In-Place Strength Without Testing Cores: The Pullout Test

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Current Practice for Acceptance Testing of Concrete

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

Future Performance-Based Specifications

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

(Rebound number method, Probe penetration test, Ultrasonic pulse velocity: Requires correlation testing for each concrete mixture)

Outline

- Explain pullout test
- Strength correlation and failure mechanism
- Describe CAPO-Test
- Case study
- Summary

Pullout Test
ASTM C 900

Designation: C900 – 15

Standard Test Method for Pullout Strength of Hardened Concrete[1]

This standard is issued under the fixed designation C900; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers determination of the pullout strength of hardened concrete by measuring the force required to pull an
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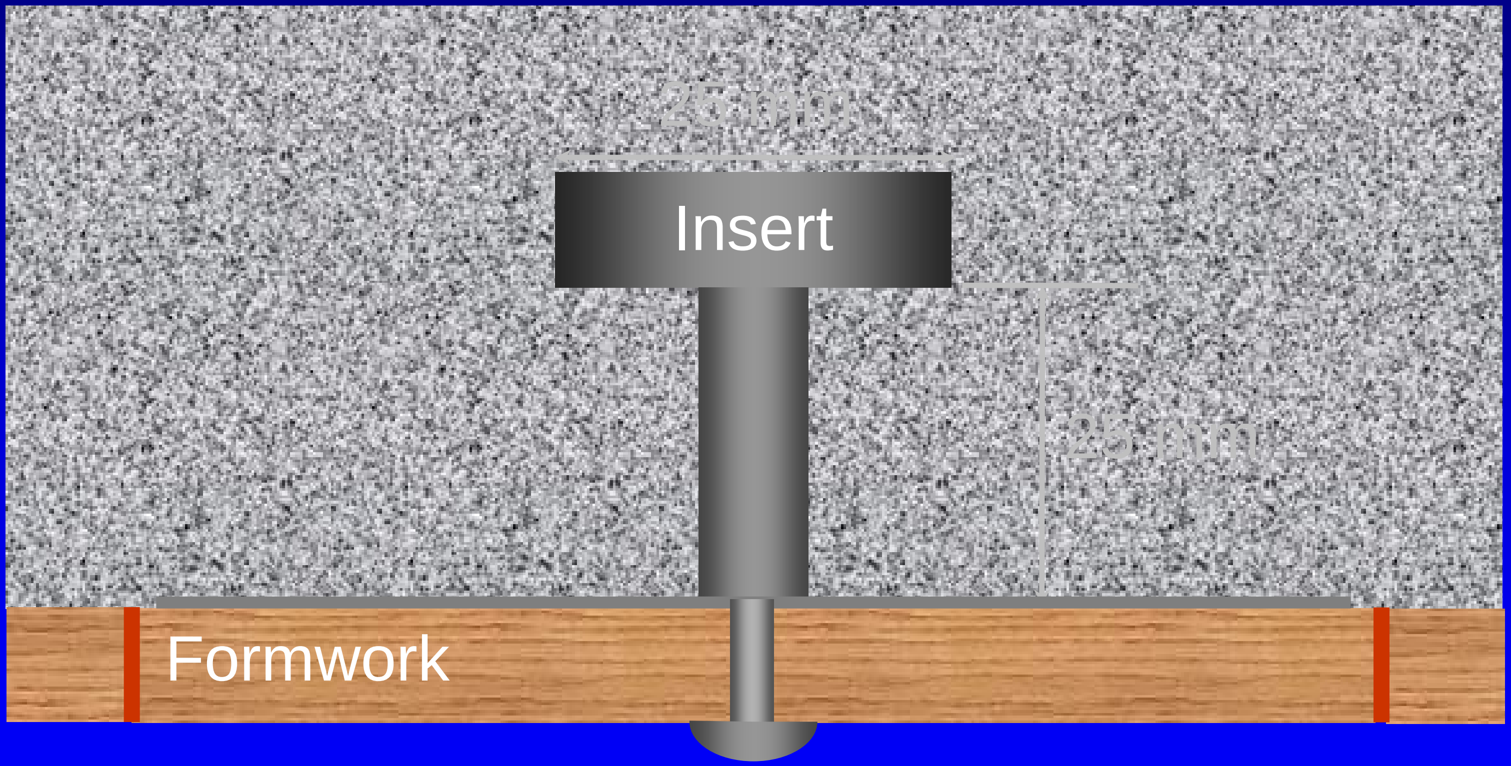
3. Terminology

3.1 *Definitions:*

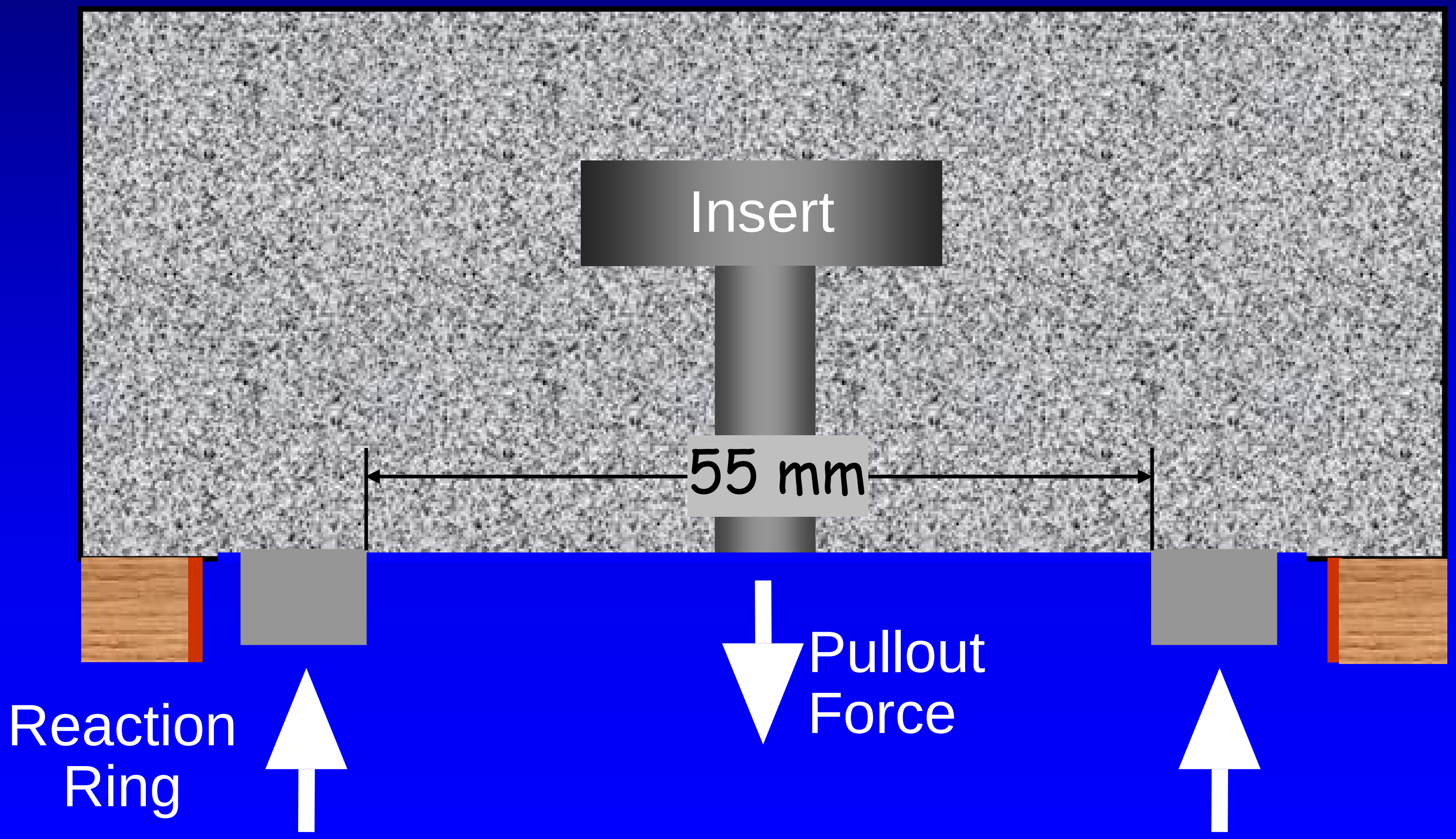
Measure force to pullout an insert anchored in concrete.

