IN-SITU PULLOUT TESTING WITH LOK-TEST,

TEN YEARS' EXPERIENCE

by

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and

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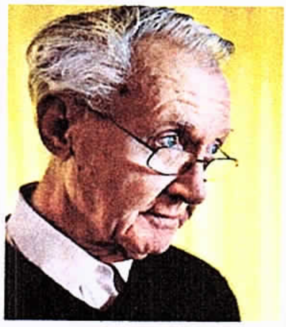

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SYNOPSIS

The development of pullout testing is reviewed briefly. Test data from 24 major calibration series in the USA, Canada, Denmark, Norway, Sweden, and the Netherlands, relating the pullout force to the compressive strength of standard cylinders or cubes are presented. One general relationship is found to exist for normal concrete. Guidelines for further calibrations, if nedded, are outlined. Variability data, in-test and in-place, are given based on a large number of tests performed during the first ten years of operation with the systems, making a statistical evaluation of in-place concrete possible, depending on the type of structural elements to be tested in-place.

PURPOSE

Pullout testing of concrete is used to determine when the strength of concrete placed and cured under actual conditions has reached a specified strength level so that, for example, post-tensioning may take place, forms or shores be removed, winter protection terminated, and curing conditions assessed.

Pullout testing is also used to evaluate dubious structural elements prior to repair or load testing, and to quality test the final product to check the joint effects of fresh concrete transportation, casting, consolidation, hydration, ambient temperature, and curing conditions, on the structure by comparing the in-situ strength and variation with the results of standard compression tests as measured at the ready-mix plant under ideal laboratory conditions.

Pullout testing is approved by ISO, ASTM, and the Scandinavian standard authorities (ref. 1, 2, 3, 4, 5, and 6). In the last decade, it has been correlated to compressive strength in a number of major calibration series - 16 to cylinder compressive strength and 8 to cube compressive strength. Furthermore, the test has been used and calibrated in situ on several structures in Scandinavia and North America.

The purpose of this paper is to present up-to-date data concerning calibration and in-test and in-place variability, and, on the basis of the experience gained so far, to recommend general relationships and procedures for further calibrations, if needed.

All pullout test data refer to the LOK-TEST and CAPO-TEST systems (18 and 10).

BACKGROUND

In the systems described, a 25 mm disc on a 7 mm diameter, conically shaped stem is placed 25 mm below the surface of the concrete. In the case of fresh concrete, the device is embedded during casting (called the LOK-TEST), while in the case of hardened concrete, it is placed in a drilled groove (the CAPO-TEST). A pull-bolt is screwed into the disc and pulled by means of a special, calibrated hydraulic jack resting on a ring with an inside diameter of 55 mm, placed on the surface of the concrete. The pulling force is correlated to the compressive strength of the concrete.

Provided the basic geometrical proportions are maintained by means of extension pieces and a lengthened pull-bolt, the embedded-disc type can be placed at any depth in the structure to monitor strength development elsewhere than the surface cover. With the drilled-in type insert, the 25 mm surface layer is usually tested, but the concrete surface can, if necessary, be ground down, say, 25-30 mm before testing.

The disc can be pulled right out, but usually it is only loaded to failure of the concrete; if it is unloaded immediately afterwards, no damage will be visible on the surface, and if the stem is reinserted in the disc after the test, there will be hardly any evidence that the concrete has been tested. If this procedure is followed, hydration will start again in the induced micro-cracks and will in time secure the rupture cone to the concrete. The drilled-in type disc is usually pulled out since its parts are rather valuable and can be reused.

The question for many years has been what material property of concrete is measured by the pull force. Several answers have been given, the most important of which are two analytical works, one comprehensive site study, one experimental study, and a number of calibrations.

Jensen & Bræstrup (7) conclude, using Coulomb's criterion for sliding failure, that the pull force is directly proportional to the compressive strength of the concrete.

Ottosen (8) concludes, by means of an axisymmetric, non-linear, finite-element computer study, that large compression forces run in a rather narrow band from the disc towards the reaction ring and that this constitutes the load-carrying mechanism. He also states that the failure in a Lok-Test is finally caused by compressive crushing of the concrete in this narrow band.

In an extensive site survey, Bickley (12) reports a high degree of correlation between the pullout force and the compressive strength, and states that it is likely that the pullout test measures a property of the concrete that is either the compressive strength itself or that has a constant relationship with this.

On the basis of an experimental study using a large-scale pullout test with different top angles than the 62° Lok-Test and Capo-Test top angle, Stone & Carino (9) report that the failure occurs in the form of shear failure of the matrix and aggregate interlock, starting at about 80% of the ultimate load.

