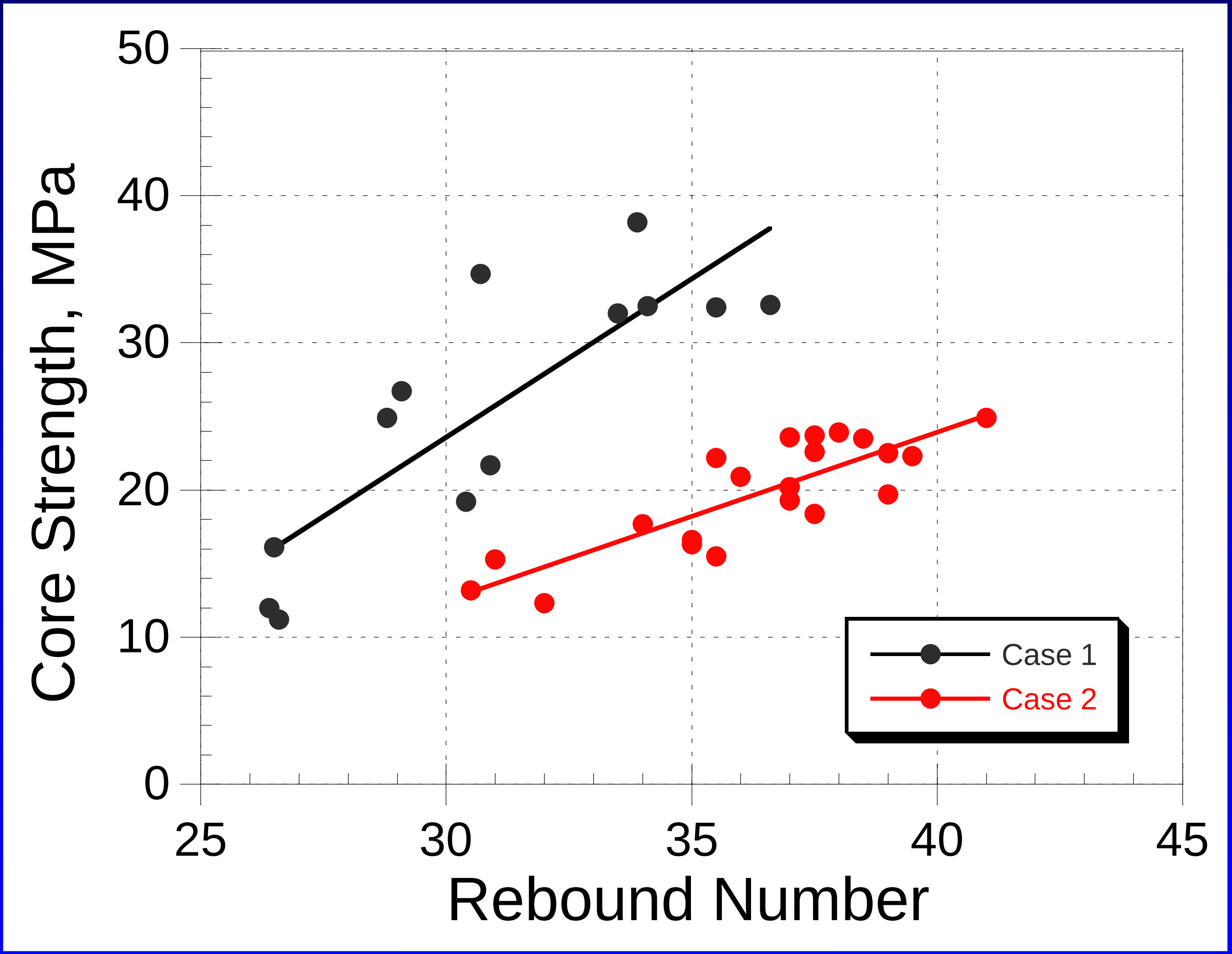
# Rebound to cores, case 1



# Rebound to cores, case 2



# Comparison of Relationships

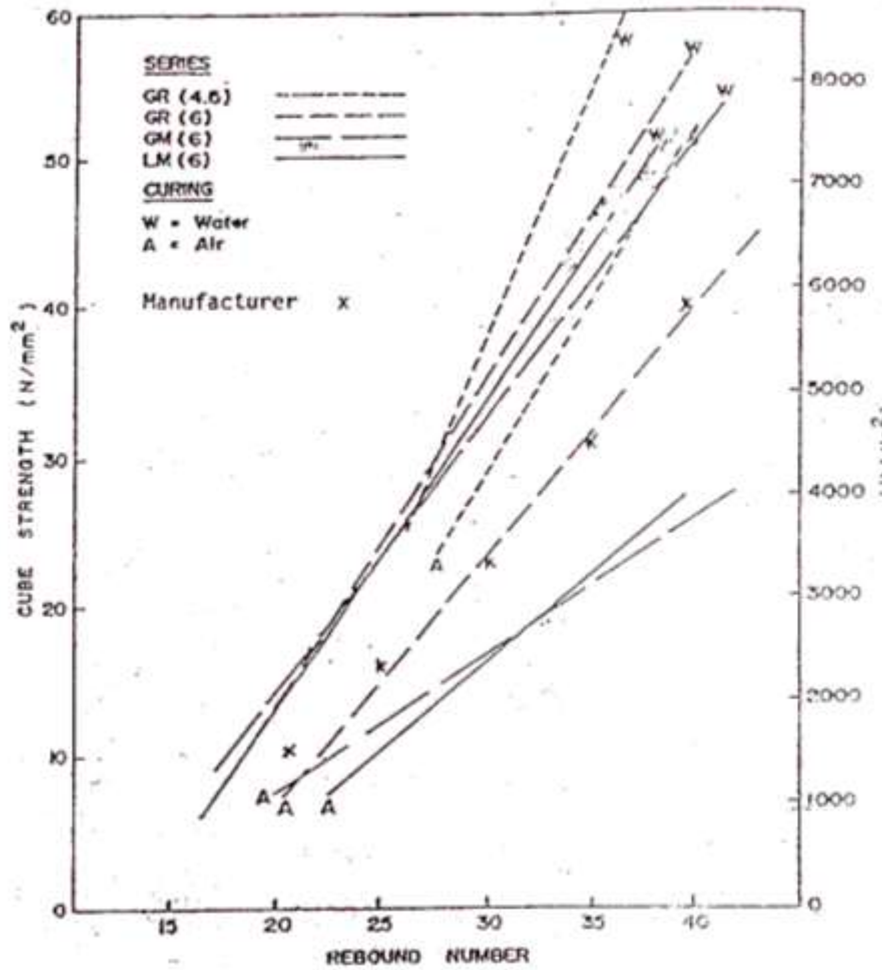


# Rebound Hammer related to cube strength

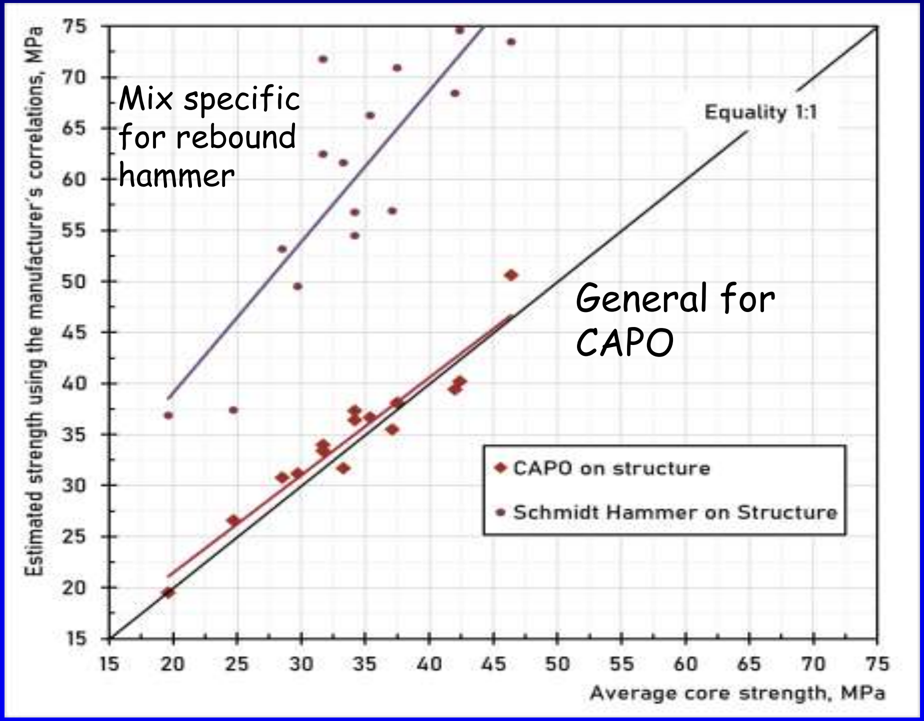
Average relationships shown for granite and limestone aggregates and curing conditions (water and air)

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

| Series | Aggregate coarse | Aggregate fine | Aggregate-cement ratio |
|---|---|---|---|
| GR(4.5) | granite | river sand | 4.5 |