- Cast-in-place (CIP): LOK-Test
- Post-installed (PI): CAPO-Test

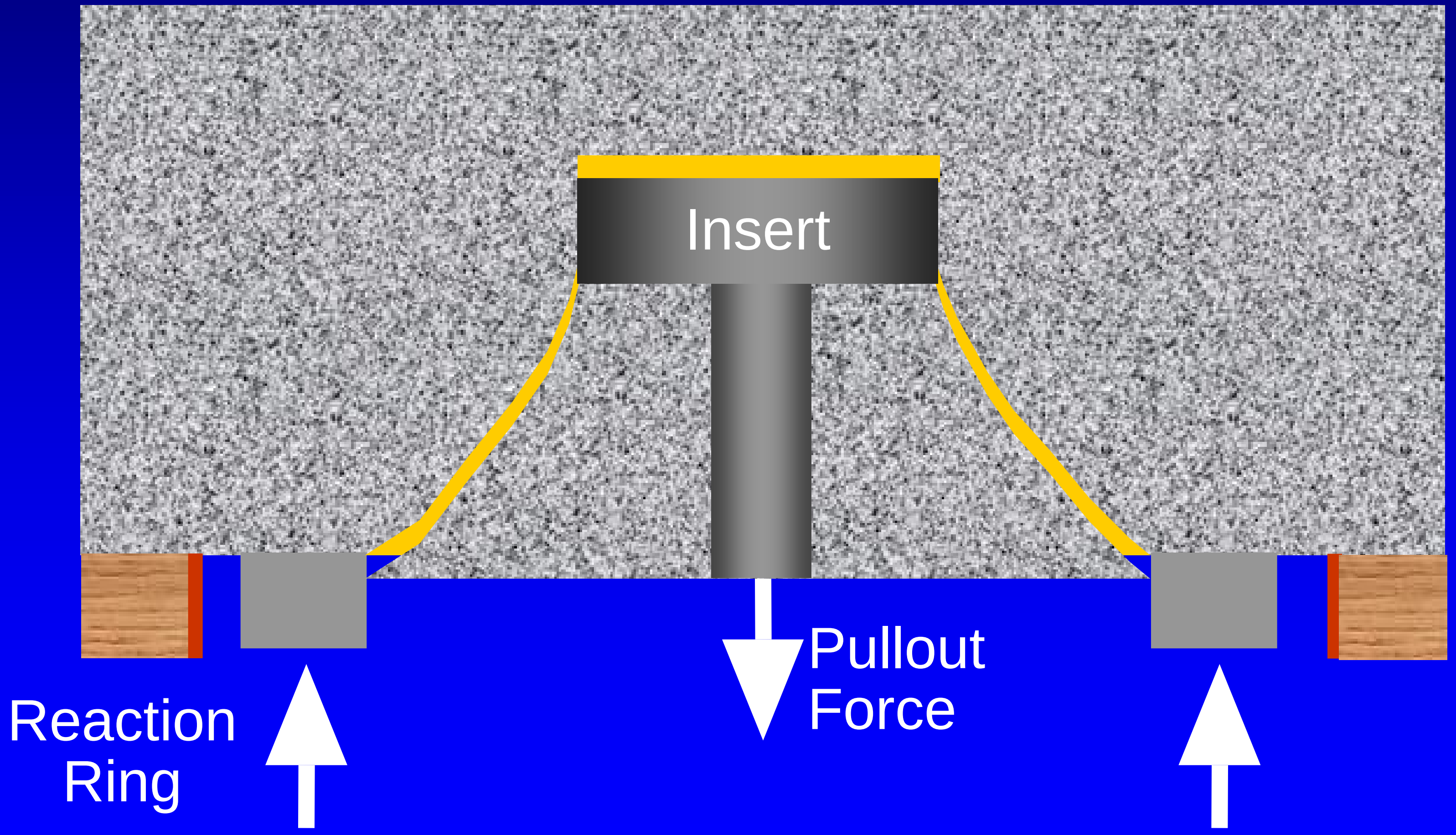
CIP-Pullout Test



CIP-Pullout Test



CIP-Pullout Test

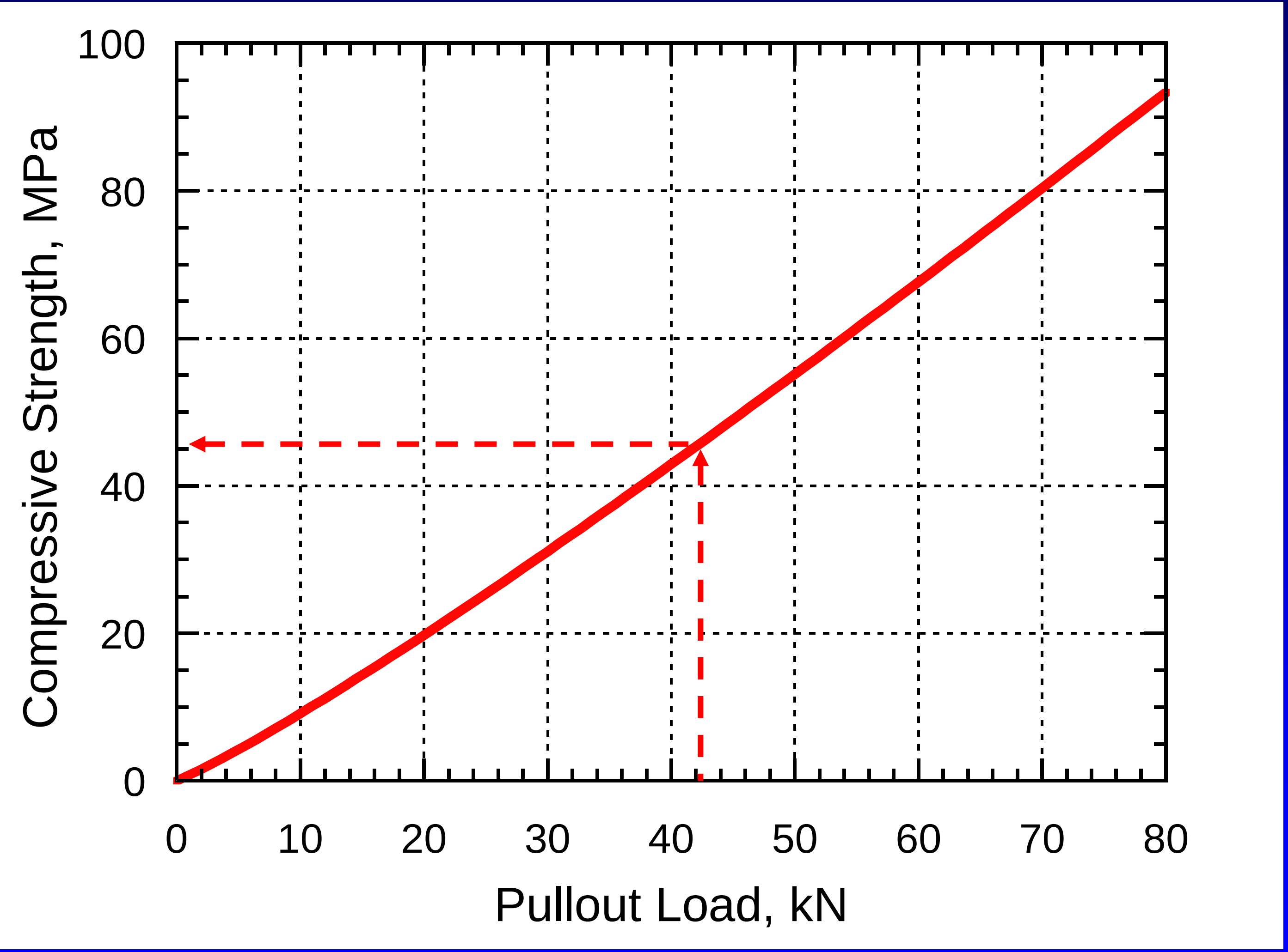


Pullout Test

Apply Pullout Load

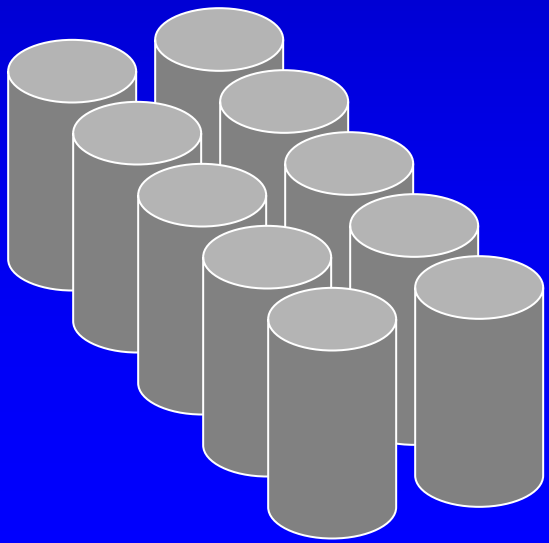
Conical Fragment

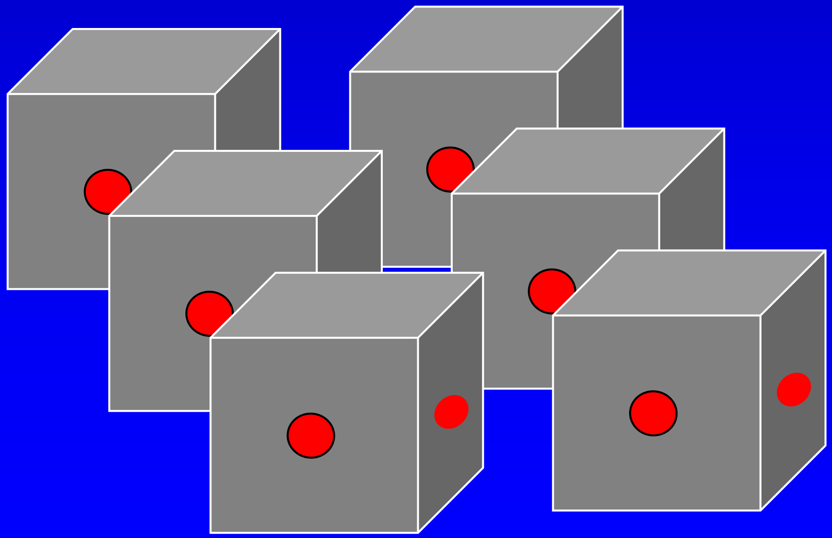
Estimate Concrete Strength



Correlation Testing ACI 228.1R

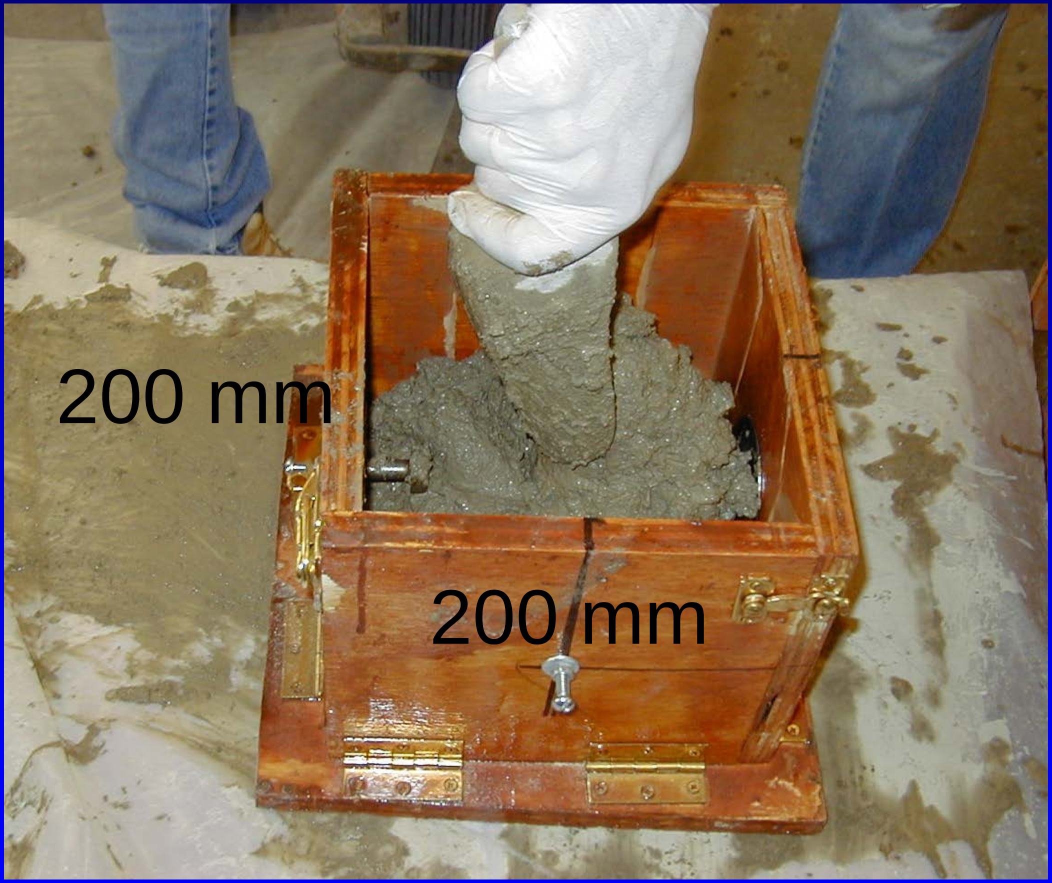
- Prepare cylinders (or cubes) for standard compressive strength testing
- Prepare 200-mm cubes with inserts
- Cure all specimens under same conditions



