LOK-TEST until today 04/10/1978

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HISTORICAL BACKGROUND

In 1959, the Danish Engineering Association set up a committee for the preparation of the new DS 411 standard, which was published in 1975. Among other things, the committee should make proposals for more recent control rules. However, it seemed unrealistic for committee members to introduce advanced statistical quality control that could account for deviations of a few percent when knowing that the existing measurement method (casting of cylinders) could yield values that differed ±20% or more from concrete strength of the structure. Of course, one had knowledge of the different measurement methods that could be used for measurement on the construction itself, but they were all indirect measurement methods that measured properties other than strength.

In June 1962 the idea came to create a small local failure by punching out a cone of the construction against a counter pressure placed on the surface. Or, as the idea really was designed, the load, on the small part of the construction only increased to the required strength. If there was no break at this load, the concrete in the place was quite good. If a break occurred earlier than expected, the strength requirement was not met.

The test was named LOK-TEST, "**LOK-ning**" being the Danish name for "punching". The disc placed 25 mm below the surface is punched by pulling it against a 55 mm in diameter counter pressure on the surface, ref [1].

RESEARCH

In the past 16 years, a large number of studies have been carried out which have been designed to verify the relationship between the pull-out force and the cylinder compressive strength, partly to investigate whether this relationship changes in relation to parameters such as w/c ratio, type of cement, aggregates and curing conditions.

In the preliminary tests, which were carried out first at the Danish Engineering Academy's Building Department, and later at the National Building Research Institute, a linear sensitive correlation between the pull-out force and the cylinder strength [1] was found, close to a 45^0 line. This showed that the LOK-strength is neither a tensile, nor or shear strength, but a strength closely related to the compressive strength. The relationship found was in any case independent of the cement type.

As it was thus shown that there were realities in this new test method, the Danish Engineering Association in 1970 commissioned the Department of Structural Construction at the Danish Technical University (DTU) to conduct an official test of the method. Dr. Herbert Krenchel, in charge of the official test program, performed very large and very careful conducted test series, summarized in two reports [2] from 1970 and 1974. The relationship found by Dr. Krenchel differs only negligently from the previously found, in any case independent of different curing times and curing conditions.

In Stockholm, Dr. Ulf Bellander performed in 1974-76, as the first researcher outside Denmark, a study, also including the Lok-Test equipment. Dr. Bellander's trials had the purpose to investigate the suitability of known NDT test methods for evaluating the strength of a concrete in-place [4], on walls and decks, related to standard cube strength for fully hardened concrete at different strength levels.

The study assesses the accuracy of the methods, the compressive strength being determined in

relation to cube strength, as a function of the values obtained by each of the other measurement methods. Then the standard deviation is calculated around the regression lines found and the maximum deviation of the observations determined from the correlations obtained. The main results are shown in table 1.

Table 1. Comparison of the accuracy of NDT methods on wall elements and decks in relation to cube strength, fully hardened concrete at different strength

Measuring method	Standard deviation residual, MPa	Max deviation from the line obtained, MPa
Ultrasound	8.0	-19.1, +12.6
Rebound hammer	4.5	-10.3, +12.3
Lok-Test	3.3	-7.7, +6.3
Cubes, lab	3.3	
Cubes on site	5.7	-10.5, +11.0

As far as LOK-TEST is concerned, Dr. Bellander also found a linear correlation between the LOK-force and the compressive strength, but in relation to standard cubes instead of standard cylinders, making this relationship, of course, not coincide with the previously found correlations to cylinder strength. However, the relationship was independent of the max. aggregate size, type of aggregates and the curing conditions. From the straight, almost 45^0 sensitive correlation lines, obtained, it is clear that Lok-Test measures a strength property closely related to the compressive strength as measured on standard specimens.

Despite this fact, countless people still don't believe it is the compressive strength which is measured, arguing the property must be related to another property, e.g. tensile or shear. "You are pulling in a cast-in disc" was their argument. What they forget is that the disc inside the concrete is pulled against a counter pressure placed on the surface.

It was therefore a very important contribution to this discussion, when Prof. Bjarne Chr. Jensen and Lic. Techn. Mikael Bræstrup in 1976, [5], published their paper "LOK-TEST determine the compressive strength of concrete" based on Coulomb's failure criterion theory, they theoretically demonstrate that it is really the compressive strength that is measured when punching out a small part out of the structure against a counter pressure.

