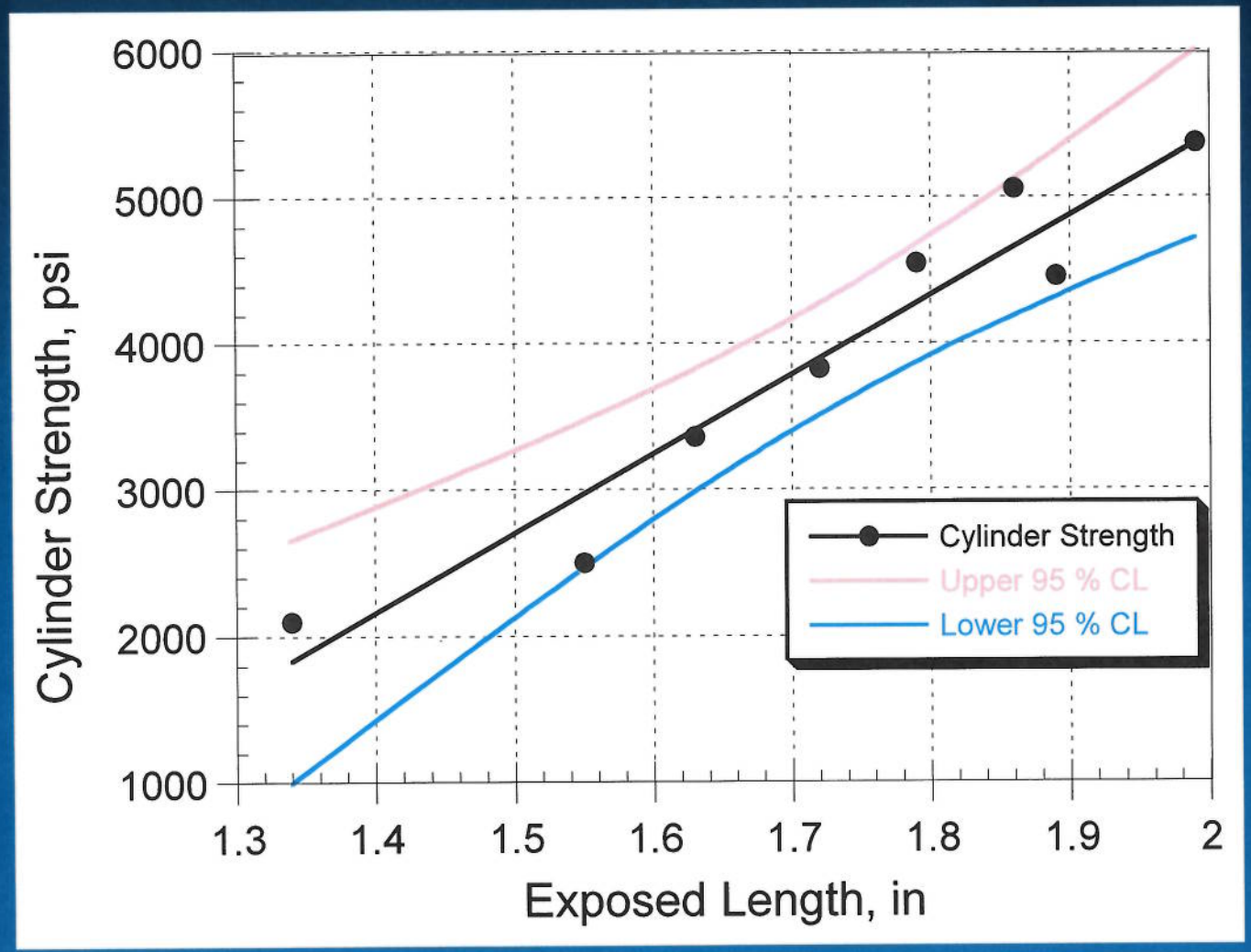
Correlation Testing
ACI 228.1R Chapter 4

- Cast slab and companion cylinders
- Subject to similar curing
- At regular strength intervals (≥ 6)
  - Test two cylinders
  - Perform at least three probe penetration tests

Example of Strength Relationship



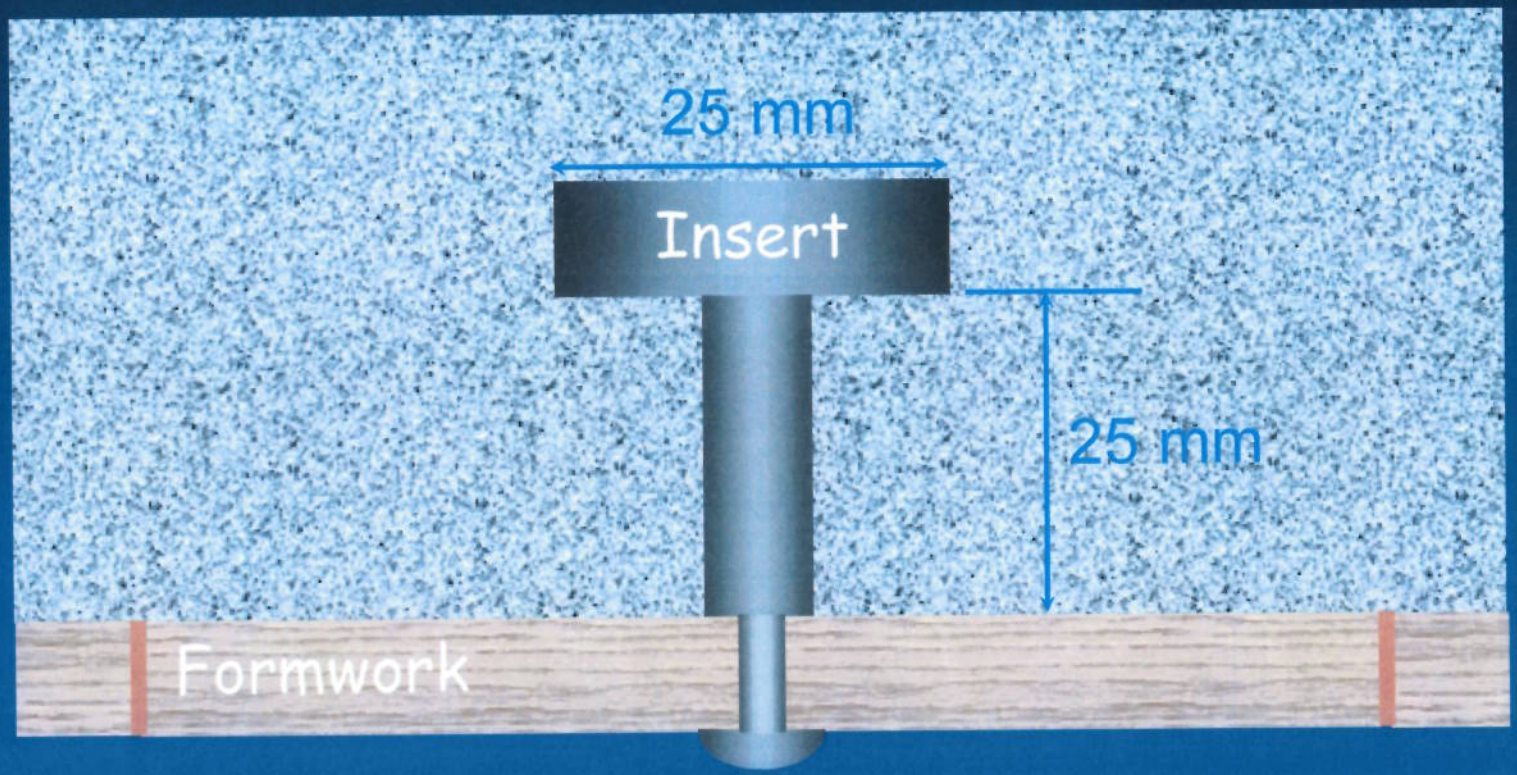
Malhotra, V.M. and Painter, K.P., Mines Branch Investigation, IR71-50, CANMET, 1971

