In-Situ Strength by CAPO-TEST

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on load carrying capacity of bridges
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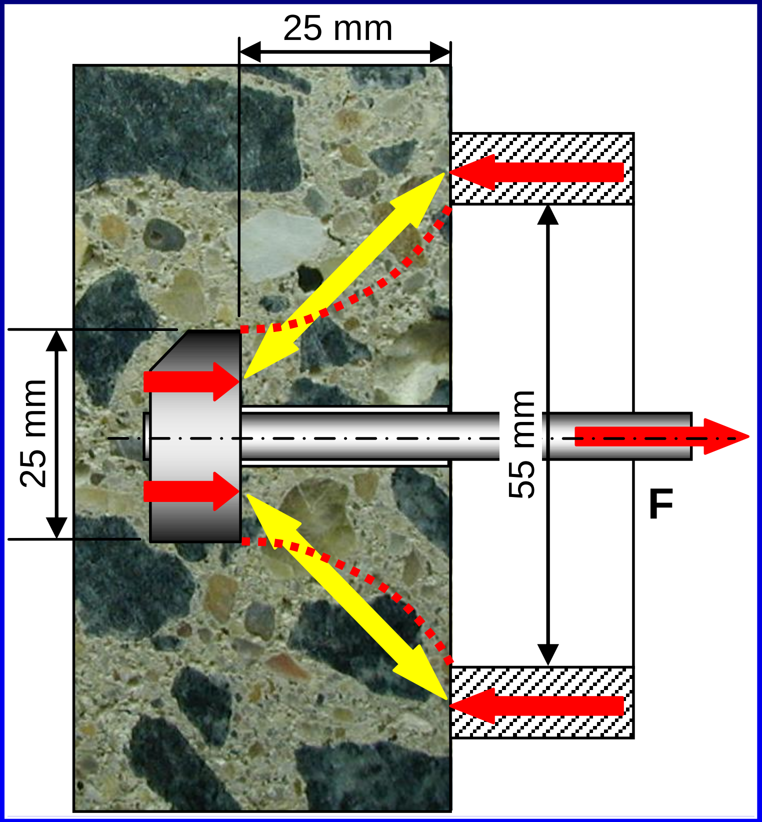
In-Situ Strength, why?

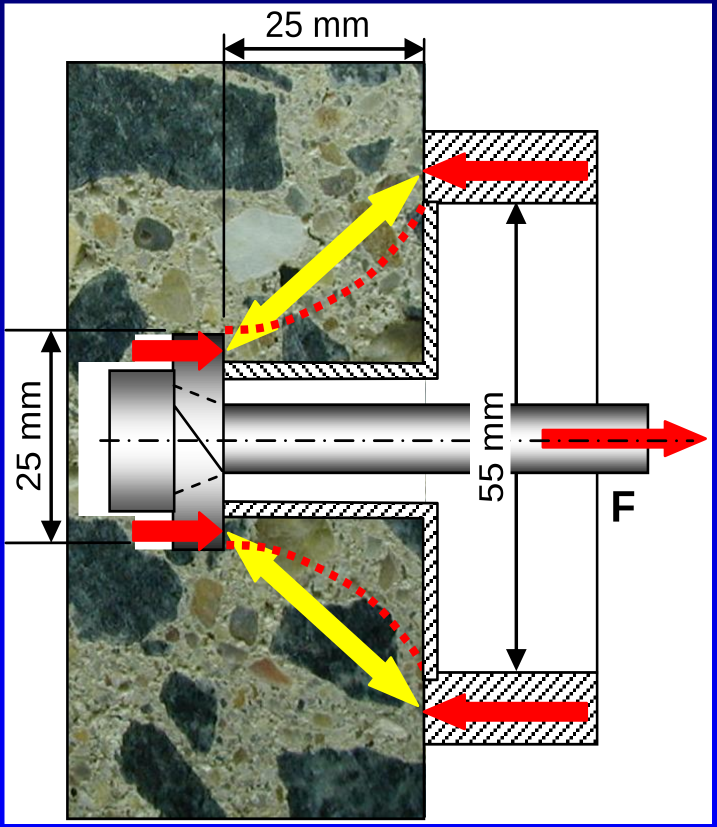
- Strength of existing structures for calculation of load carrying capacity
- Timing of safe and early loading operations
- Control of effects of transportation, compaction and curing, in-place
- Quality of the cover layer protecting the reinforcement
- Low strength of laboratory specimens
- Changed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

Evaluation of in-place strength

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

LOK-TEST CAPO-TEST





Examples

London, UK
Strength of industrial floor

Translink, UK,
Residual strength of tunnel segments

Trinity Square, Toronto, CA,
Strength for early loading

Bridge Leznow, Poland
Residual strength

Cigar Lake Uranium Mine, CA
Strength of gunite concrete

Great Belt Link, Denmark
Strength of cover layer

What is measured in a LOK-TEST and CAPO-TEST?

Analysis by Jensen & Bræstrup

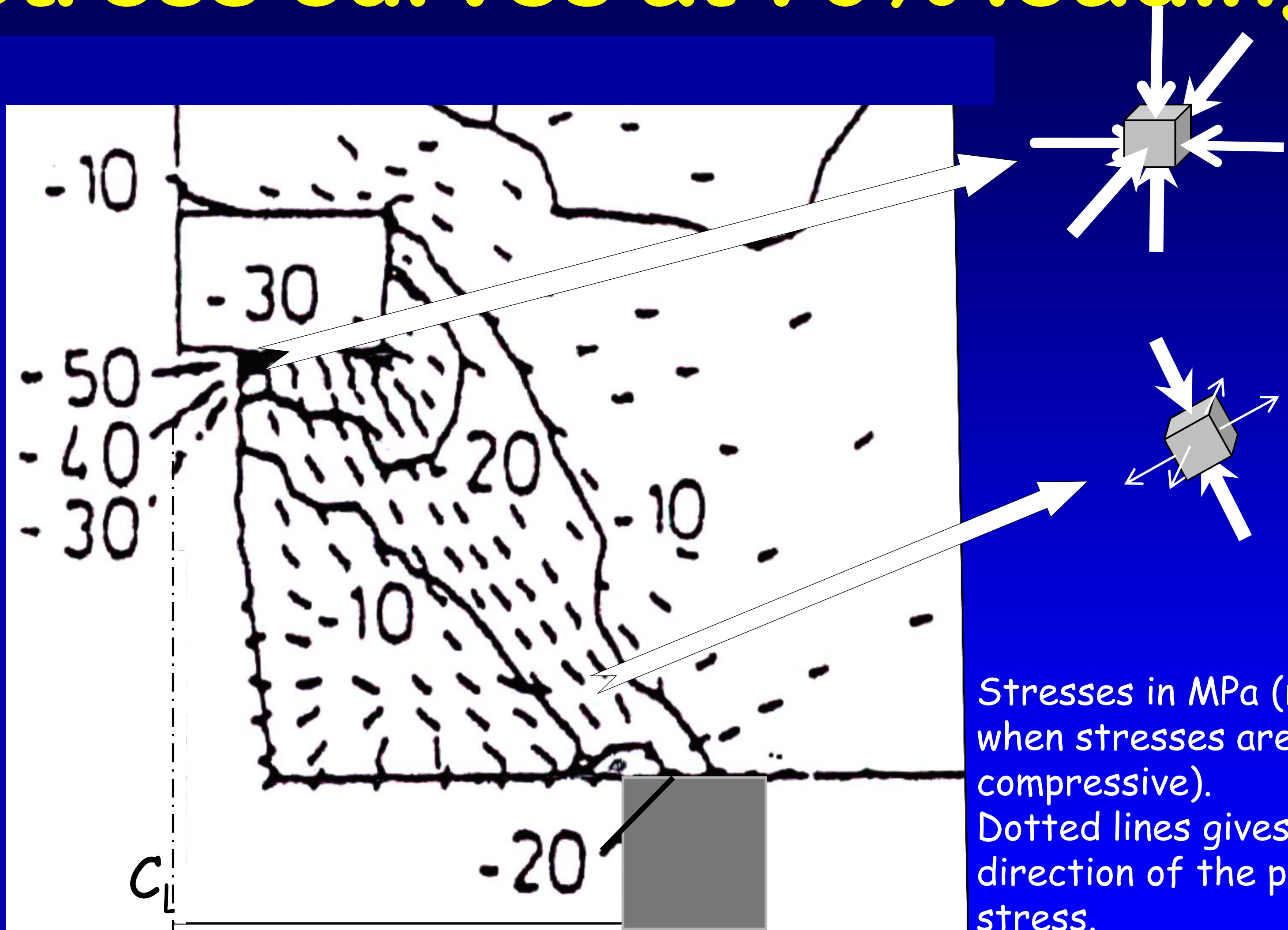
- Jensen, B.C. & Bræstrup, M.W.: "LOK-Test Determine the Compressive Strength of Concrete", Nordisk Betong, 3-1976

Conclusion:
"Plastic analysis may be applied to determine the load-carrying capacity of the concrete embedded bolt which is pulled out under application of a counterpressure (LOK-TEST). It is shown that when the angle between the direction of deformation and the failure surface is equal to the angle of friction for the concrete, then the pullout 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 70% loading

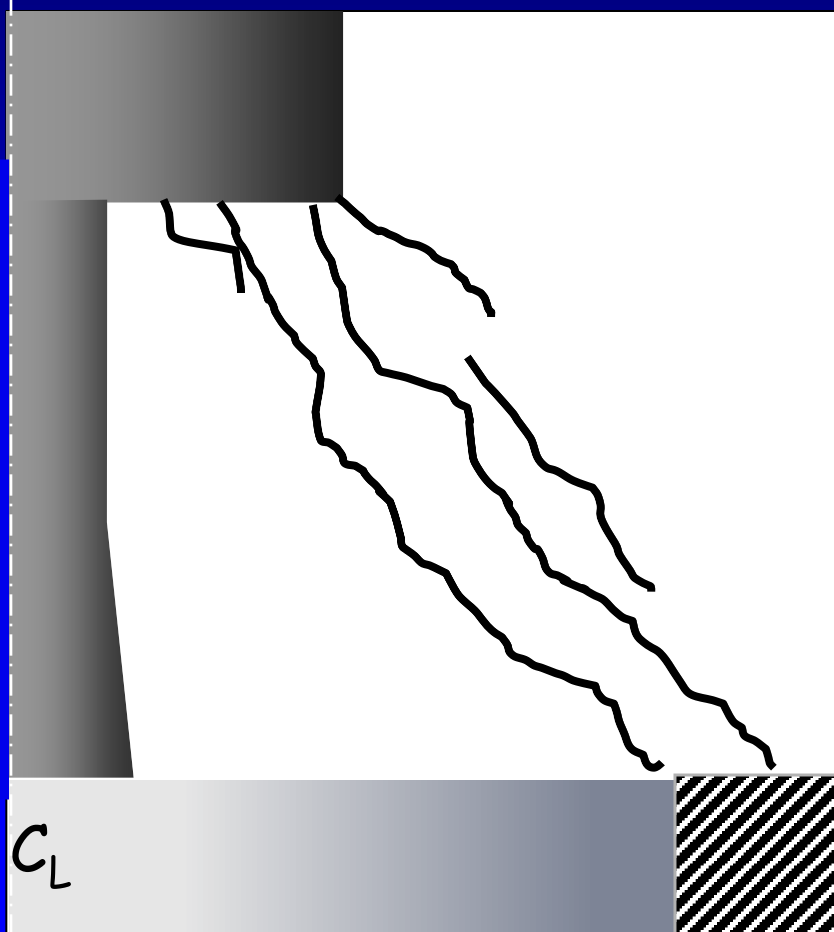


Stresses in MPa (negative when stresses are compressive).
Dotted lines gives the direction of the principal stress.

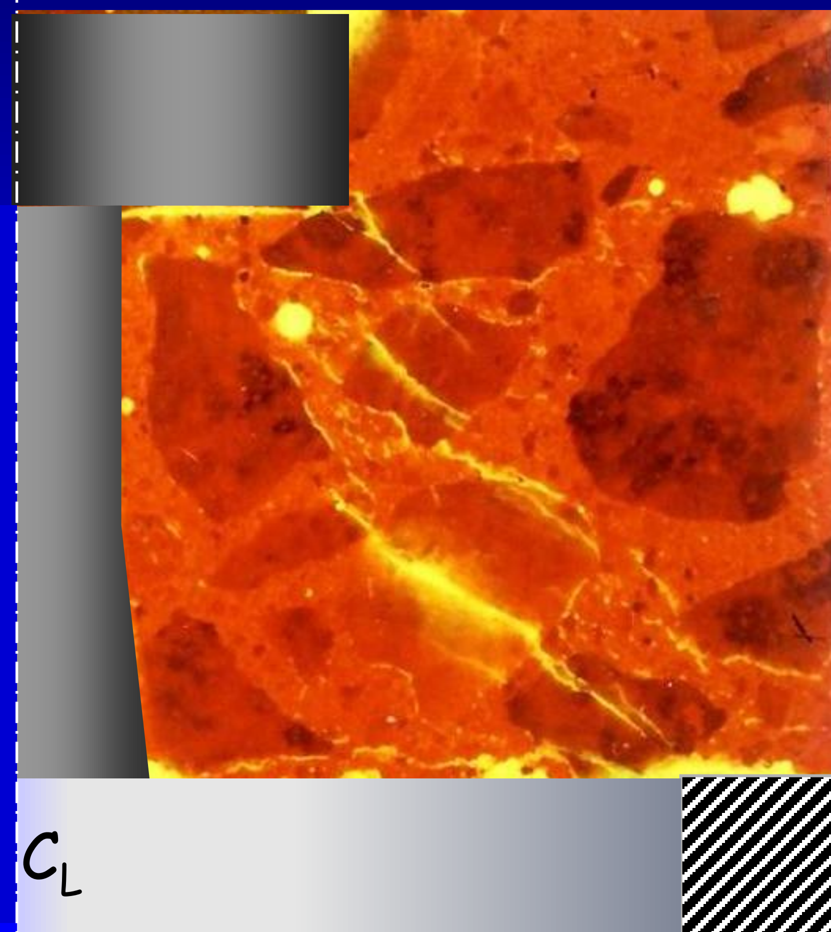
Calculations are made for a uniaxial compressive strength of 31.8 MPa. Note the much higher stresses (up to 50 MPa) are present right below the disc due to concentrated tri-axial loading in this area.

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

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

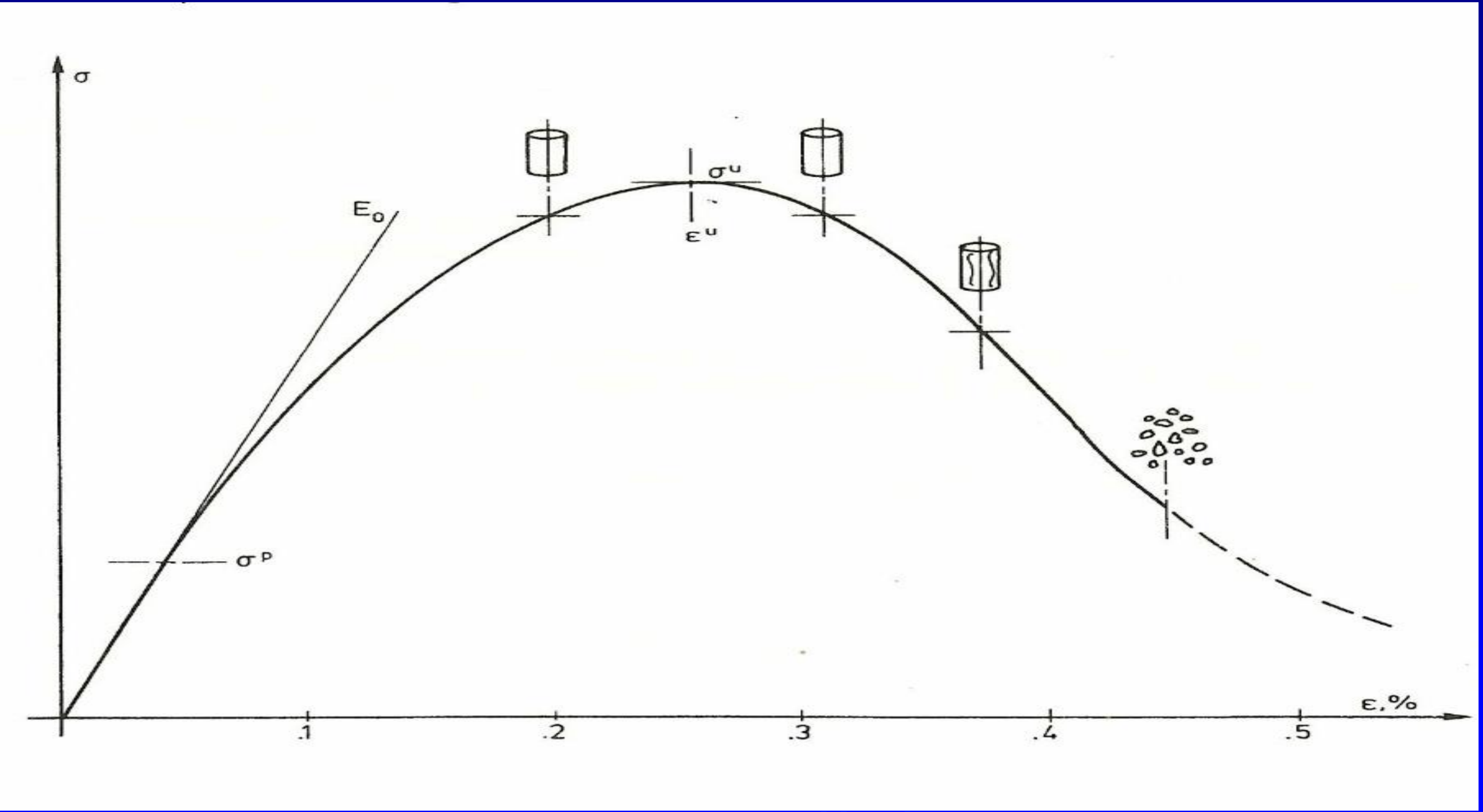
Krenchel, H. & Shah, S.P.: "Fracture analysis of the pullout test", Dept. of Structural Engineering, Technical University of Denmark, RILEM, Materials and Structures, Dunod, Nov-Dec. 1985 no 108

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

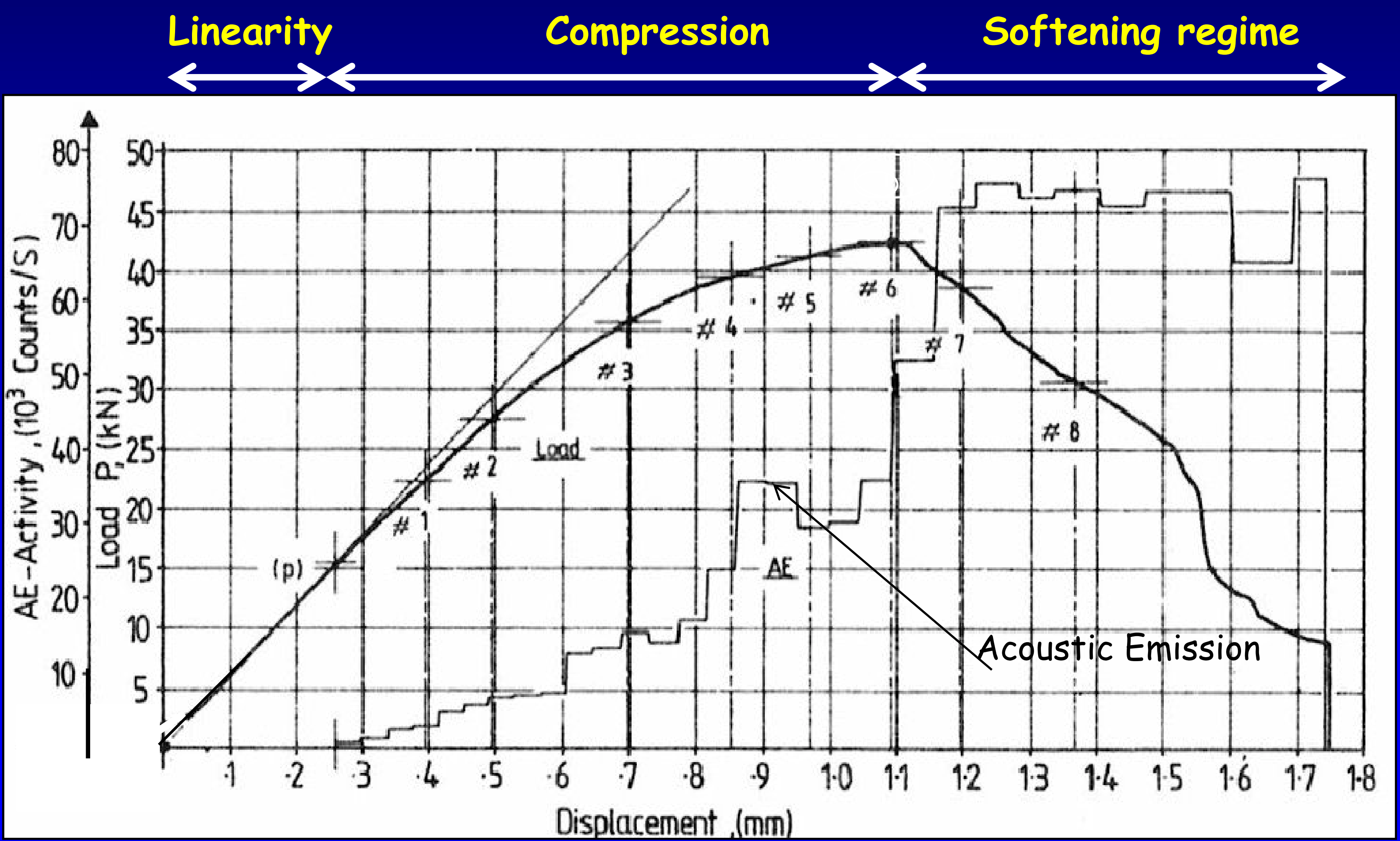
Krenchel, H. & Mossing, P.: "LOK-Styrkebestemmelse af Beton, Brudmekanisk Analyse", Deprtment of Structural Engineering, Technical University of Denmark, Serie R, No 198, 1985