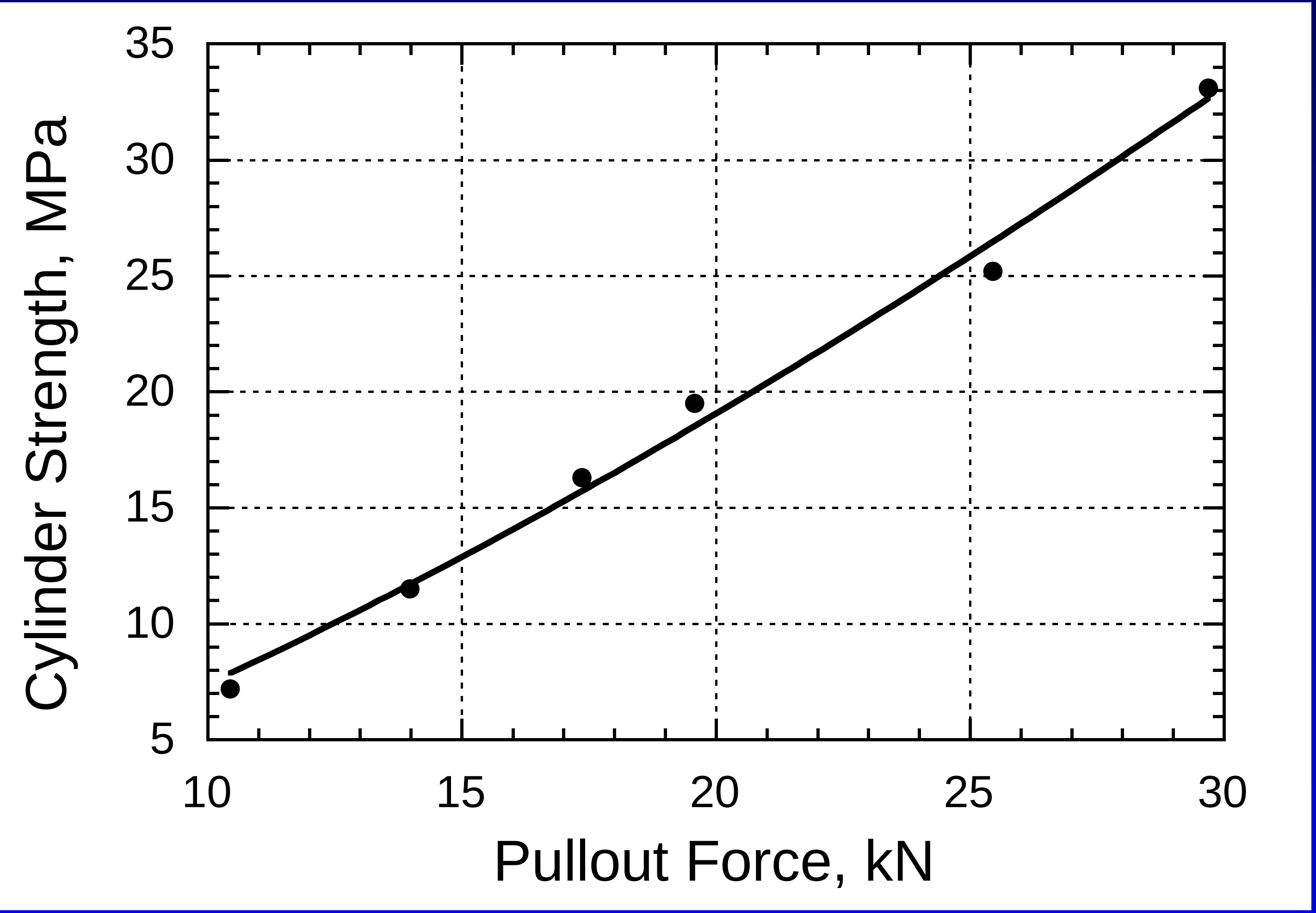


Correlation Testing

- At ages of 1, 2, 3, 7, 14 and 28 days:
  - Test 2 cylinders (or cubes) for compressive strength
  - Perform 8 pullout tests (2 cubes)



Example of Correlation



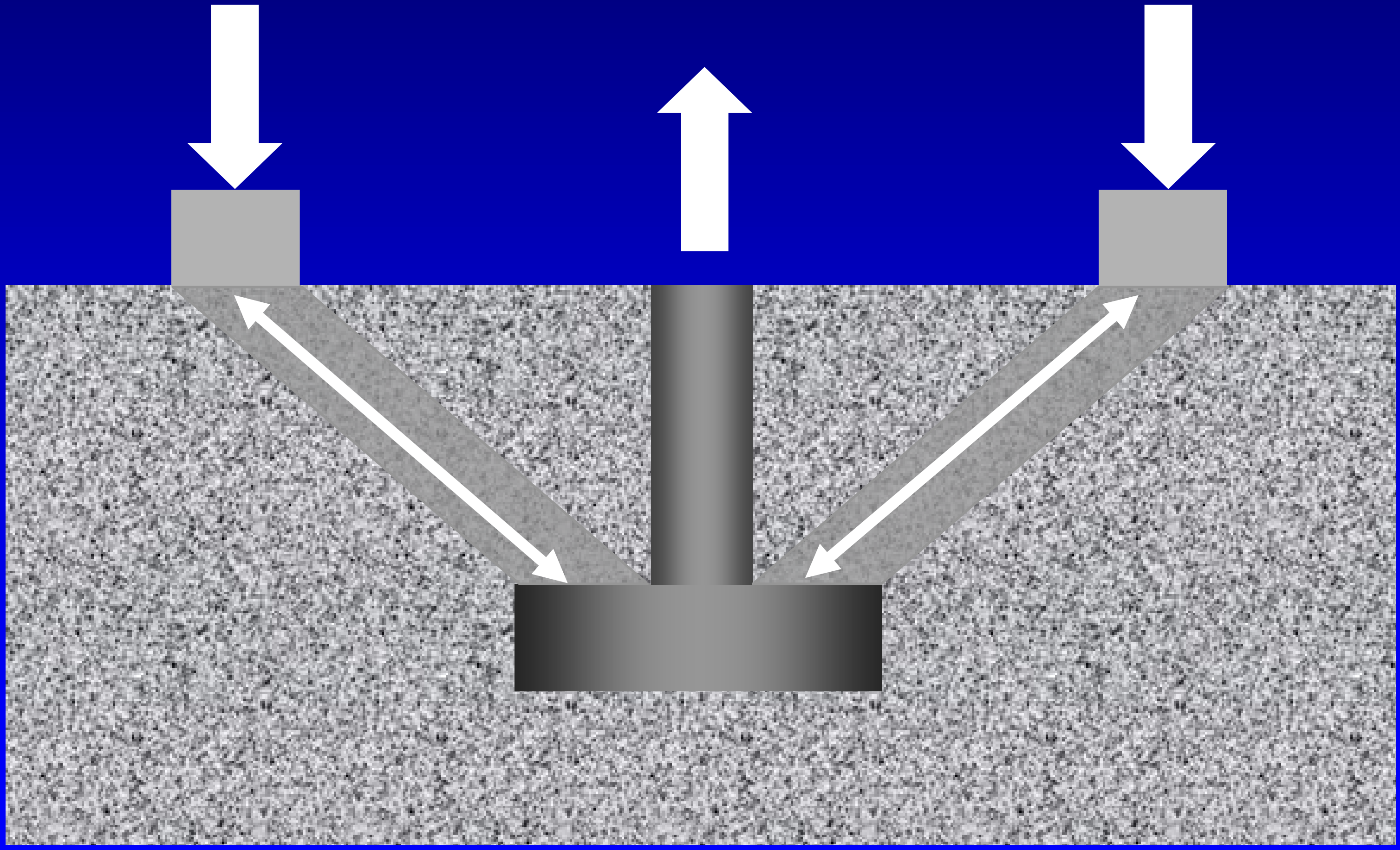
http://www.nrmca.org/research/HVFAC_Final_Report_final.pdf

Why is there a correlation?

- Analytical studies of pullout test have been done
  - Plasticity theory
  - Compression-strut theory
  - Aggregate-interlock theory
- Pullout strength is related fundamentally to concrete strength