| GR(6) | granite | river sand | 6.0 |
| GM(6) | granite | 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

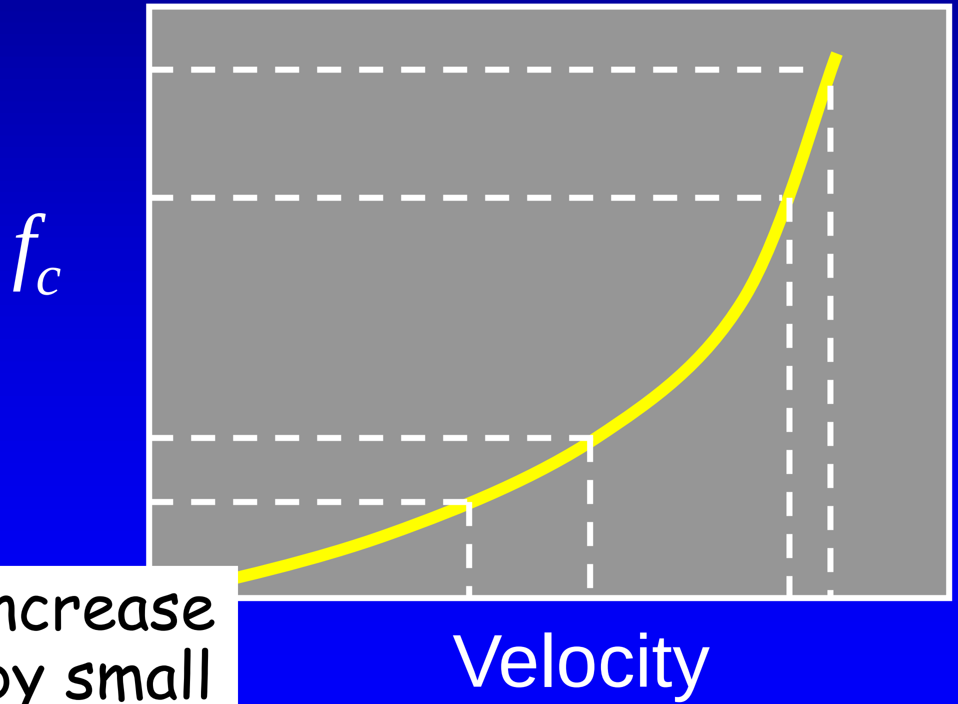
- Strength is not measured physically as it is with cores or LOK-TEST / CAPO-TEST pullout
- A rebound value is obtained, related not only to the Elasticity of the material, but also Aggregate type, Air voids, Carbonation, Surface texture Surface moisture condition and Rigidity of the test object
- Correlation 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$^{o}$ slopes, with large scatter of results