ASTM C900 Pullout Strength of Hardened Concrete

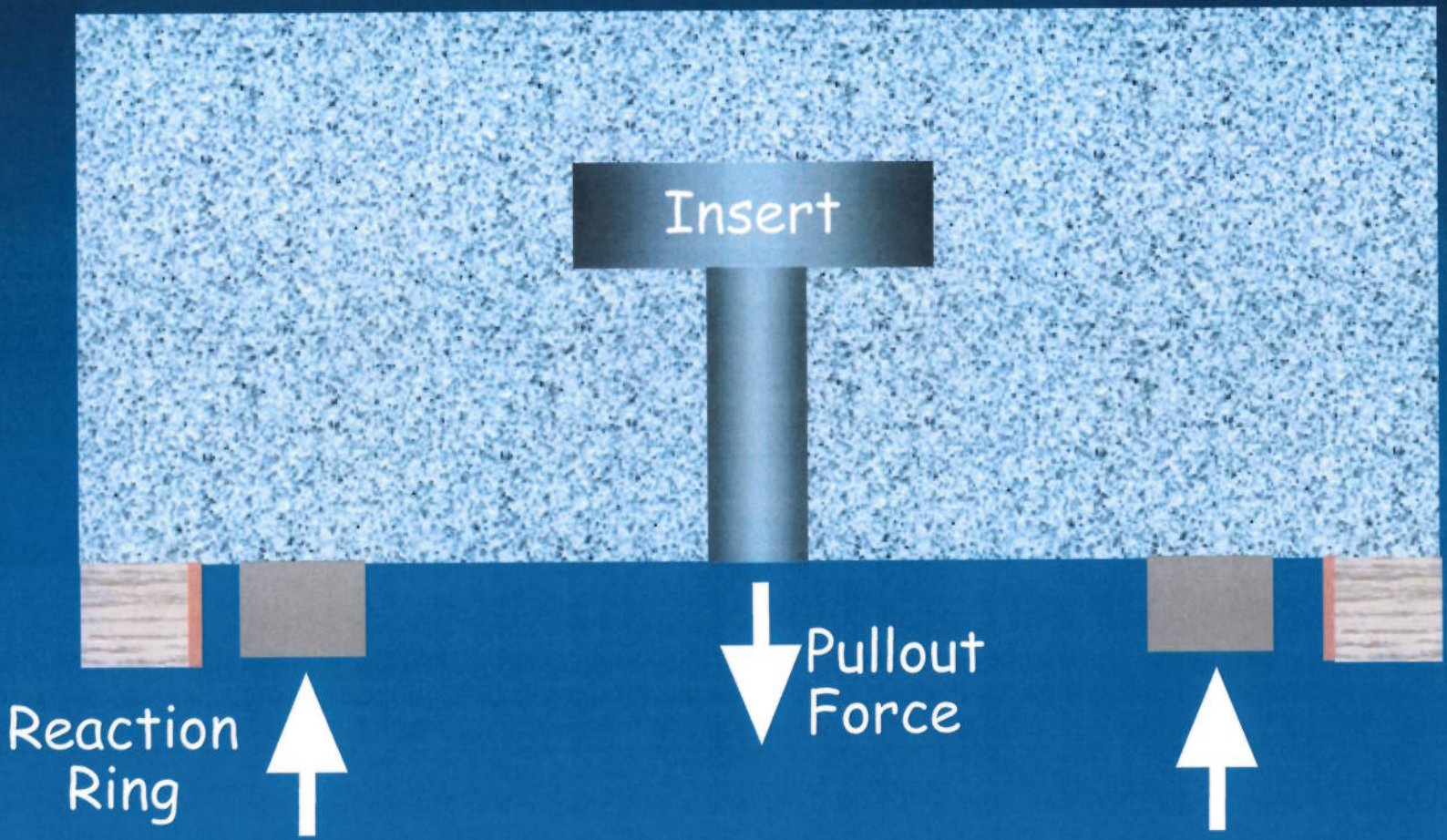
Measure force to pullout an insert anchored in concrete.

- Cast-in-place (CIP): attached to formwork or inserted into top surface of freshly cast slab (during construction)
- Post-installed (PI): placed into drilled hole with undercut slot (existing construction)