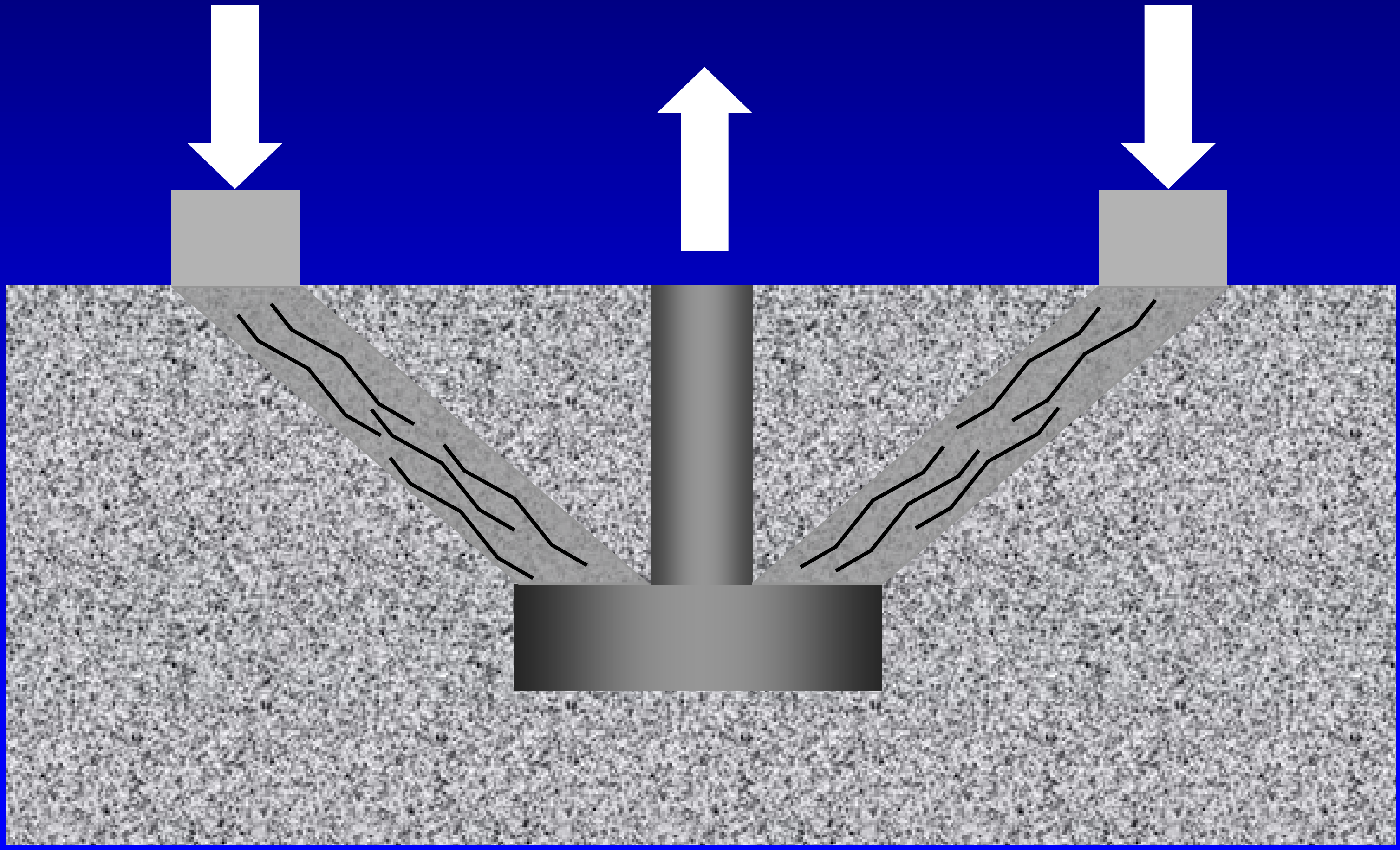
Pullout Failure Mechanism

Compression strut theory

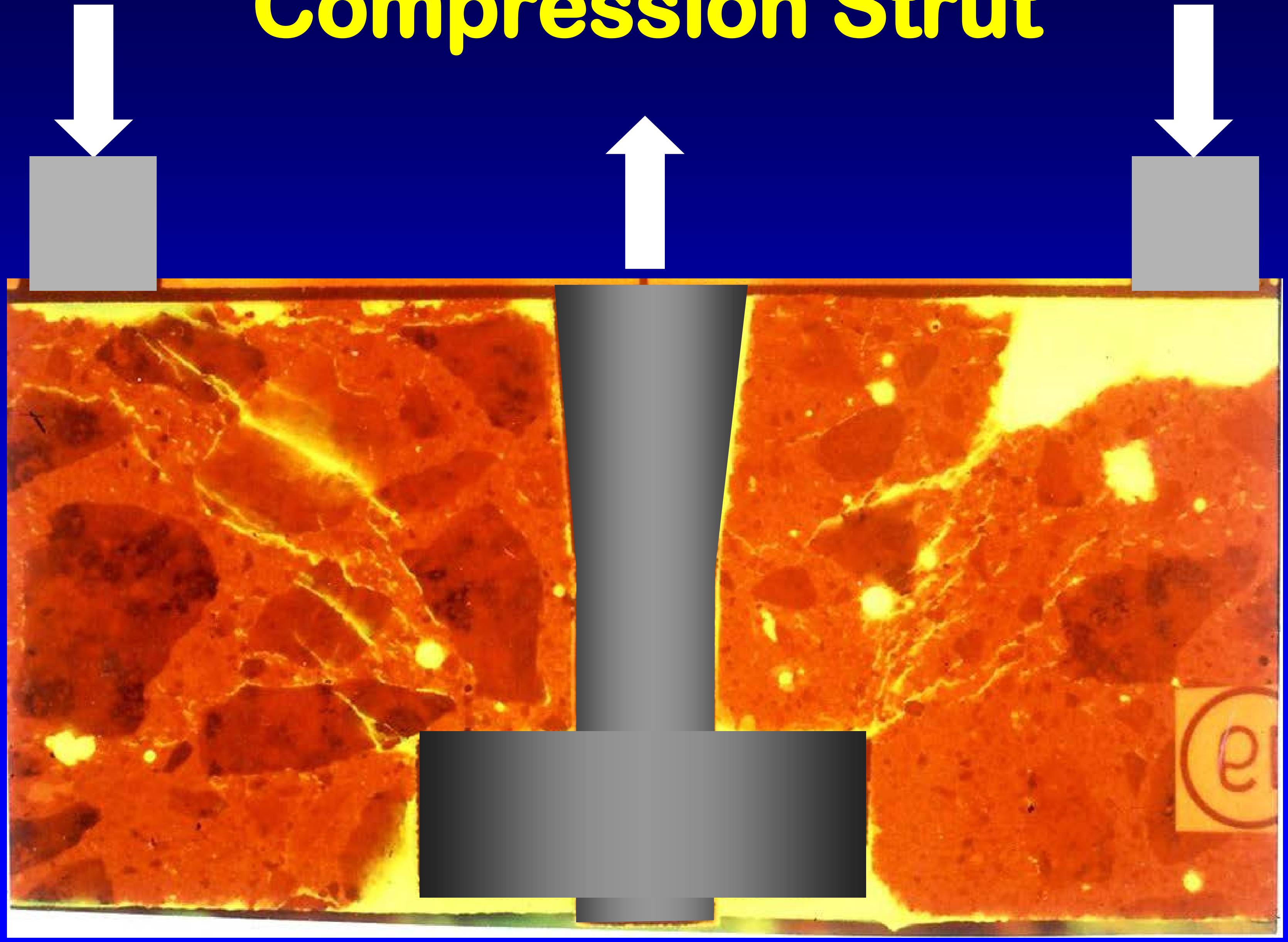


Pullout Failure Mechanism

Compression strut theory



Compression Strut

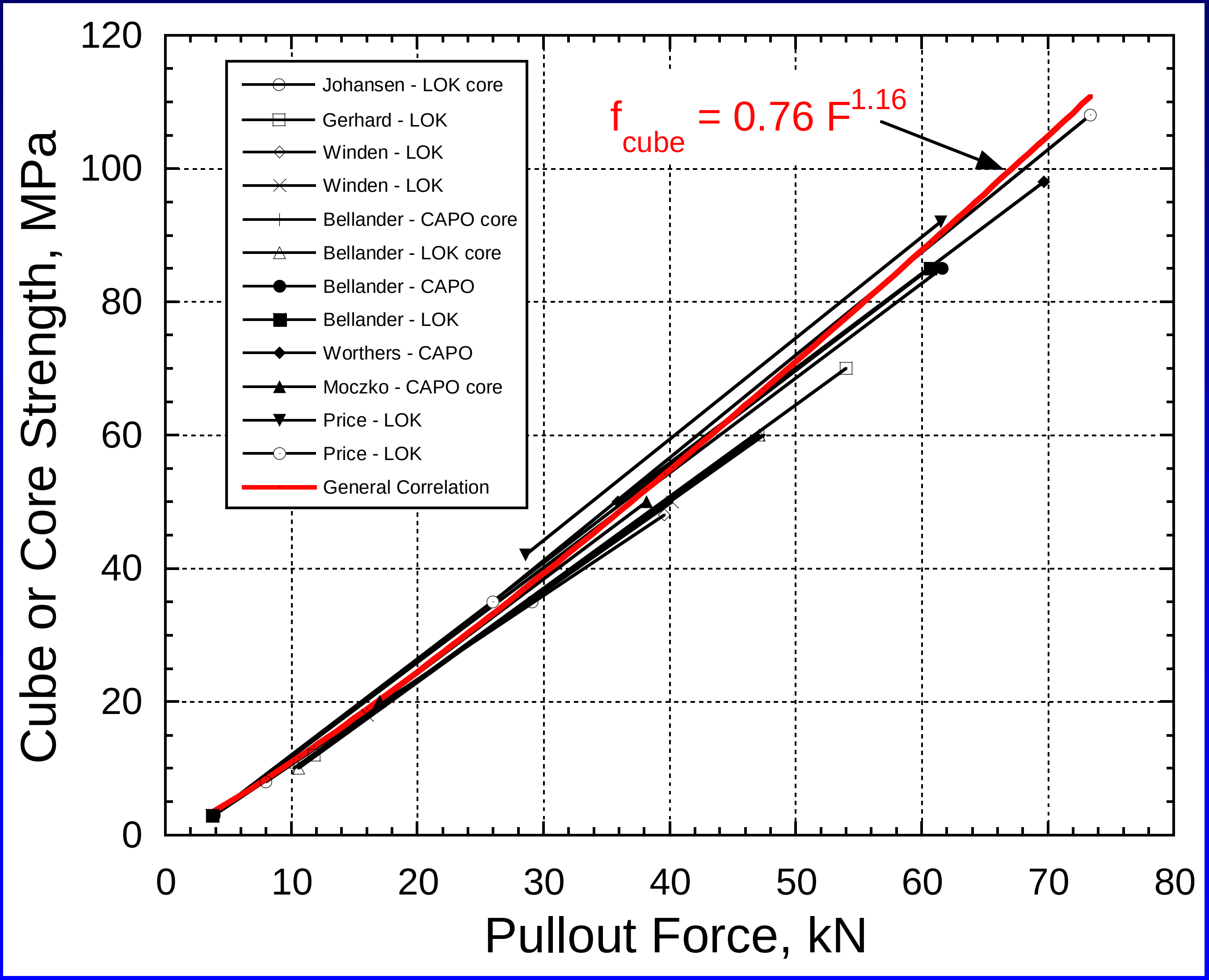


Robust Correlation

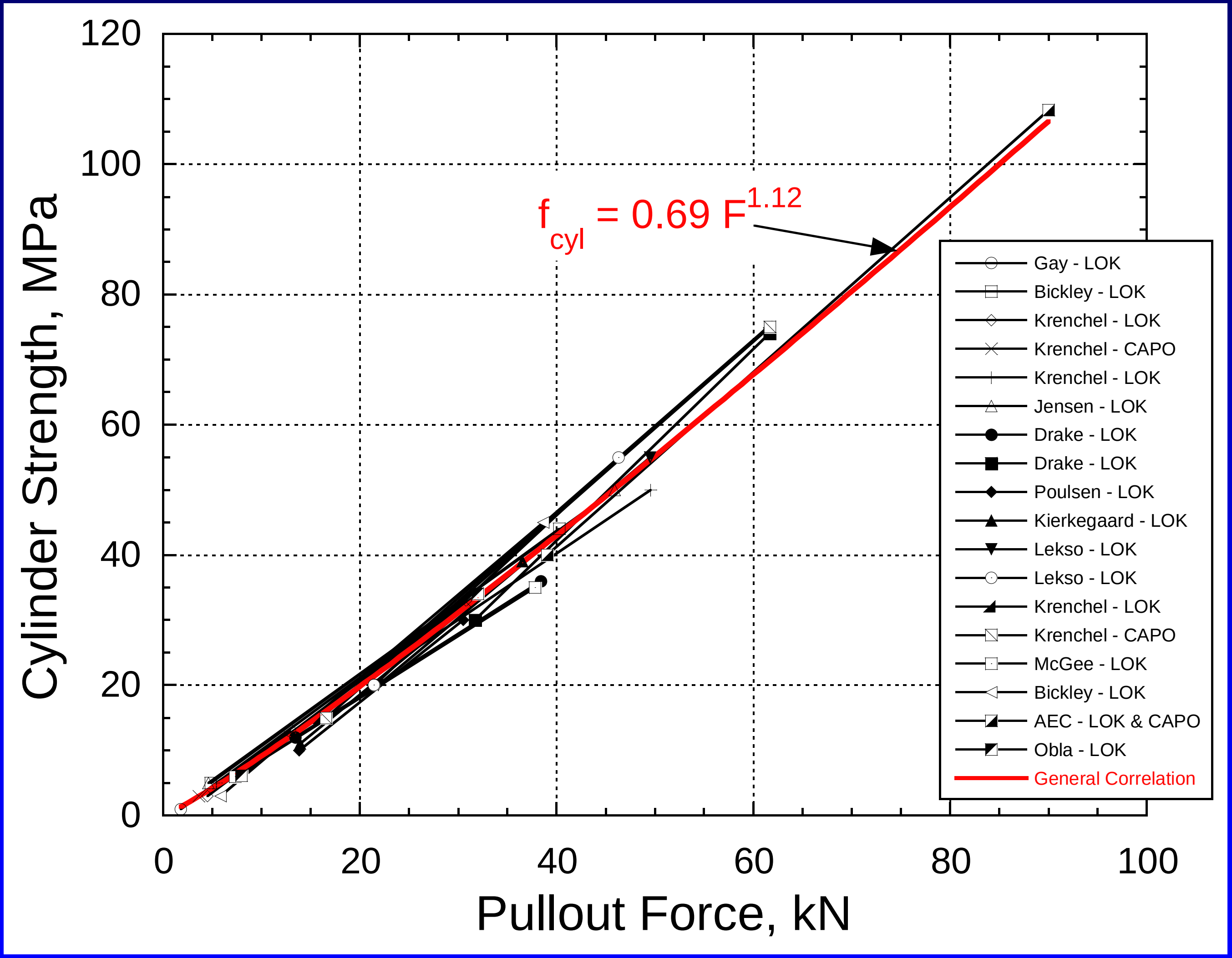
Not affected by:

- Type of cementitious materials
- Water-cement ratio
- Age
- Air entrainment
- Types of admixtures
- Shape or size of normal density aggregate up to 40 mm
    - Lightweight aggregate, however, produces significantly different correlation

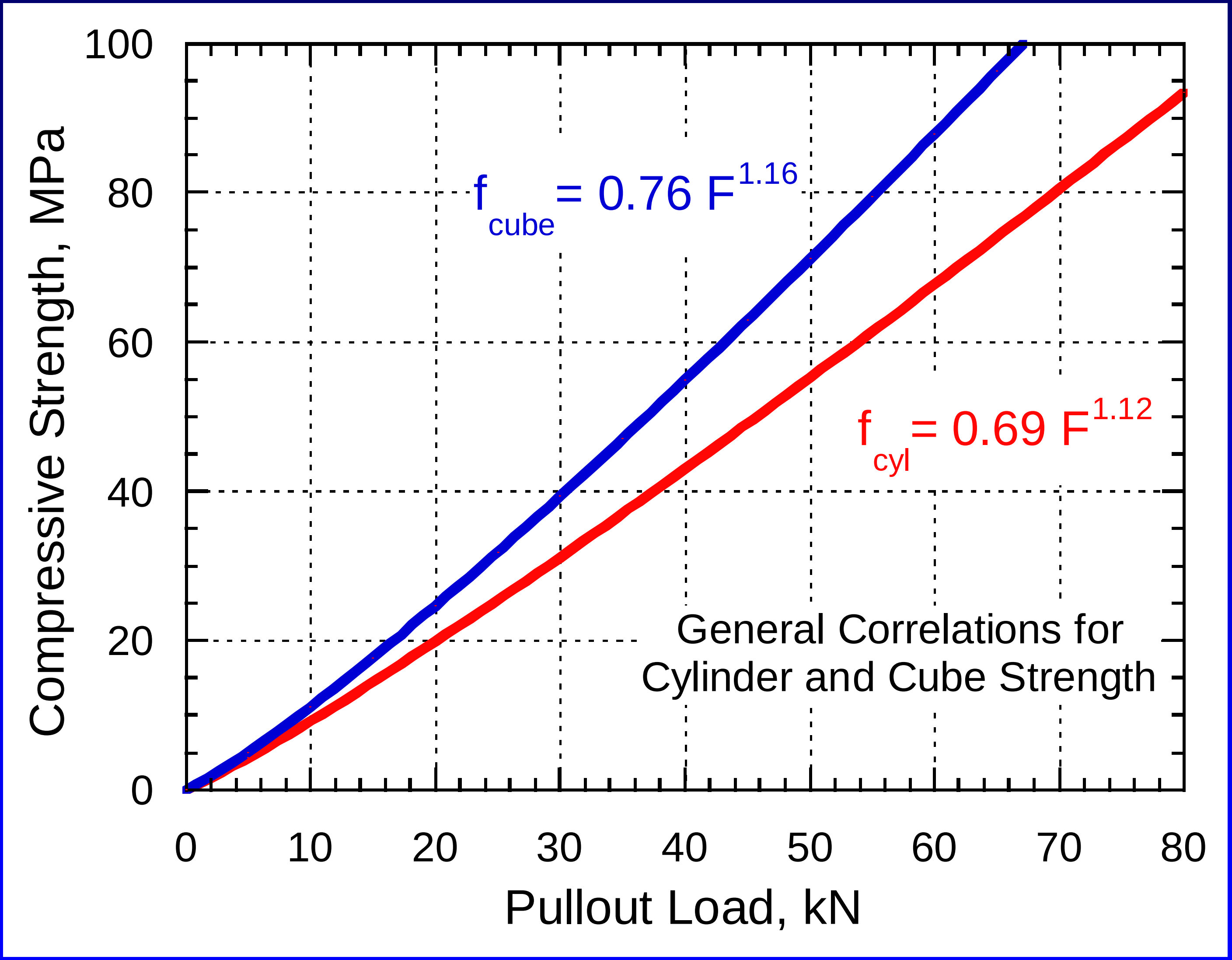
Cube Strength Correlations



Cylinder Strength Correlations



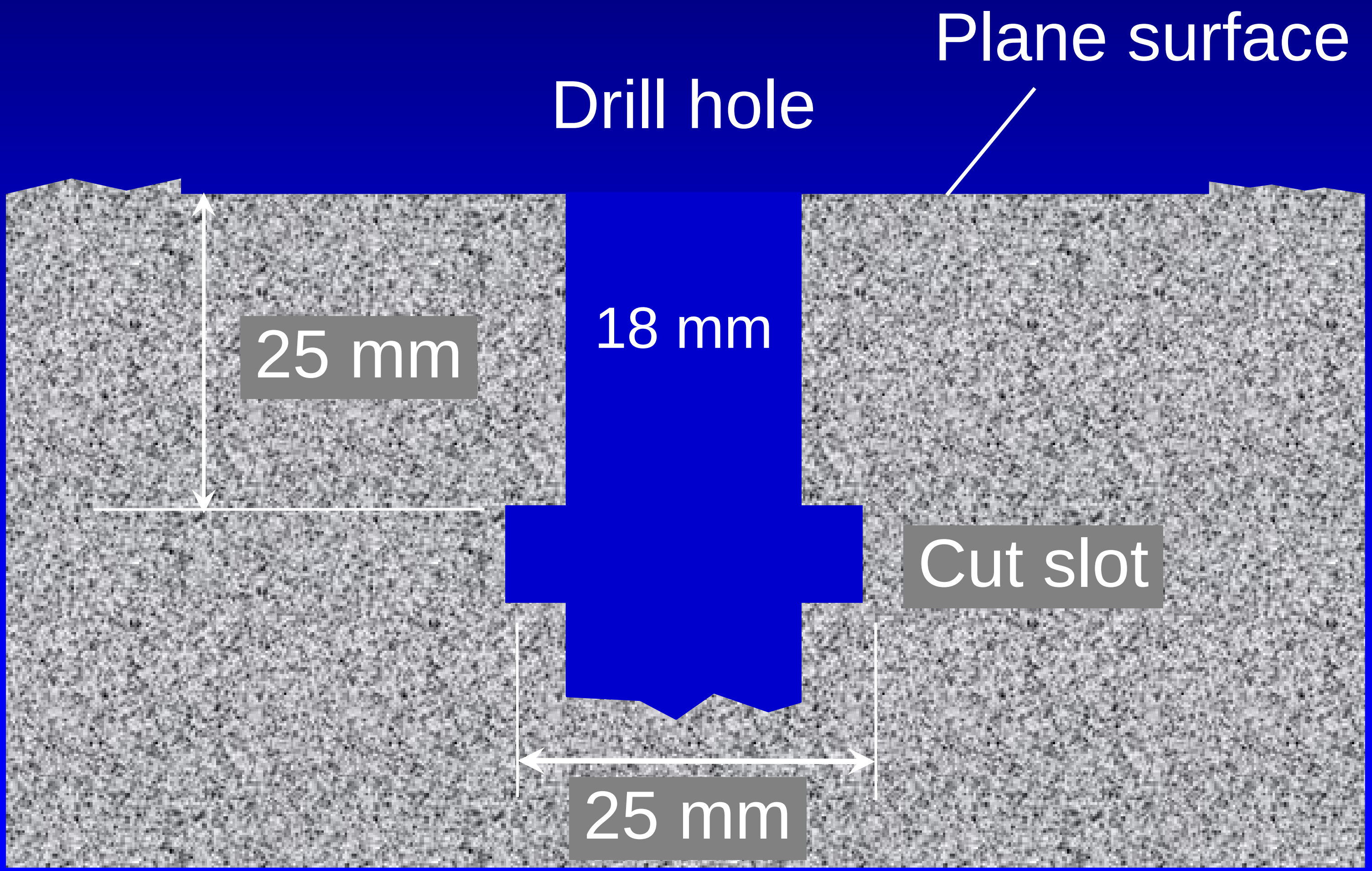
Manufacturer's General Correlations



Post-Installed Pullout Test CAPO-Test

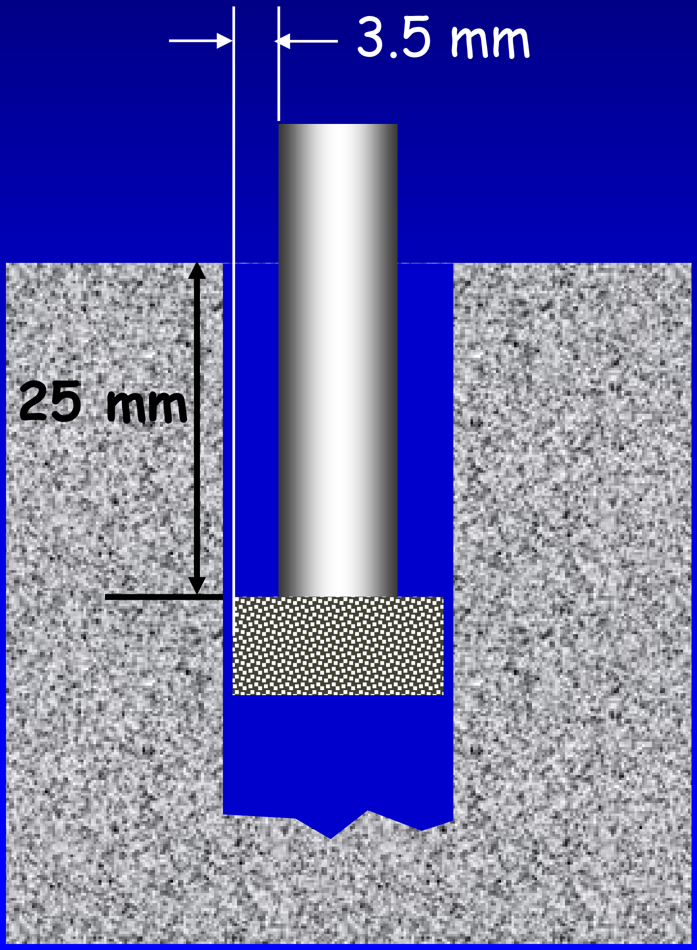
- Does not require pre-planning test locations
- Can perform test at any accessible location
- Permits testing of existing structures
- Immediate test results compared with cores