# Strength Relationship UPV

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

Empirically: $E \propto \sqrt{f_c}$

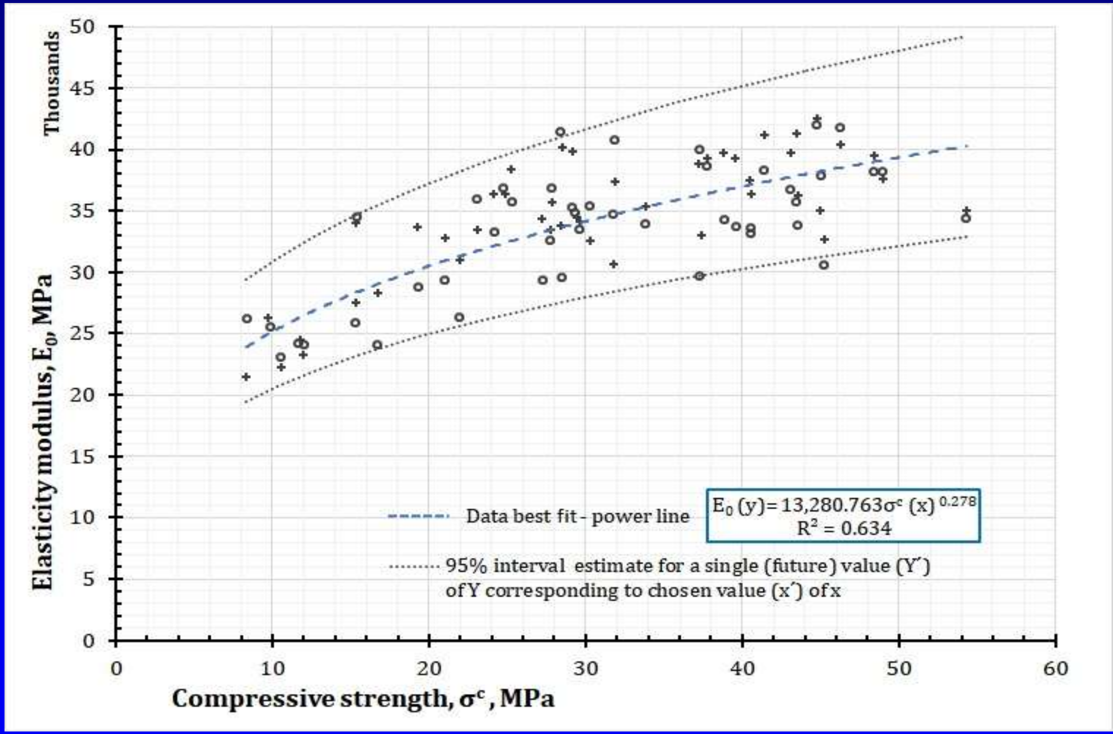
$\therefore f_c \propto (V)^4$




For mature concrete, large increase in strength is accompanied by small increase in velocity, mix specific.