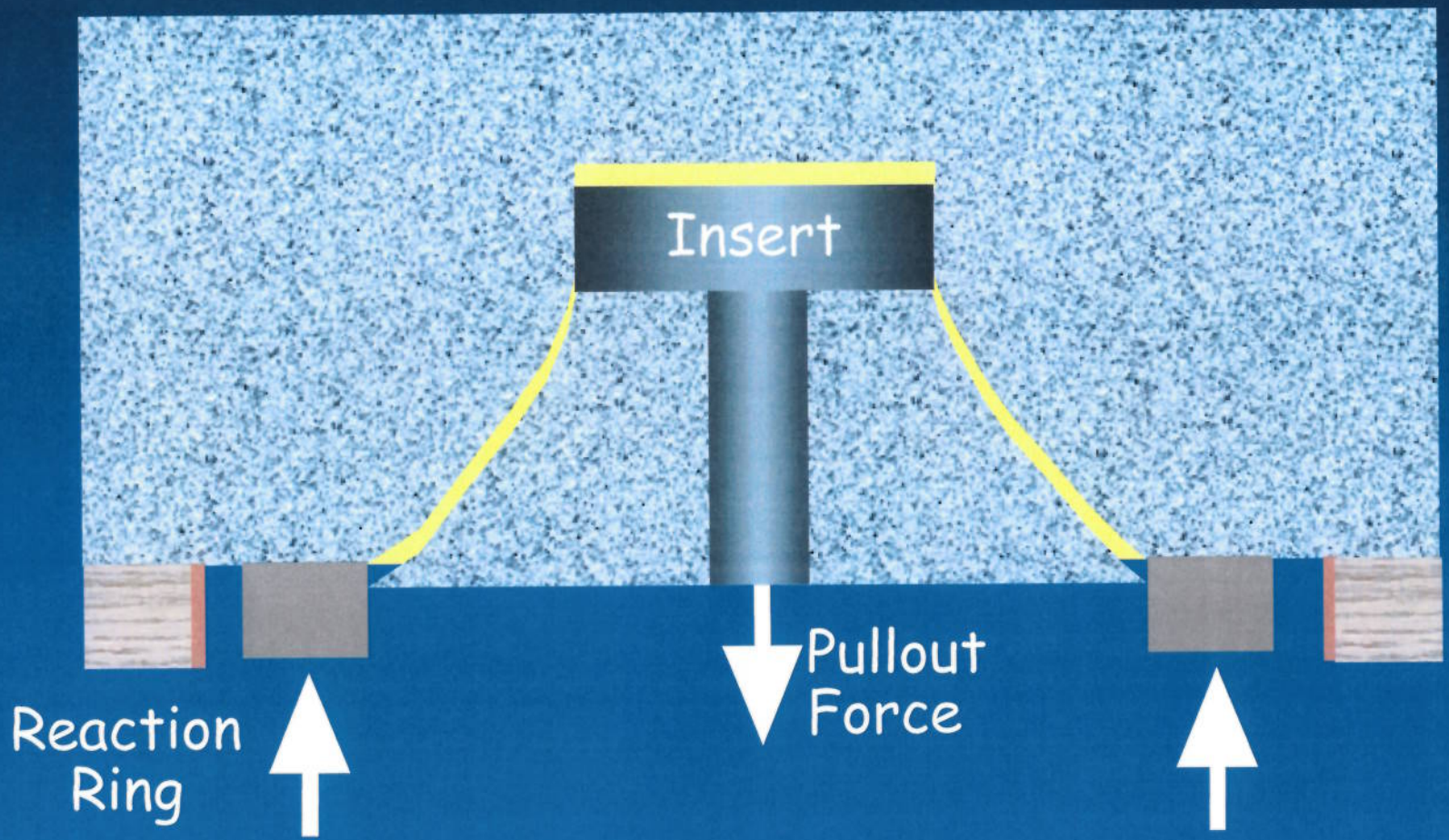
CIP-Pullout Test



CIP-Pullout Test

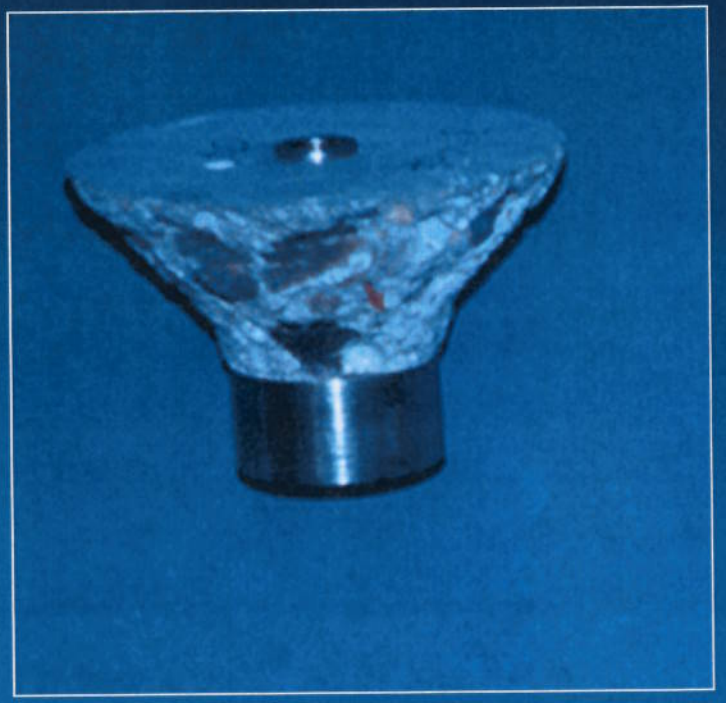


CIP-Pullout Test



CIP Pullout Test-LOK Test

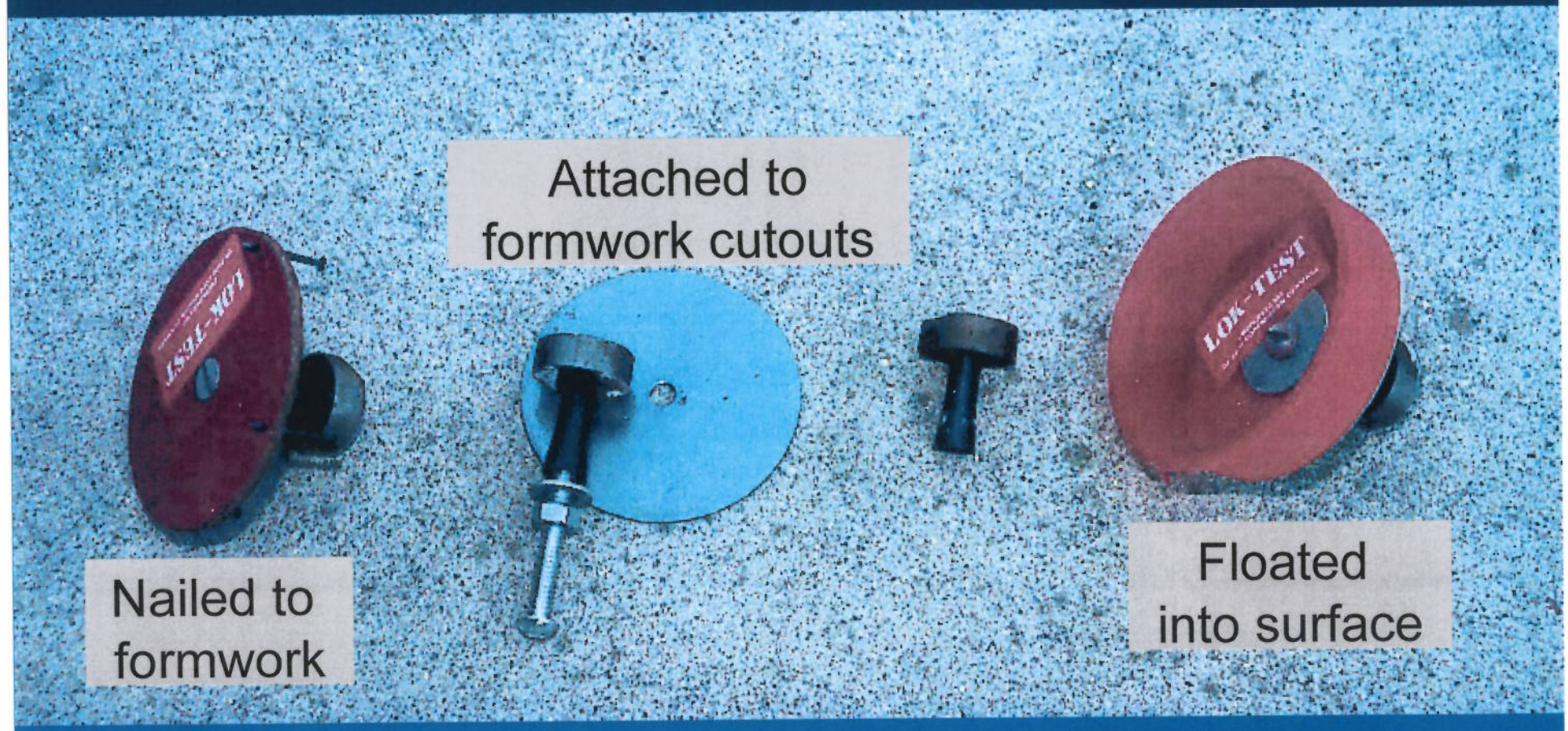
Pullout Insert



Conical Fragment

Courtesy of Germann Instruments

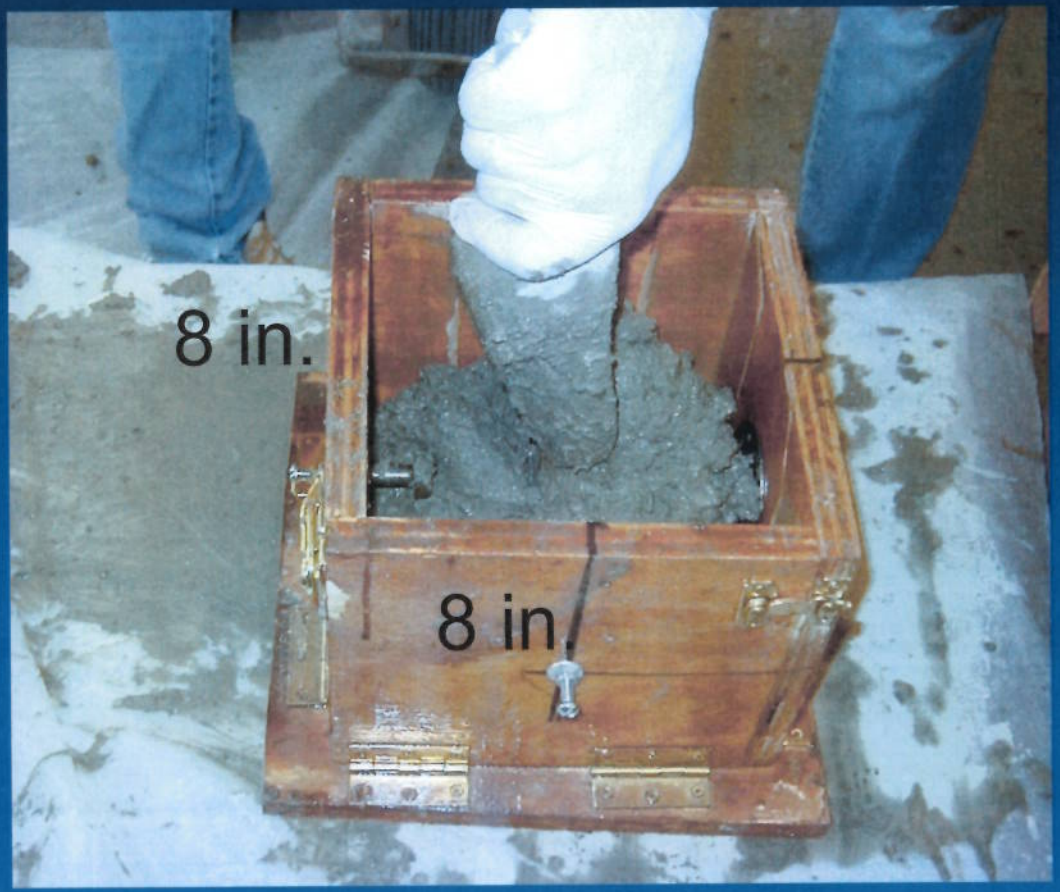
Insert Hardware



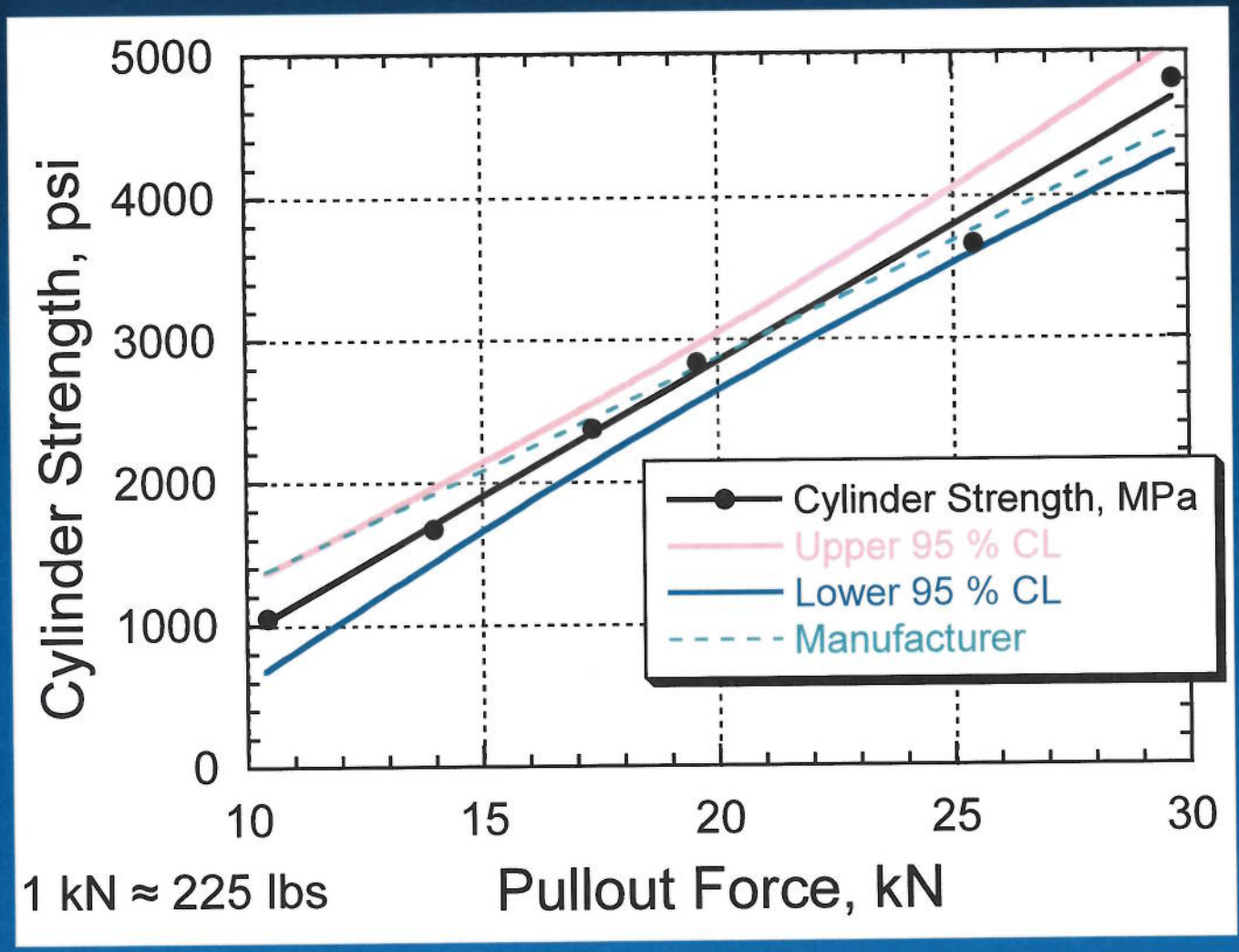
Correlation Testing ACI 228.1R Chapter 4

- Cast 8 in. cubes with inserts on side faces and cast companion cylinders
- Subject to similar curing
- At regular strength intervals (≥ 6), such as 1, 2, 3, 7, 14 and 28 days:
  - Test two cylinders