Stress-strain curve from uniaxial compressive test

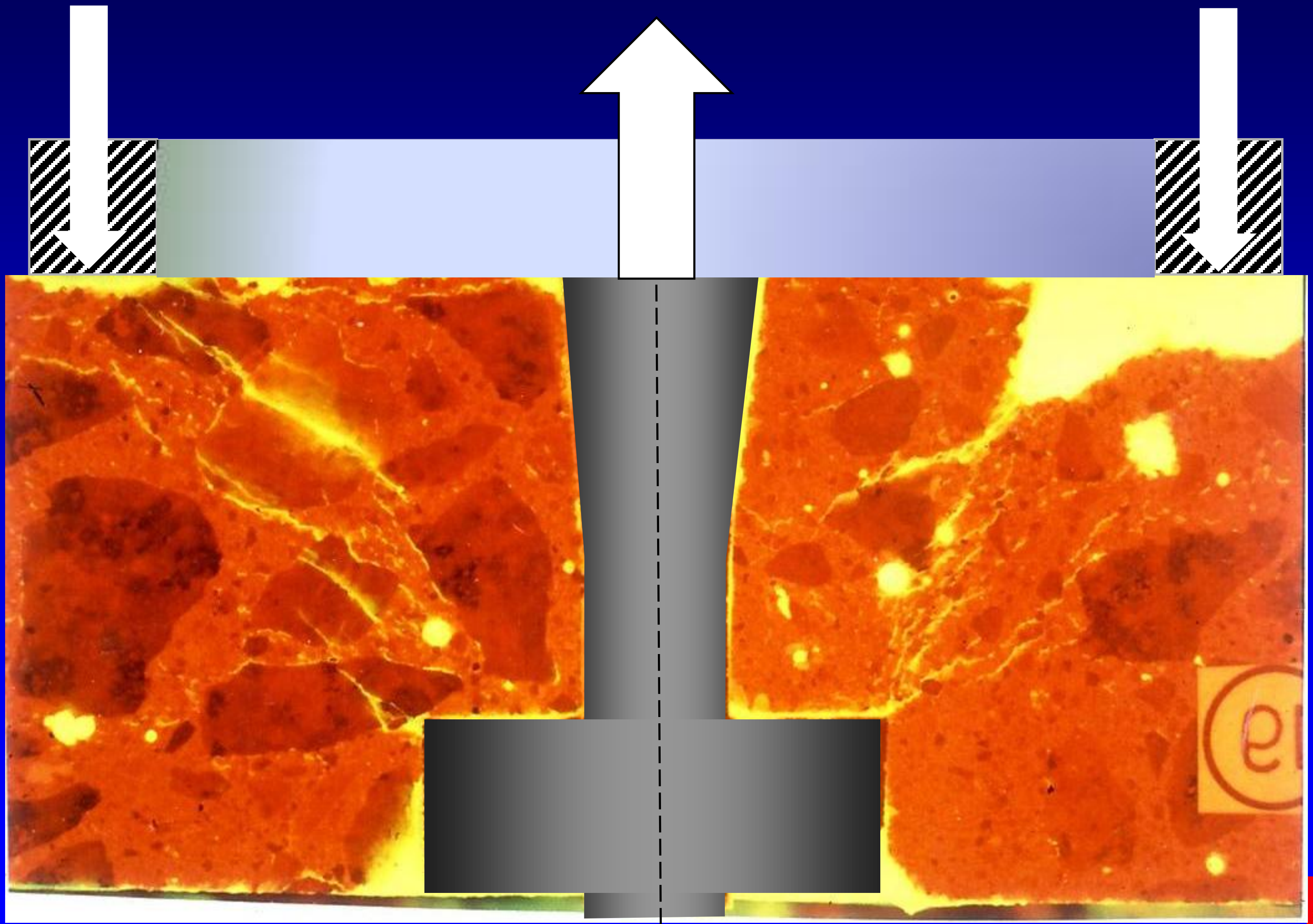
Linearity Compression Softening regime



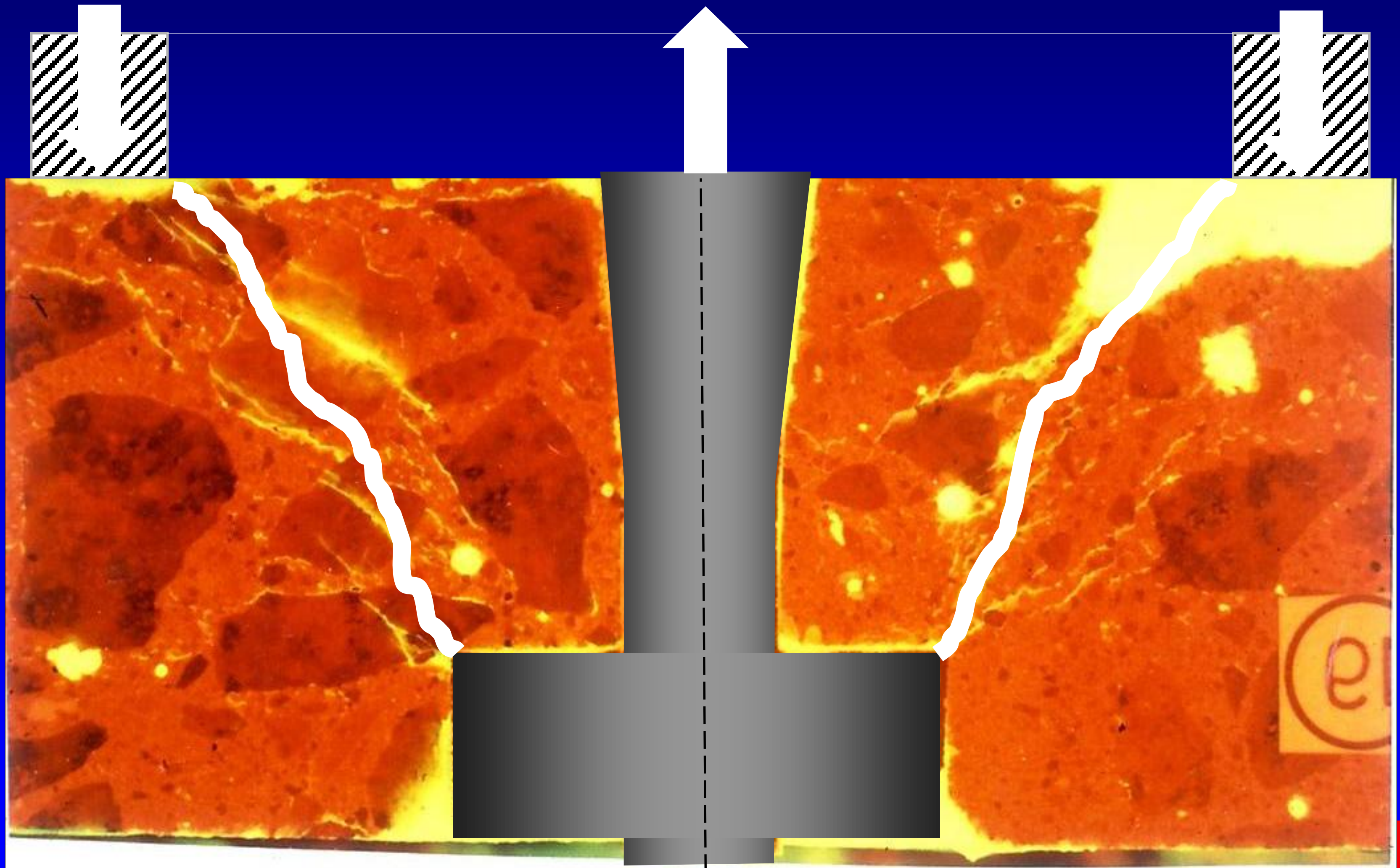
Load displacement curve for pullout test



98% load level



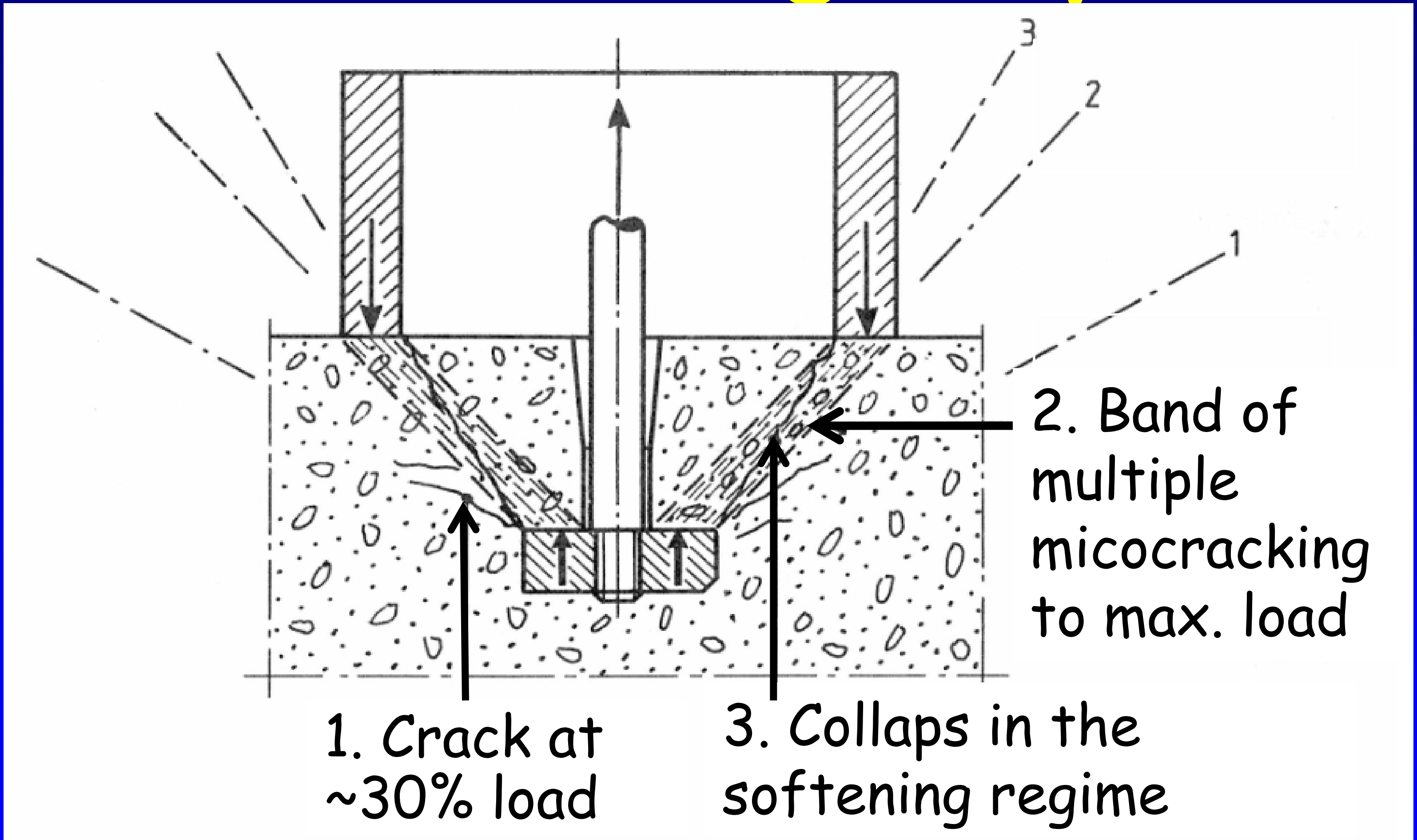
Situation at collaps into the softening regime



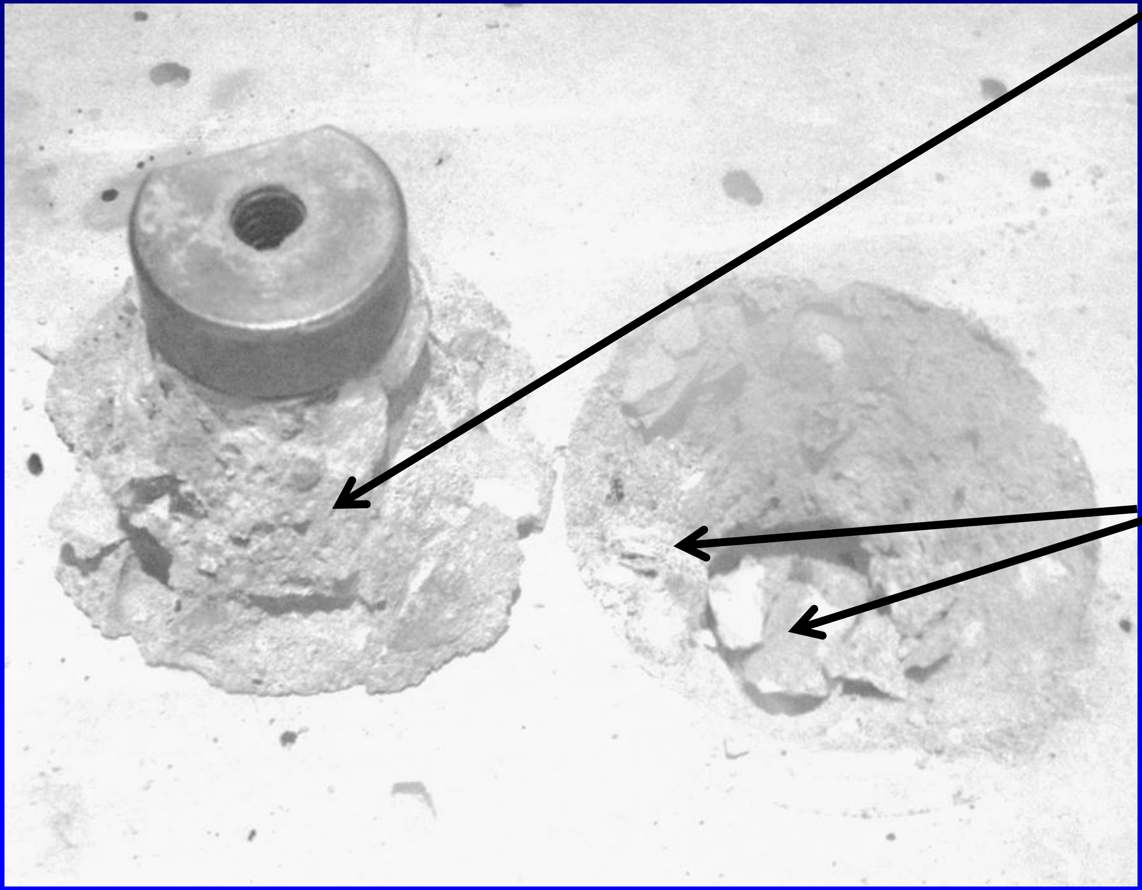
Explanation

1. At about 30% of the load a circumferential crack is developed at a open angle running from the outer edge of the disc. This is where the liniarity is lost.
2. From thereon multiple microcracks are developed in a compression band between the disc and the counterpressure
3. A collaps happens into the softening regime at increased loading, forming the final pullout cone

The three different stages of internal cracking in a pullout



LOK-TEST pullout failure



"Leave" 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

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

Crushed material in the compression zone

GI

CAPO-TEST Failure

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

GI

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)