Prepare Concrete



Surface Planing

Cut Slot



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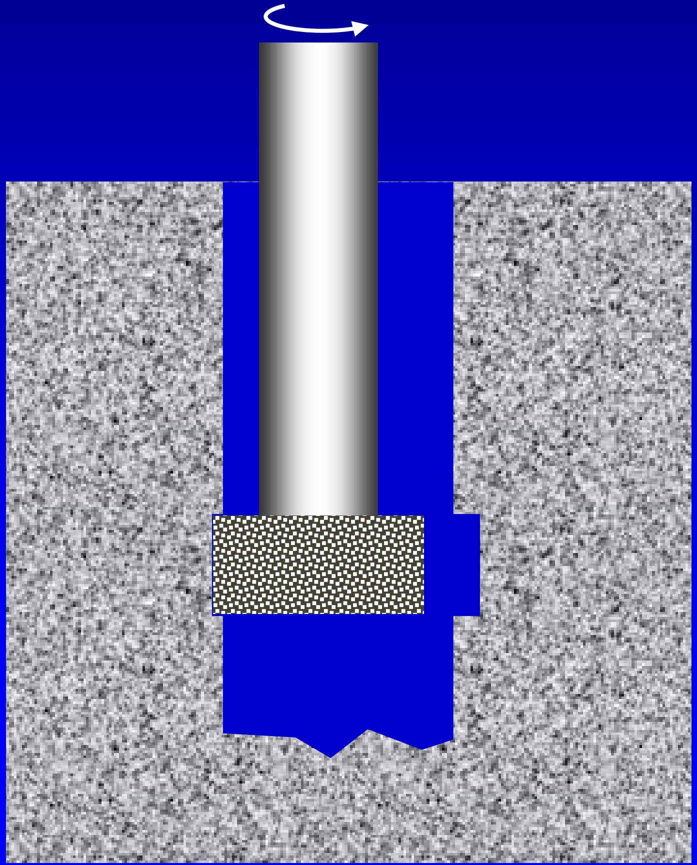

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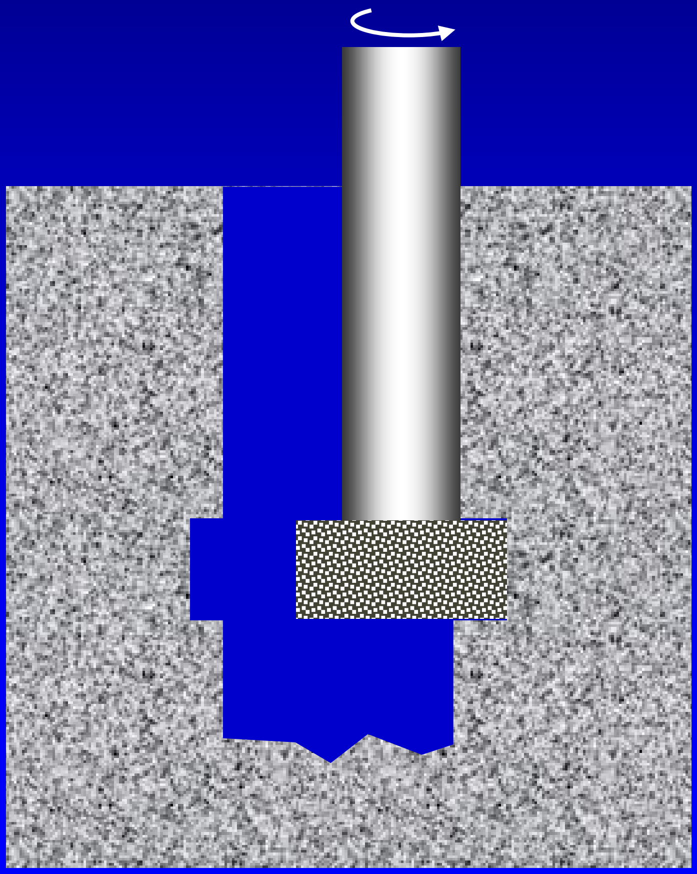
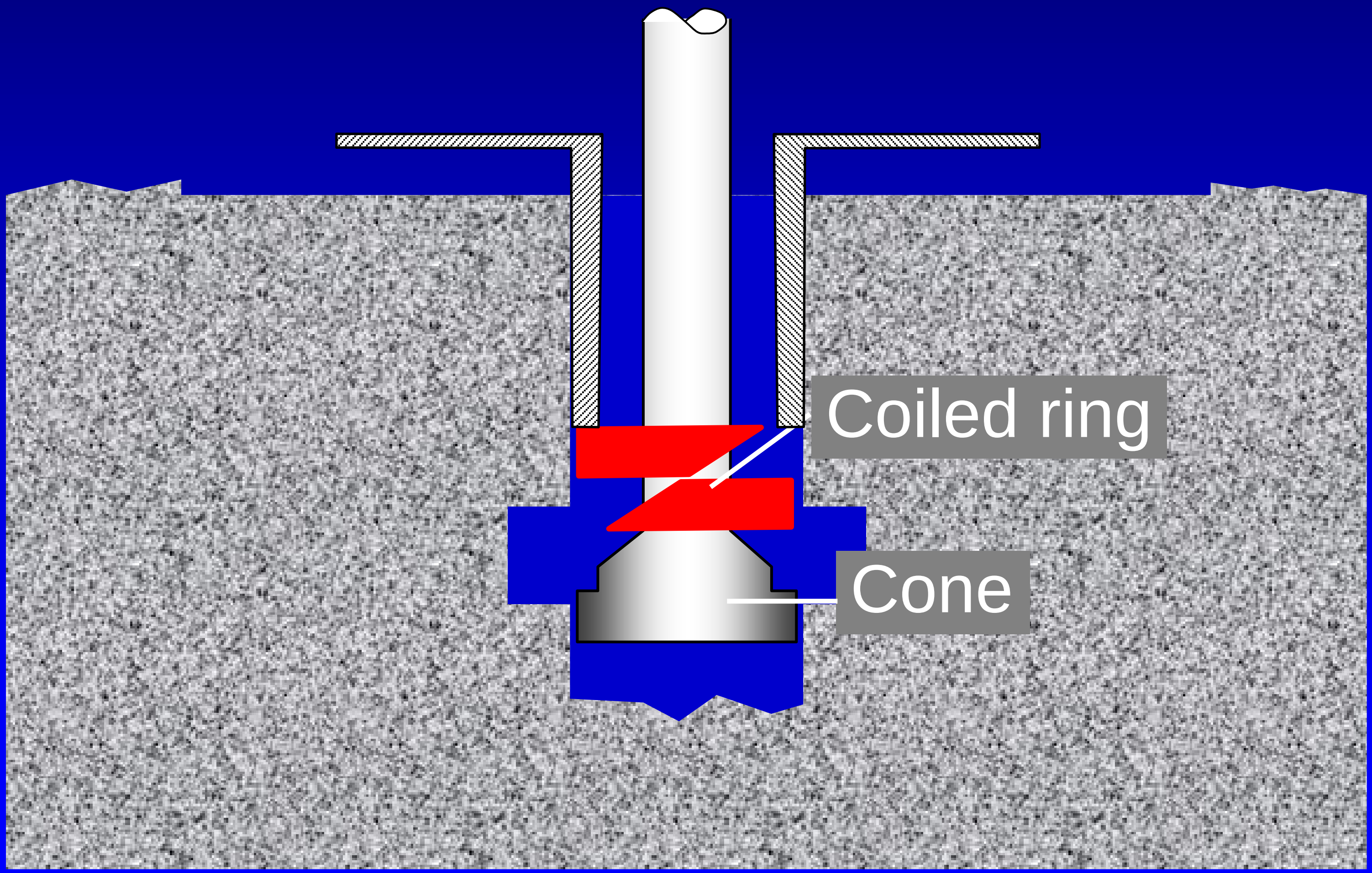
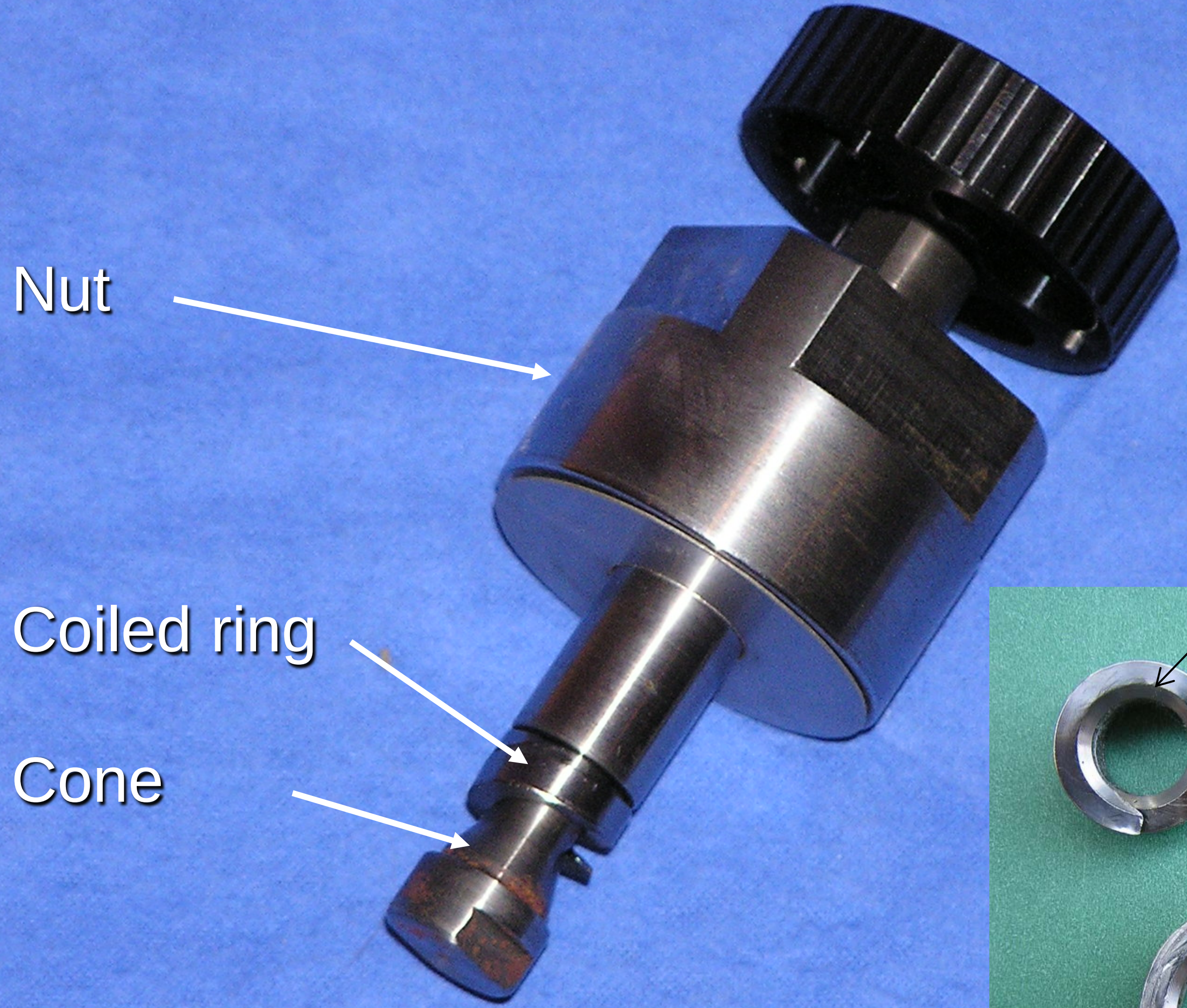