  - Pullout 8 inserts (2 cubes)

Cube with Inserts



Example of Strength Relationship



NRMCA Study of high volume fly ash 2008

Robust Correlation

Not affected by:

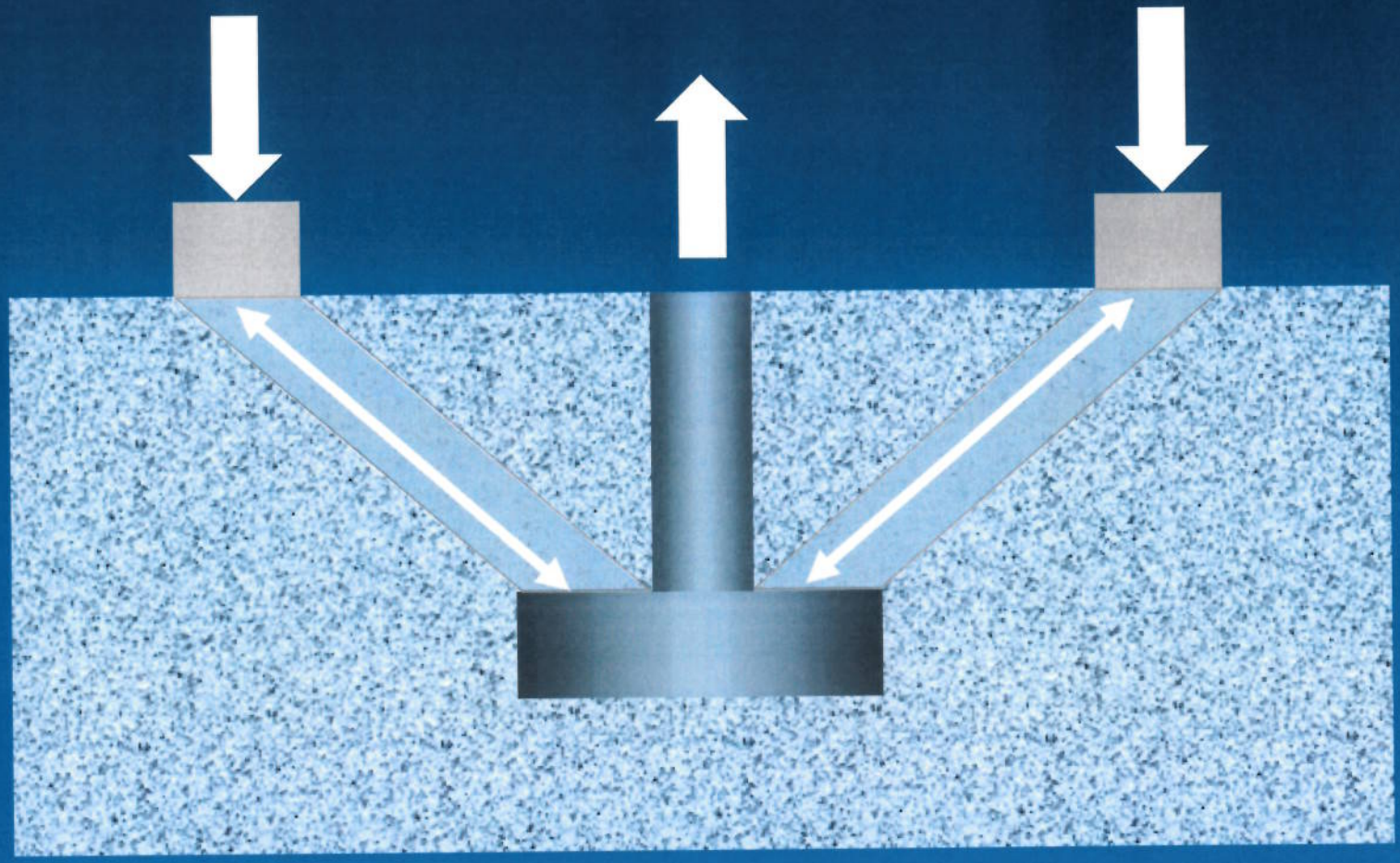
- Cementitious materials
- Water-cement ratio
- Age
- Air entrainment
- Admixtures
- Shape or size of aggregate up to 1 $\frac{1}{2}$ in.
  - Lightweight aggregate, however, produces significantly different correlation

Correlation

- Pullout strength is related fundamentally to concrete strength
- Analytical studies have been performed
  - Compression-strut theory
  - Fracture mechanics and aggregate-interlock theory