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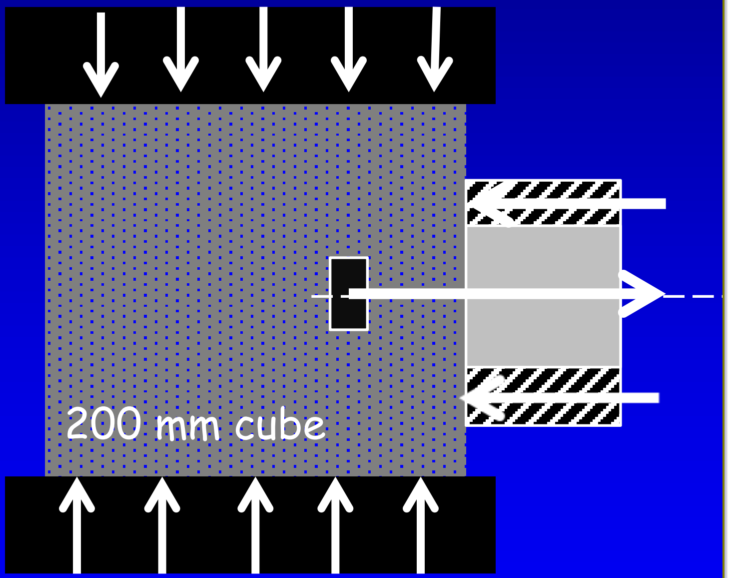
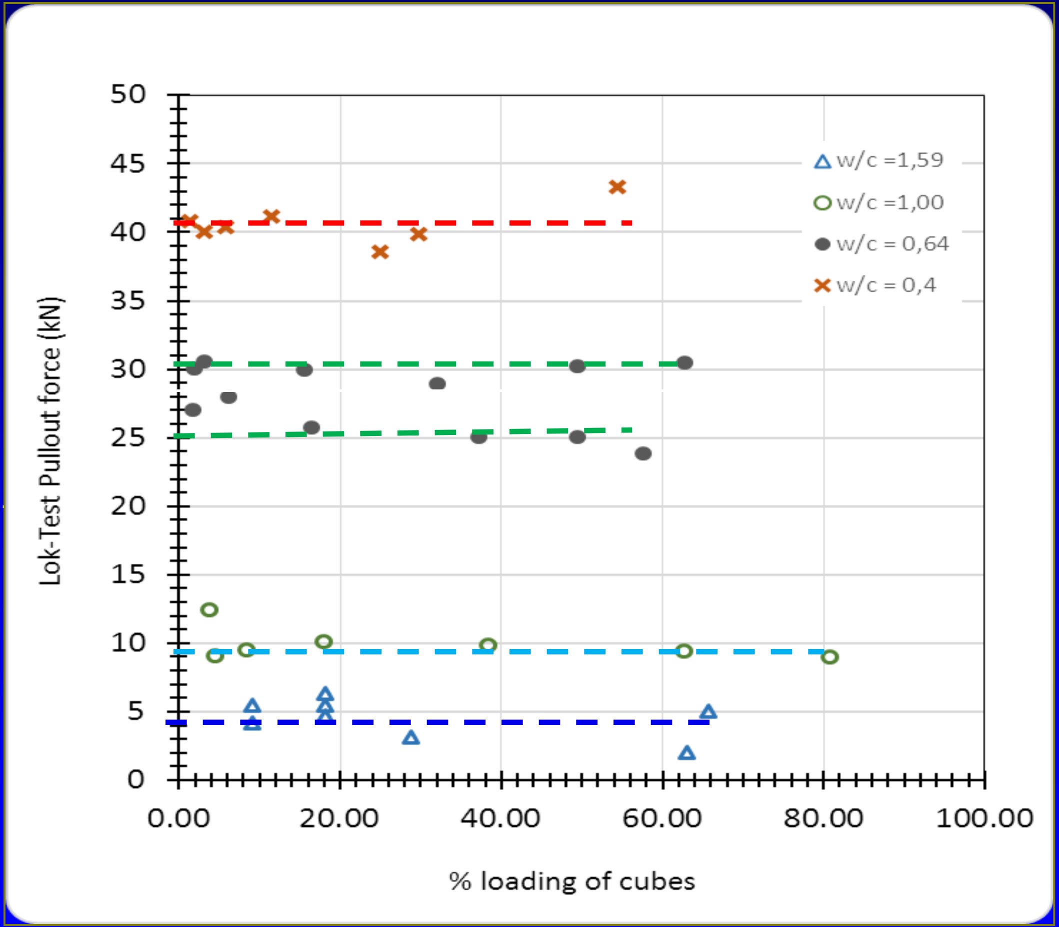
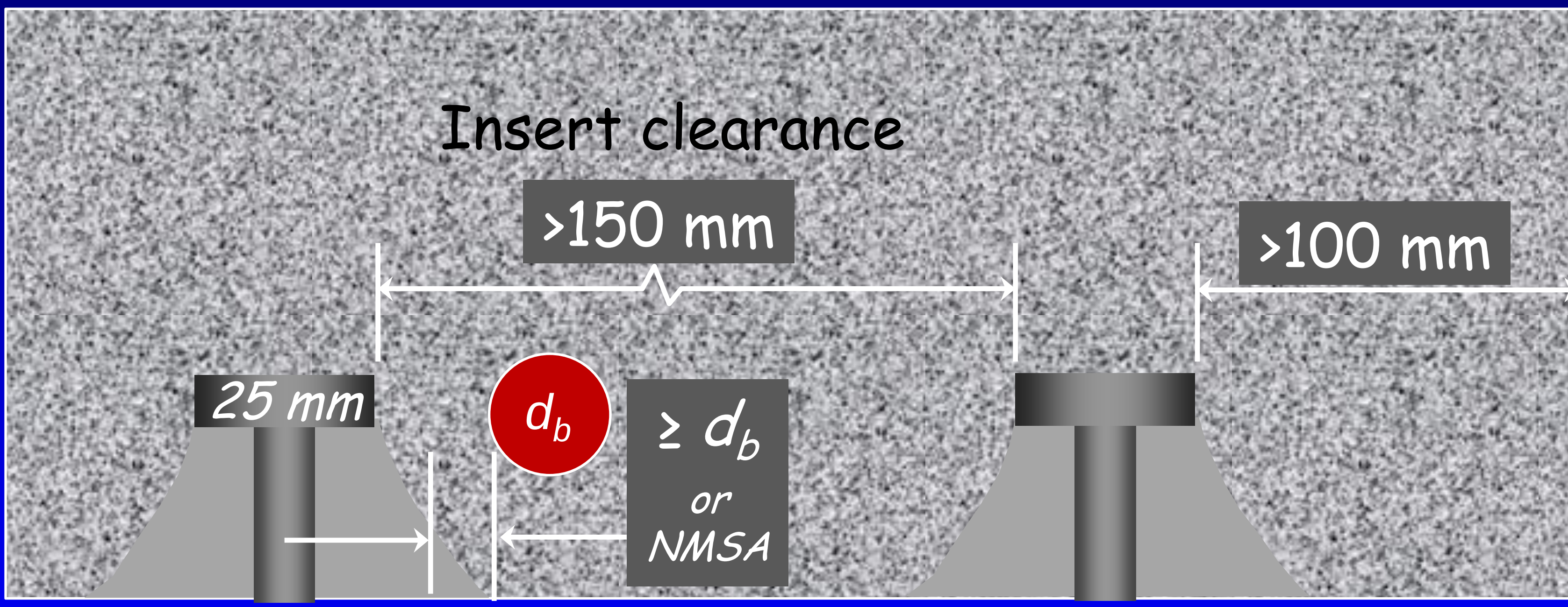




Clearance Requirements ASTM C900



Reinforcement clearance

Edge distance

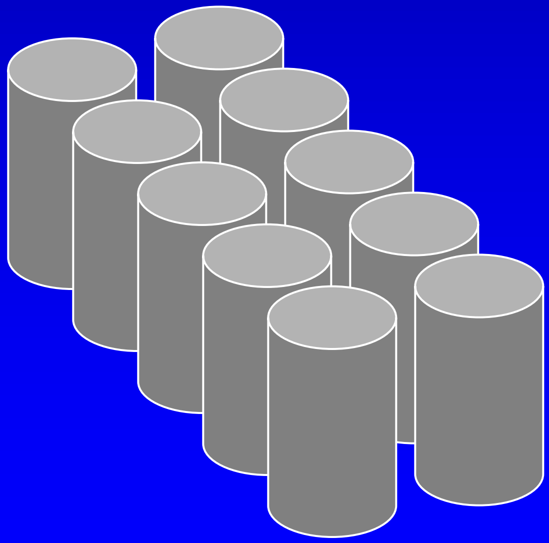
Correlations in the laboratory

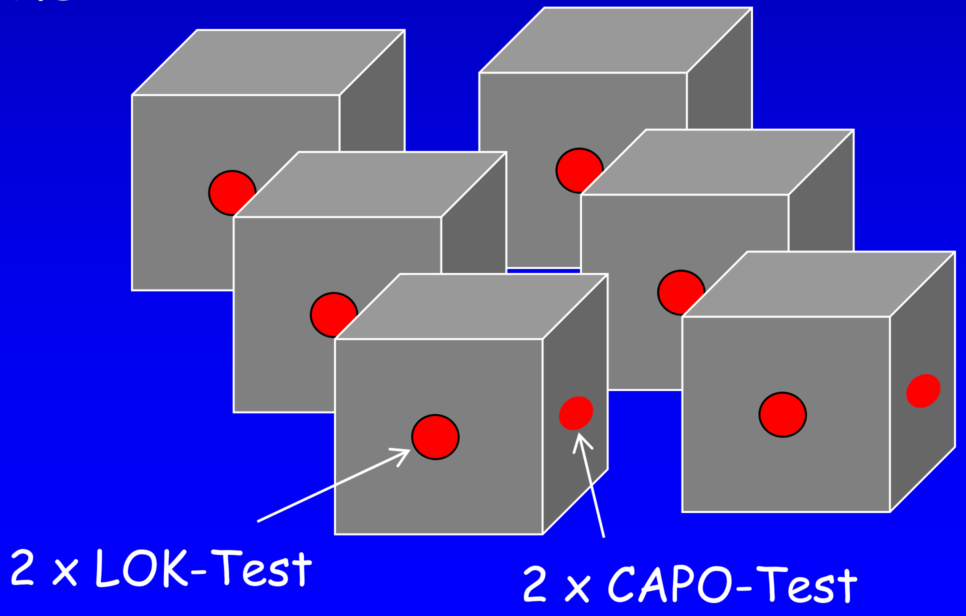
- To 150 mm x 300 mm cylinder strength
- To 150 mm cube strength

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

Correlation Testing

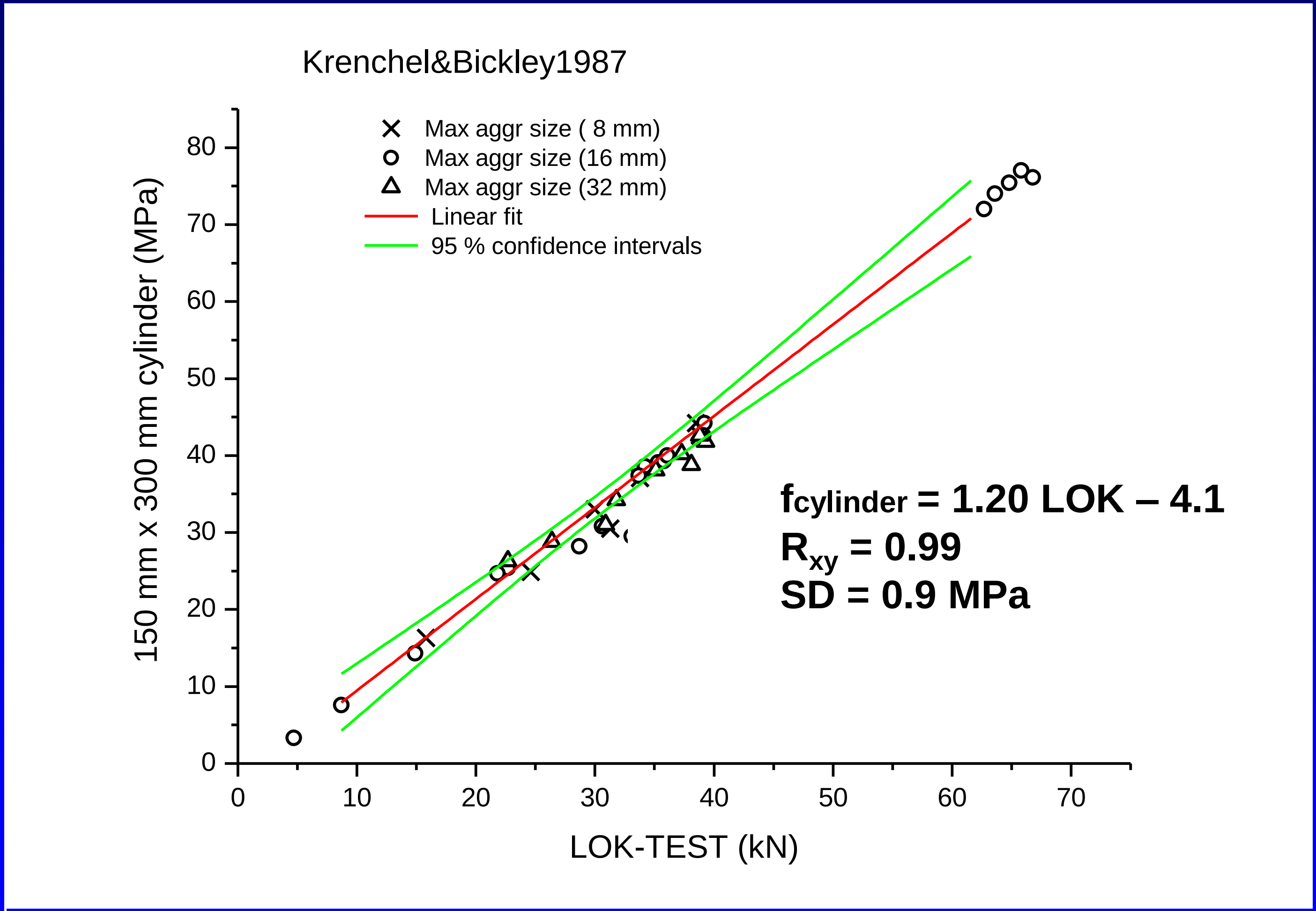
- Prepare cylinders (or cubes)
- Prepare 200 mm cubes with inserts
- Compact and cure under same conditions





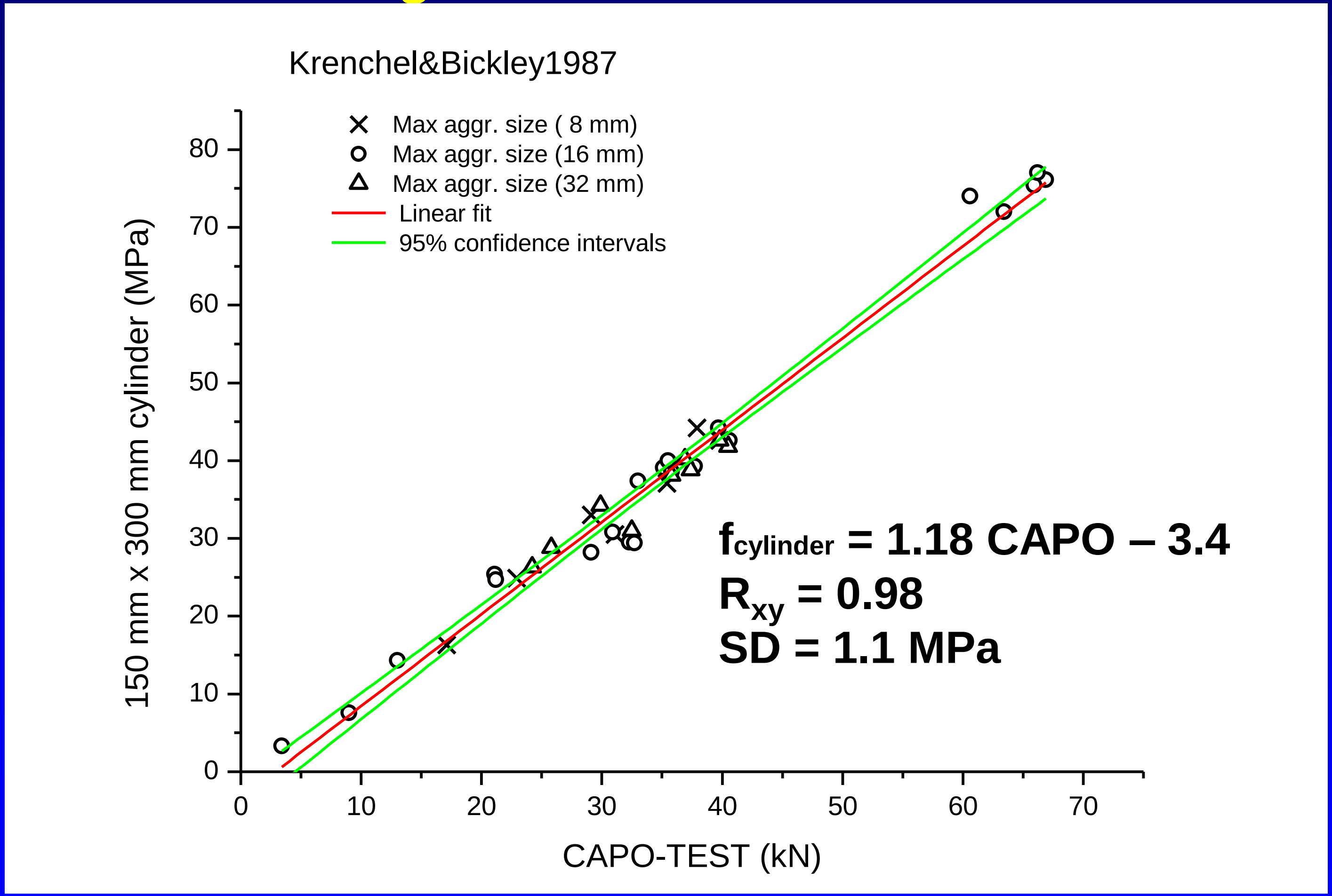
Cylinder relationships

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



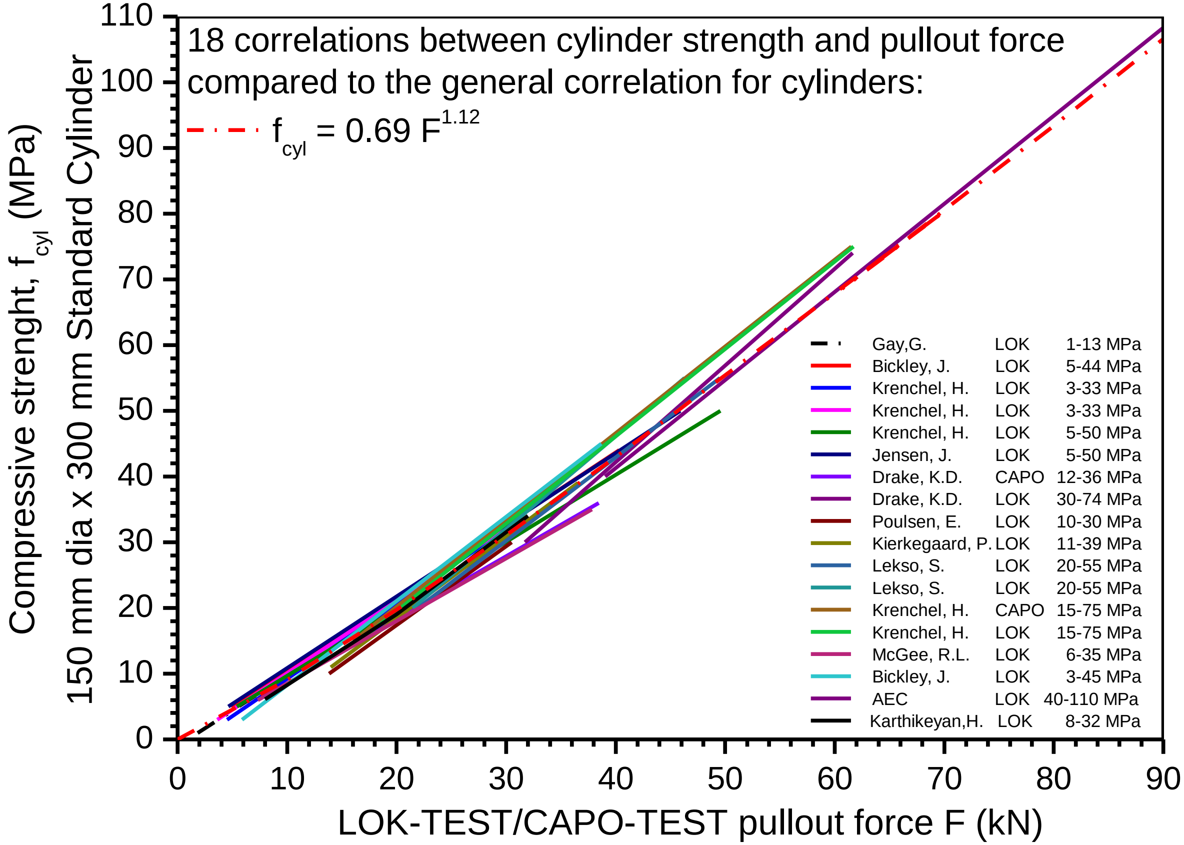
Aggregate type: Sea Gravel and Granite (for strength > 70 MPa)

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



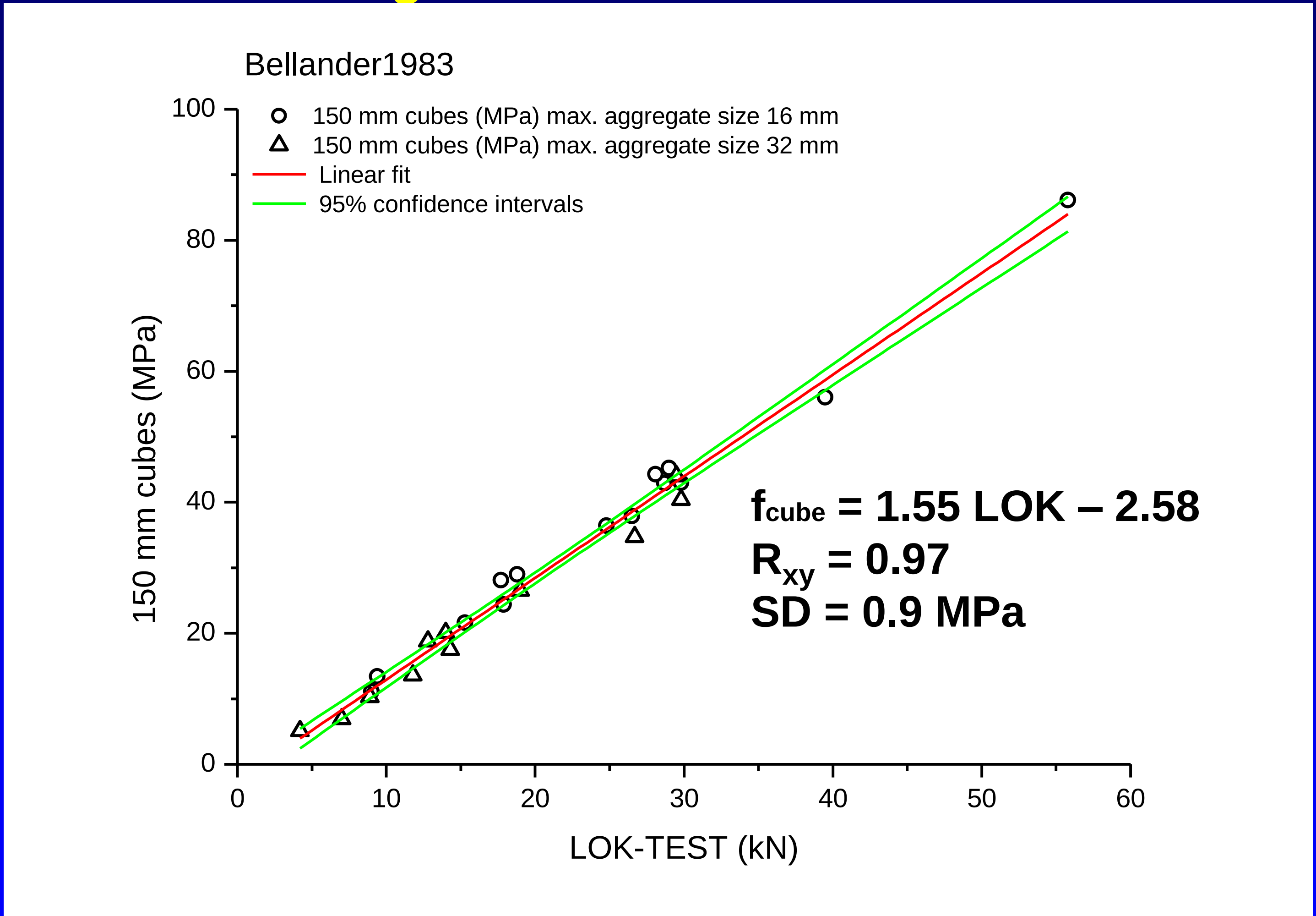
Aggregate type: Sea Gravel and Granite (for strength > 70 MPa)