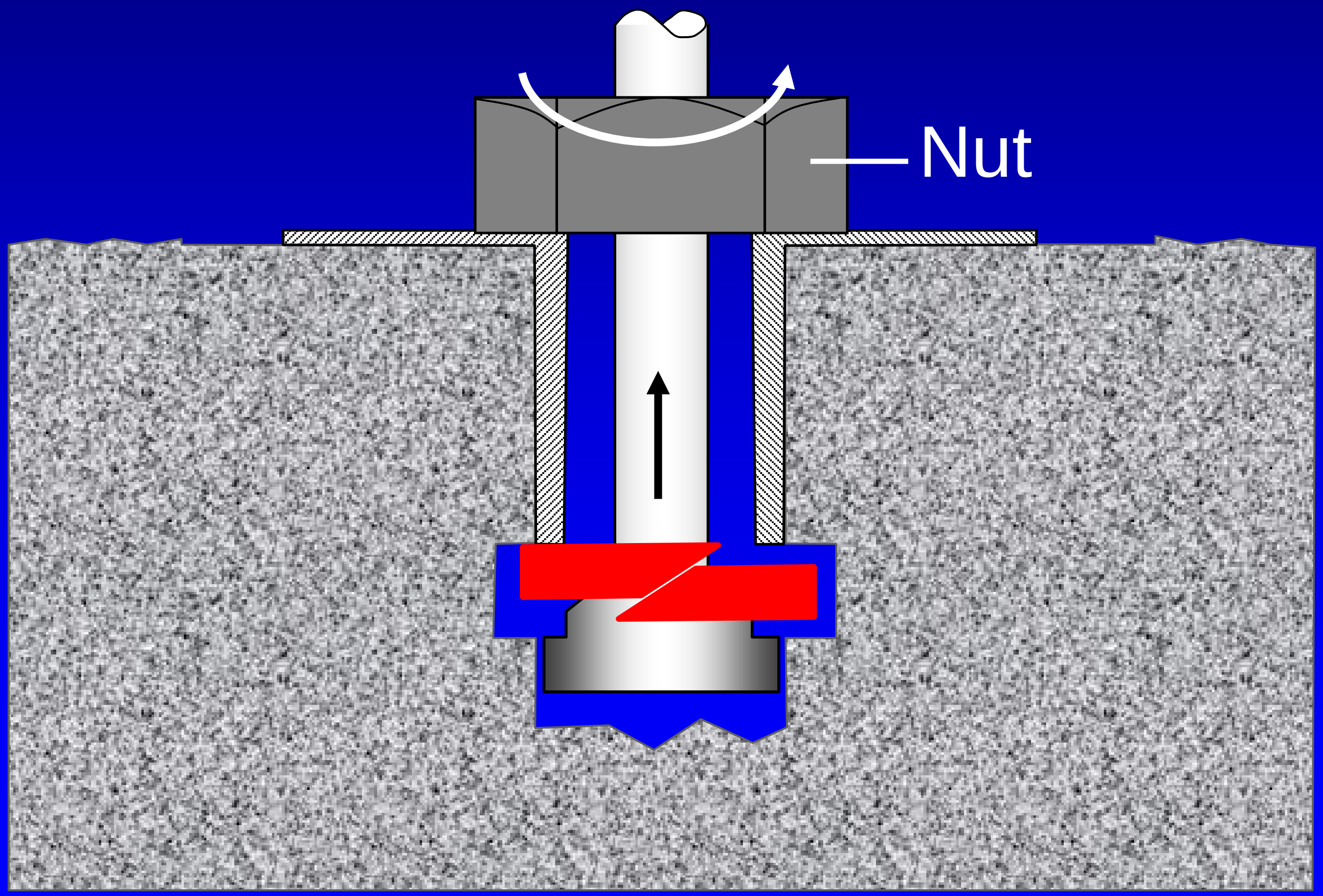
Insert Expansion Cone and Coiled Split-Ring



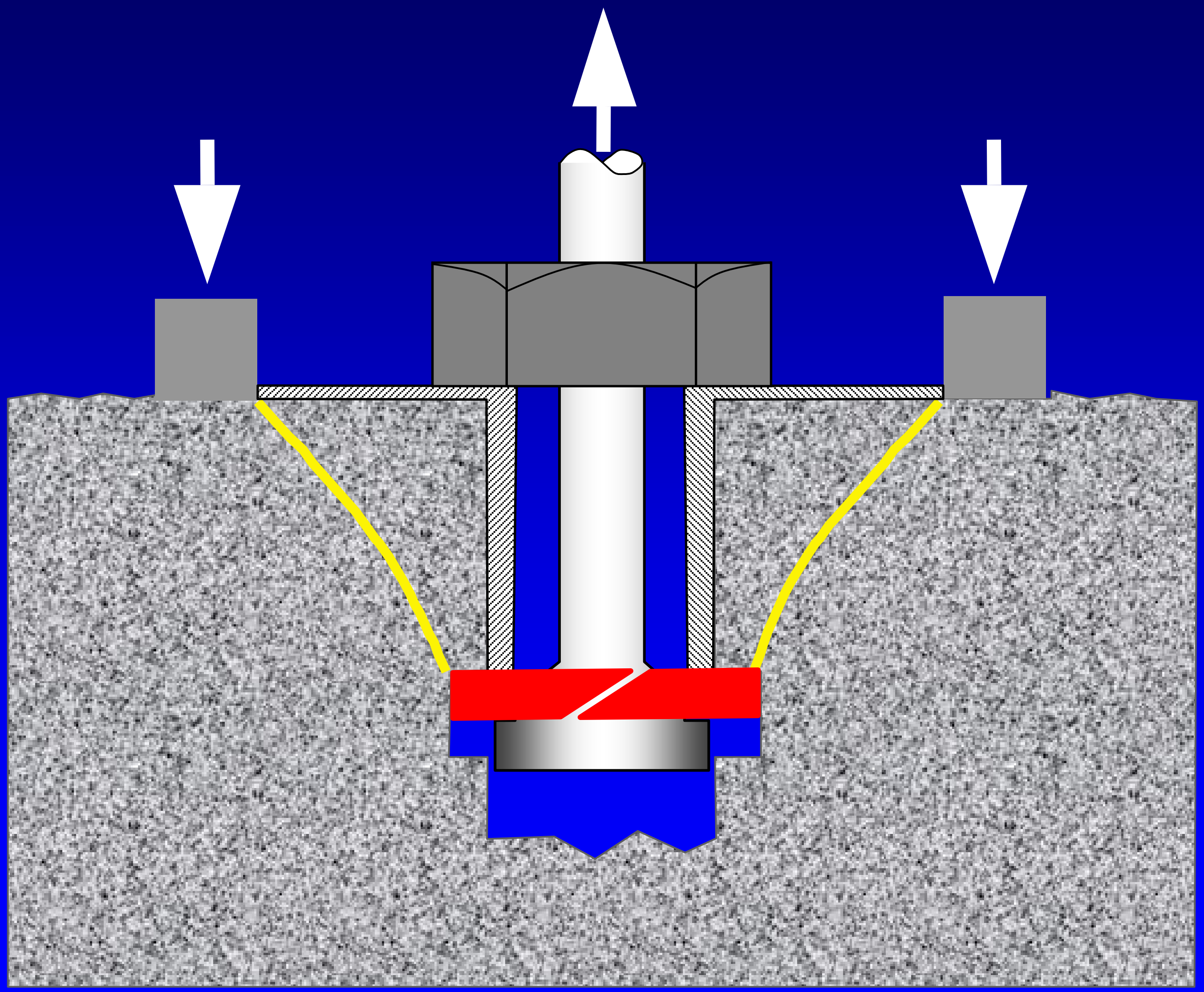
Ring Expansion Hardware



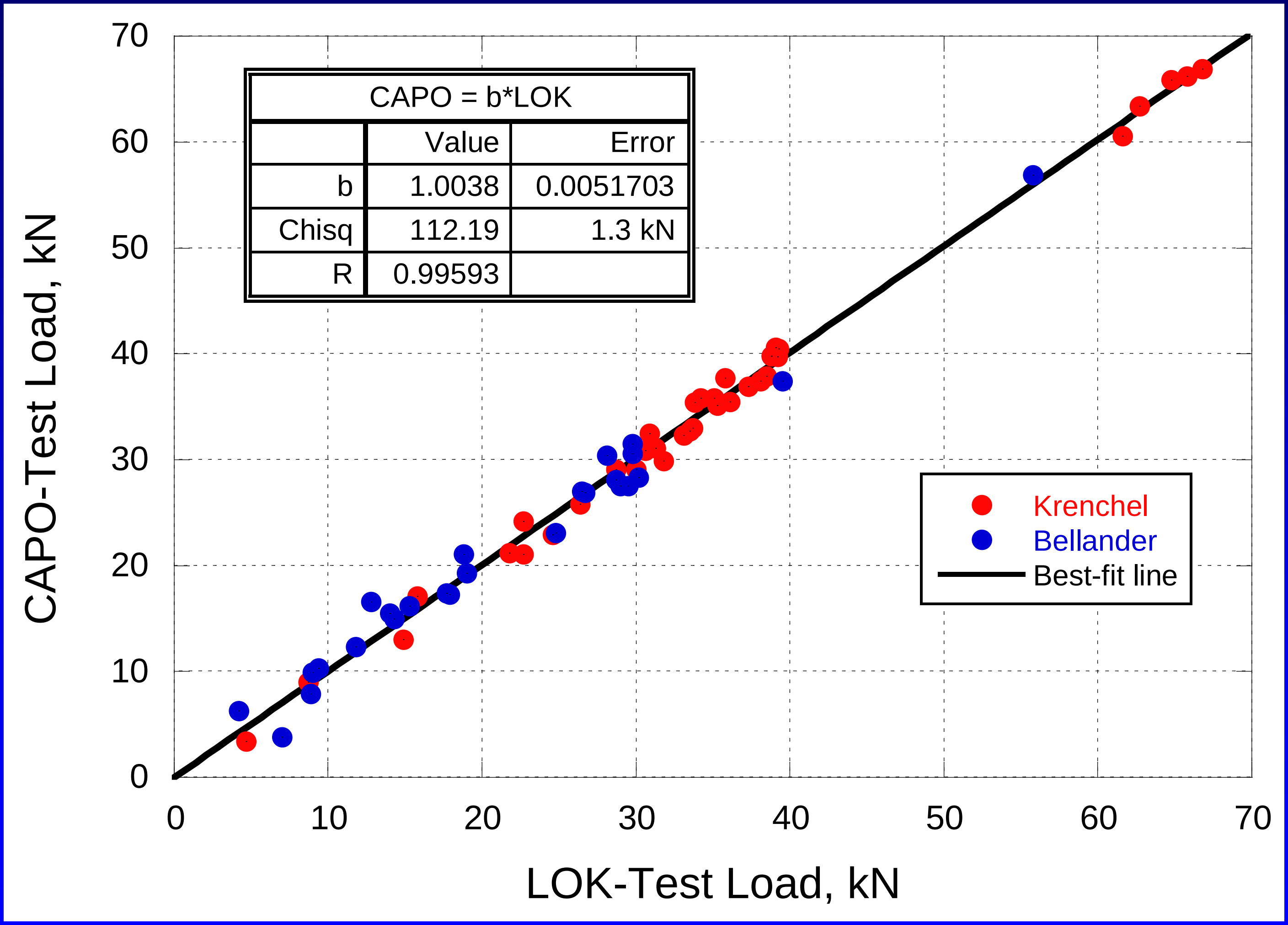
Expand Ring



Pullout the Expanded Ring



CAPO-Test vs LOK-Test



Case Study

ACI MATERIALS JOURNAL TECHNICAL PAPER

Title No. 113-M76

November/December 2016

CAPO-TEST to Estimate Concrete Strength in Bridges

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

This paper addresses whether carbonation in existing concrete structures affects the compressive strength estimated using the CAPO-TEST, a post-installed, pullout test conforming to ASTM C900 and EN 12504-3. Fifteen bridges, ranging from 25 to 52 years of age at the time of testing, were investigated. For each bridge, average values of core strengths and CAPO pullout strengths were obtained. Carbonation depth, which varied from 2 to 35 mm (0.08 to 1.4 in.), was measured using chemical staining methods. It was anticipated that, as the depth of carbonation increased, the pullout strength would increase for the same underlying concrete strength. Thus, the in-place compressive strength estimated on the basis of the manufacturer's general correlation would be expected to systematically exceed the strength measured by the cores. It was found that, on average, the compressive strength estimated from the CAPO-TEST and the general correlation was only 2.8% greater than the measured core strength. More importantly, there was no correlation between depth of carbonation and the relative error of the estimated strength based on the CAPO-TEST.