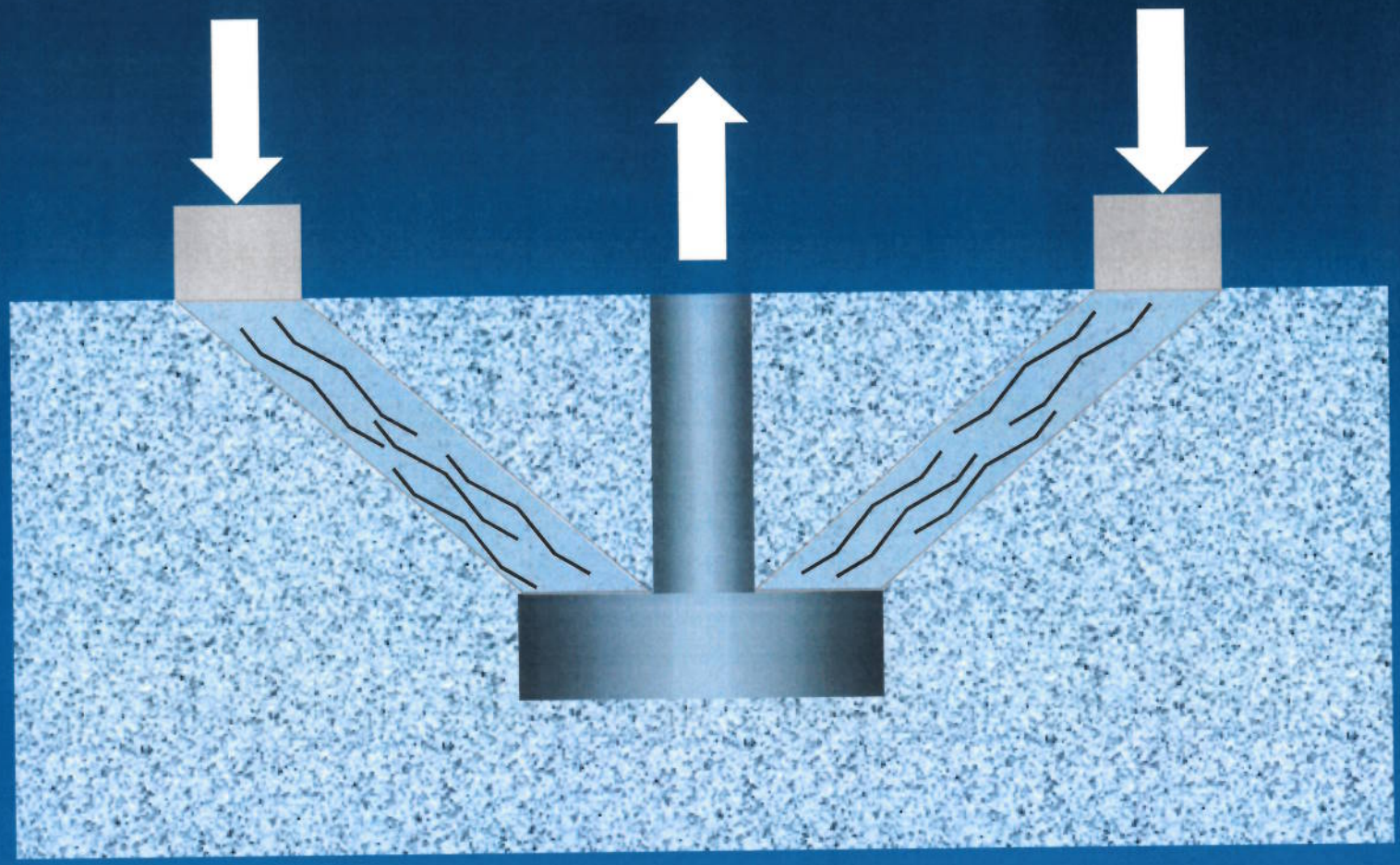
Pullout Failure Mechanism

Compression strut theory

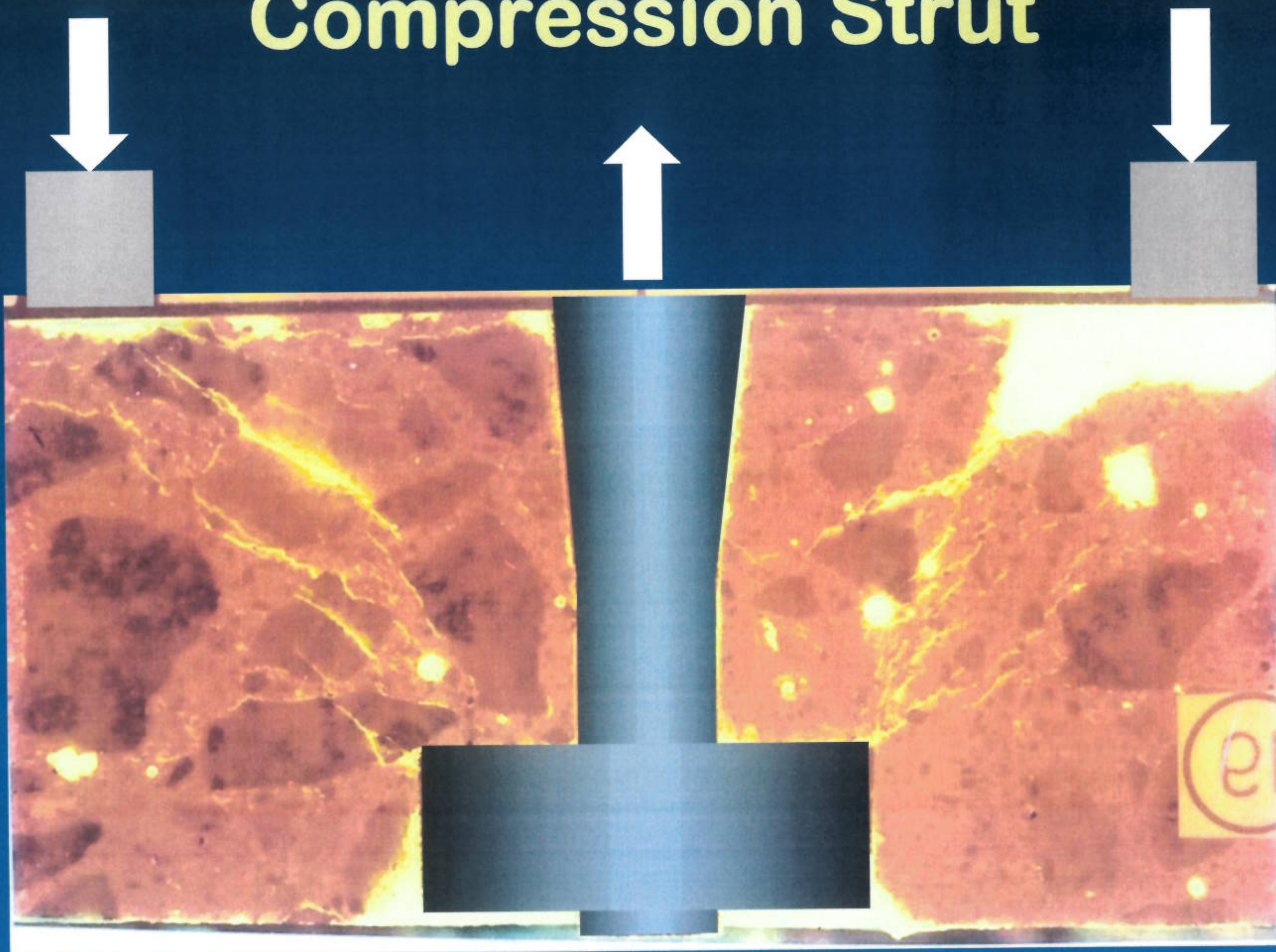


Pullout Failure Mechanism

Compression strut theory



Compression Strut



Implementation

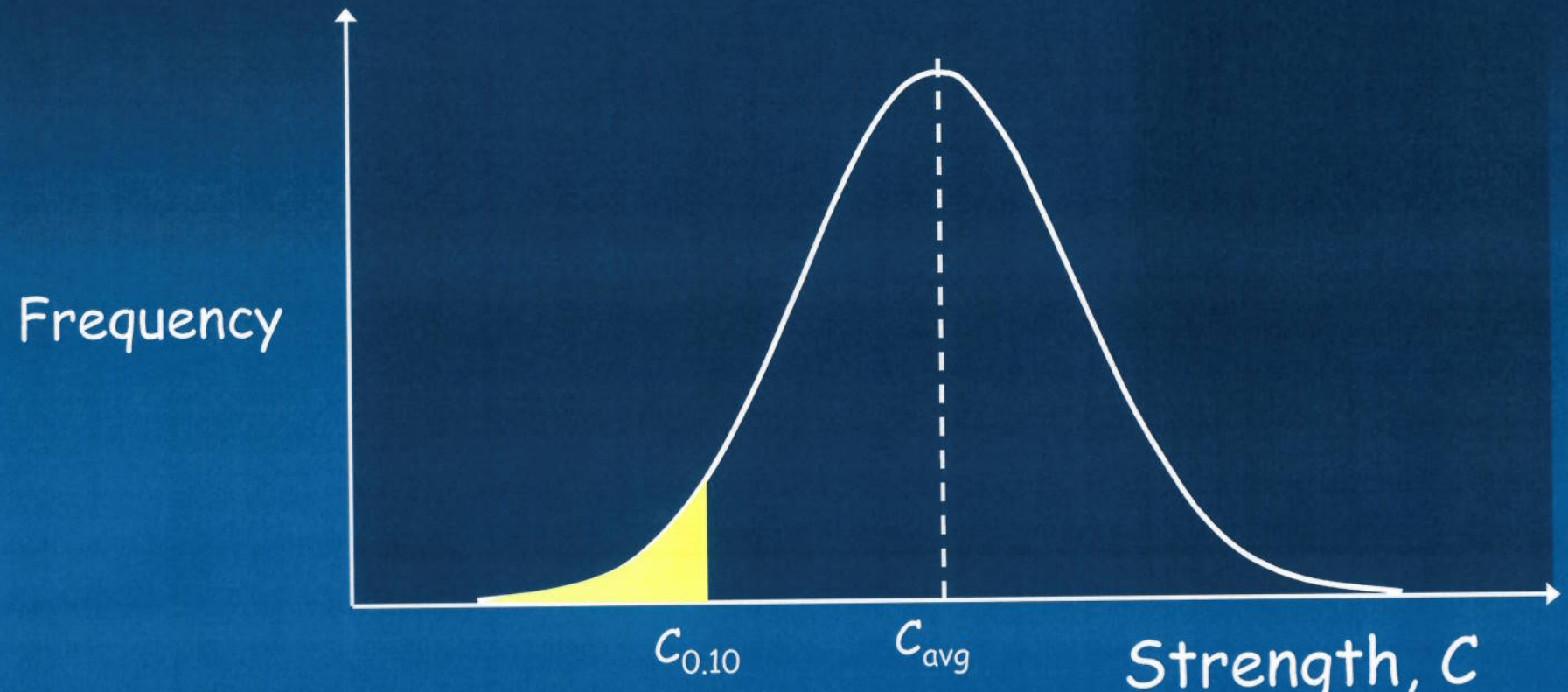
- In-place tests measure property related to concrete strength
- Empirical strength relationship is required for the specific concrete mixture