It is not certain whether the the fact that the geometrical properties are different has any influence on the failure mechanism, but even if these properties were similar, there would still, from a practical testing point of view and many years' experience of the Lok-Test and the Capo-Test, be several objections to Stone & Carino's study. Firstly, when the Lok-Test or Capo-Test rupture cone is pulled out, crushed material is always present in the failure zone. The amount of such materials depends on the size of aggregate used - a small amount for 4-8 mm maximum aggregate size and a larger amount for 18-38 mm. Stone & Carino used a mortar-like mix. Otherwise, the one-inch strain gauges they used to detect stresses in the material during pullout would not have functioned properly. In a Lok-Test size pullout, such a mix would be close to a pure mortar or a very fine shotcrete mix, and with such mixes it is, in fact, difficult to find traces of crushed material, although it is there - in the form of a fine powder. Secondly, on a normal Lok-Test failure cone there are several circumferential cracks, not just one forming the rupture surface as indicated by Stone & Carino. A typical failure surface consists of fish-scale layers standing circumferentially in the truncated zone between the disc and the counterpressure ring, exactly as predicted by Ottosen's analyses. This phenomenon is more pronounced on a Capo-Test rupture cone than on a Lok-Test cone, although it can also be observed on the latter, as will be seen in figure 1. Thirdly, the form of progress of loading and failure as observed on the Lok-Test pull-machine gauge indicates not brittle failure as suggested by Stone & Carino, but highly ductile failure. Consequently, the failure must closely approximate compressive rather than tensile failure.

In the opinion of the authors, there is no doubt that the failure in a Lok-Test and a Capo-Test is a compressive failure - the straight-lined correlations clearly indicate this - but that the stress propagation during pullout is probably complex, involving triaxial compressive stresses, and is influenced by the relationship between the strength of the cement paste and that of the aggregates and by the maximum aggregate size.

Theoretical and experimental models may stipulate a relationship between pullout force and compressive strength. However, such models are never better than the realism of their basic assumptions. Increasingly realistic models will probably be developed as time passes, but until the perfect model is made, the relationship will have to be established empirically by ordinary calibration tests.

As the 150 x 300 mm standard cylinders or the 150 mm standard cubes are used as the basis for design and control throughout the world, it is necessary for the pullout system to be correlated to such compression tests so that the answer obtained from the pullout test is a measure of the in-place compressive strength of the concrete, regardless of type of compressive failure in these two types of standard test (30).

CORRELATION DATA, PULL-OUT FORCE TO STANDARD CYLINDER STRENGTH

Table 1 summarizes all calibrations made to-date, giving author, year of publication, article reference, number of correlation series (referring to the subsequent figures), number and type of reference specimen, number and position of pullout test, variable investigated, correlation found between pull force and cylinder strength, testing range used, maximum aggregate size, standard deviation and coefficient of variation (in-test or in-place), and coefficient of correlation.

Two different calibration procedures were used to produce the data. With the first, pullout inserts were placed centrally in the bottom of the cylinder moulds by means of a screw, washer and nut through a 6 mm hole in the mould. The cylinders were cast in three layers, with vibration after each casting (by rod or on a vibration table). Excess material was removed from the top of the cylinder, and the surface was smoothed. The cylinder was cured in a vertical position, first in the mould and then out of it, to required age for testing. The pullout test was performed exactly to failure, the maximum pull force was recorded, and the instrument was unloaded immediately afterwards, leaving only a slightly raised ring - if any - the size of the counterpressure ring on the bottom. The cylinder was capped with sulphur and then compressed to failure in a standard compression machine.

Investigations have shown no effect on the cylinder strength (or the cube strength) from pullout testing when this procedure is followed (12, 25).

With the second procedure, standard cylinders were cast without any inserts and additional 200 mm cubes were cast with inserts positioned centrally in two opposite, vertical faces. The cylinders and the cubes were cast in three layers, with vibration on a vibration table after each casting, and smoothed on the top. After one hour in a vertical position a little more concrete was added and a top plate was worked into position against the steel cylinder mould by a sliding and rotary motion. The plate was then secured to the mould and the specimen was placed in a horizontal position and tapped lightly to ensure good contact between the concrete and the end plates. Placing horizontally resulted in both end surfaces of the specimen being plane and square to the axis of the cylinder and thus satisfactory for testing.

However, calibrations No. 5 and 10 were made with cylinders cast and cured vertically, carefully planed at the top surface end one hour after casting, and supplied at the time of testing with an intermediate, circular fibreboard plate at both ends of the cylinder.

The 200 mm cubes were cast and compacted in exactly the same way as the cylinder, but with inserts attached to the side faces. If tested at early ages, correction was made for the slightly different maturities of the cylinder and the cube due to a greater concrete mass in the cube and hence comparatively larger hydration, by using mini-maturity meters (29) cast in the specimens, and the utmost care was taken to produce specimens with equal compaction and curing conditions.

The latter procedure, using cylinders without inserts and 200 mm cubes with inserts, is normal Danish practice, while the former, using inserts embedded in cylinders, is common in North America for the calibration tests.

