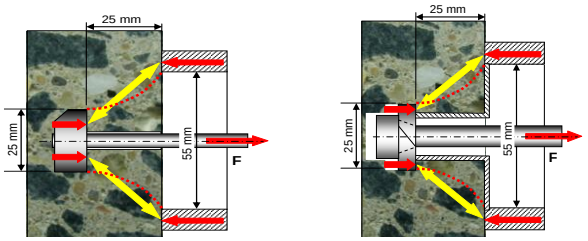
# Case 4.1 Correlation between Pullout force and Compressive Strength

The pullout systems:




LOK-test CAPO-test

The first major correlation between LOK pullout force and standard cylinder strength was made at DTU (where LOK-test was designed), in the early 1970´ties:

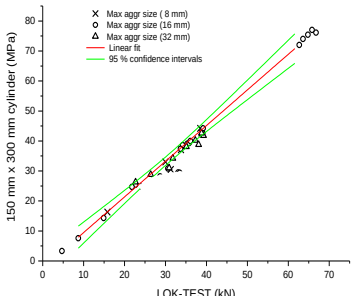



*Fig.1 First experimantal found correlation between LOK-force and standard cylinder compressive strength, 1974*

More experimental correlations were made at DTU in Denmark for different parameters producing the same relationship, making the pullout system interesting, one straightlined 45 degree relationship, close to 1 MPa compressive strength to 1 kN pullout force, indicating the same property being measured, the compressive strength.

For understanding this relation, three major studies were made: one by means of plasticity theory, one by a non-linear finite elements analysis, and one by fracture analyses to explain the failure mechanism, in:

**1976:** ***Jensen, B.Chr. & Bræstrup. M.W.: "LOK-test determine the Compressive Strength of Concrete", Nordisk Betong, nr. 3-4 , Sockholm, Sweden***

**1981:** ***Ottosen, N.S. "Nonlinear Finite Element Analysis of a Pull-Out Test",Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Vol. 107, NO ST4, USA***

**1985:** ***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***

The results from the two theoreticl studies, in 1976 and in 1981, are shown in fig. 6, comparing the uni-axial compressive cylinder strength to LOK-test pullout force

For details click the link:

- Section 1: Theoretical Analysis, Fracture Mechanism and Correlations

In the following years, many major correlation were performed in Denmark, Sweden, Norway, Holland. Canada, USA, Poland, England and KSA, investigating the following parameters: types of cementitious materials, water-cementitious ratio (w/cm), age, air entrainment, use of admixtures, curing conditions, stresses in the structure, stiffness of the member tested, carbonation, as well as shape, type, and maximum size of aggregate up to 40 mm.

Ref:

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

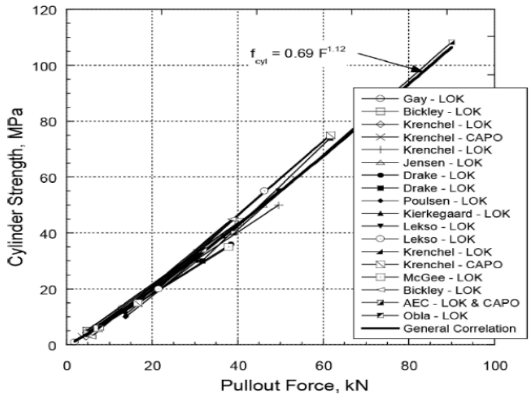



*Fig.2. Eighteen correlations between pullout force and standard cylinder compressive strength.*

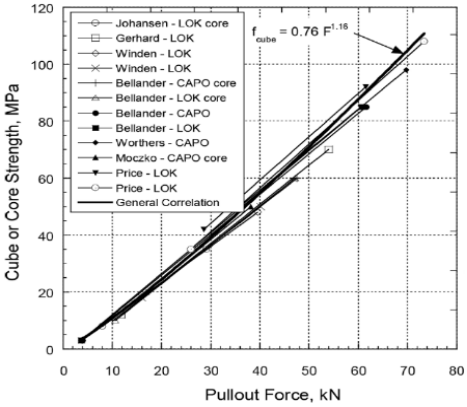



*Fig.3. Twelve correlations between pullout force and standard cube / core compressive strength.*

And, it was found that the pullout forces by LOK-test and CAPO-test had a 1:1 relationship.