- Statistical analysis
  - Develop strength relationship
  - Obtain reliable estimate of in-place strength

Analysis of In-Place Test Results

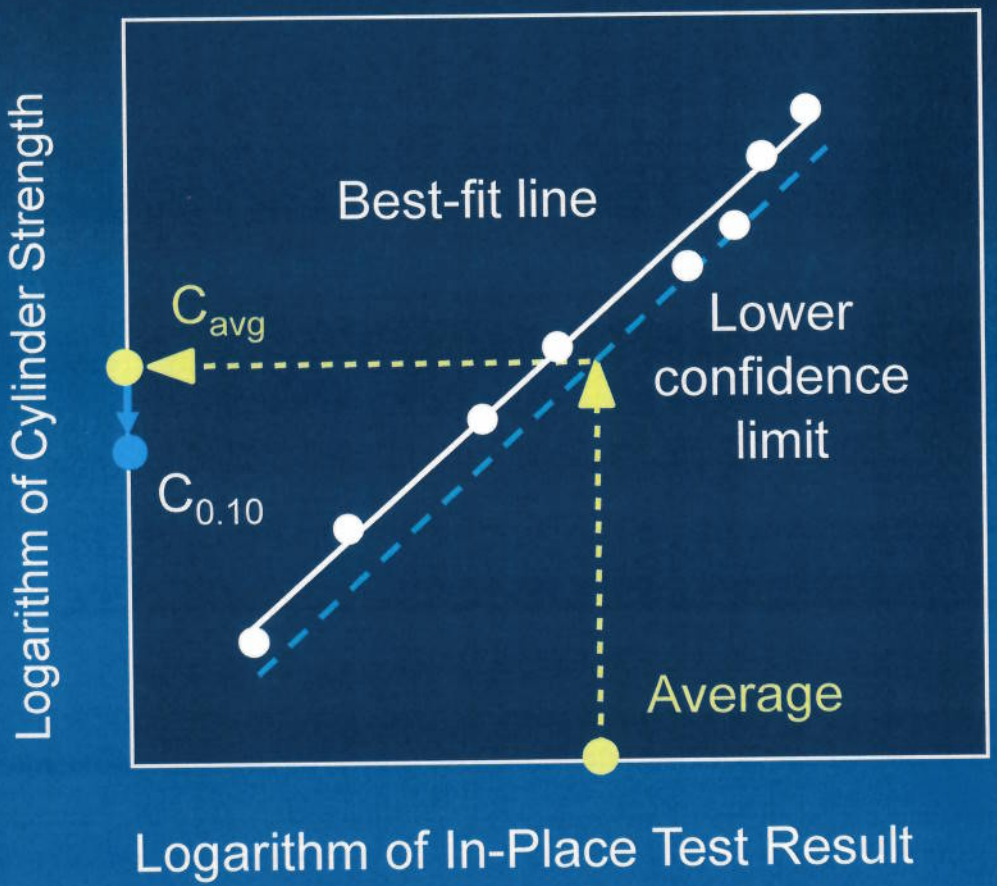
Chapter 6 of ACI 228.1R

- Account for uncertainty of strength relationship (regression)
- Account for variability of in-place test data
- Account for variability of in-place concrete (batch-to-batch)