# Elasticity and compressive strength

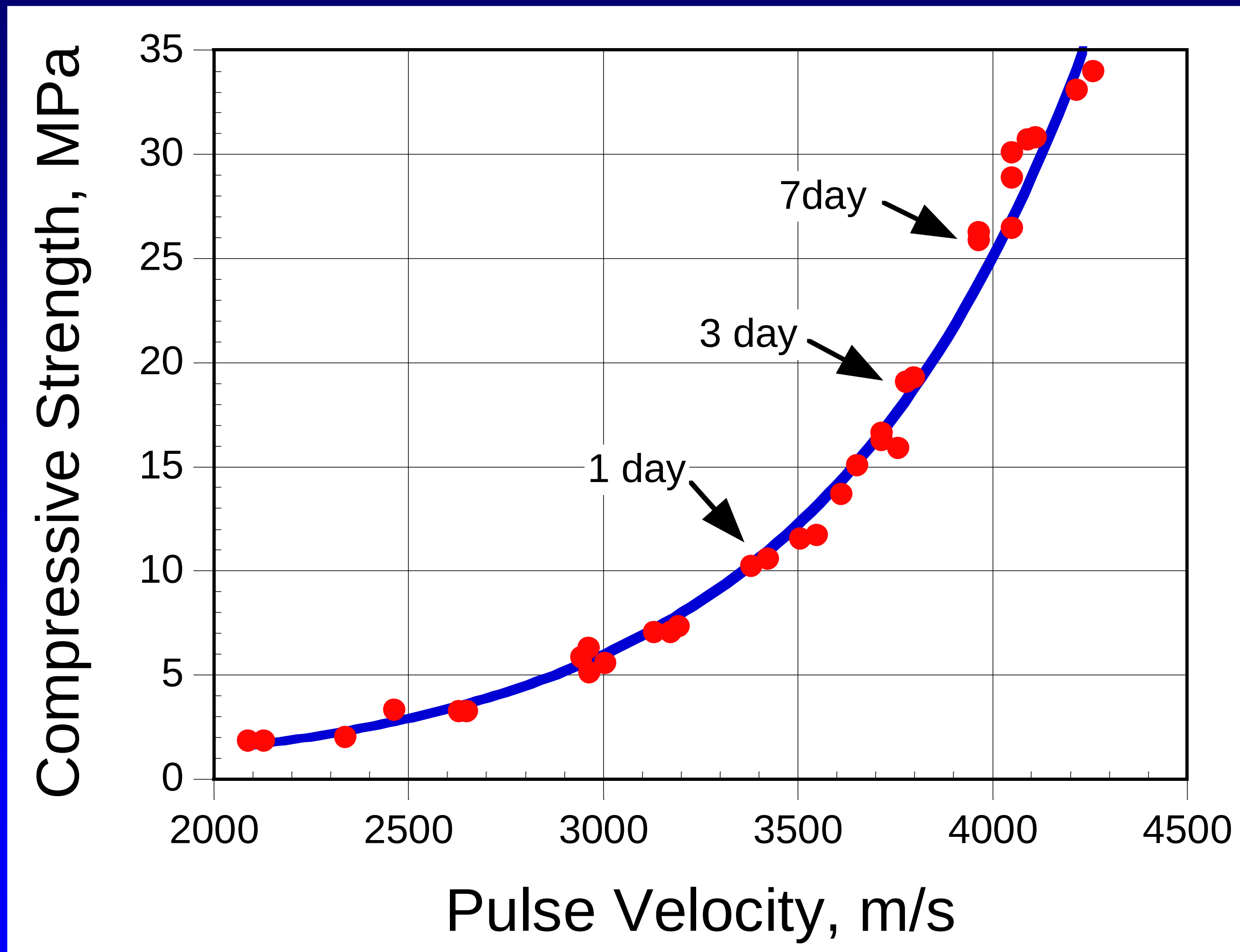
$$E \propto \sqrt{f_c}$$




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



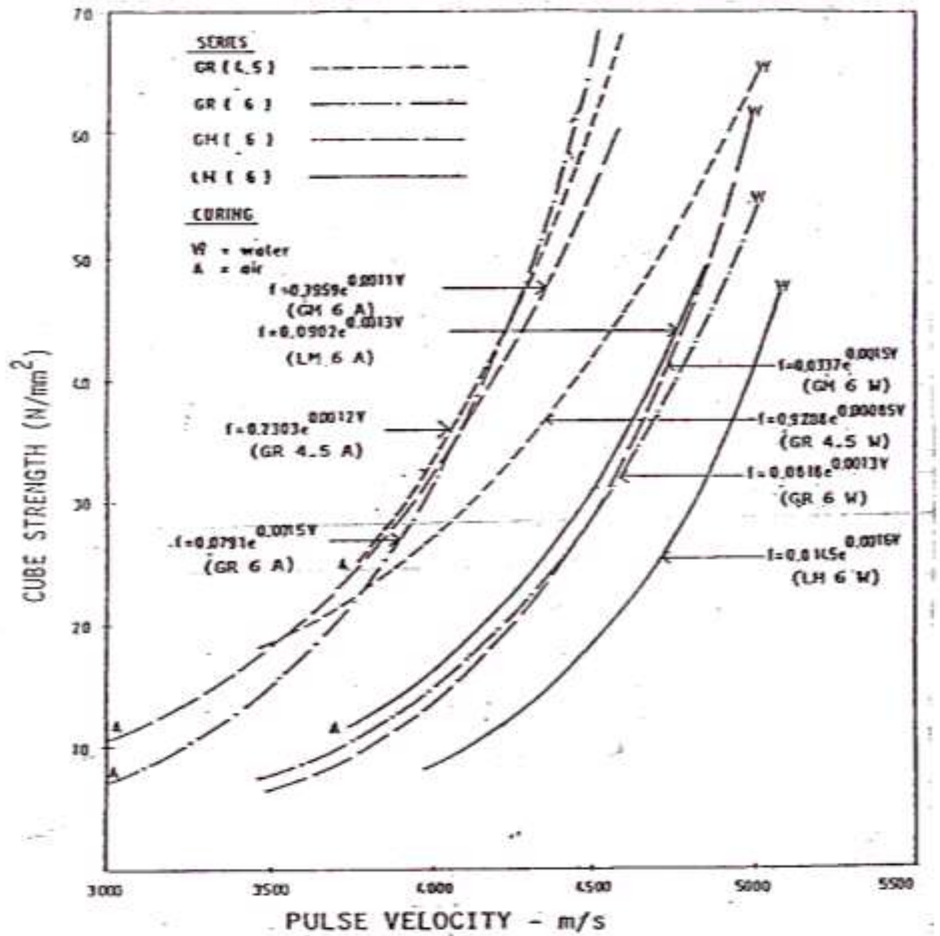
# UPV (Ultrasound Pulse Velocity) related to cube strength