The cylinder with embedded inserts procedure generally gives the smallest in-test variability and is very simple and reliable as long as visible, radial cracking of the cylinder bottom does not occur during pullout. If it does, the pullout force will be reduced, but the cylinder compressive strength is normally unaffected, thus resulting in a misleading correlation. This radial cracking phenomenon is analysed in (8) and discussed and tested in (10). As a general guide, the pullout force is reduced substantially when pulling out of 150 mm specimens compared with minimum 200 mm specimens when the maximum aggregate size is 18 mm or more or the concrete compressive strength is greater than 40 MPa.

If these limits are exceeded it is recommended that minimum 200 mm specimens be used for the pullouts.

Figure 2 illustrates the correlations given in table 1, and figure 3 shows the recommended calibration between pull force and cylinder compression strength. The calibrations are:

(1) $P = 0.96\, f_c + 1.00$ for $2\ \text{kN} \leq P \leq 25\ \text{kN}$

(2) $P = 0.80\, f_c + 5.00$ for $25\ \text{kN} < P \leq 65\ \text{kN}$

where the pull force P is measured in kN and the cylinder strength f_c in MPa. The 95% confidence limits based on an average of two cylinders and four pullouts are indicated as well in figure 3, for a maximum aggregate size of both 16 mm and 32 mm (14). The limits are calculated on the basis of 250 compressive cylinders and 500 pullouts using the Danish calibration procedure described above, which gives a higher variation than the North American procedure. The confidence limits shown can therefore be regarded as conservative. The variability obtained with the two procedures is discussed later, in relation to table 3.

CORRELATION DATA, PULL-OUT FORCE TO STANDARD CUBE STRENGTH

In general, Lok-inserts were secured to one of the vertical faces of the 150 mm cube. The reference compression cube was cast without inserts, or the cube used for pullout was compressed with the pullout surface towards the upper compression plate. The utmost care was taken to produce specimens with identical maturity, compaction and curing conditions.

Here, too, the radial cracking during pullout should be observed and eliminated as described earlier in order to avoid misleading calibrations.

Table 2 summarizes the major calibrations similar to table 1, comparing pullout force to 150 mm cube compressive strength. Figure 4 illustrates the correlations found, and figure 5 gives the recommended calibration, together with the 95% confidence limits for an average of three cubes and three pullouts when the maximum aggregate size is 18 mm or 38 mm (28).

The recommended conversion equation has been found to be:

(3) $P = 0.75\, f'_c + 2.20$ for $3\ \text{kN} \leq P \leq 65\ \text{kN}$

where the pull force P is measured in kN and the cube strength f'_c in MPa.

VARIABILITY

Table 3 shows the in-test variability of the pullout test compared with the cylinder, cube or core test, as reported by the various researchers, 1-24 in tables 1 and 2. Based on 24 major calibration series covering 4,253 pullouts and 2,963 reference compression tests, the general conclusion is that the in-test variability of this pullout testing system is about the same as in laboratory-made standard cylinder or standard cube tests.

It will also be seen that the variability of the 200 mm cube strength measured with pullouts is significantly higher than if 150 x 300 mm cylinder bottoms are tested.

For shotcrete panels (shot horizontally), the variability for pullouts is considerably less than for drilled cores taken from the same material.

In-place concrete variability data as measured with pullout are given in table 4, based partly on North American in-situ testing and partly on Scandinavian field testing covering a total of 137 different structures and 6,693 pullout tests..

Tables 5-13 give in detail the main results from tables 3 and 4.

It will be seen from a comparison of the in-test variabilities (table 3) and the in-place variabilities (table 4) that the variation in the in-situ strength of beams and columns is about the same as the variation in the strength of laboratory-cast 200 mm cubes and that the in-place variation in the strength of bottom slabs, walls and foundations is about the same or a little higher. Top slabs and in-place shotcrete generally show a higher variability. The greatest variation is measured on dubious structures with poor quality concrete due to, say, fire damage, poor consolidation, initial setting of the concrete during transportation, thermal cracks, alkali reactivity of flint aggregates, excessive use of water in the mix, variations in the quality of the concrete delivered to the site, frozen concrete, chloride and/or impurities in mixing water, insufficient curing and protection, different maturity, separation during casting, bleeding, and/or incorrect addition of admixtures.

CONCLUSIONS

On the basis of a total of 24 major calibration series carried out in Denmark, Canada, USA, Sweden, Norway, and the Netherlands, it is found that one calibration to cylinder compressive strength and one to cube compressive strength is unaffected by such variables as w/c-ratio, type of cement, age, curing conditions, form, size and source of aggregates (maximum size 38 mm), air entrainment, flyash, and admixtures.

The calibration curves obtained demonstrate great stability from laboratory to laboratory, from site to site, and from country to country.

The relations are not affected significantly by the joint effects of the position of the pullout in the reference specimen (middle of cube or bottom of cylinder), by capping or no-capping of cylinder, by different compaction procedures from laboratory to laboratory, by the mould material used (steel or plastic), by radial cracking tendencies in 150 mm specimens when the maximum aggregate size is less than 18 mm or the compressive strength level of the concrete is below 40 MPa, by the use of different Lok-test pull machines, or by different compression test machine characteristics, or by whether the pullout test is a Lok-Test or a Capo-Test.