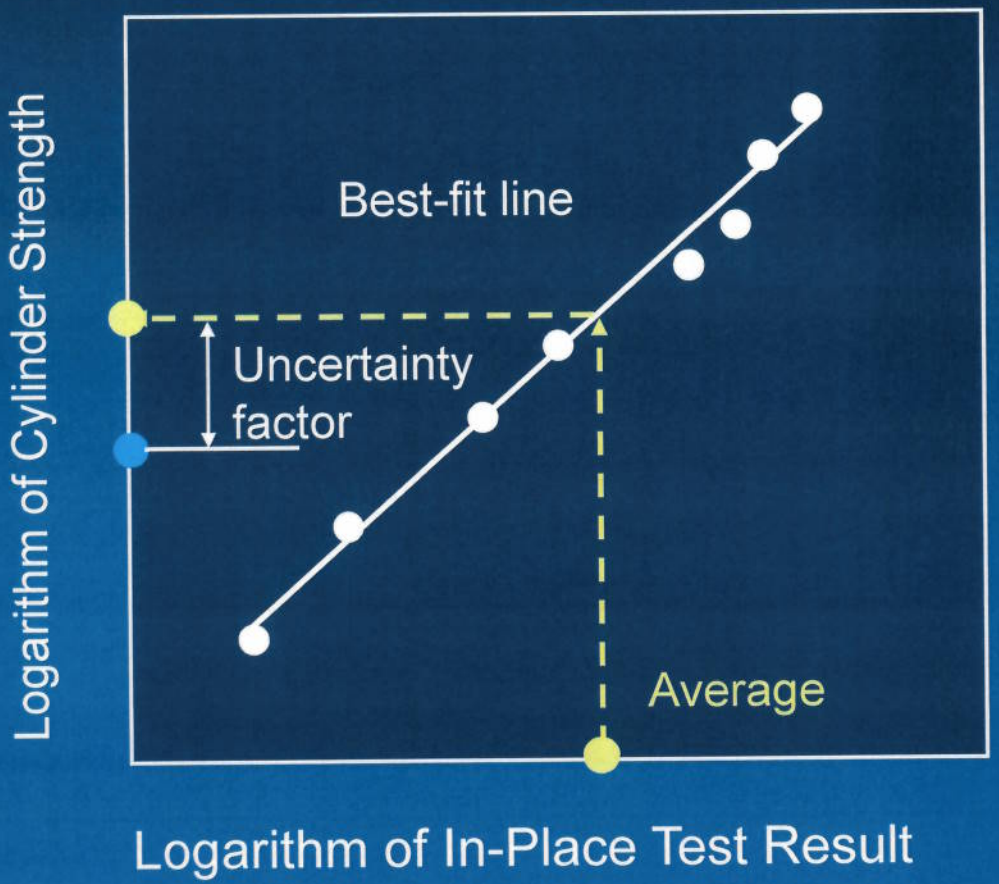
10th Percentile Strength



NIST Statistical Method



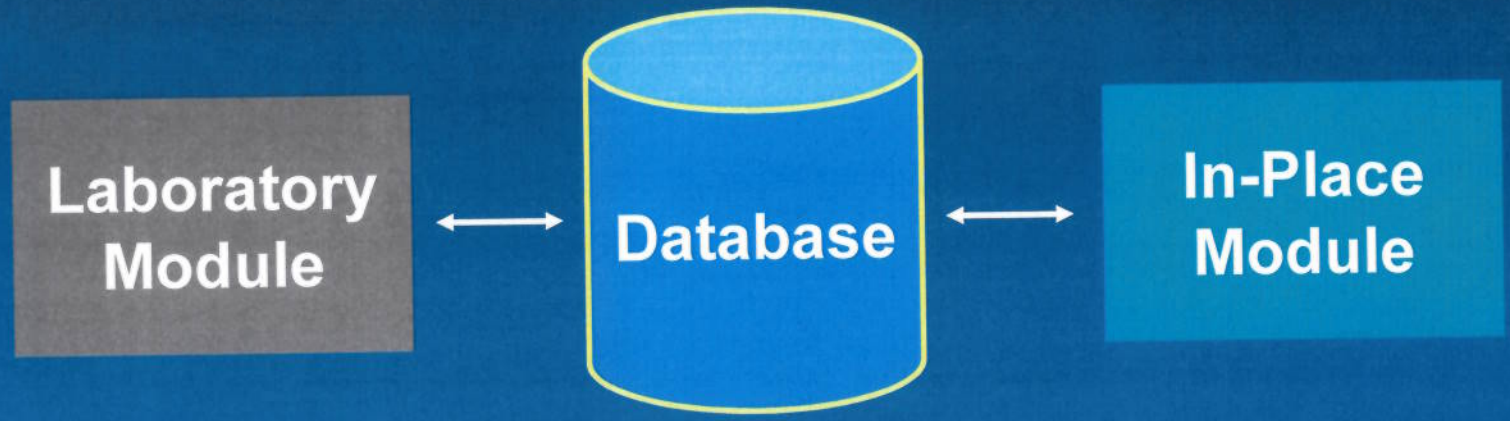
Incorrect Statistical Method



INPLACE Program

Concrete International, Dec. 1998

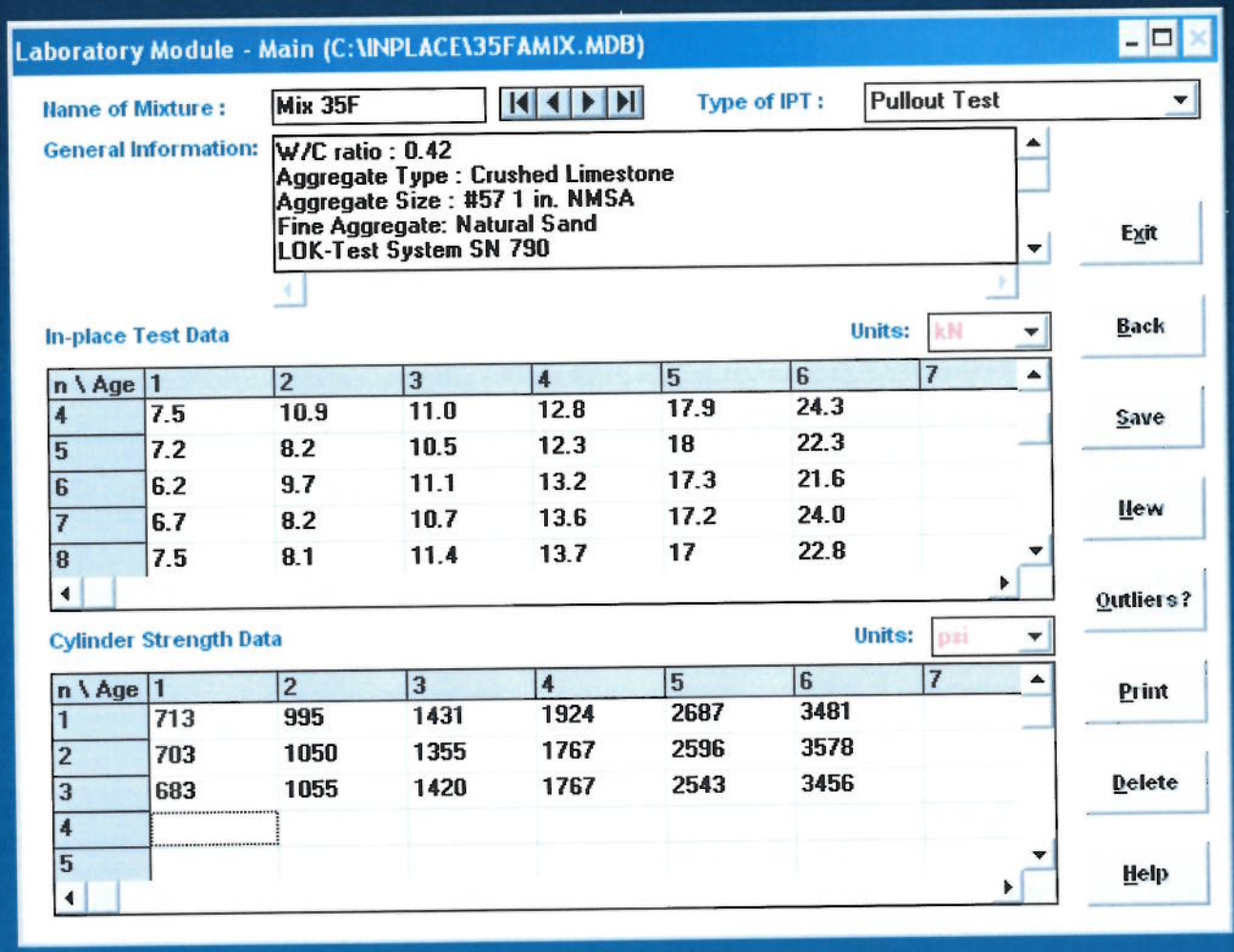
Developed at Purdue University with NIST funding; based on NIST procedure (Section 6.2.4 in ACI 228.1R)