In 1975, the public authorities in Denmark became interested in LOK-TEST. Mr. Georg Christiansen from the State Road Laboratory, initiated an excellent cooperation between the Danish State Railroads, (Mr. P. L. Avnstrøm) and the Road Directorate (Mr. H. H. Gotfredsen), who, with the help of, among others Cowiconsult, performed a new very large series of experiments. The results from this are shown in the report from the Danish State Railways (DSB) and the State Road Laboratory [3]. Also, in these tests, the linear correlation between the LOK-TEST and the cylinder strength is found, and the line only has a slight deviation from the previously found ones, which is probably due to differences in the measurement of the cylinder strength on a different compression machine.

The last experimental trial to be mentioned was performed by Poul Erik Poulsen at the Danish Engineering Academy with the assistance of the Danish Technological Institute [6] funded by the Danish Council of Technology. The purpose of this experiment was to determine the strength of a construction by crushing it and then comparing this real strength with the results obtained by measuring with other test methods. The structures that were crushed were reinforced column elements having a cross section of 30 cm x 30 cm and a height of 1 meter. In these experiments, the linear relationship was again found - between the final LOK-strength and the compressive strength by crushing

To assess the suitability of the individual test methods, the correlations were established, and the coefficients were calculated between the actual strength and the results of the different measurement methods. The correlation coefficient, as is well-known, is a number that expresses how good the relation is between two parameters. If the coefficient of correlation is "1", the relationship is perfect – the two variables measure the same property, if the coefficient of correlation is "0", there is no link at all between the variables.

The correlation coefficients obtained in this study are shown in table 2.

Table 2. The Correlation coefficients obtained by five different methods seen in relation to the actual strength of a structural element measured by crushing the entire element.

Measuring method	Correlation coefficient	Amount of observations, n
Ultrasound	0.50	72
Rebound hammer	0.53	216
Lok-Test	0.96	179
Molded cylinder	0.84	32
Cores	0.92	72

Figure 1 below summarize the findings between the various test methods and the actual compressive strength of the structure by crushing the 1-meter high columns, 30 cm x 30 cm in square.

COMPARATIVE STRENGTH TESTING

8x3 columns tested by crushing and 8x3 columns tested in parallel by:

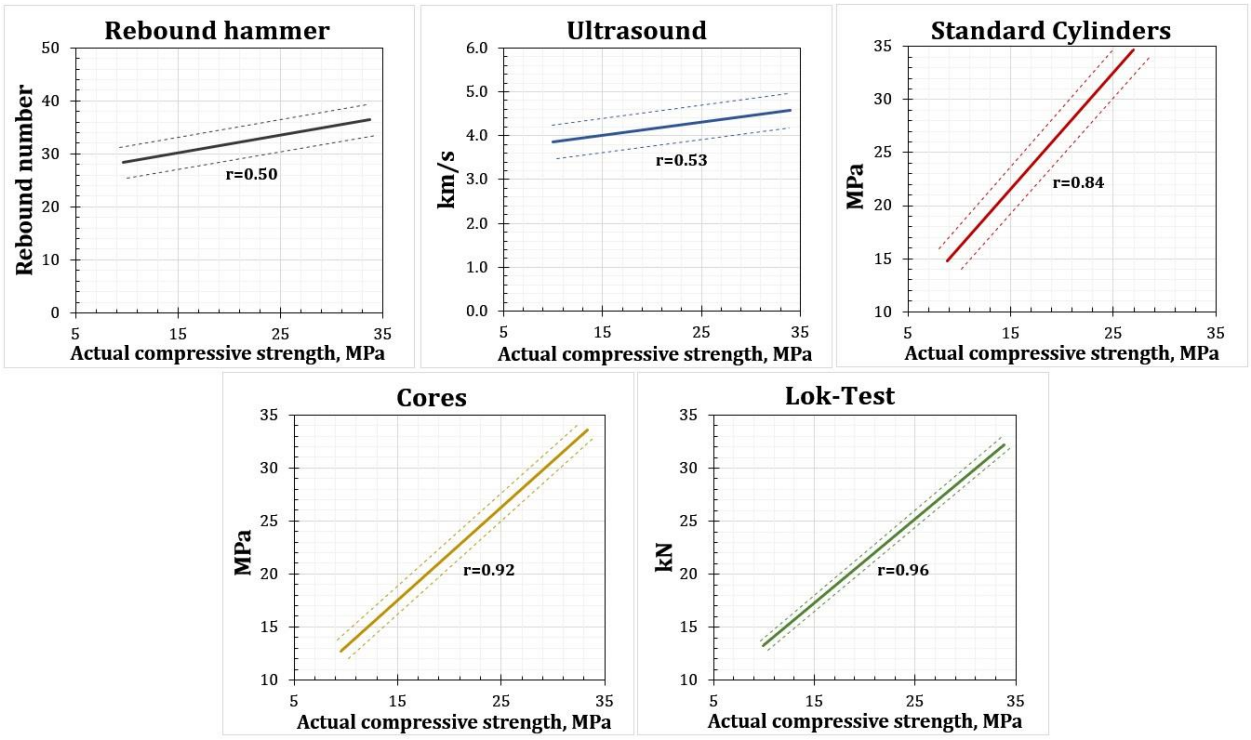
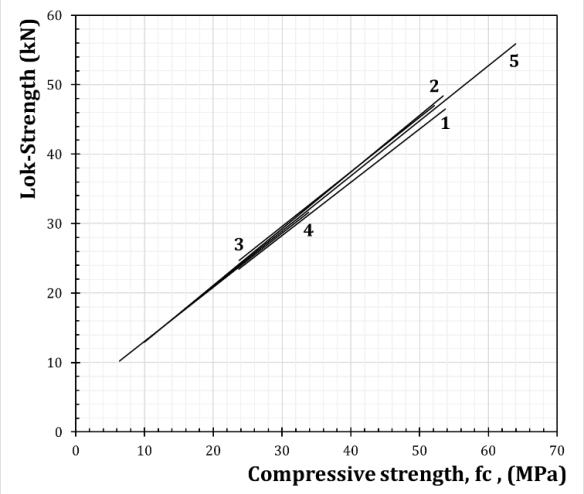