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

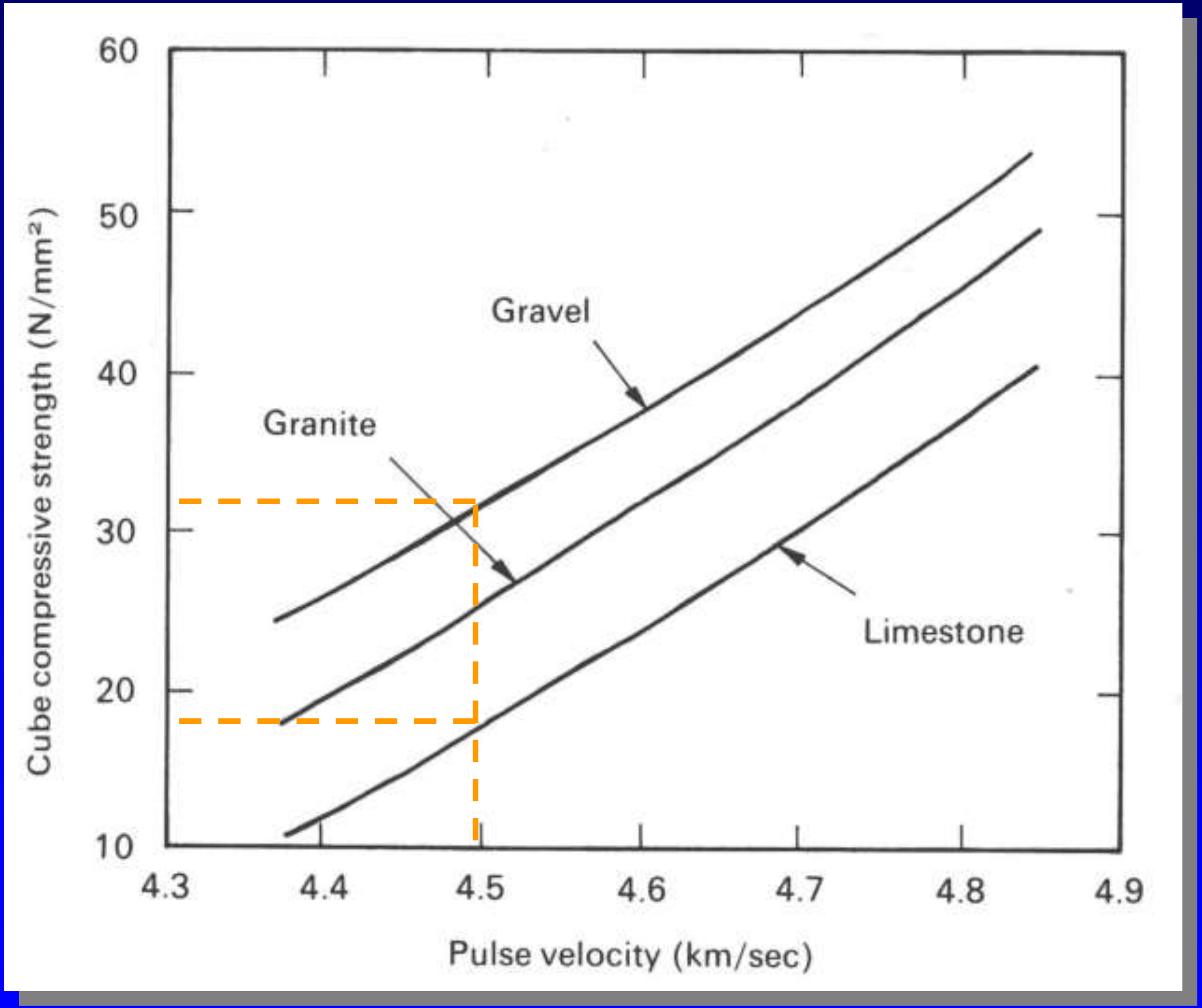
Ref: Tam, C.T.: "Application of NDT in Appraisal of Buildings", 4th Int.´l Conf. On Inspection, Appraisal, Repair and Maintenance of Buildings & Structures, 28-30 March, 1995, Hong Kong

CONCRETE MIXES

| Series | Aggregate coarse | Aggregate fine | Aggregate-cement ratio |
|---|---|---|---|
| GR(4.5) | granite | river sand | 4.5 |
| GR(6) | granite | river sand | 6.0 |
| GM(6) | granite | mining sand | 6.0 |
| LM(6) | limestone | mining sand | 6.0 |