Only one factor has been found to influence the calibrations significantly: radial cracking during pullout of 150 mm specimens when the maximum aggregate size is 18 mm or more or when the strength of the concrete is 40 MPa or more.

In such cases it is recommended that at least 200 mm specimens be used for pullout tests for further calibrations. Great care should be taken to ensure the same compaction, moisture conditions and temperature during hardening, of the pullout specimen and the reference specimen at the time of testing.

The linear calibration curves, combined with the high coefficient of correlation demonstrated (0.91 - 0.99, average 0.95) indicates that rupture at pullout loading in Lok-Test or Capo-Test is most probably caused by compression failure in the area of the concrete between the embedded disc and the surface reaction ring.

The variability in pullout tests made on laboratory-cast 150 mm specimens (cylinders or cubes) is about the same as in normal tests using standard cylinders or standard cubes (a pullout standard deviation of 1.9 to 2.5 kN and a coefficient of variation of 6.8 to 7.5% is typical).

If pullouts are carried out on larger specimens than 150 mm x 300 mm cylinders or 150 mm cubes, higher variations must be expected (on average, a standard deviation of 2.8 kN and a coefficient of variation of 9.9%), demonstrating the somewhat higher strength variation in such specimens.

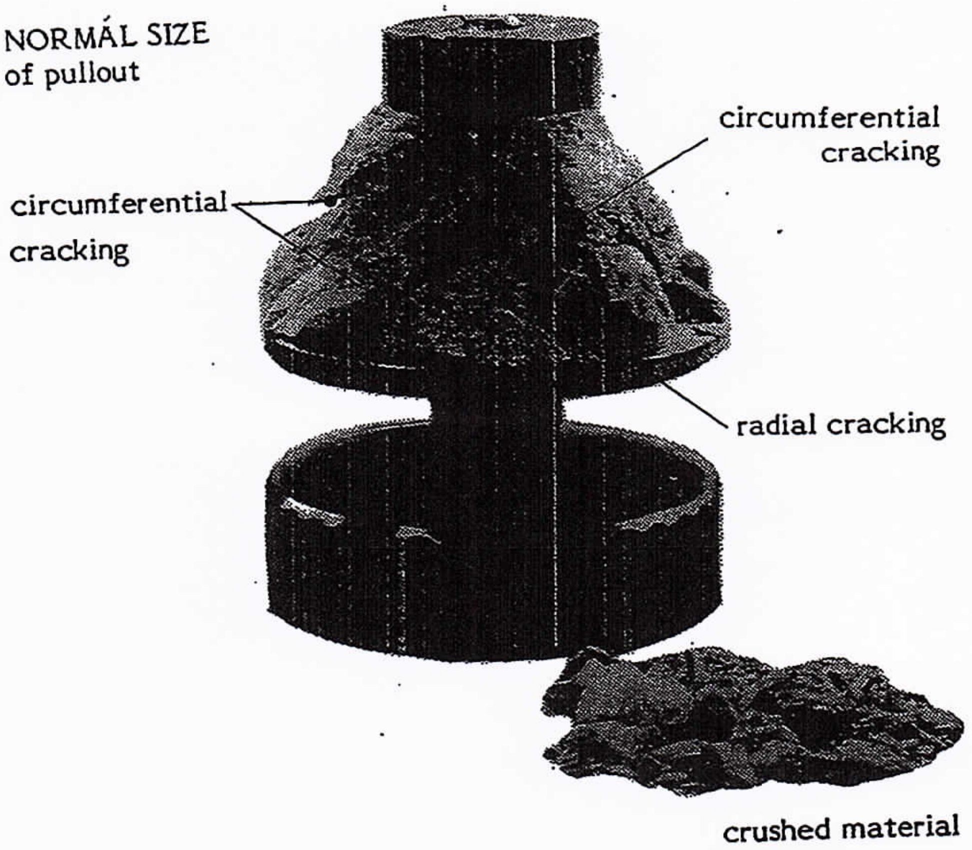
The standard deviation of the compression strength of normal, in-situ concrete lies between 2.7 kN and 3.5 kN, and the coefficient of variation between 7.8% and 12.5%. The strength is most uniform in beams and columns. Slab bottoms, walls and foundations demonstrate somewhat higher variations (s = 3.1 - 3.2 kN and v = 9.7 - 10.0%), while the highest strength variability is found to exist in the top parts of slabs and beams (s =3.5 kN and v = 12.5%).

In-situ shotcrete has a considerably higher variation in vertical walls than in laboratory specimens shot in a horizontal plane. In situ, the standard deviation of the compressive strength has been found to average 4.0 kN, with a coefficient of variation of 13.4%, where the corresponding laboratory values are 1.3 kN and 4.5%.