18 correlations to cylinder strength 1990-2013

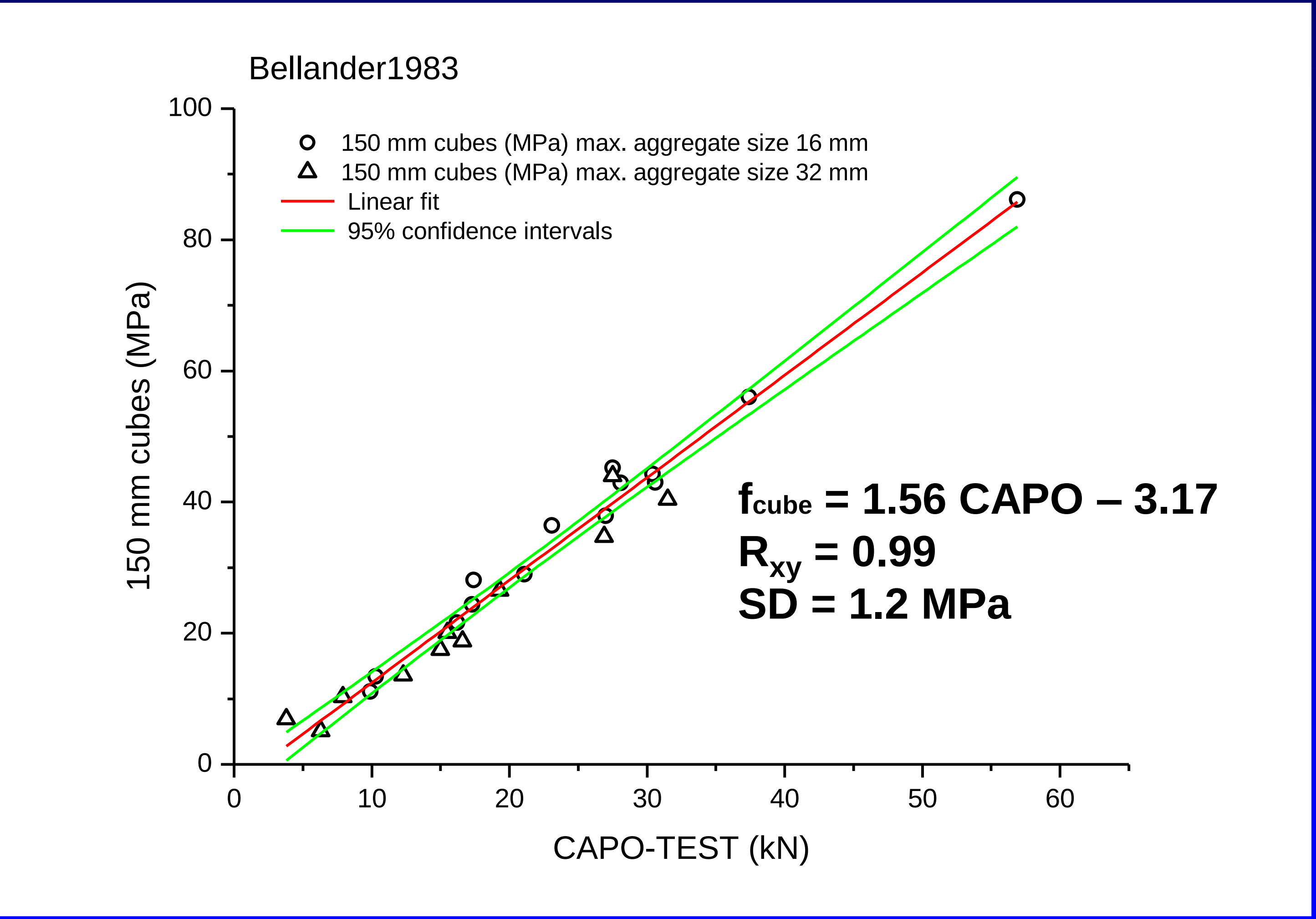


Cube relationships

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



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



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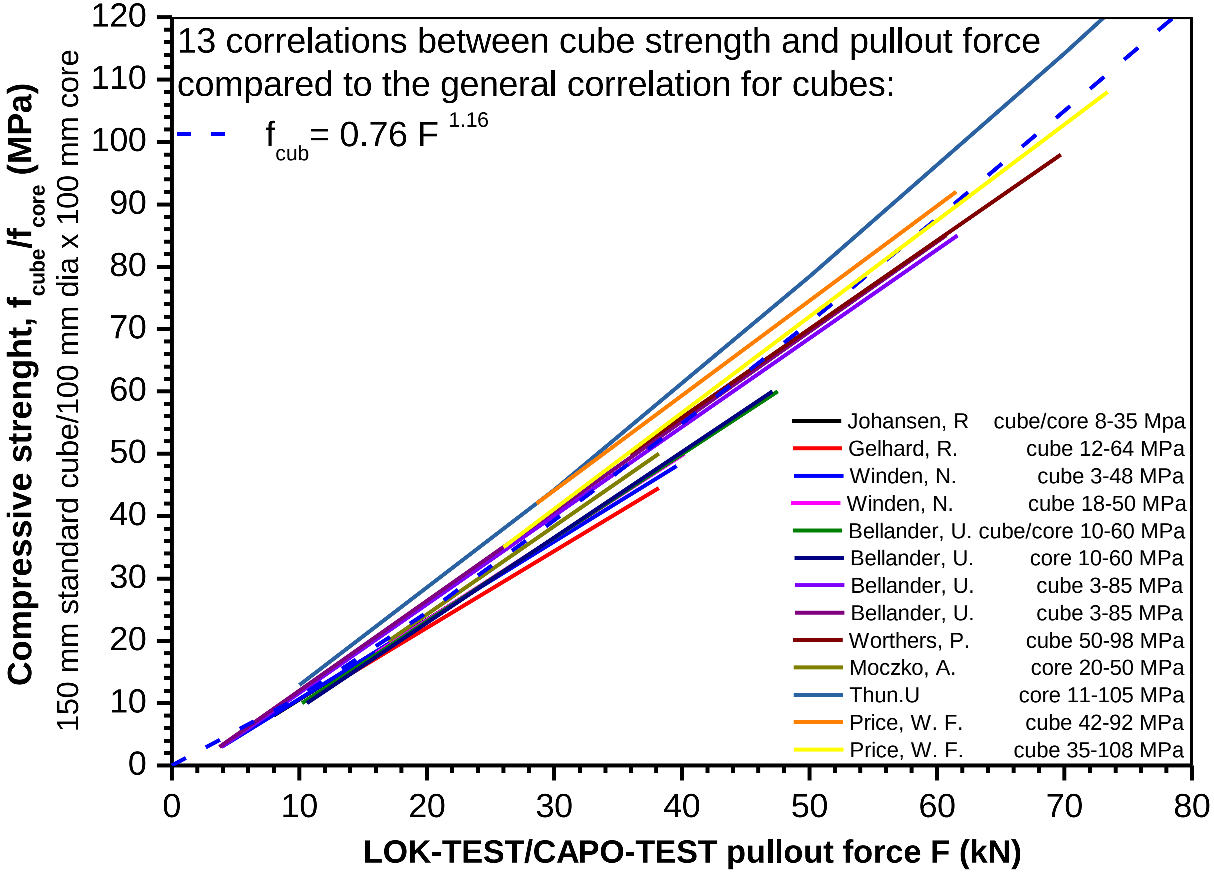
13 correlations to cube strength



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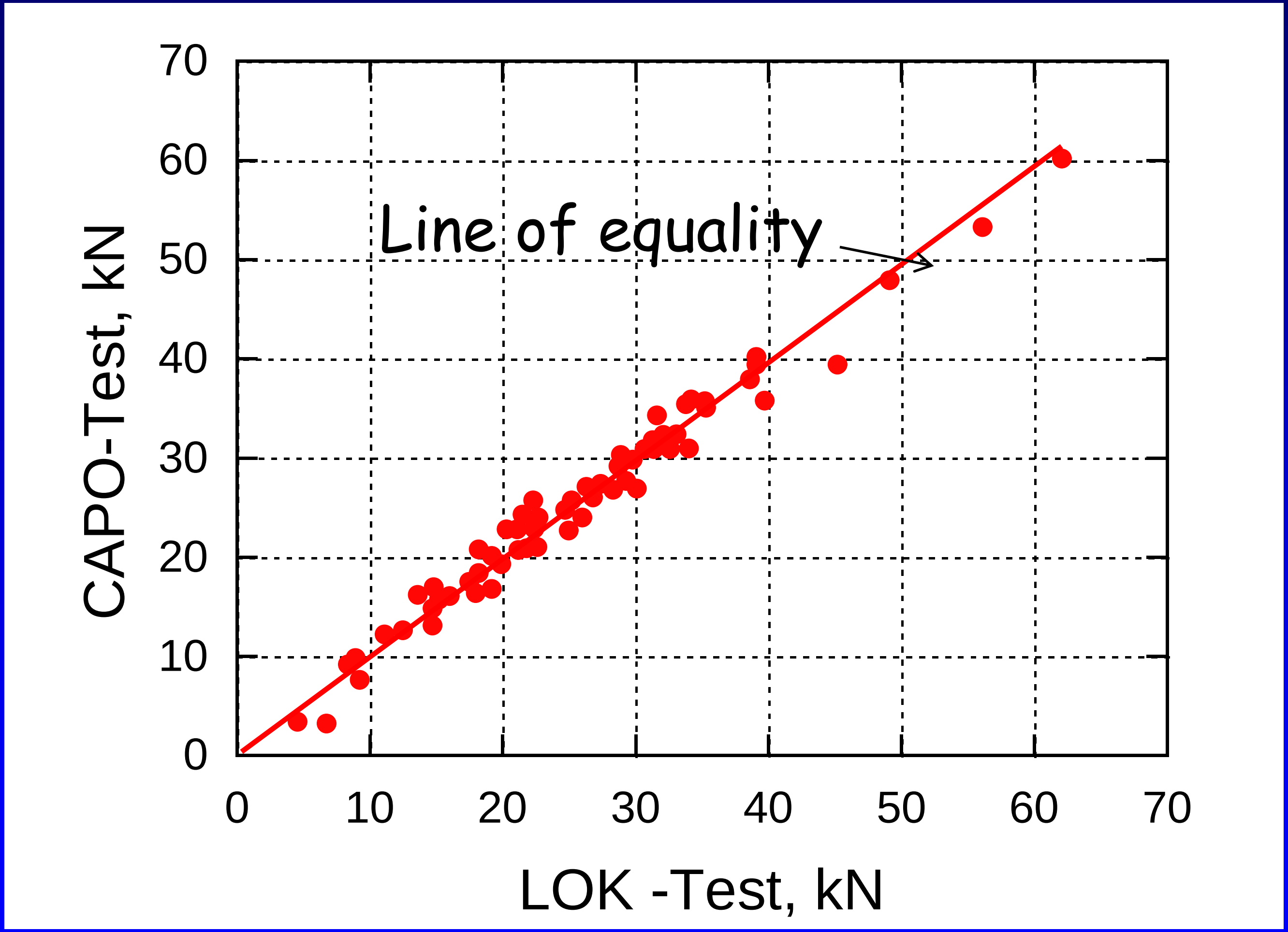
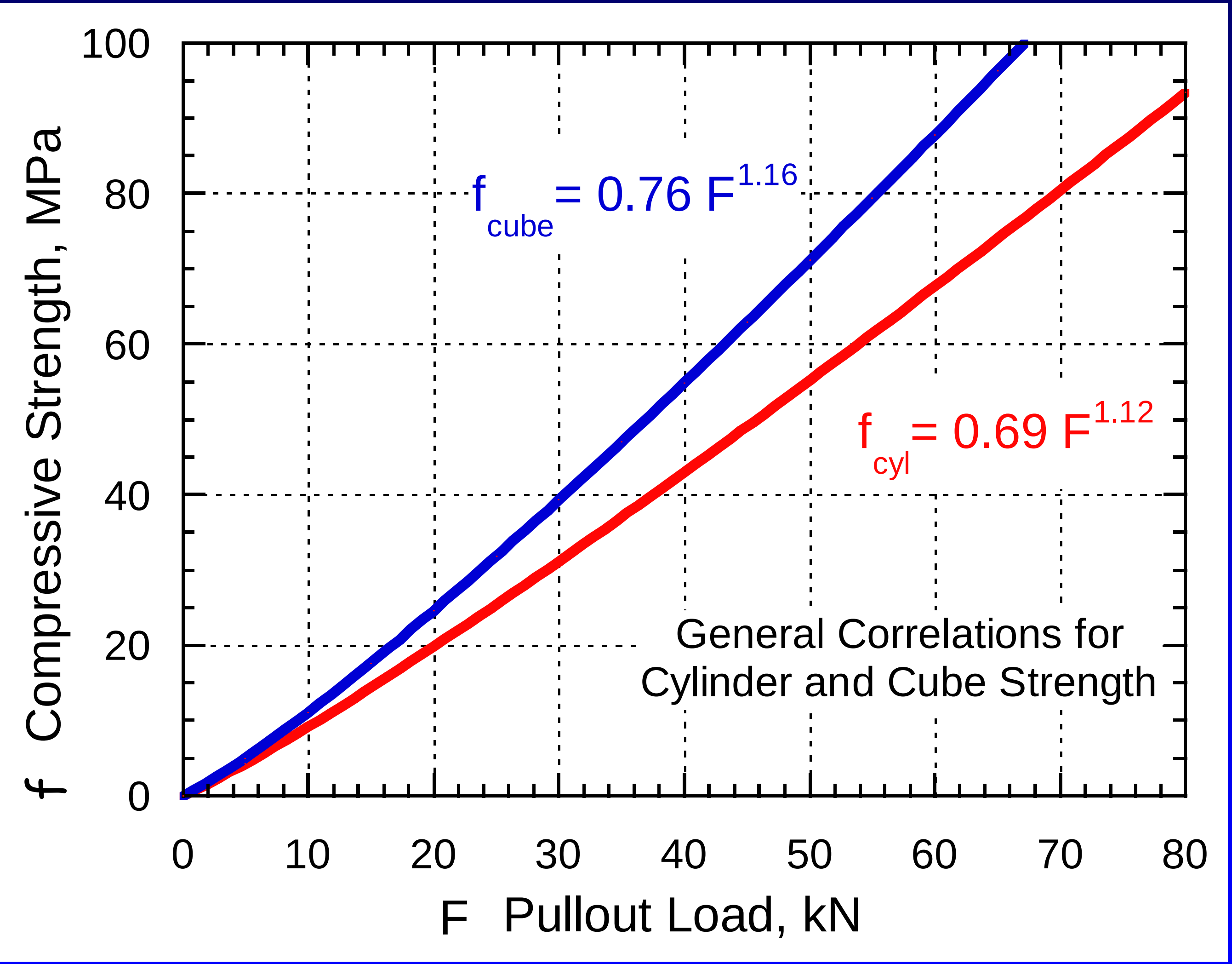
CAPO-TEST to LOK-TEST



Refs: Krenchel (1982), Bellander (1983), Yun (1990), & Meyer (1994)

General Correlations



Robust Correlation

Not affected by:

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

Variations

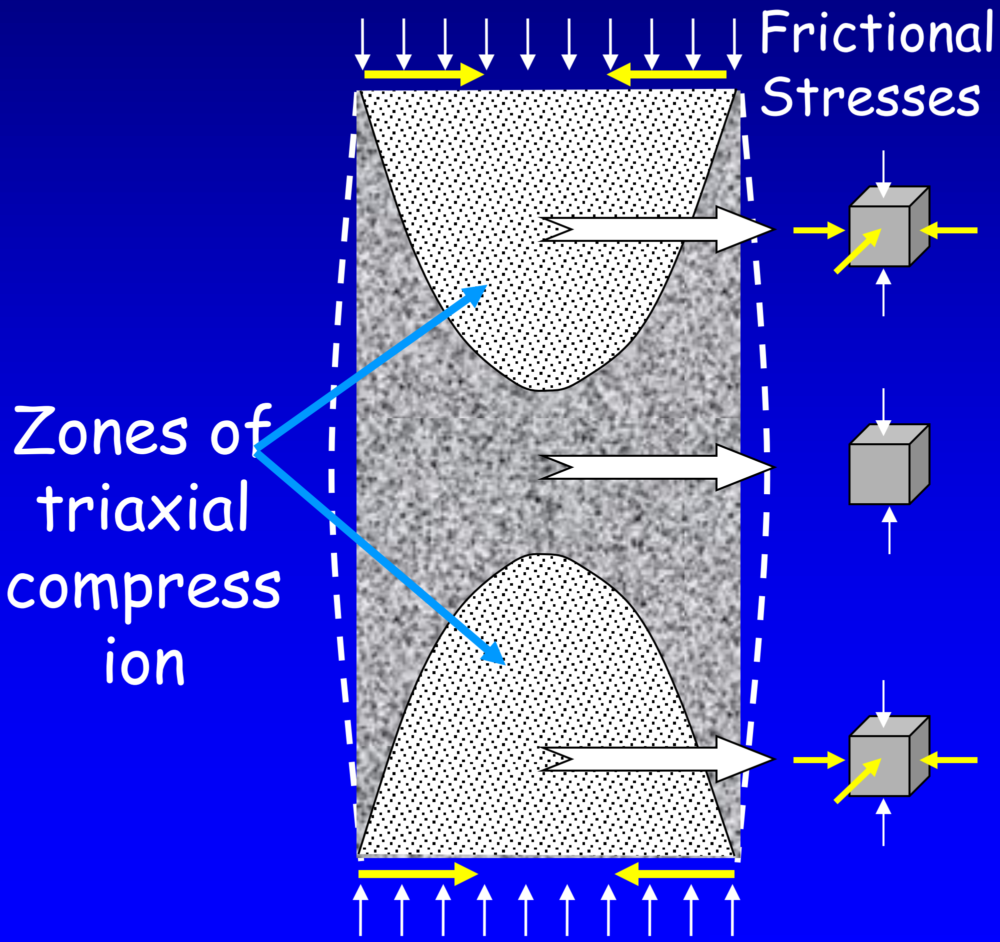
Calibration Procedure, laboratory	Pullout V	Pullout n	Standard spec. V	Standard spec. n
Danish	9.4 %	2188	4.3%	1177
North American	7.5%	994	6.4%	994
Swedish/Dutch/English	6.8%	1180	6.2%	963