# Example
## Aggregate Type



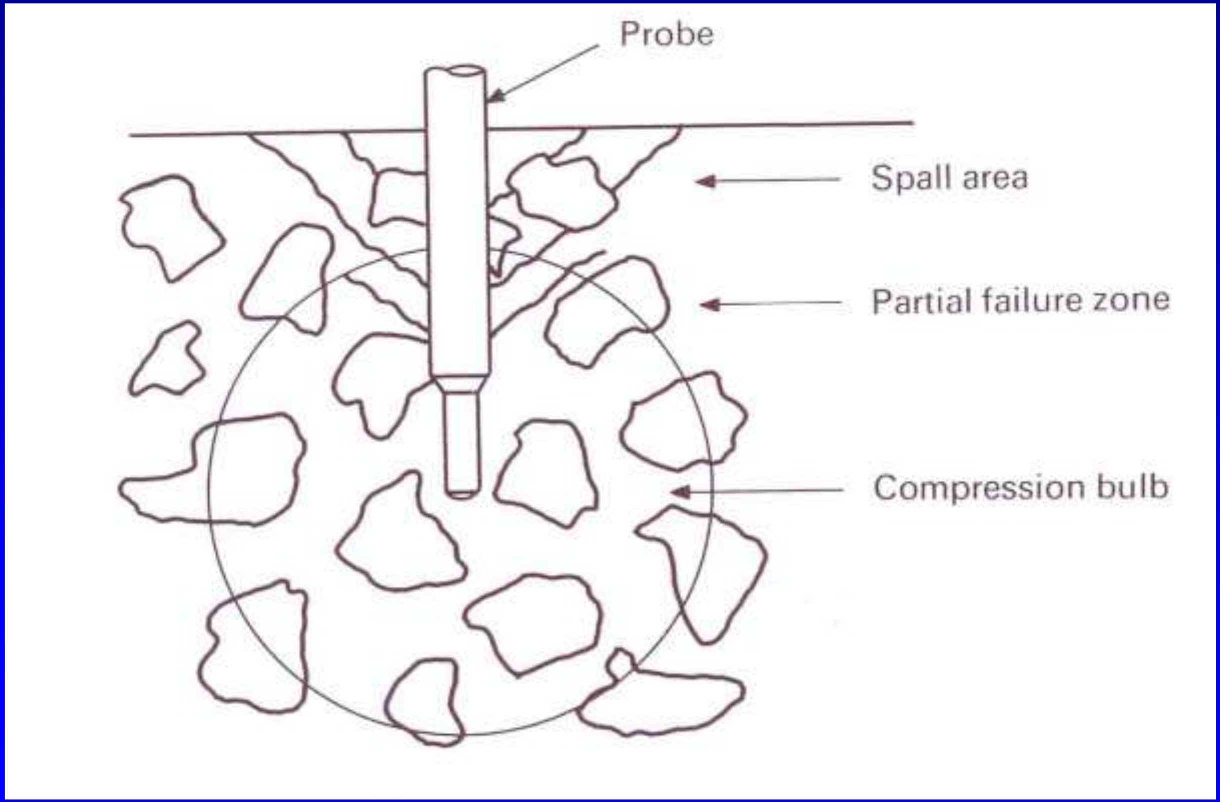

Ref: Bungey, 1982

# Factors Affecting UPV for Given Concrete Mix

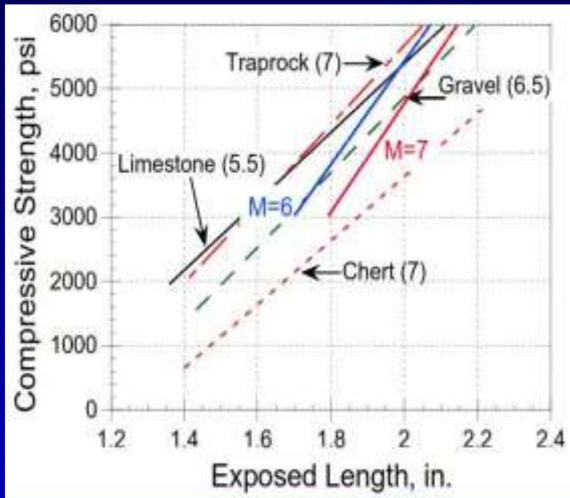
- Aggregate type
- Aggregate content
- Moisture content
  - Saturated concrete 5 % greater UPV than dry
- Presence of reinforcement
  - Perpendicular to pulse path
  - Parallel to pulse path

# Windsor Probe

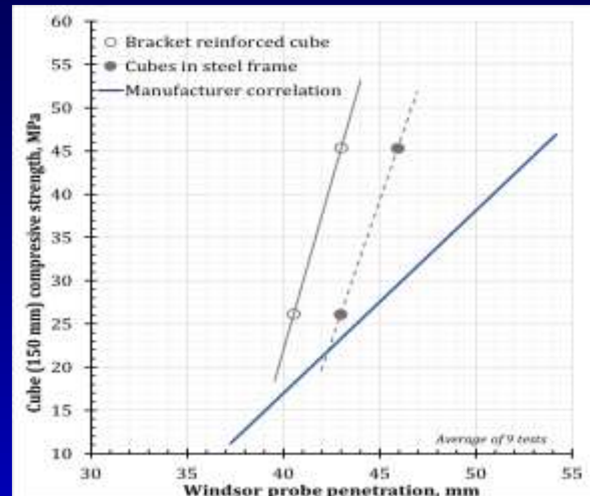
**Penetration Resistance of Hardened Concrete by shooting a probe into the concrete and measure the pentartion depth**