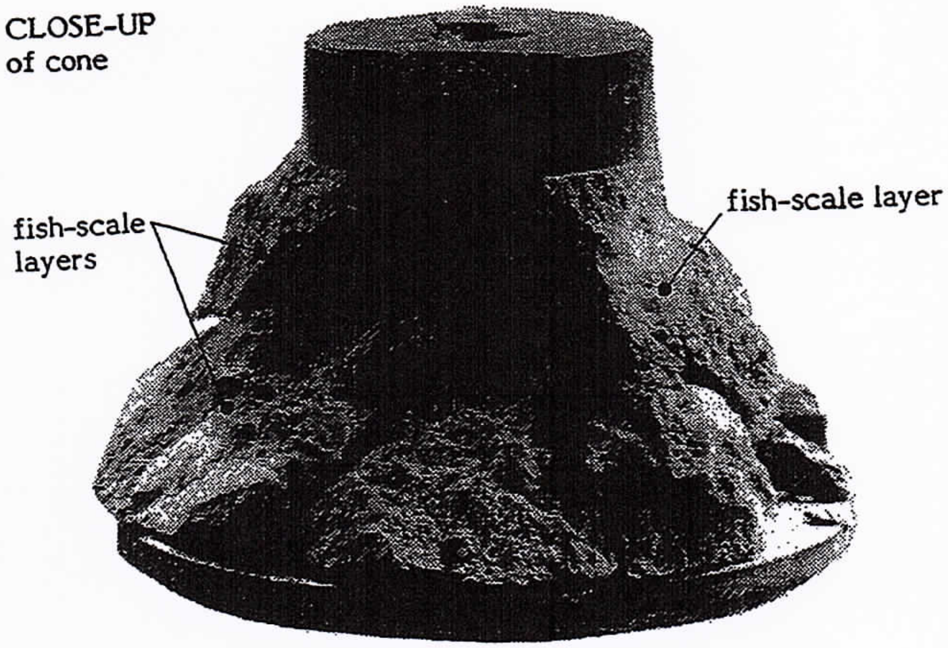
The strength variation in situ is found to be highest for dubious structural elements, with an average standard deviation of 4.5 kN and a coefficient of variation of 14.7%.

Therefore, a rational evaluation of in-place concrete strength and quality can be based on a statistical approach, using a statistically valid number of pullout tests.