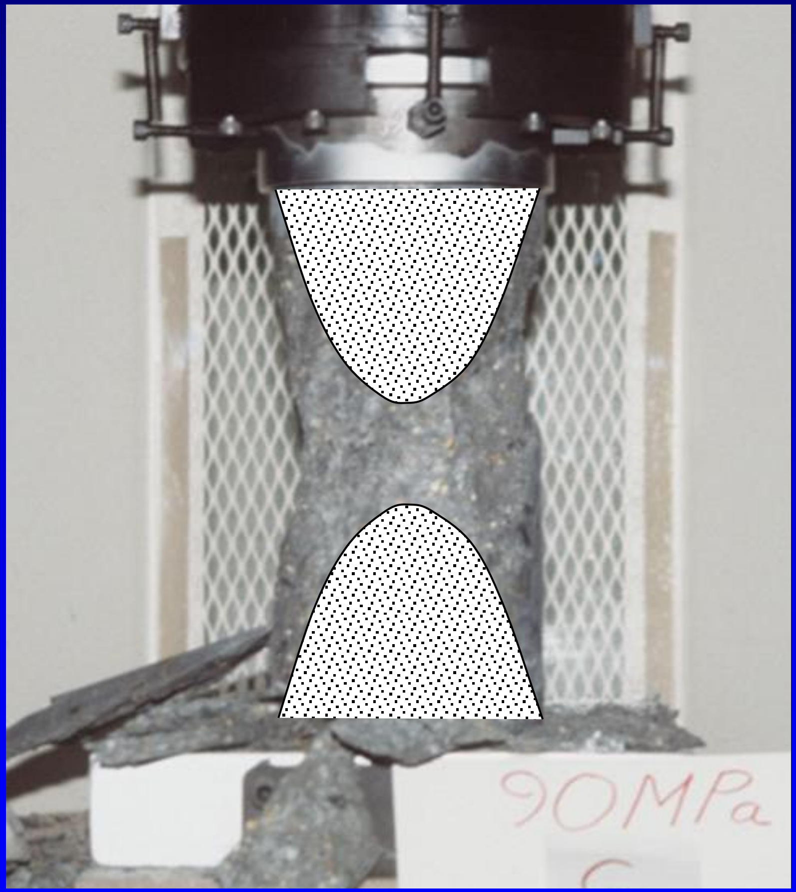
Structure, On-site testing	LOK-TEST V	LOK-TEST n	CAPO-TEST V	CAPO-TEST n
Shotcrete			3.2%	310
Slabs, bottom	10.5%	5320	7.1%	35
Slabs, top	12.9%	955	9.3%	623
Beams & Columns	8.1%	677	8.0%	434
Walls & Foundations	10.1%	1020	10.4%	534
Dubious Structures	14.7%	1225	15.3%	3334

Ref.: Petersen (1994)

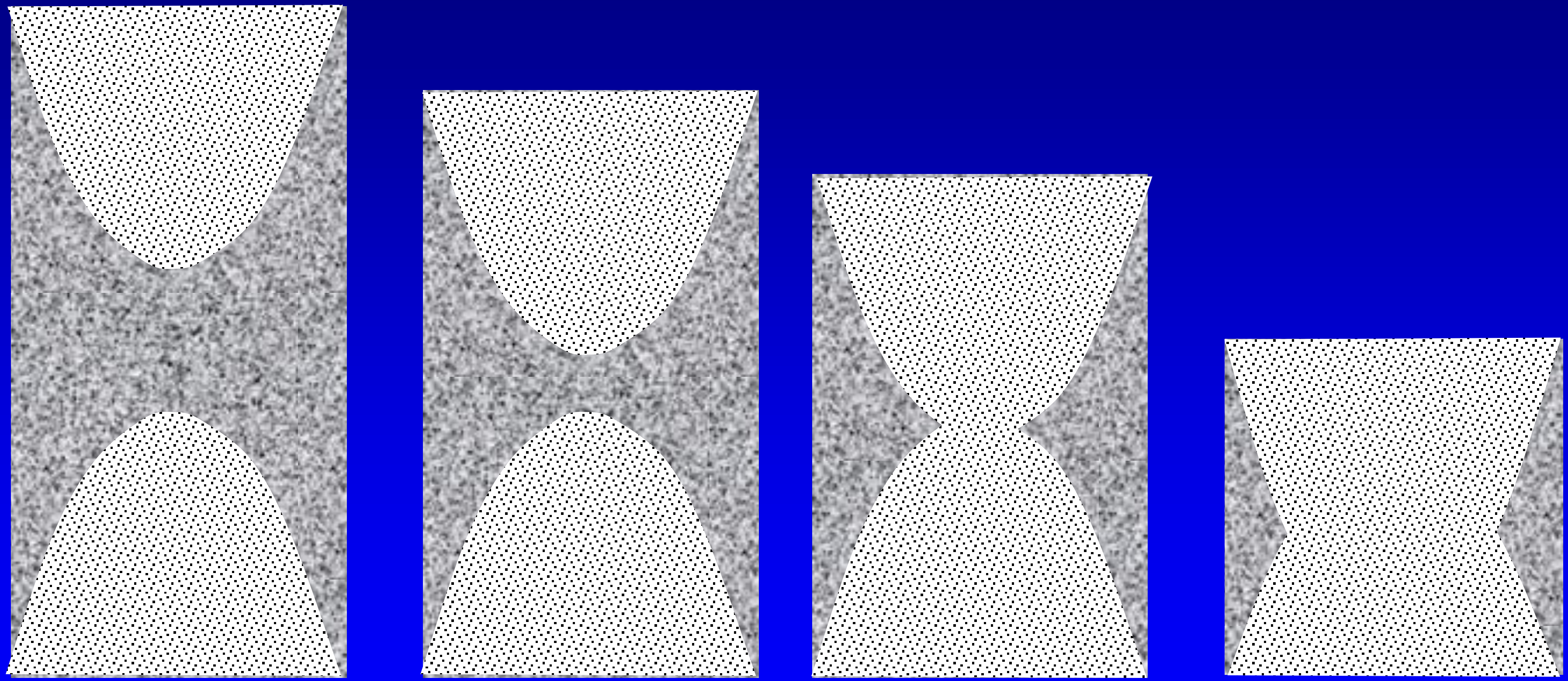
Why is the strength from a 150 mm cube higher than a 150 mm x 300 mm cylinder ?

Effect of End Friction – Triaxial Compression





As L/D Decreases
Strength Increases



CORES

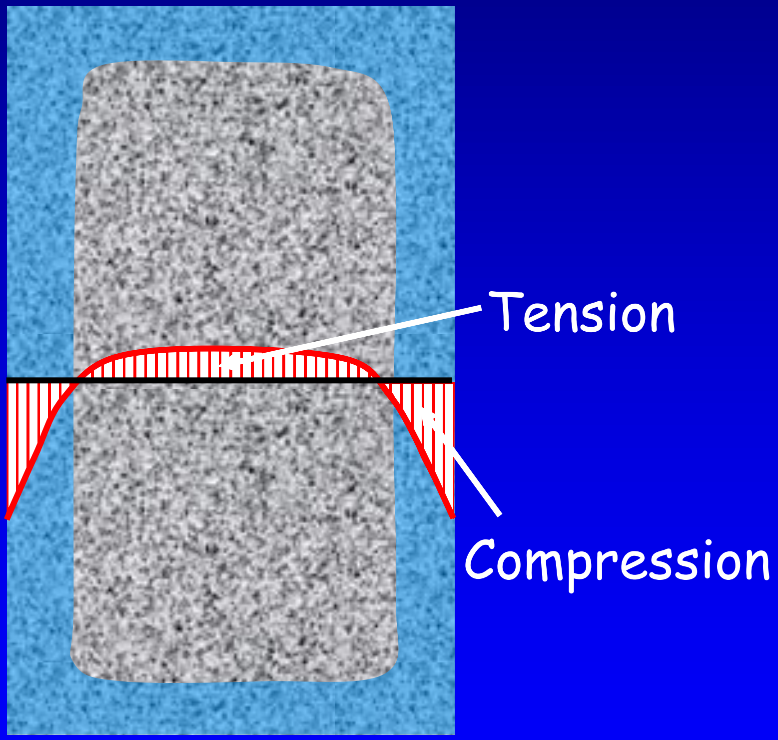
- The ratio of the maximum aggregate size in the concrete to the diameter of the core has a significant influence on the measured strength when it is greater than about 1:3.
- Testing a core with a nominal diameter of 100 mm and equal length (L/D=1) gives a strength value equivalent to the strength value of a 150 mm cube manufactured and cured under the same conditions.
- Testing a core with a nominal diameter at least 100 mm and not larger than 150 mm and with a length to diameter ratio equal to 2.0 gives a strength comparable to a 150 mm by 300 mm cylinder manufactured and cured under the same conditions.

Preferred diameter of core is 100 mm

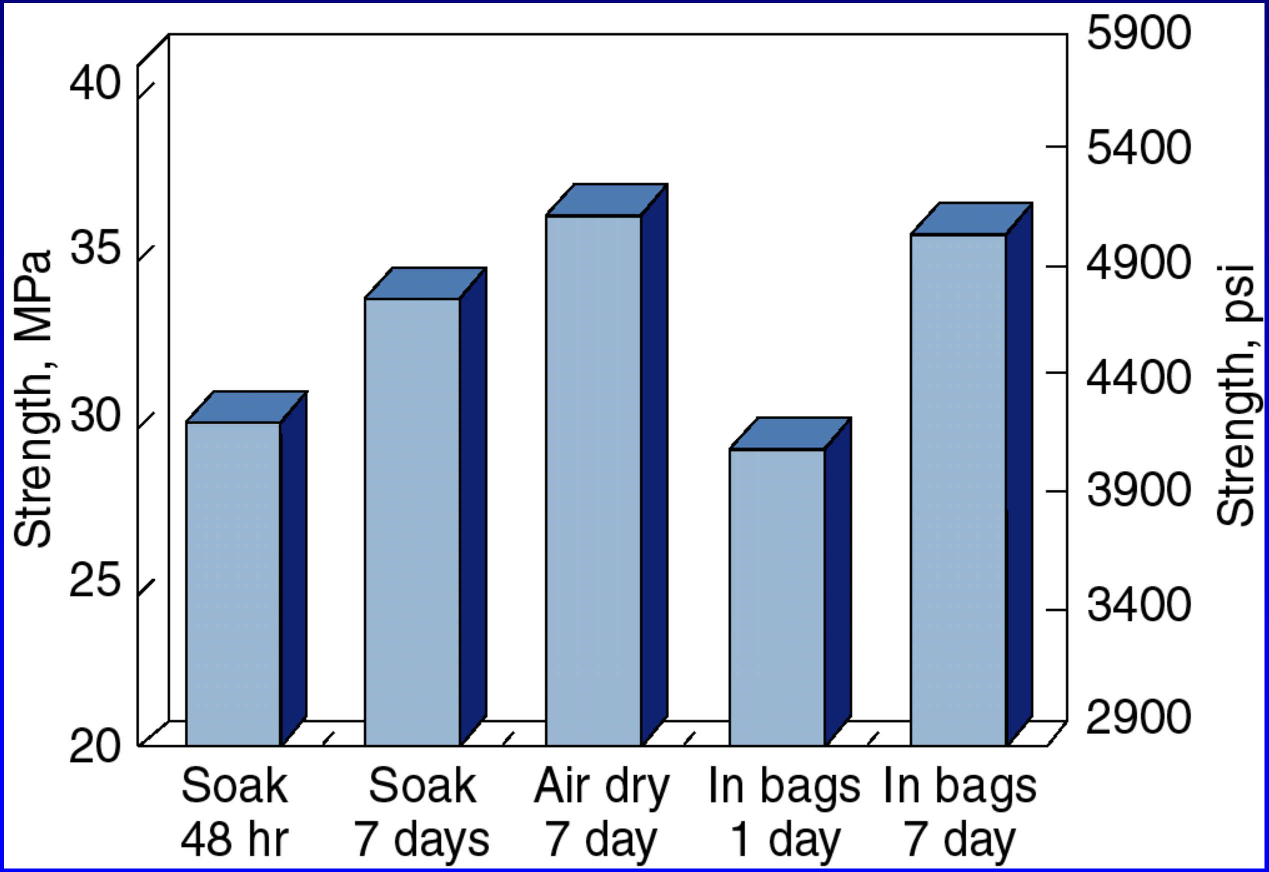
Cores

Moisture Gradients Immediately After Wet Drilling

- Moistened concrete tends to swell
- Swelling is restrained by dry interior
- Results in internal stresses; outer region in compression
- Measured strength is reduced



Effect of Core Conditioning on Strength



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

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

- f_c — In-place strength
- $F_{\ell/d}$ — Correction for L/D
- F_{dia} — Correction for D
- F_{mc} — Correction for moisture content
- F_d — Correction for "damage" due to coring
- f_{core} — Core strength

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

- $f'_{c,eq}$ — Equivalent specified strength
- K — Statistical factor
- $\overline{f_c}$ — Average in-place strength

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

Comparative study Polish bridges for increased loading

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

NOTE: All Schmidt Hammer results have been reduced by an "Aging Factor" of 1.4 recommended by manufacturer

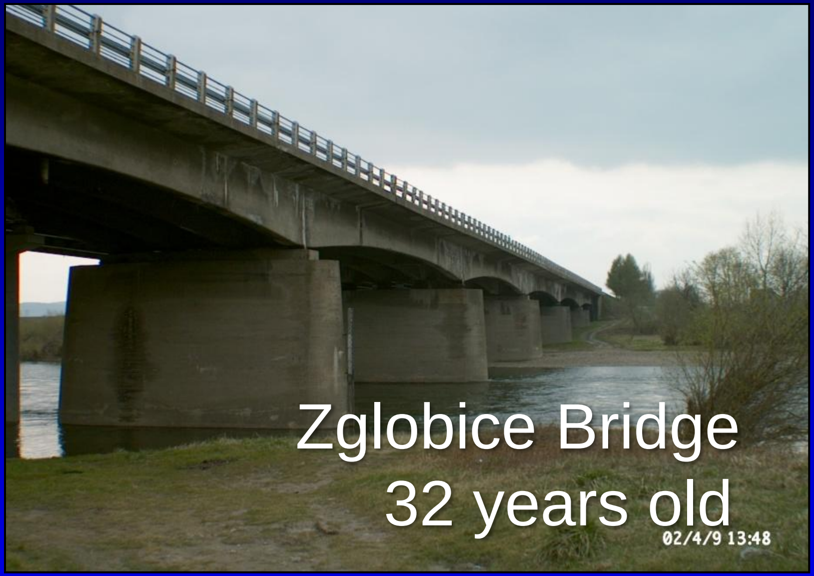
CAPO-TESTing on Polish bridges

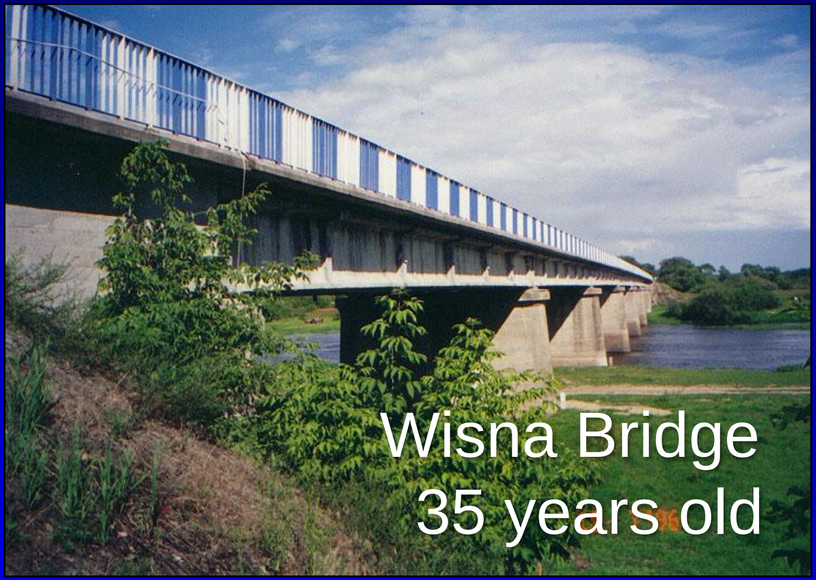
COMA-Meter

Bridge No.	*Cores from structure*		*Capo-Test on structure*		*Schmidt Hammer on structure*		*Schmidt Hammer on cores*	
	MPa	Av. of	**MPa**	**α(CT)**	**MPa**	**α(L)**	**MPa**	**α(LM)**
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

Comparative Strength Estimates from Polish Bridges, summary



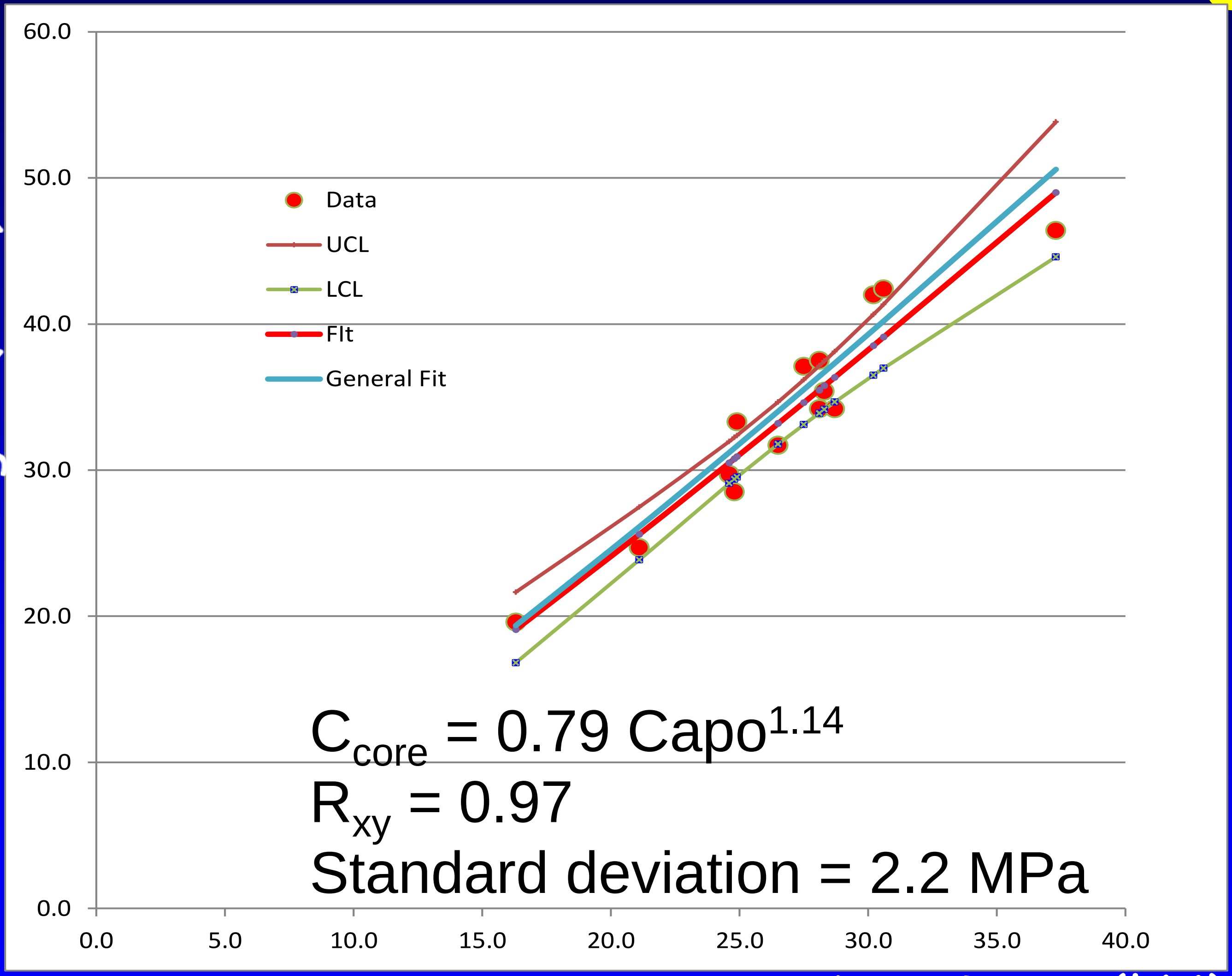


Average	Cores (MPa)	V (%)	CAPO-TEST (MPa)	V (%)	Schmidt on Structure (MPa)	V (%)	Schmidt on Cores (MPa)	V (%)
Strength	32.8	9.5	33.5	11.7	55.9	16.4	44.5	15.1