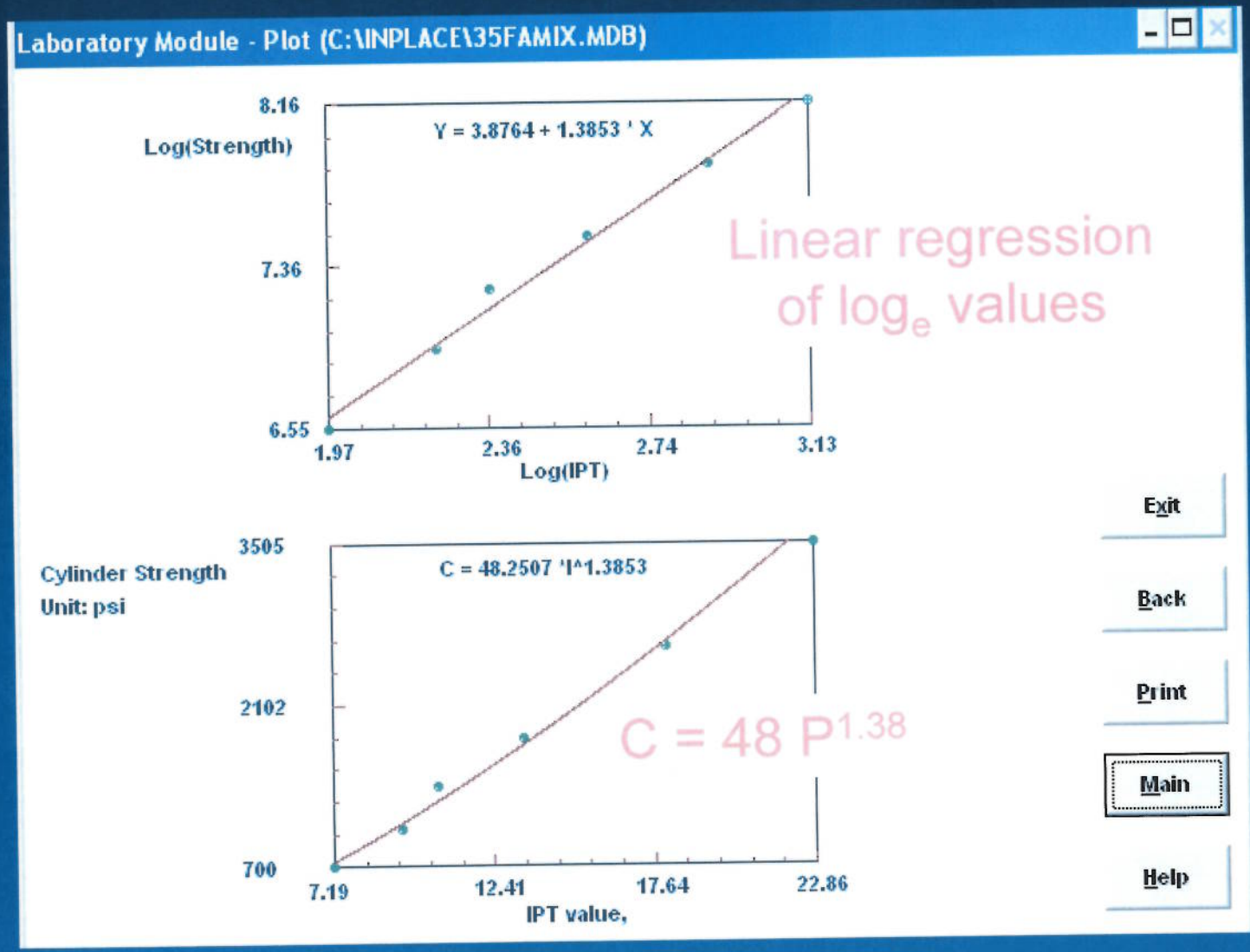
Input laboratory test data and compute correlation

Input field test data and estimate strength

Data Input


Laboratory Module - Main (C:\INPLACE\35FAMIX.MDB)
Name of Mixture :
Mix 35F
Type of IPT :
Pullout Test
General Information:
W/C ratio : 0.42
Aggregate Type : Crushed Limestone
Aggregate Size : #57 1 in. NMSA
Fine Aggregate: Natural Sand
LOK-Test System SN 790
Exit
Back
In-place Test Data
Units:
kN
Save
n \ Age | 1 | 2 | 3 | 4 | 5 | 6 | 7
4 | 7.5 | 10.9 | 11.0 | 12.8 | 17.9 | 24.3
5 | 7.2 | 8.2 | 10.5 | 12.3 | 18 | 22.3
6 | 6.2 | 9.7 | 11.1 | 13.2 | 17.3 | 21.6
7 | 6.7 | 8.2 | 10.7 | 13.6 | 17.2 | 24.0
8 | 7.5 | 8.1 | 11.4 | 13.7 | 17 | 22.8
New
Outliers?
Cylinder Strength Data
Units:
psi
n \ Age | 1 | 2 | 3 | 4 | 5 | 6 | 7
1 | 713 | 995 | 1431 | 1924 | 2687 | 3481
2 | 703 | 1050 | 1355 | 1767 | 2596 | 3578
3 | 683 | 1055 | 1420 | 1767 | 2543 | 3456
4
5
Print
Delete
Help

Strength Relationship



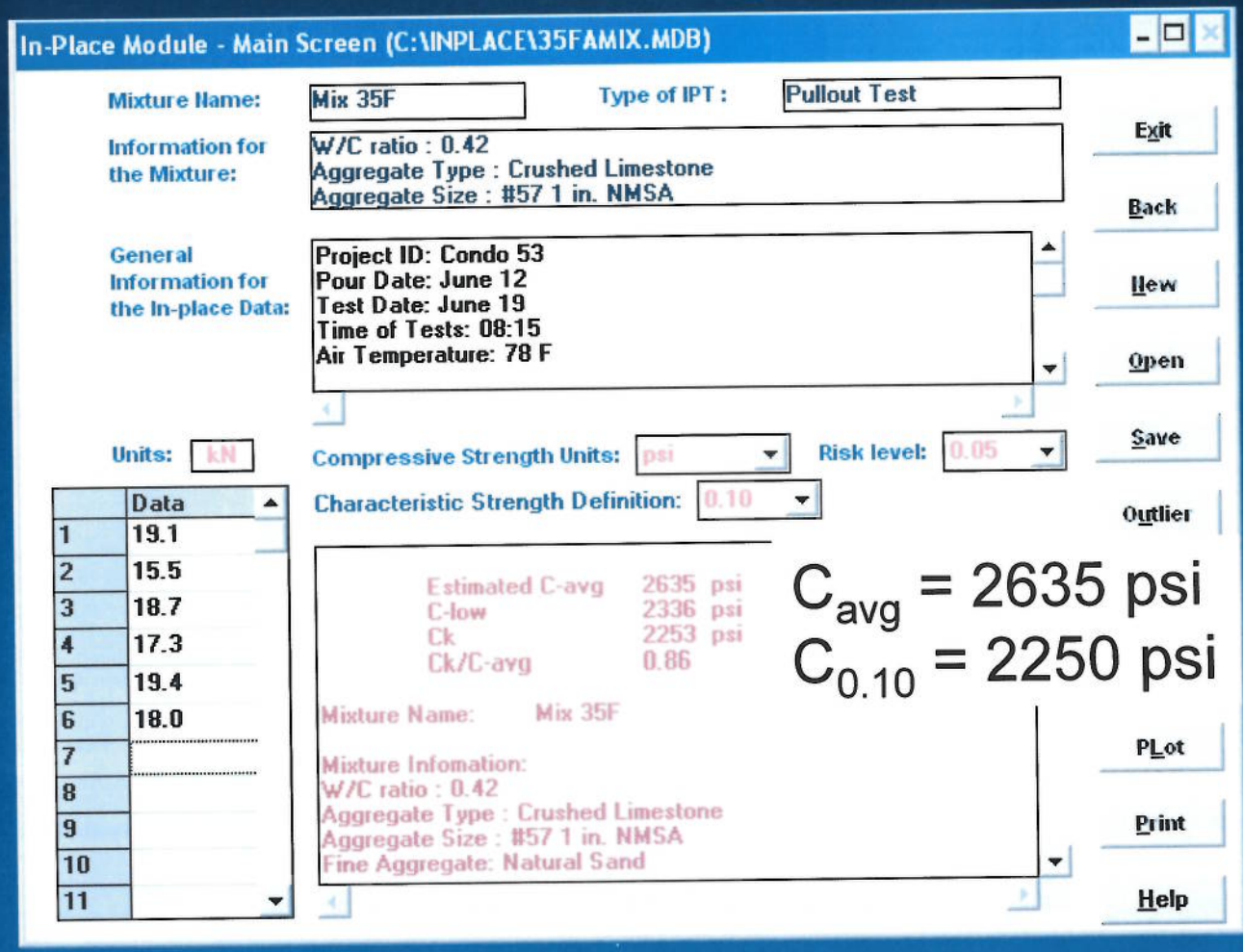
In-Place Results

Pullout Force, kN

Case 1	Case 2	Case 3
19.1	13.6	14.4
15.5	16.4	18.2
18.7	20.4	21.0
17.3	17.8	16.3
19.4	19.4	15.9
18.0	20.4	22.2
		19.8
		14.5
		19.0
		18.8
6	6	10
18.0	18.0	18.0
1.4	2.7	2.7
8.0%	14.9%	14.9%

n	
Average	
St. Dev.	
CV	

In-Place Strength
Case 1



C_{avg} = 2635 psi

$C_{0.10}$ = 2250 psi

Summary

In-place Compressive Strength, psi

	Case 1	Case 2	Case 3
C_{avg}	2635	2610	2610
$C_{0.10}$	2250	2010	2130
$C_{0.10}/C_{avg}$	0.86	0.77	0.82

Summary

- Performance specifications will rely on tests to measure quality characteristics of installed concrete
- Alternatives to field-cured cylinders and cores are available to assess in-place strength
- Rely on strength-relationships
- Statistical software to evaluate test results