FIGURES



NORMÁL SIZE
of pullout



CLOSE-UP
of cone

Figure 1
LOK-TEST rupture cone and crushed material belonging to it

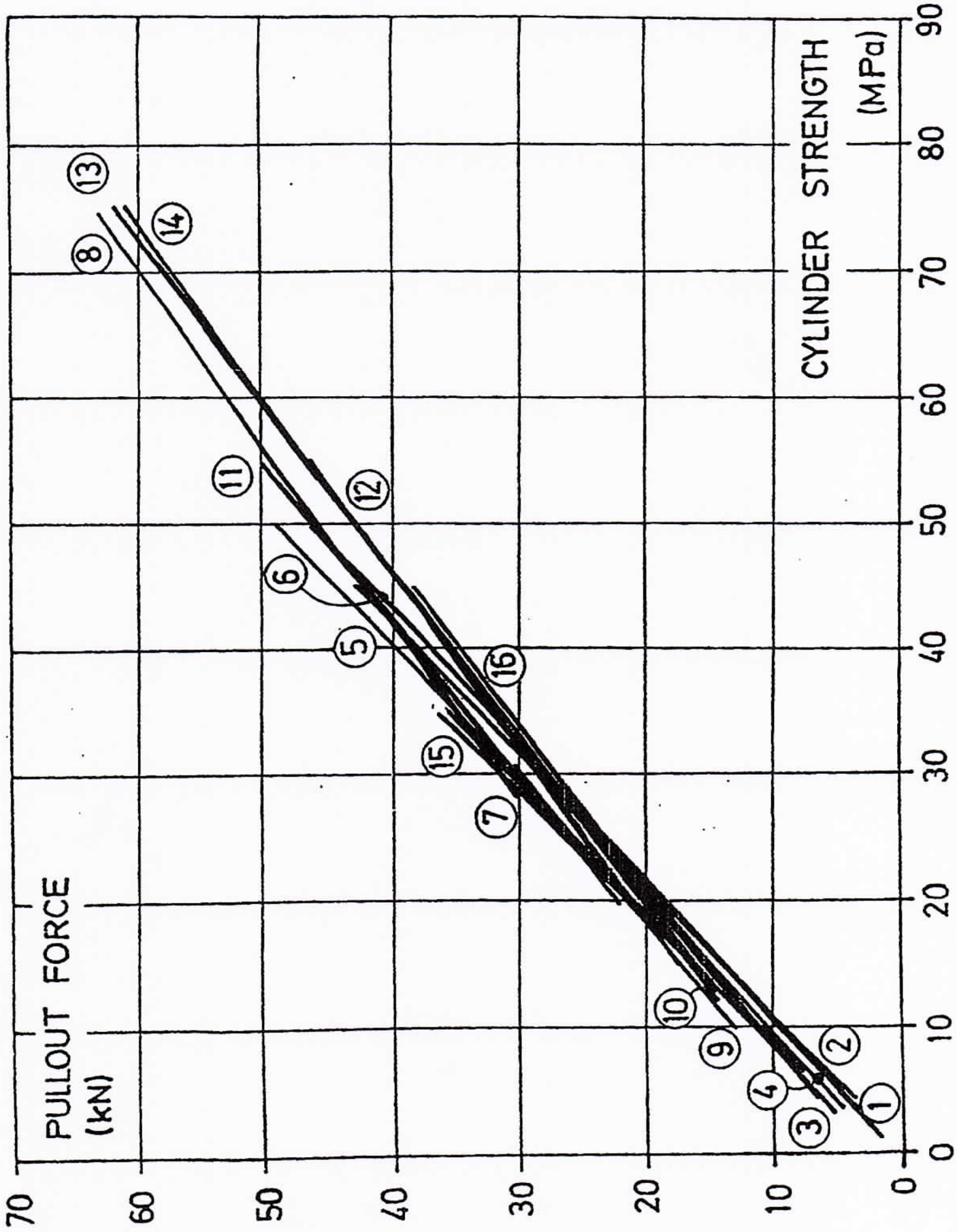


Figure 2
Sixteen correlations between pullout force and standard cylinder compression strength

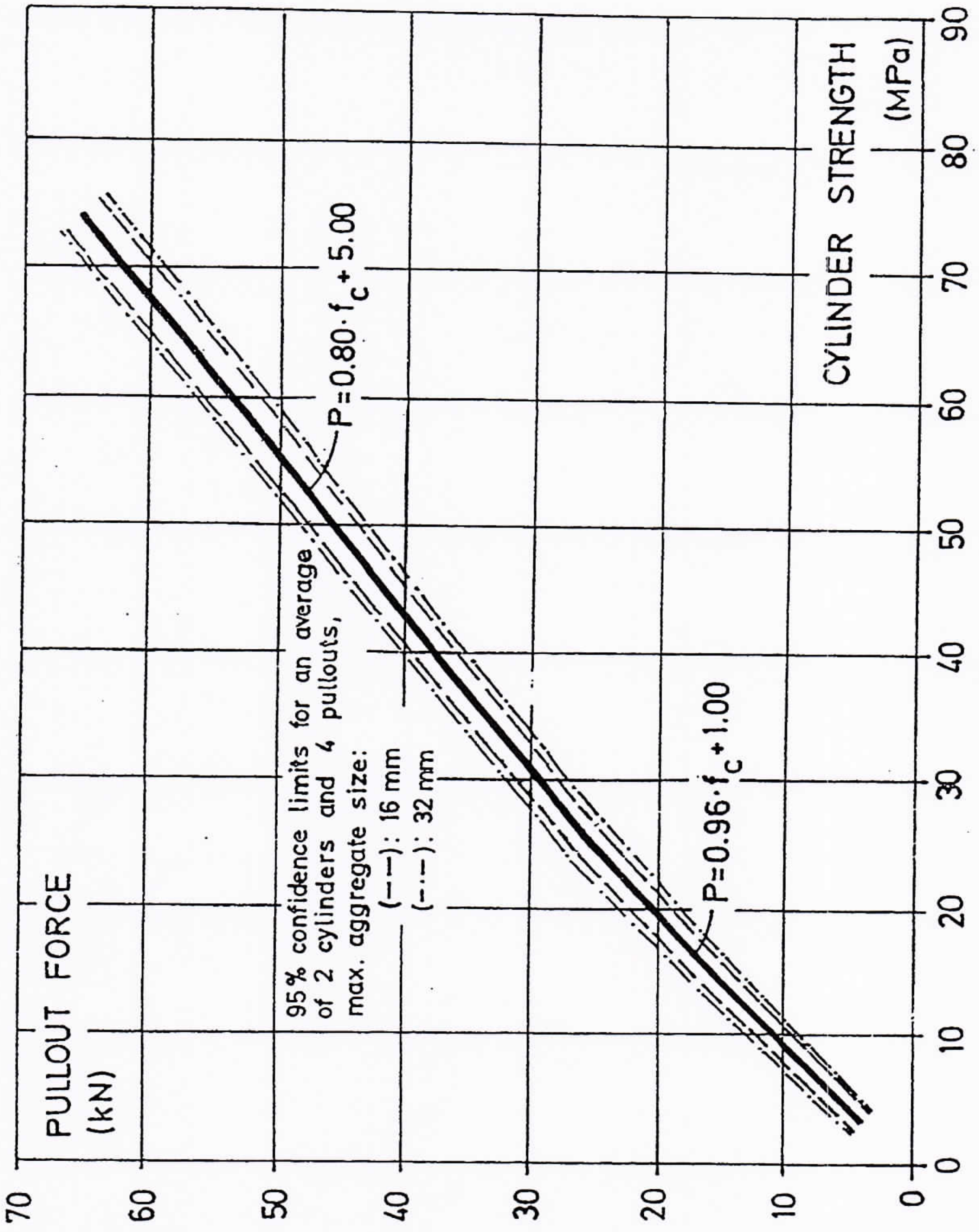


Figure 3
Recommended correlation between pullout force and standard cylinder compression strength