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*

Correlation from Polish bridges



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

Capo-Test (kN)

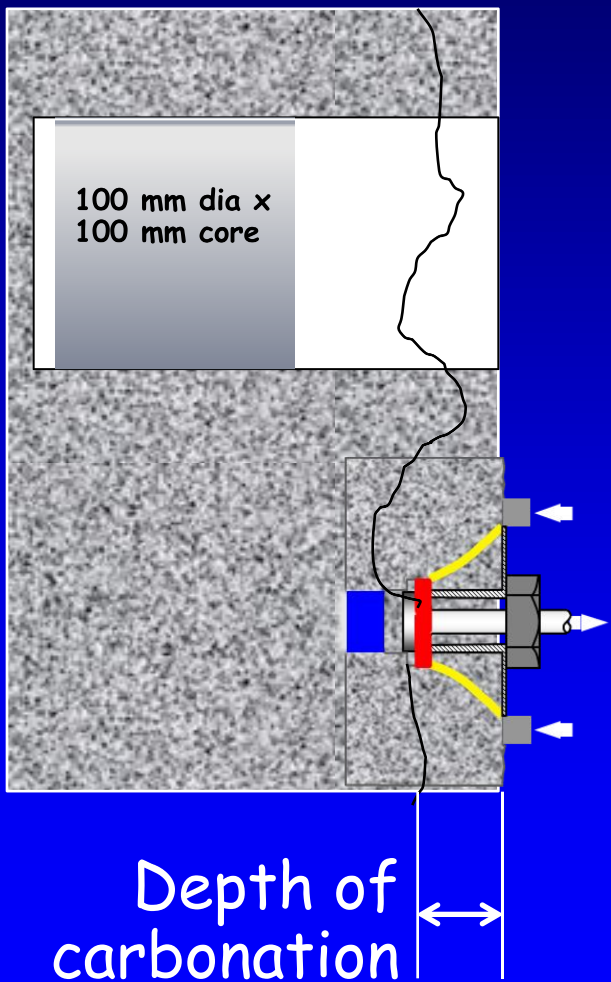
Comparison to the general correlation for cubes

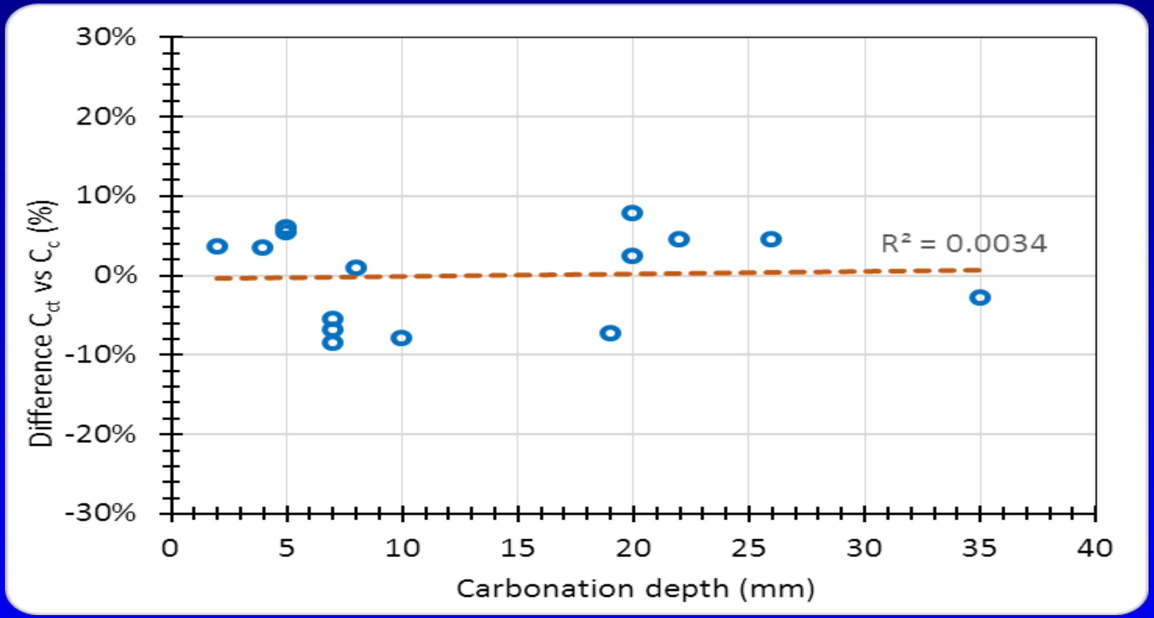
Note that the correlation found $C_{core} = 0.79\ Capo^{1.14}$ match closely the general correlation for cubes $C_{cube} = 0.76\ Capo^{1.16}$

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:

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

Effect of carbonation





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

Ref: Moczko, (2010)

Considerations using CAPO-TEST

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

Consideration

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

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

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

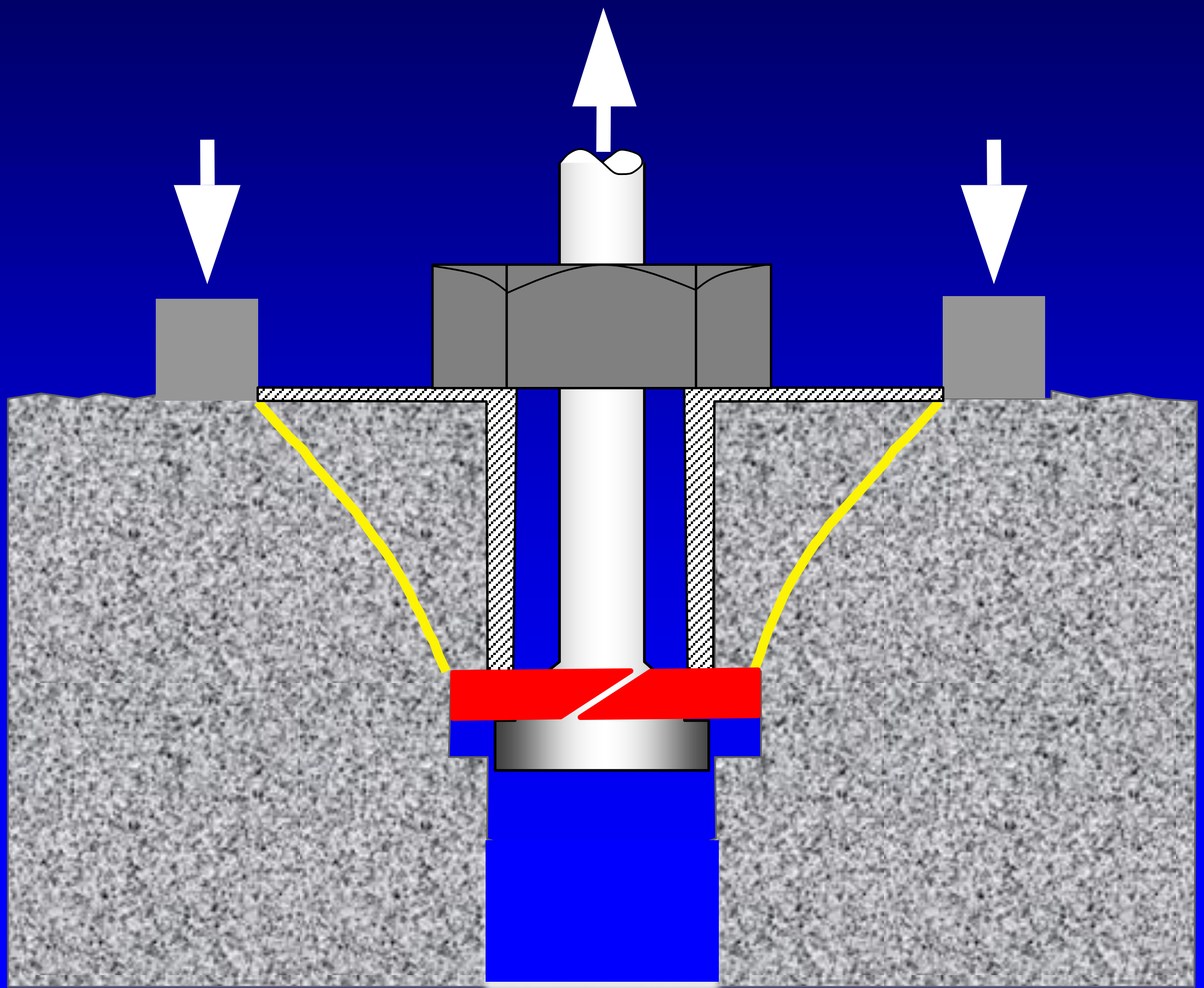
To check this effect, LOK-TEST inserts may be embedded deeper in the structure, and surface planing prior to CAPO-TEST may be done at a required depth.

CAPO-Test advantages

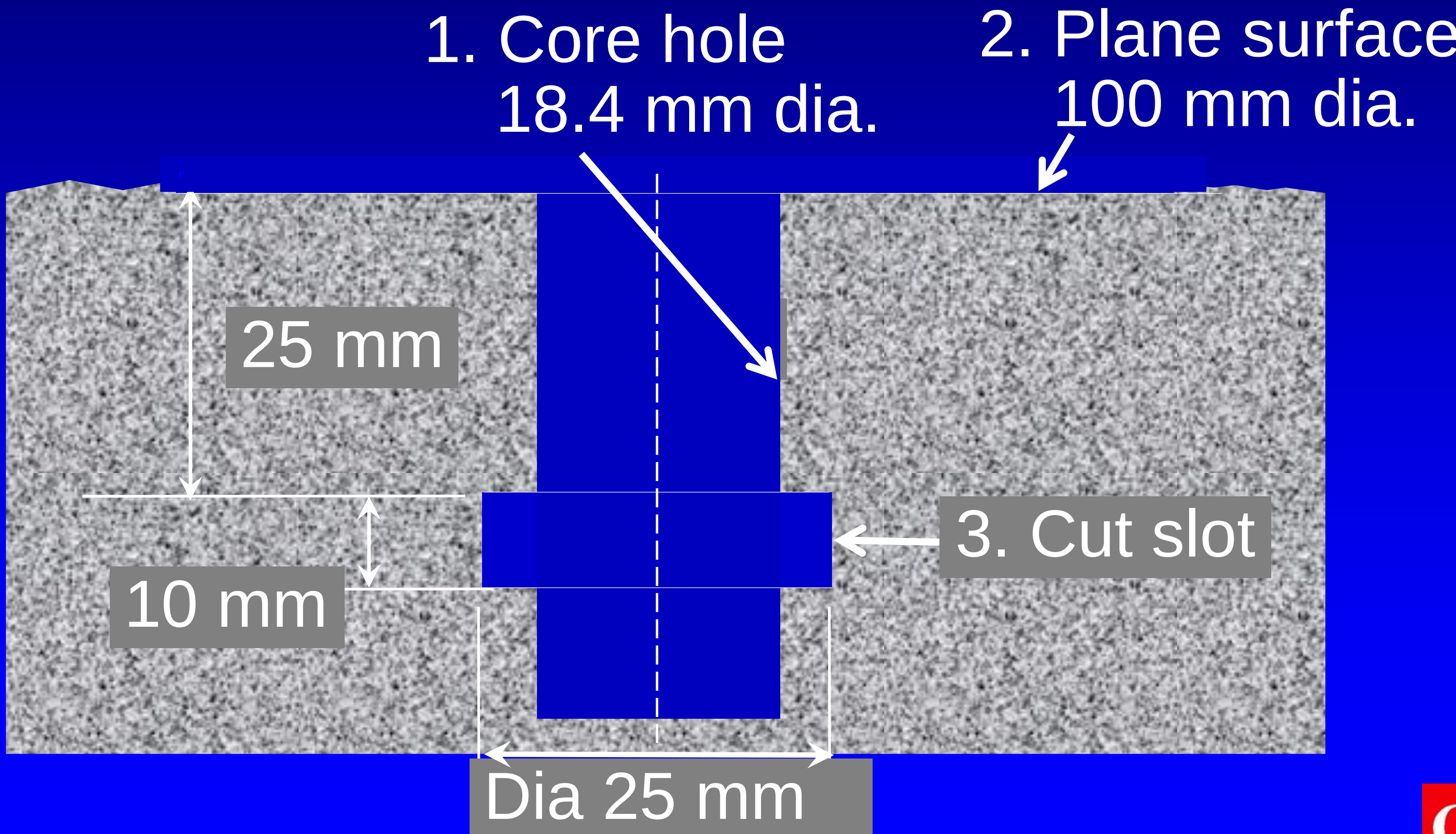
- Does not require pre-planning test locations
- Can perform test at any accessible location
- Permits testing of existing structures
- 20-30 minutes per test
- Test results immediately available
- Cause only a small fracture cone hole compared to a 100 mm coring hole.
- Portable equipment (electricity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