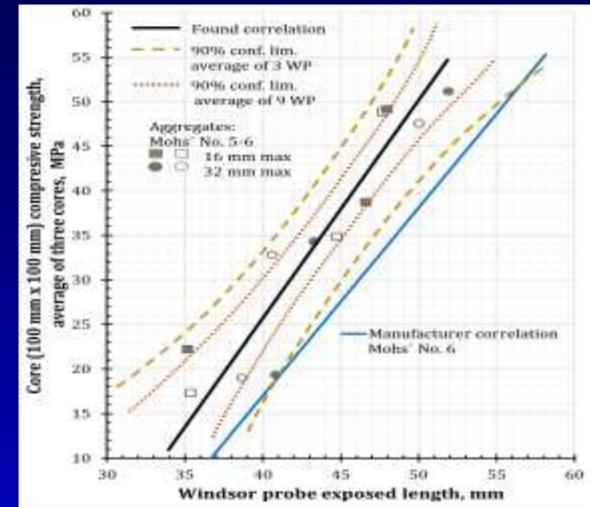
# Correlations



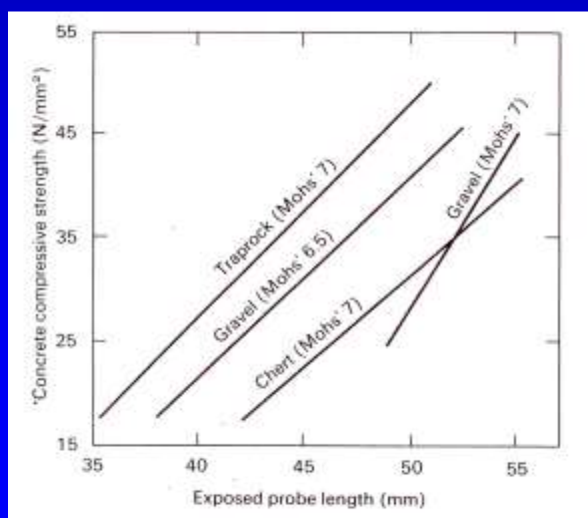

Malhotra, 1974



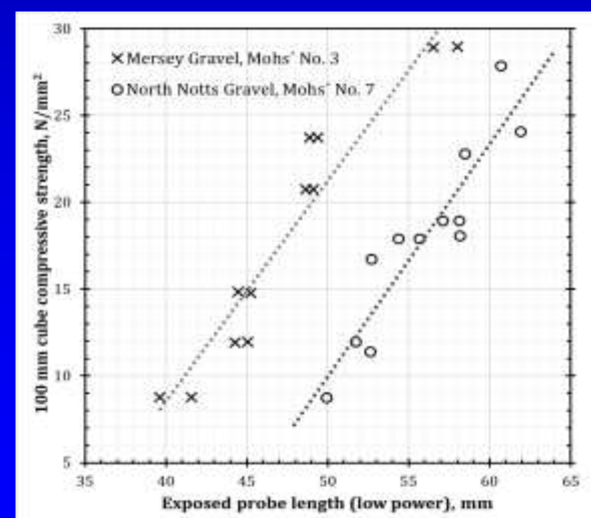

CBI, 1978




CBI, 1978

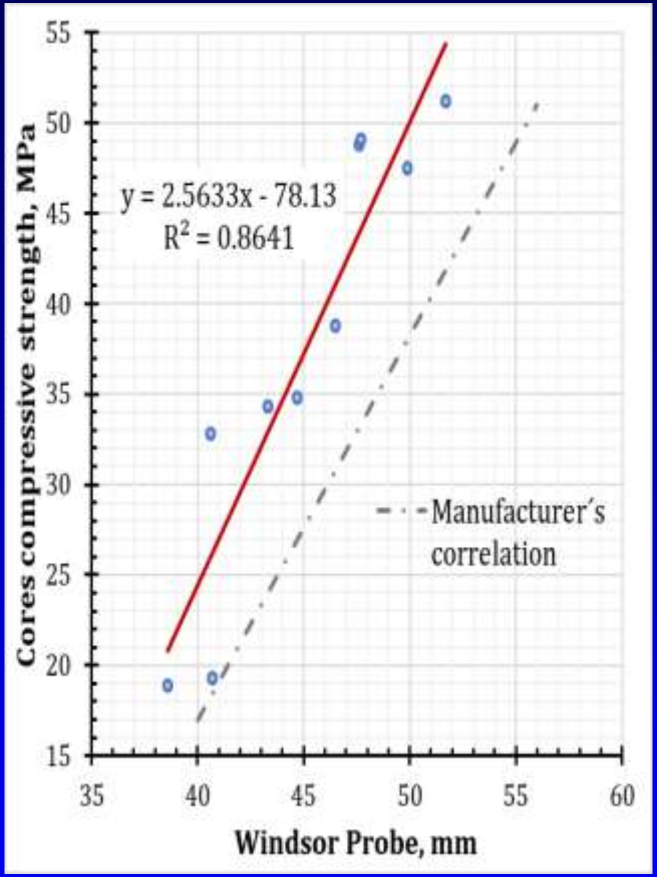


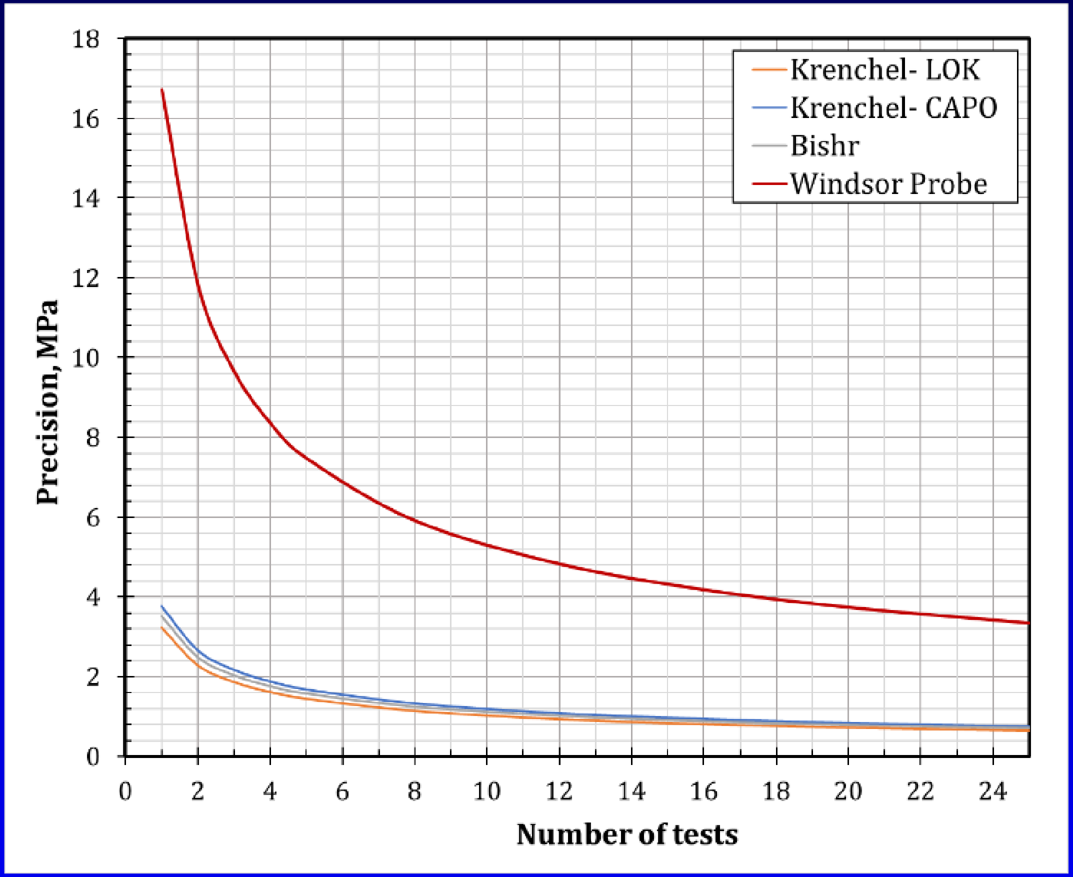

Bungey, 2002




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

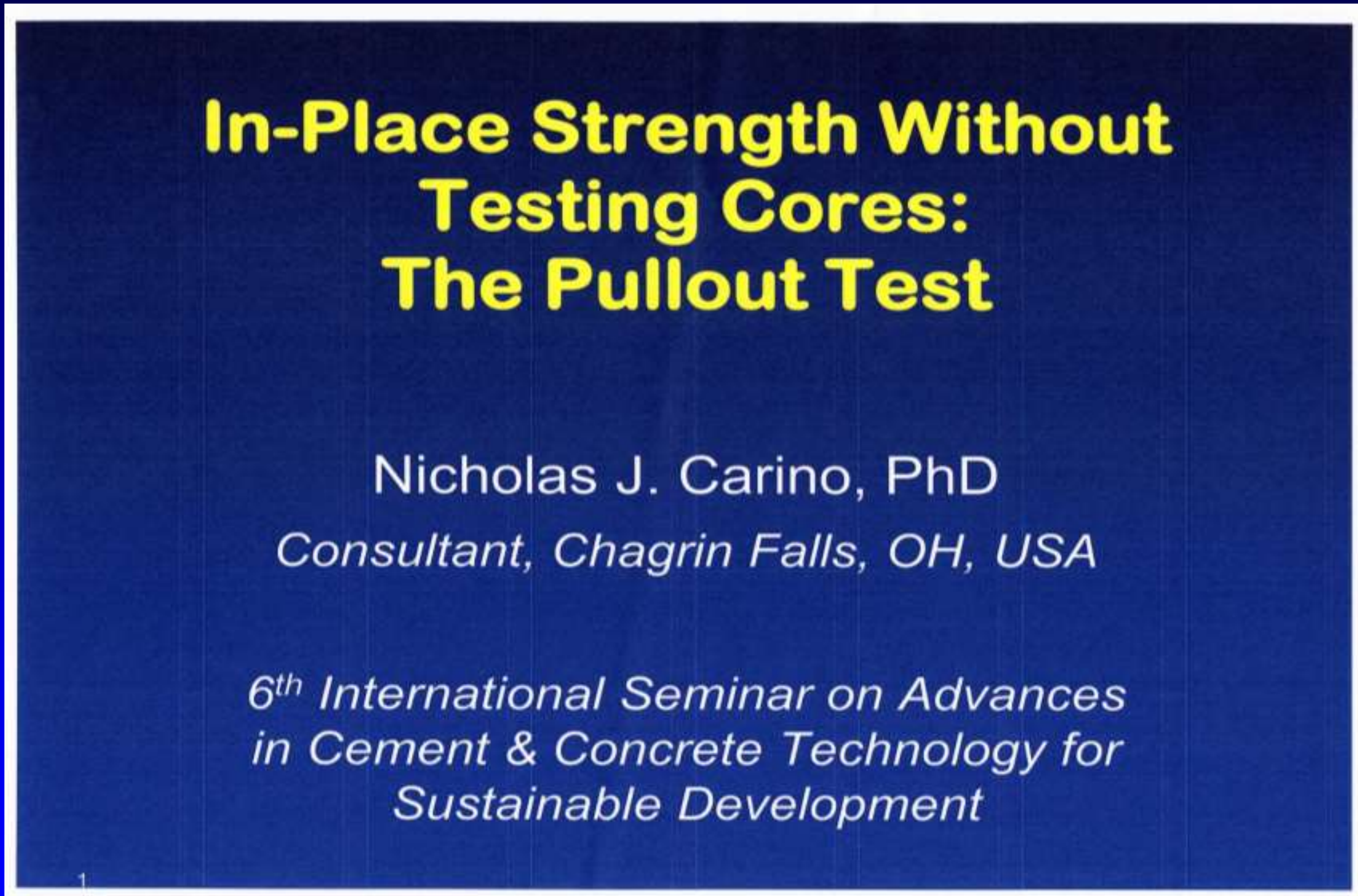
Report on Methods for Estimating In-Place Concrete Strength

Reported by ACI Committee 228

## 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.

# 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



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# 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

  (Rebound number method, Probe penetration test, Ultrasonic pulse velocity) → Requires correlation testing for each concrete mixture
  - Pullout test → Reliable estimates

# 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**