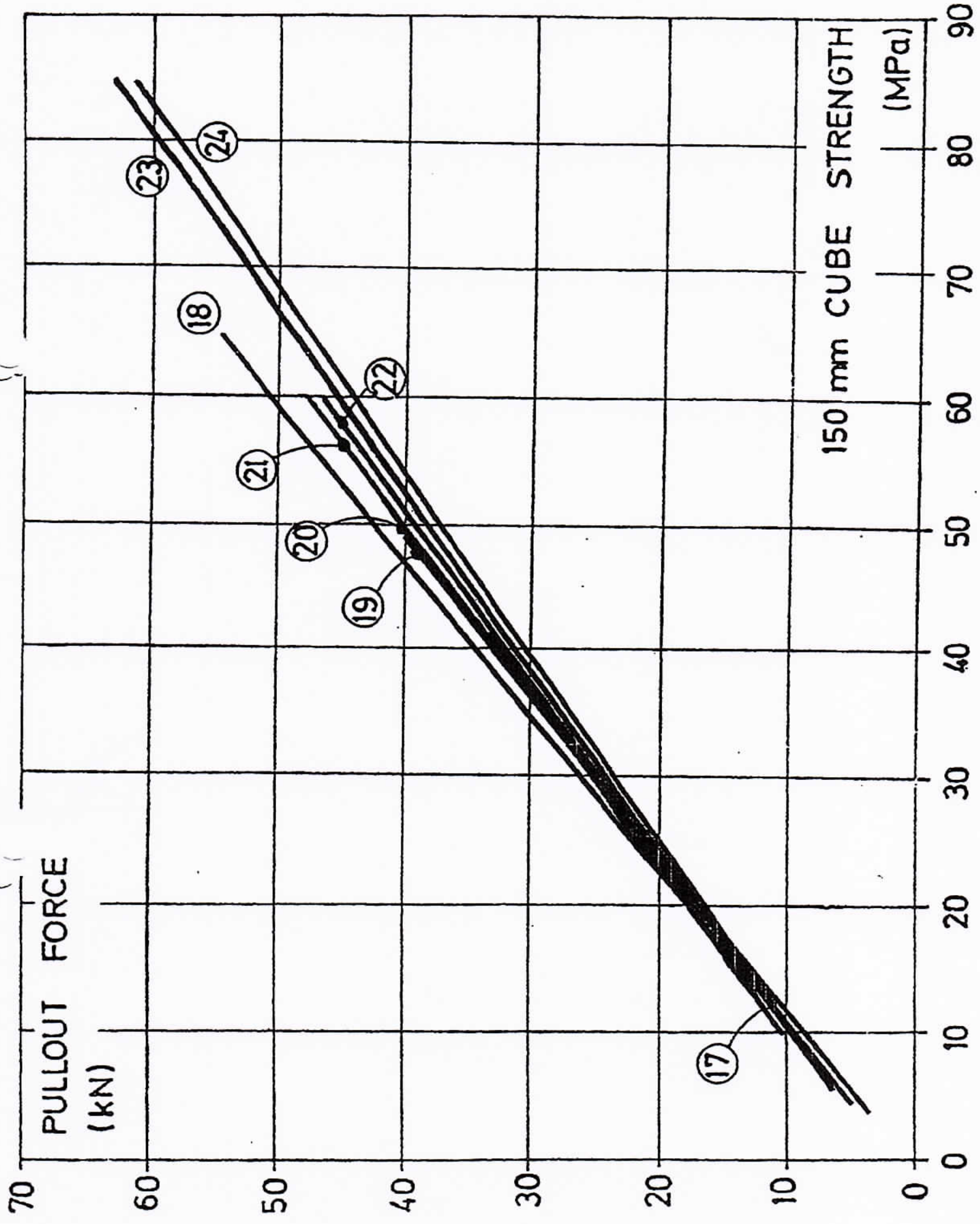


Figure 4
Eight correlations between pullout force and standard cube compression strength