CAPO-TEST Procedure

CAPO-TEST Pullout

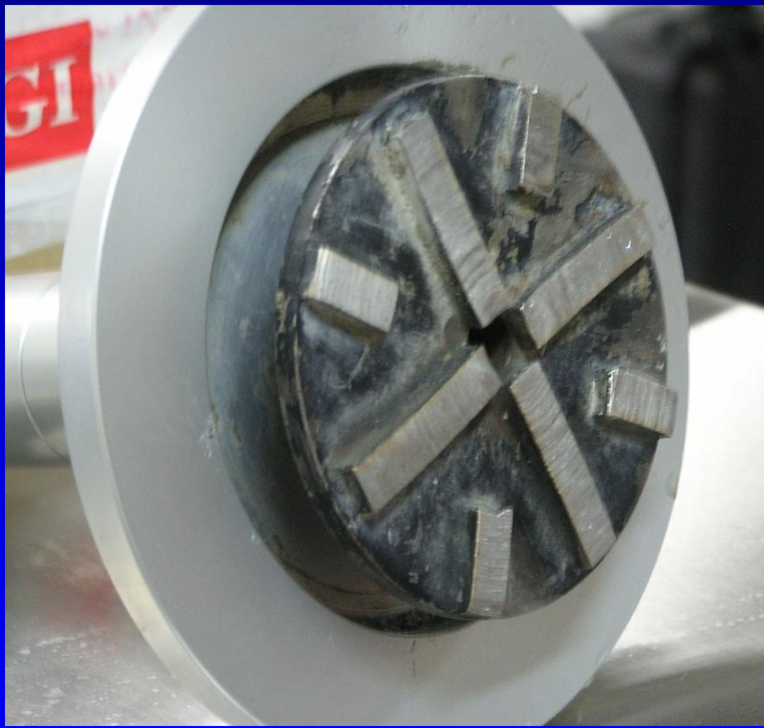


Prepare Concrete

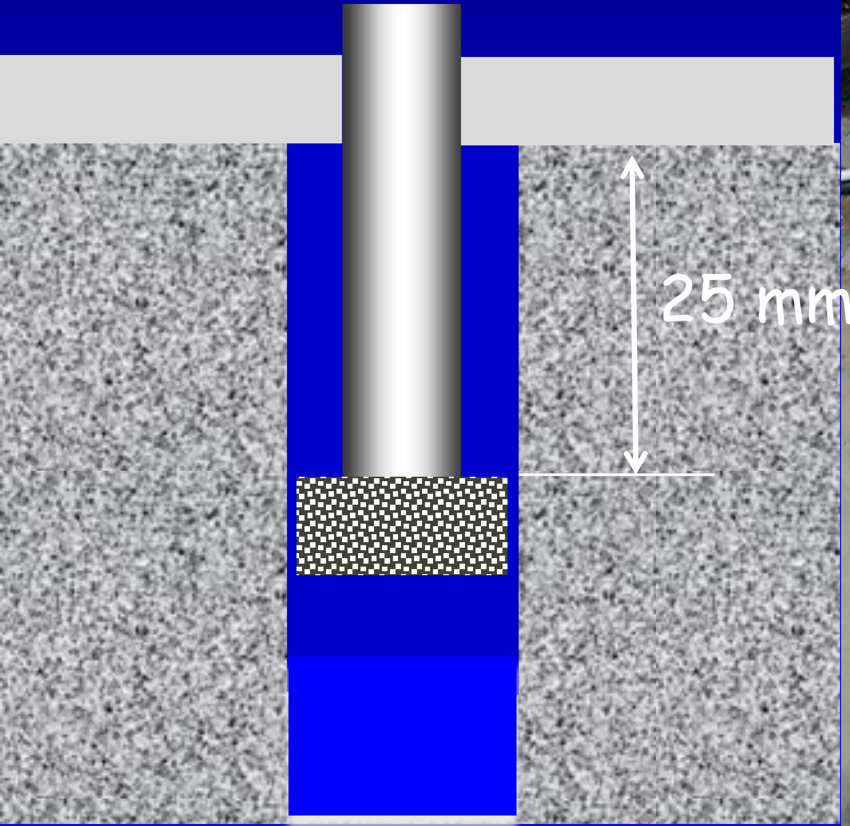


Core Hole

Plane surface



Cut Slot



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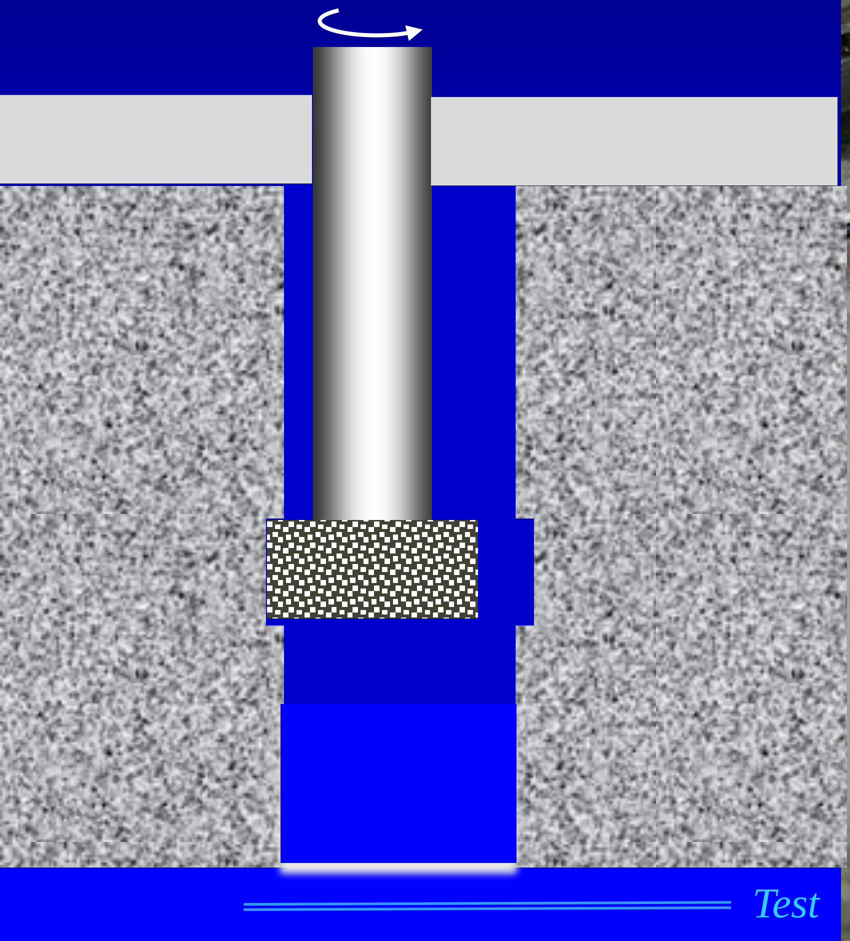
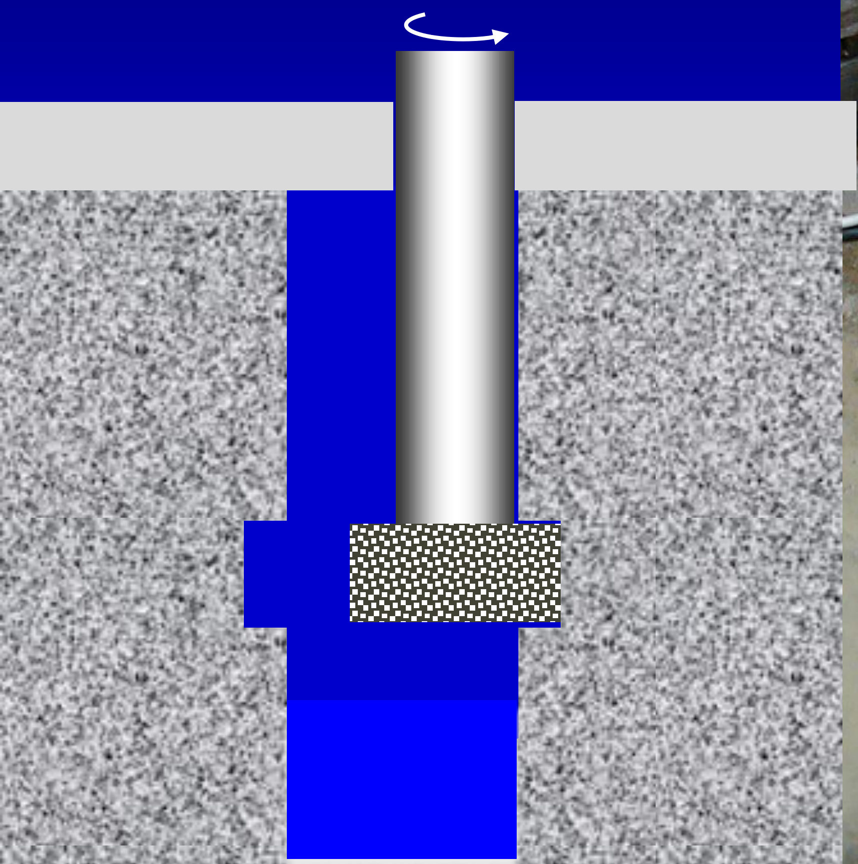
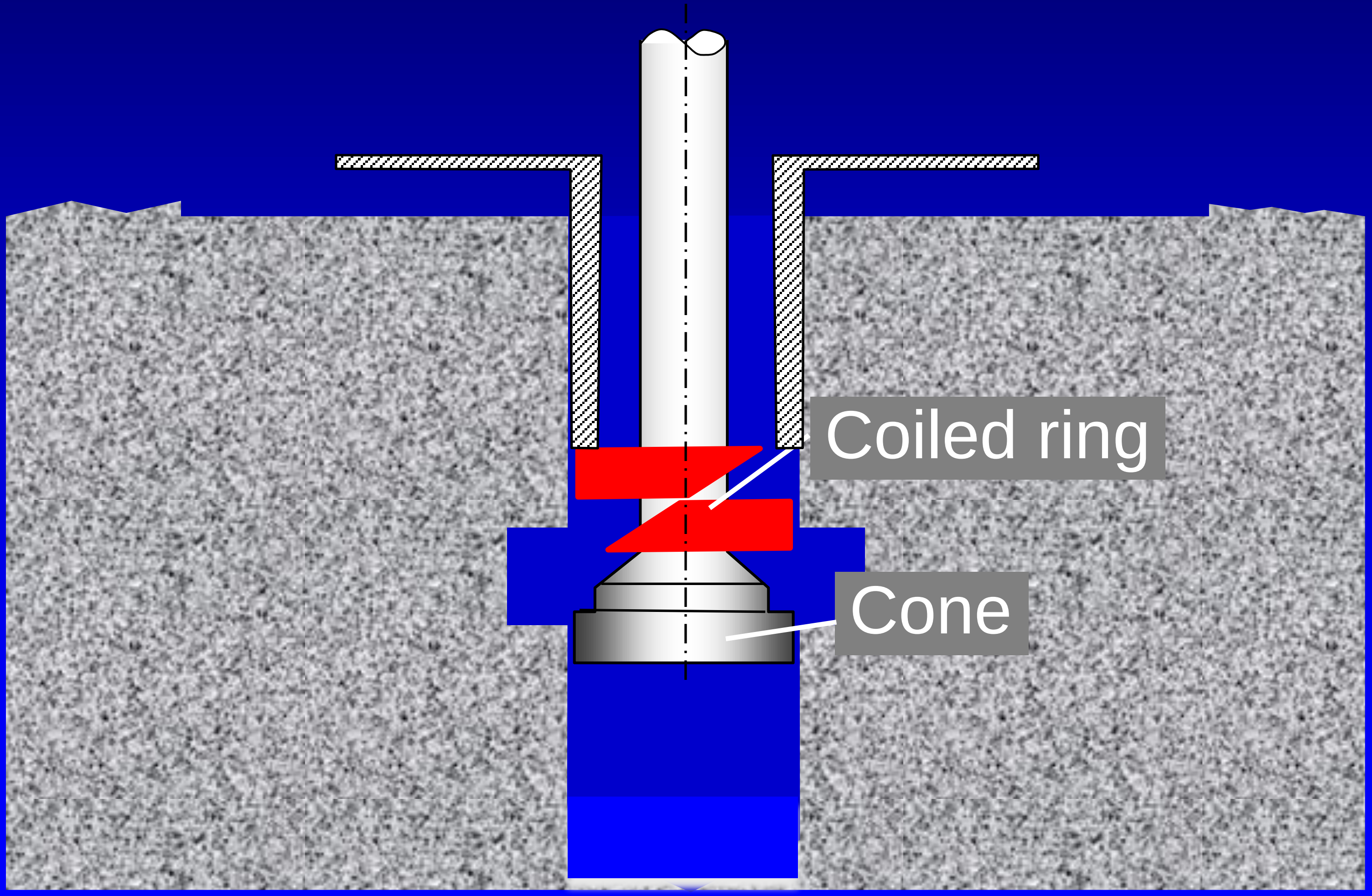


Cut Slot

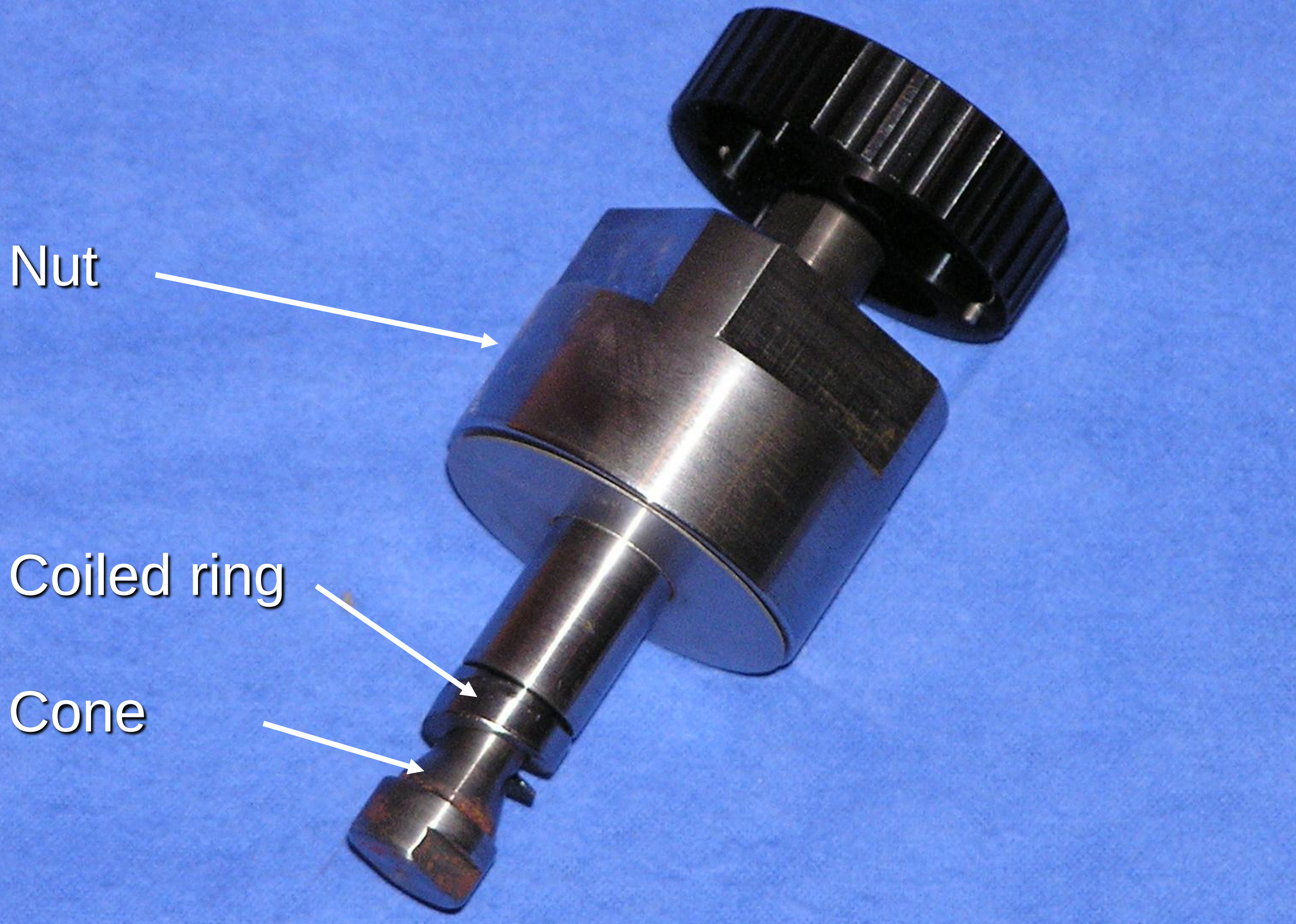


Test

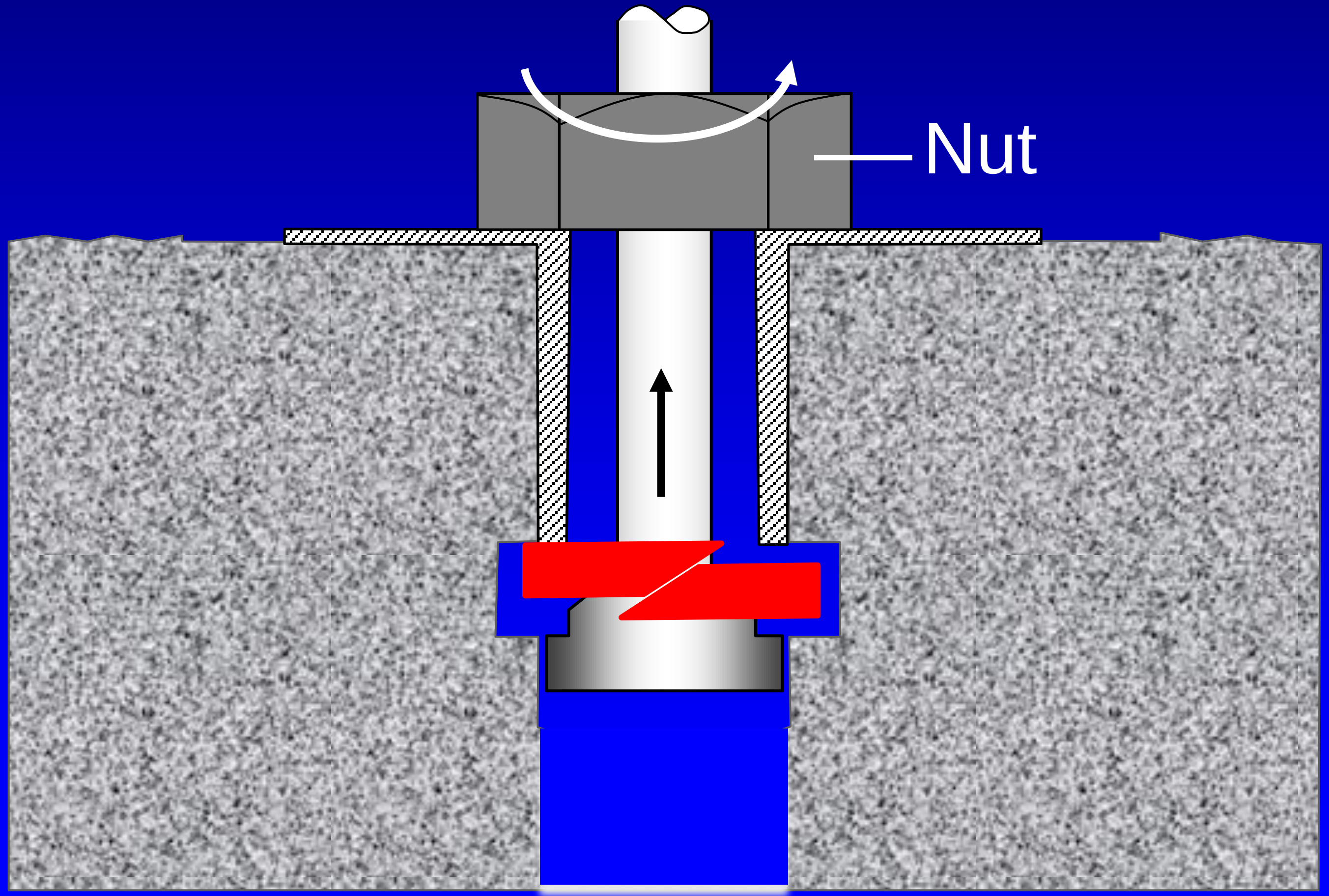
Insert Expansion Cone and Coiled Split-Ring



Ring Expansion Hardware



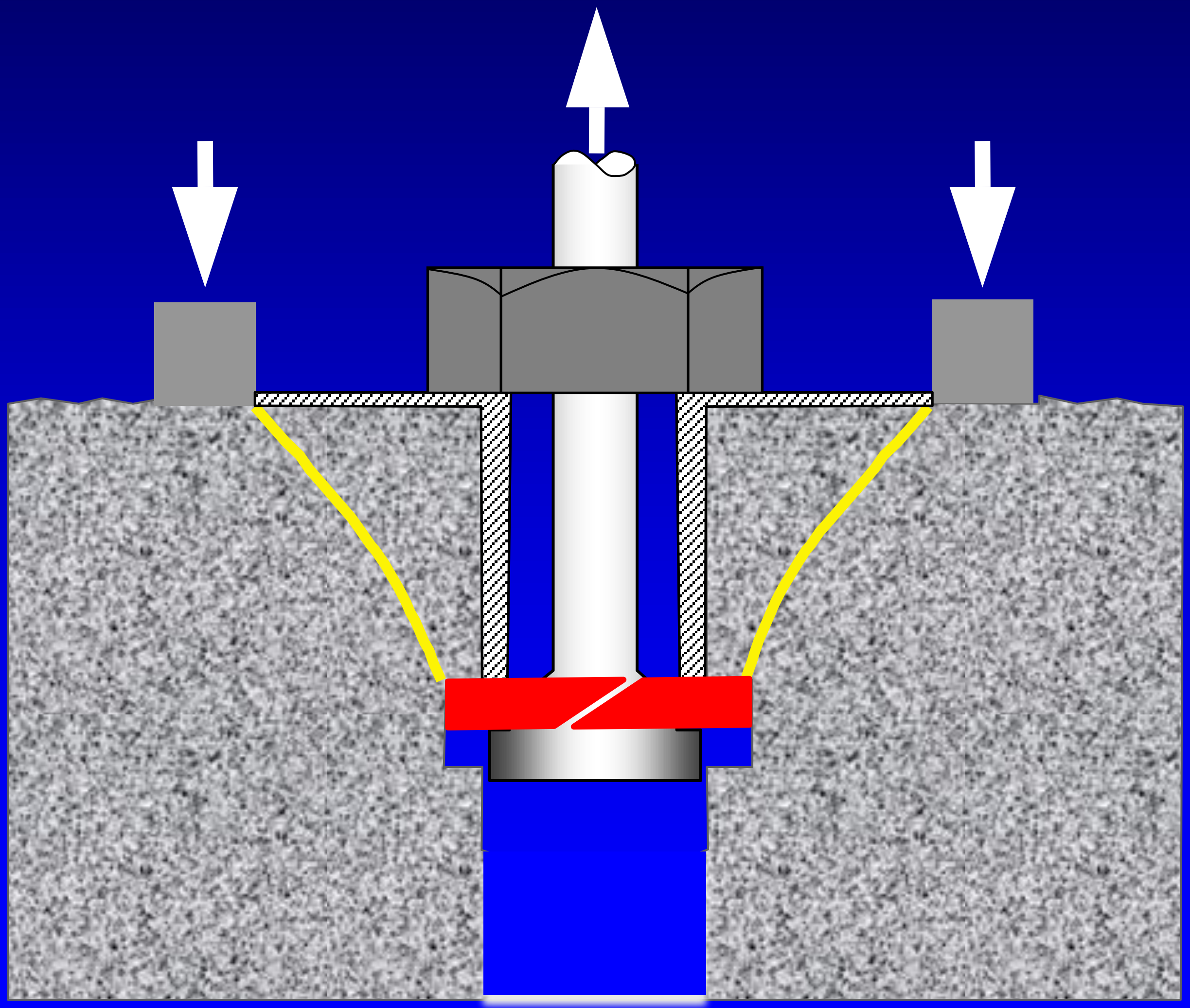
Expand Ring



GI

Expand Ring

Pullout the Expanded Ring against a 55 mm counterpressure



GI

Apply Pullout Force

Acceptable Test

Sharp 55 mm diameter edge from counterpressure

Criteria for correct CAPO testing

CAPO Equipment

Prep. Kit

Pullmachine

DSV Kit with
Surface Planner

Inserts

EN 12505-3: 2005:

"The correlation between strength and pullout force for the apparatus being used should be established experimentally. It has been shown that for a given type of apparatus the relationship between pullout force and compressive strength is similar over a wide range of concretes and that a general correlation can be used with reasonable accuracy"

ASTM C 900-06:

"For a given concrete and a given test apparatus, pullout strengths can be related to compressive strength test results…..Before use, the~~se~~ relationships must be established for each test system and each new concrete mixture"

Summary

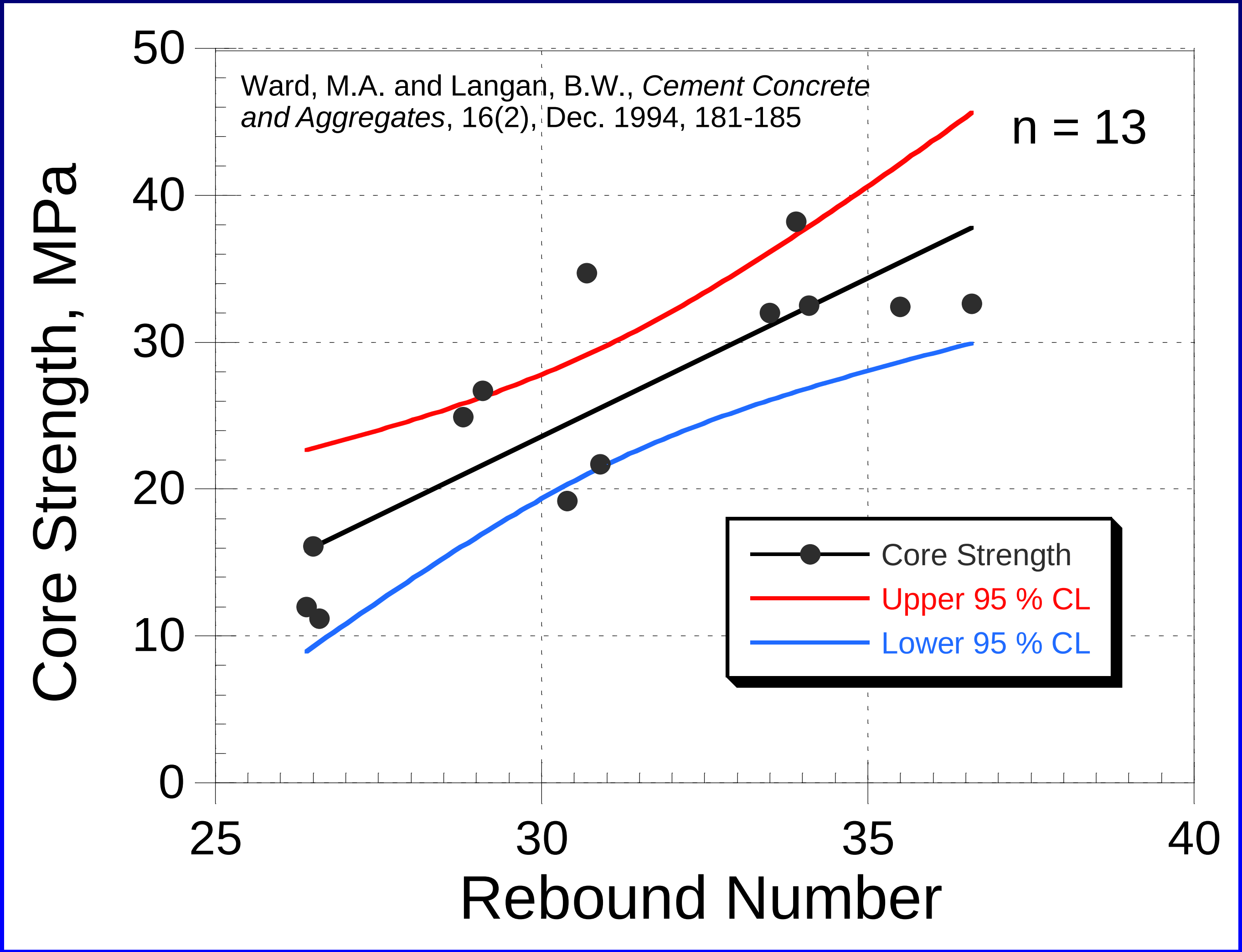
- Pullout test is a reliable method for estimating in-situ compressive strength of the cover layer
- Can be used for new construction and existing construction
- General correlations according to **EN 12505-3: 2005**
- Following ASTM C 900-06 confirm general correlations for LOK-Test
- For CAPO-Test cores can be drilled out for comparison to the general correlation