Figure 1. Correlations obtained between strength of columns (actual compressive strength) and five 1different test methods performed on adjacent columns. The dotted lines are the 95% confidence limits. "r" is the coefficient of correlation.

SUMMARY

The main results from the 5 independent major Danish trials, [1], [2], [3], [6] and [7] made until today can be summarized in a single figure below, showing the relationship between the compressive strength (either standard cylinders of crushing of columns) and the LOK-strength.

Figure 2. The result of 5 independent Danish trial series comparing compressive strength to LOK-Strength, compressive strength measured by standard cylinders or crushing of reinforced columns (30 cm x 30 cm x 1 meter)



1. RESEARCH BY LOK -TEST aps
2. RESEARCH BY TECHNICAL UNIVERSITY, COPENHAGEN
3. RESEARCH BY ROAD AND RAILWAY DEPARTMENTS
4. RESEARCH BY DANISH ENGINEERING ACADEMY
5. RECOMMENDED CONVERSION EQUATION
L (kN) = 5 + 0.8f´c(MPa)

Figure 2.

For use in practice, the equation (1) between mean LOK-Strength (L_m) and mean compression strength of standard cylinders f_c is used

$$L_m = 5 + 0.8\, f_c \qquad (1)$$

Or, the conversion of characteristic values, L_c to f_{cc}, the equation (2) applies, ref [8] and [9]

$$L_c = 4 + 0.7\, f_{cc} \qquad (2)$$

based on 95% confidence limits

LITERATURE

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[3] Jensen, 0. Westermann og Leksø, Steen: "Prøvning af beton- konstruktioners styrke med Lok-Test", Statens Vejlaboratorium, Laboratorierapport nr. 30, december 1976 og DSB, Teknisk Rapport nr. 1, V.7, 1977.

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[7J Leksø, Steen: "Støbte betonprøvers personafhængighed", Statens Vejlaboratorium, Laboratorierapport nr. 28, 1976.

[8] Leks0, Steen m.fl.: "Fastlæggelse af beregningsprocedure ved Lok-Test måling", Statens Vejlaboratorium, Interne Notater nr. 77, 1978.

[9J Leveringsbetingelser og Prøvningsmetoder nr. 10: "Vejledning i udførelse af styrkekontrol i betonkonstruktioner med Lok-Test udstyr", Statens Vejlaboratorium 1977.