Keywords: CAPO-TEST; carbonation; core strength; correlation; existing structures; in-place strength; pullout test.

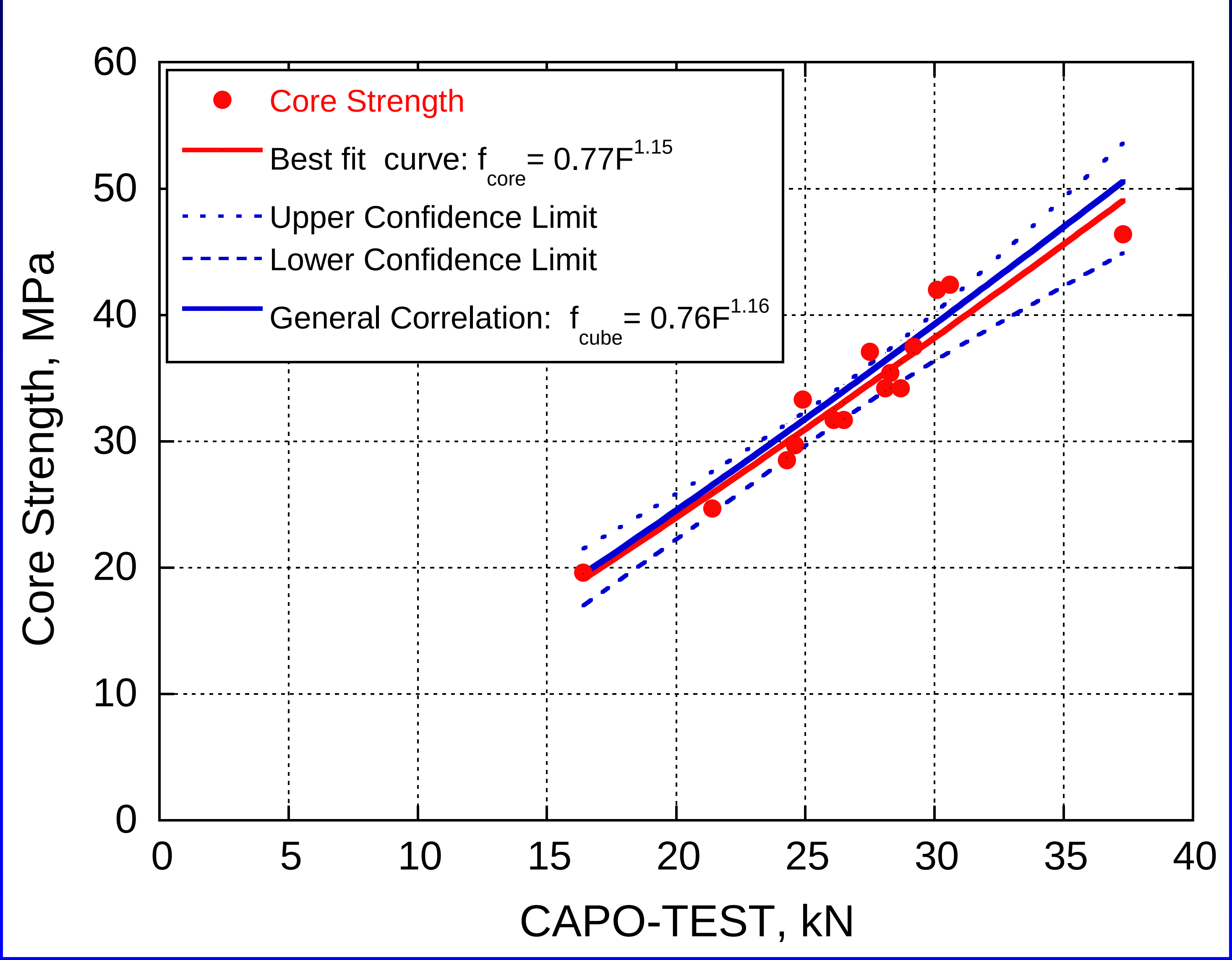
of the authors[4] in a comparison of strengths estimated by rebound hammer compared with measured core strengths. Despite the use of a recommended "aging reduction factor" of 0.7 to account for carbonation, the estimated compressive strength from rebound values was found to be, on average, approximately 25% higher than the core strengths.[4] Without applying this "aging reduction factor," the strength estimate would have been, on average, approximately 80% higher than the core strengths. There is no general correlation between rebound number and compressive strength. Therefore, each structure has to be evaluated based on a correlation developed with cores from that structure.

Another popular technique is measuring the speed of a pulse of ultrasonic stress waves, typically called the ultrasonic pulse velocity (UPV). For a given concrete strength, there are several factors that will affect the UPV of the concrete, such as aggregate type, aggregate content, and moisture content.[3] In mature concrete, small differences in UPV can correspond to large differences in compressive

Polish Bridge Study

- Tested 15 bridges: ages 25 to 52 years
- Measured depth of carbonation (2 to 35 mm)
- Tested drilled cores with L/D = 1 to represent cube strength
- Conducted companion CAPO tests
- Used manufacturer's correlation to estimate cube strength from CAPO-Test
- Investigated effect of carbonation depth

Correlation



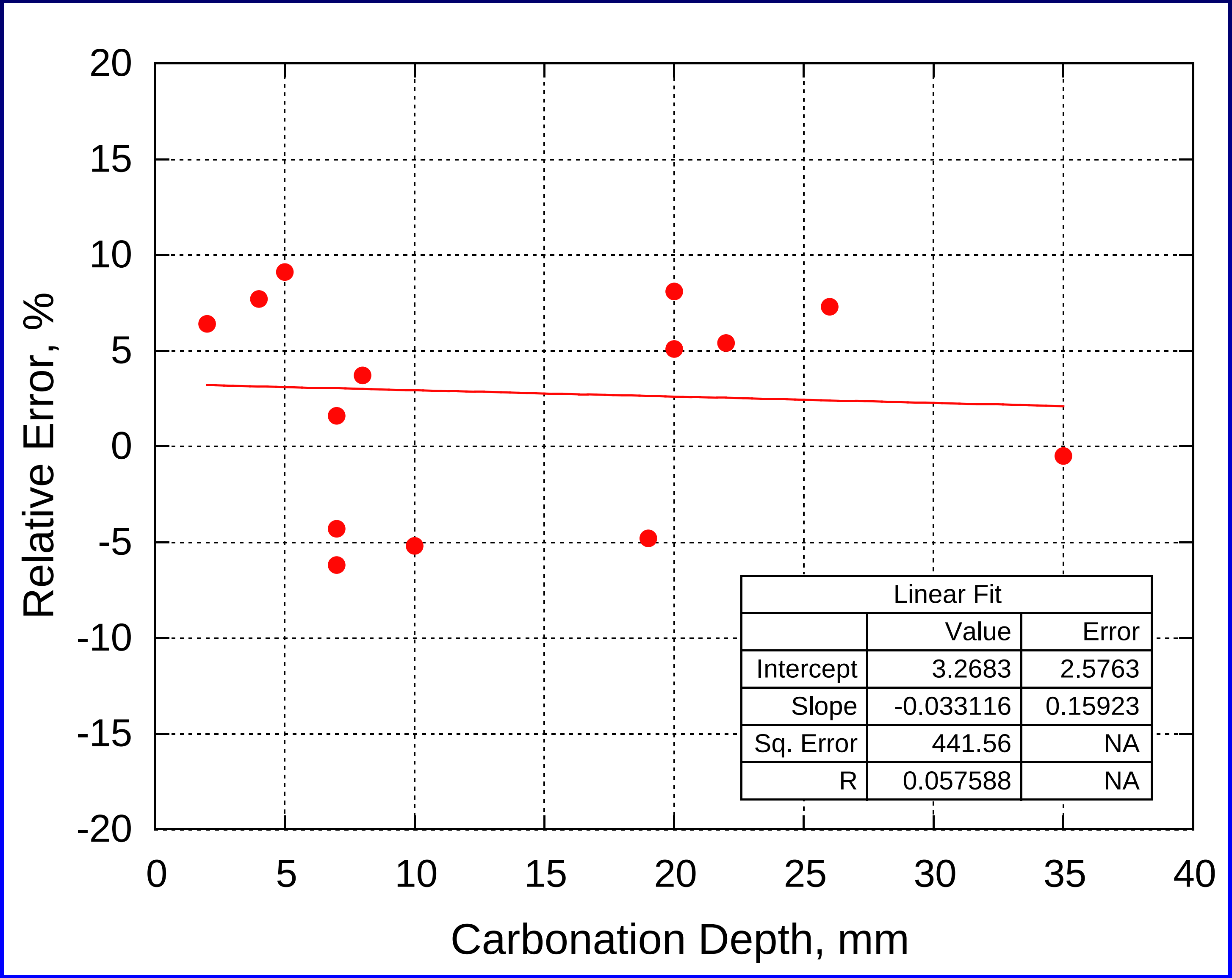
Relative Error

$$\alpha_{CT} = \frac{Estimated\ Cube\ Strength - Core\ Strength}{Core\ Strength} \times 100\ \%$$

Summary for 15 Bridges

Bridge No.	Carbonation depth, mm	Average core strength, MPa	Average CAPO-TEST, kN	Estimated compressive strength, MPa	Relative error, α_{CT}, %
1	2	34.2	28.1	36.4	6.4
2	4	24.7	21.4	26.6	7.7
3	5	46.4	37.3	50.6	9.1
4	5	34.2	28.7	37.3	9.1
5	7	37.1	27.5	35.5	-4.3
6	7	42.0	30.1	39.4	-6.2
7	7	37.5	29.2	38.1	1.6
8	8	35.4	28.3	36.7	3.7
9	10	42.4	30.6	40.2	-5.2
10	19	33.3	24.9	31.7	-4.8
11	20	29.7	24.6	31.2	5.1
12	20	28.5	24.3	30.8	8.1
13	22	31.7	26.1	33.4	5.4
14	26	31.7	26.5	34.0	7.3
15	35	19.6	16.4	19.5	-0.5

Error vs. Carbonation Depth



Summary

- Pullout test offers the possibility of estimating in-place concrete with acceptable reliability
- Stress state created by reaction ring leads to a compression strut that explains the good correlation with compressive strength
- CAPO-Test allows testing without pre-placing inserts
- Polish bridge study
  - On average, CAPO-Test estimate was 3 % greater than core strength
  - Carbonation did not appear to affect CAPO-Test results

Thank You !

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