Other systems intending to estimate compressive strength in-situ

Rebound Hammer

Ultrasound (UPV)

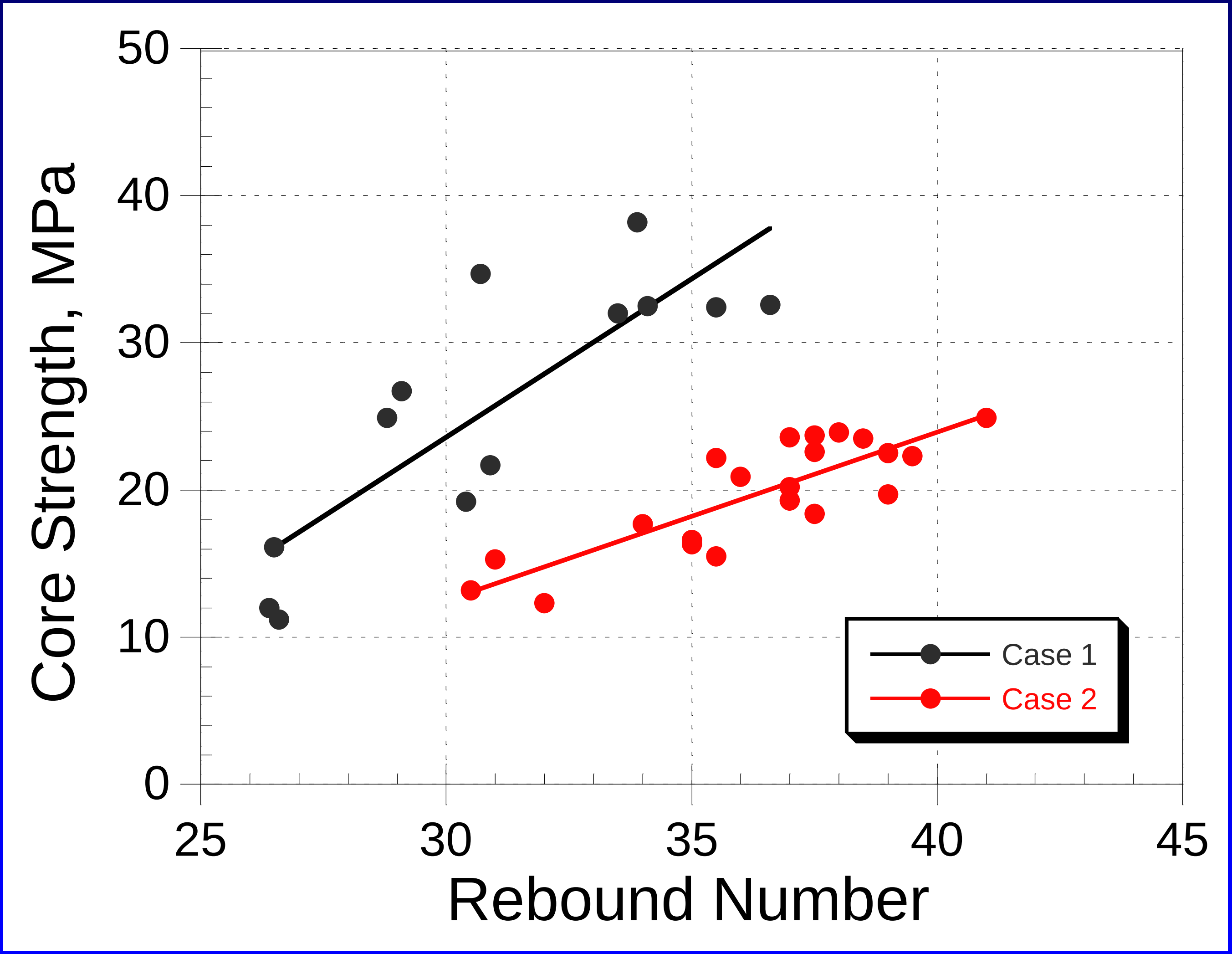
Rebound number to cores, mix specific



Factors Affecting Rebound Number

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

Comparison of Relationships

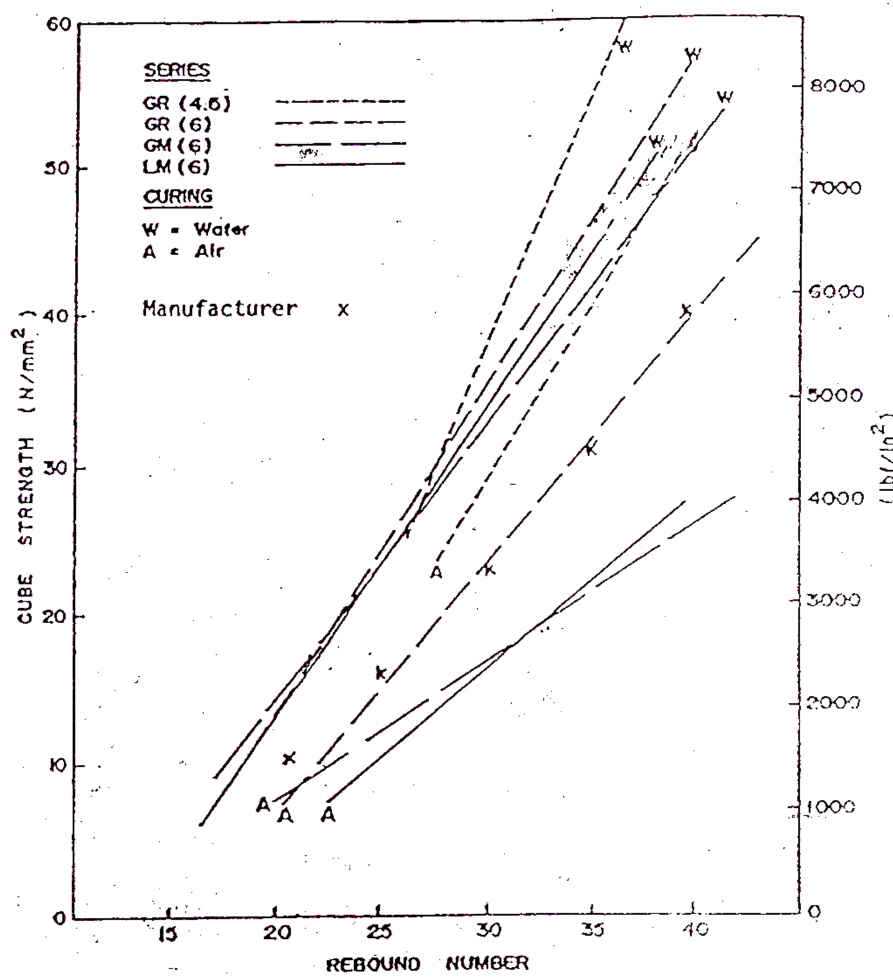


Rebound Hammer related to cube strength

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		Aggregate-cement ratio
	coarse	fine	
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



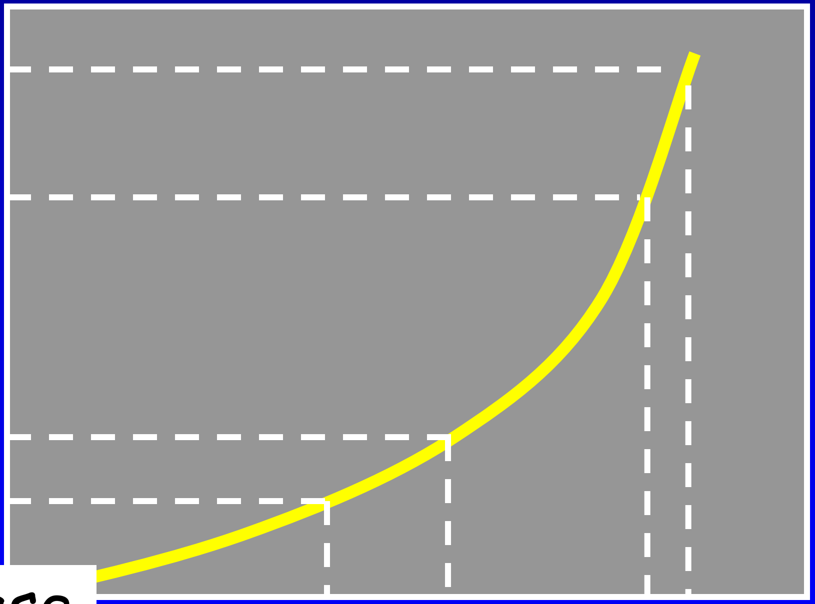
Strength Relationship UPV

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

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

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

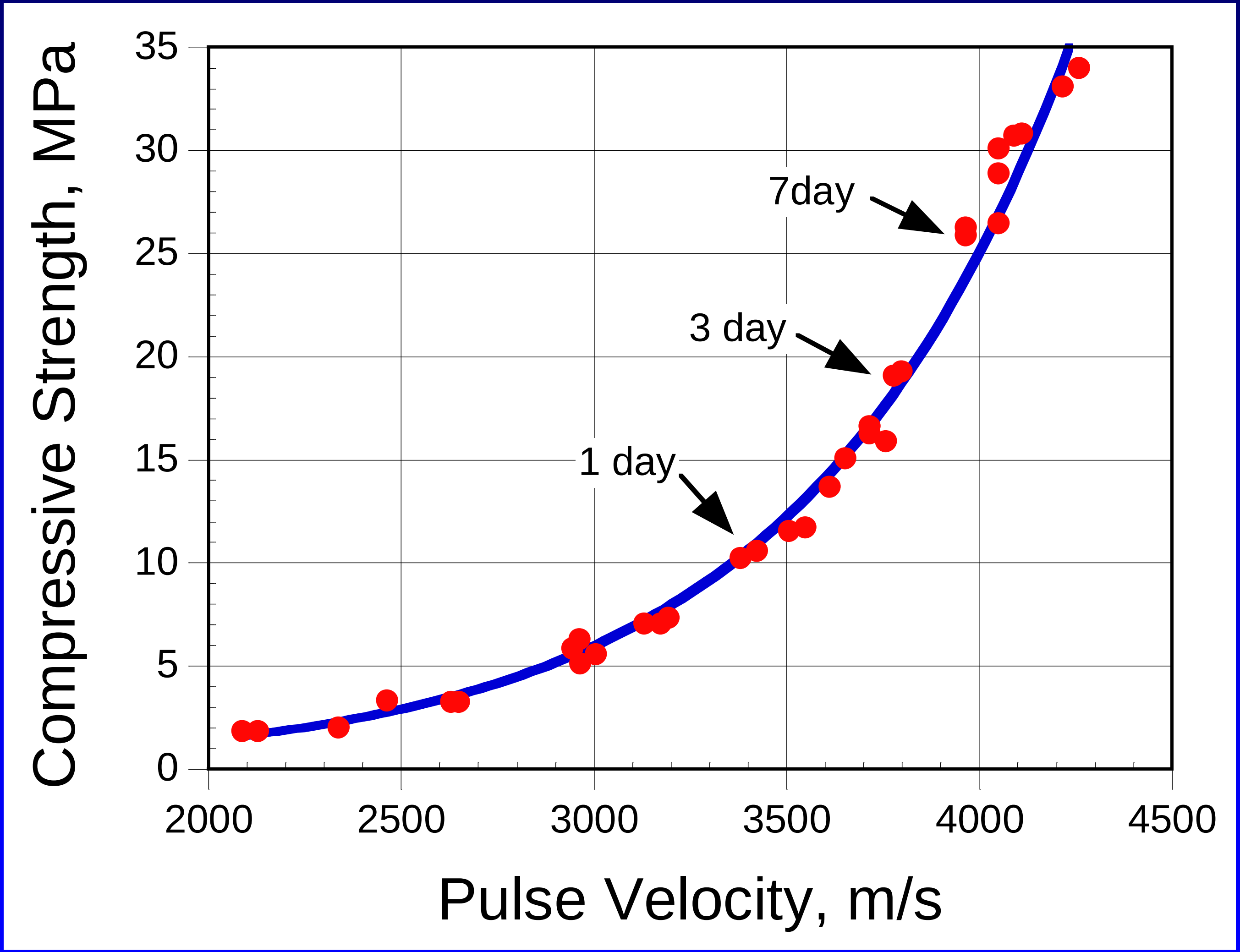
f_c



Velocity

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

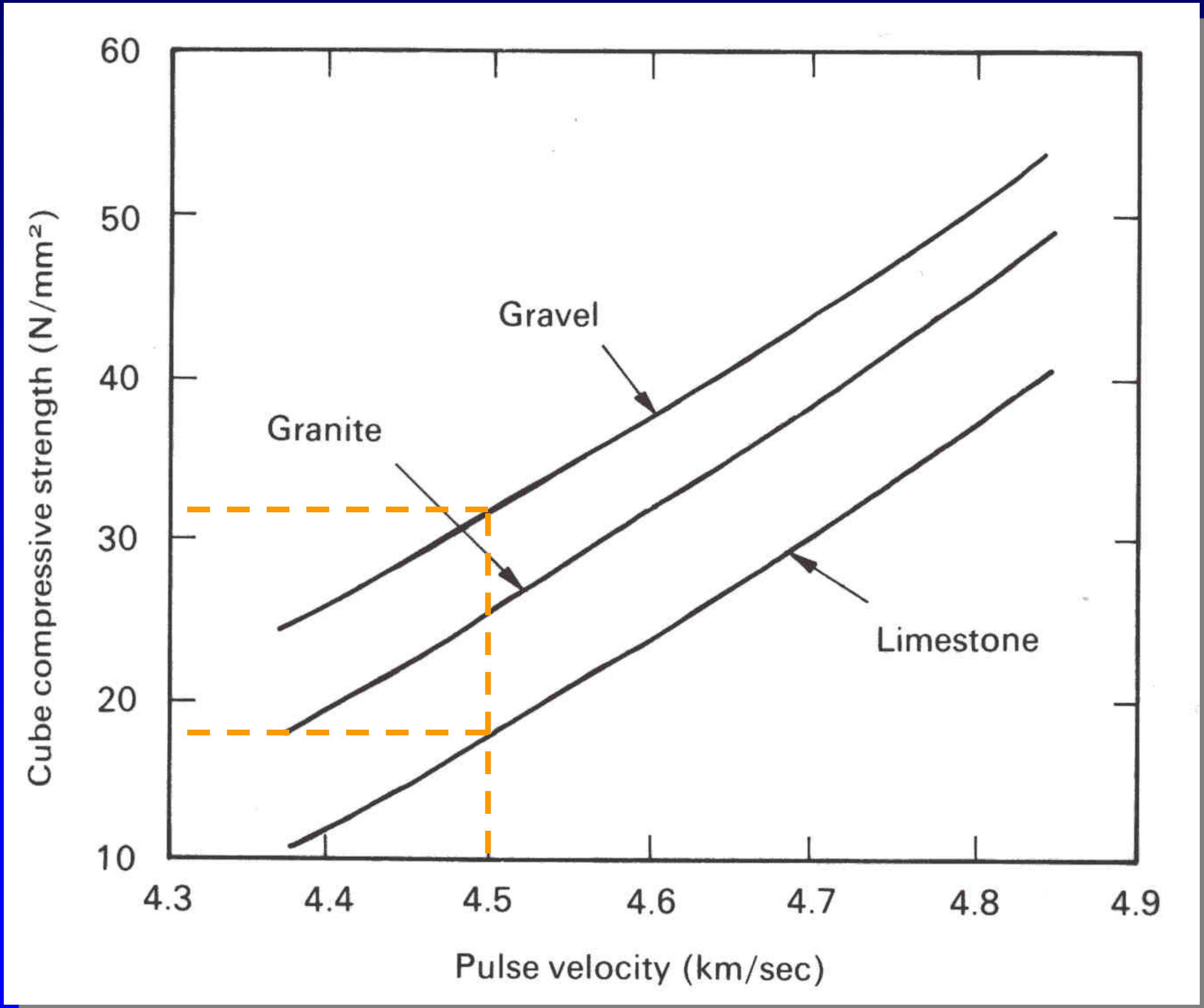
Relationship for a specific mix



Factors Affecting UPV for Given Concrete Strength

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

Example
Aggregate Type



Ref: Bungey, 1982

UPV (Ultrasound Pulse Velocity) related to cube strength

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

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		Aggregate-cement ratio
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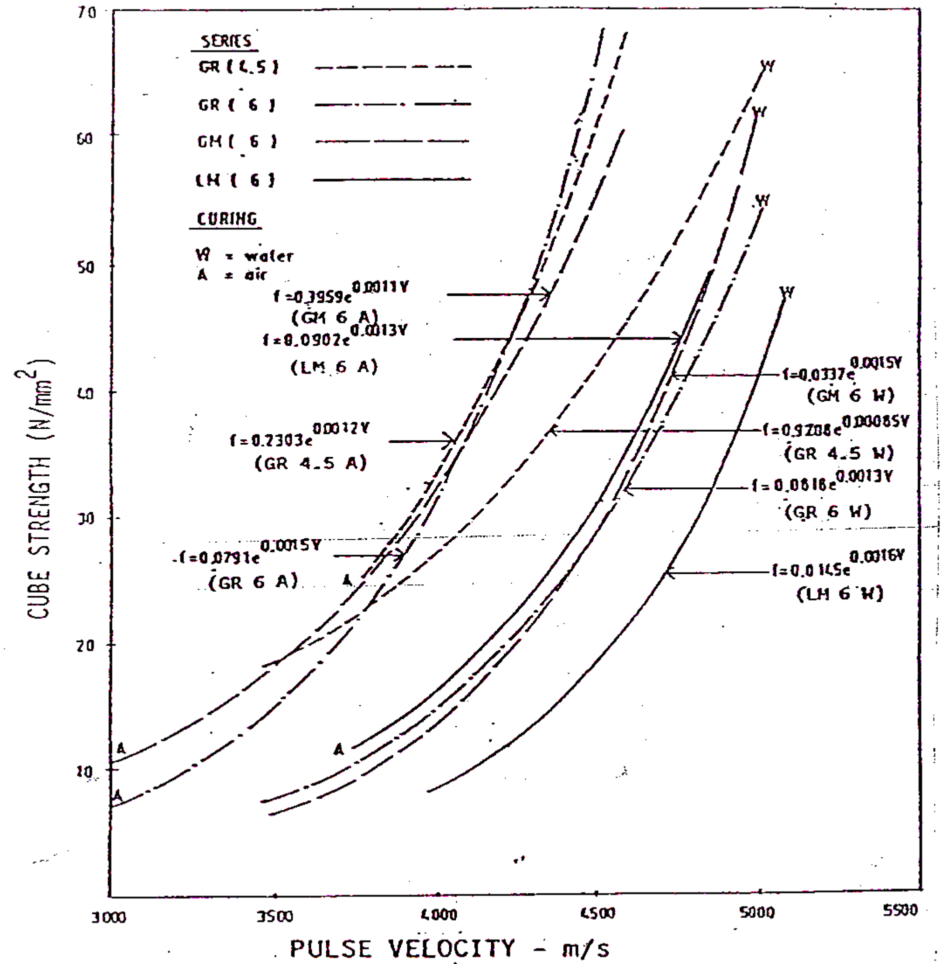

Evaluation techniques by

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

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

Thank you for your attention

www.germann.org