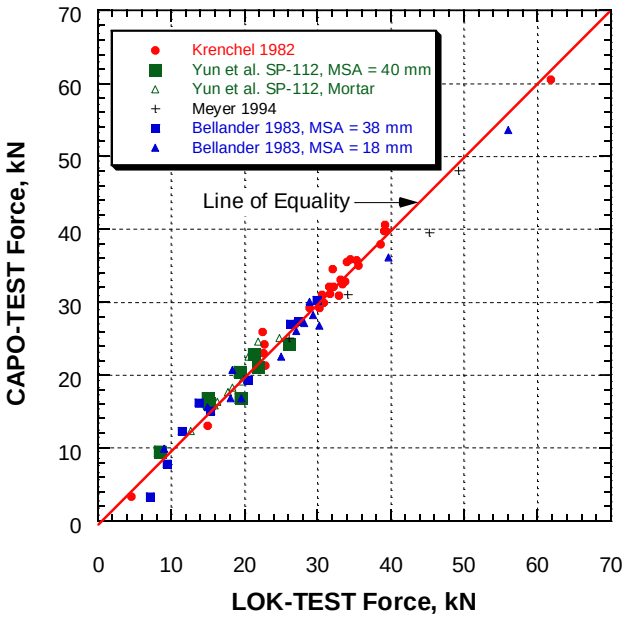



*Fig.4. Relationship between LOK-test and CAPO-test pullout force, relationship being 1:1*

From the experimental correlations found, fig.1 and fig.2, the following general correlations can be deducted:

1. For standard cylinders (150 mm x 300 mm) compressive strength $f_{cyl}$ in MPa related to pullout force F in kN, shown in fig.5:

$$f_{cyl} = 0.69\ F^{1,12}$$

2. For standard cubes (150 mm x 150 mm x 150 mm) compressive strength and cores (100 mm dia x 100 mm) compressive strength in MPa related to pullout force F in kN, also shown in fig.5

$$f_{cube} = 0.76\ F^{\ 1.16}$$

It should be noted that all correlations were done by different laboratorties each with their own compression machine.

The procedure for the correlation can be found in:

*Petersen, C.G. & Poulsen, E.: "Pullout testing by Lok-Test and Capo-Test with particular reference to the in-place concrete of the Great Belt Link", Dansk Betoninstitut A/S, Birkerød, Denmark, 1991*
*Appendix 2. Relation of pull-out force versus compressive strength (p. 85-99)*

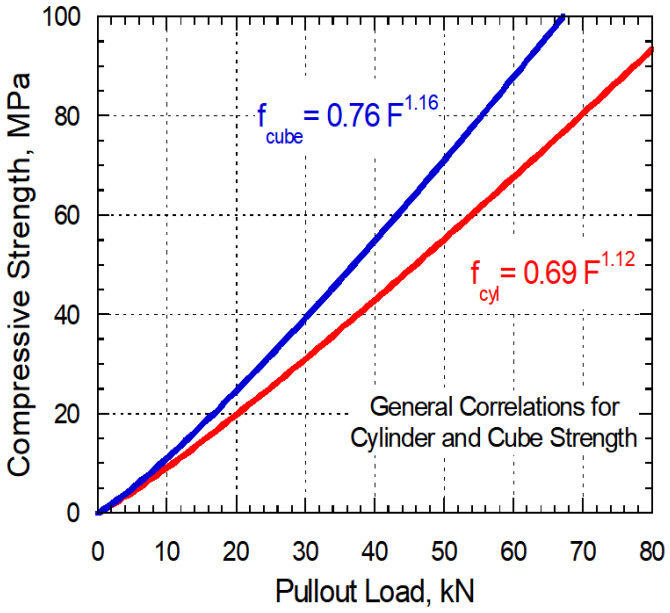
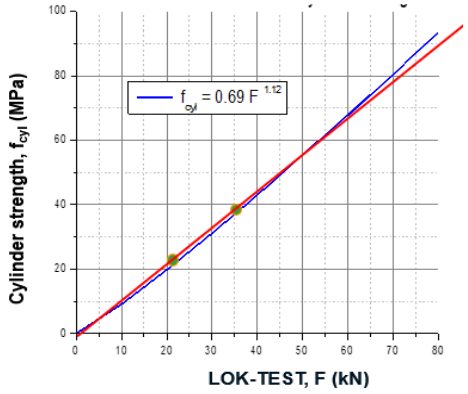



*Fig.5. General correlations between pullout force (LOK or CAPO) and standard cube – and core - and standard cylinder compressive strength*

**Note:** For the same concrete, the cube compressive strength is ~28% higher than the cylinder, as the stress distribution in standard cubes is tri-axial, while uni-axial in standard cylinders.

Comparing the general correlation for cylinder to pullout force to the two theoretical studies mentioned previous page from 1976 and 1982:




*Fig, 6. The theoretical studies results (red line and dots) compared to the experimental found general correlation for uni-axial stress, the standard cylinder compressive strength (blue curve)*

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