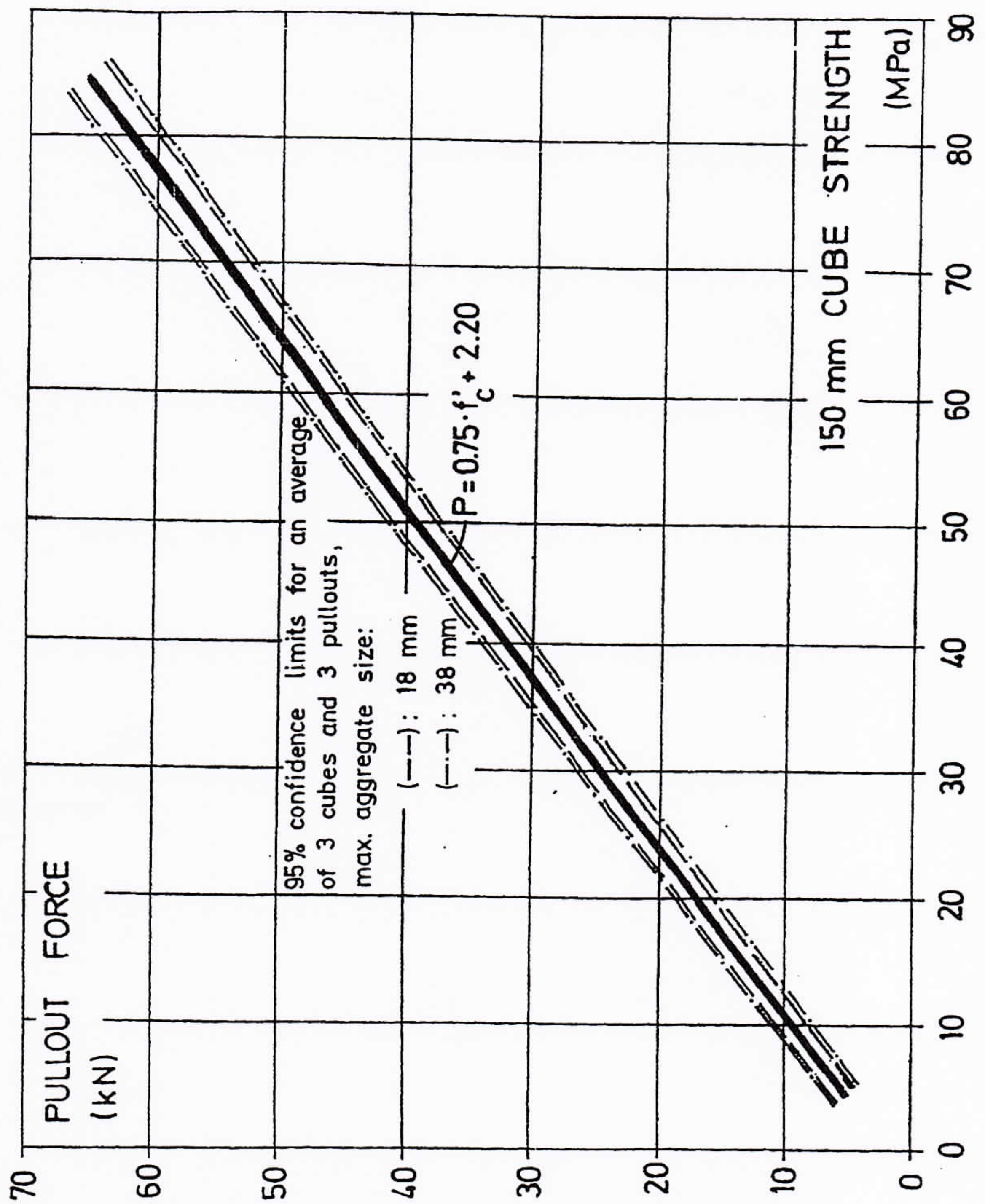


Figure 5
Recommended correlation between pullout force and standard cube compression strength

TABLES

Table 1	Correlation data for sixteen calibration series relating pullout force to standard cylinder compression strength, ref. 11 - 23.
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Table 3	In-test variability of concrete specimens cast in the laboratory
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Table 5	In-test variability of pullout tests and standard cylinder test. After pullout testing the cylinder is compressed.
Table 6	In-test variability of pullout tests and standard cylinder test. Pullout tests are placed centrally on two opposite, vertical faces of 200 mm cubes. Cylinders are cast without pullout inserts.
Table 7	In-test variability of pullout tests and standard cube test. Pull-out insert is placed in vertical face of cube, 150 mm when tested at low strength and 200 mm when tested at high strength. 150 mm cubes cast for cube test without embedded pullout inserts.
Table 8	In-test variability of pullout tests and cores (80 mm dia. x 160 mm). Pullout tests made on top part of horizontal, shotcrete panels.
Table 9	In-place variability of beams and columns
Table 10	In-place variability of walls and foundations
Table 11	In-place variability of slabs, 25-40 mm top part
Table 12	In-place variability of shotcrete walls
Table 13	In-place variability of different types of dubious structure

AUTHOR (ref) year of publishing	CORRELATION NO.	NUMBER AND TYPE OF REFERENCE SPECIMENS	NUMBER AND PLACEMENT OF PULLOUT TESTS	PARAMETER INVESTIGATED	CORRELATION	RANGE	MAX AGGR SIZE	STANDARD DEVIATION AND COEFFICIENT OF VARIATION				COEFFICIENT OF CORRELATION
					Pullout force P (kN) – Cylinder strength f_c (MPa)	(MPa)	(mm)	Pullout force s (kN)	v (%)	Cylinder strength s (MPa)	v (%)	
GAY, G. (11) 1978	①	46 cylinders, capped	46 on cylinder bottoms	curing time (c.t.)	$P_L = 0.906 \cdot f_c - 0.90$	1.5-13.0	18	0.5	9.0	0.5	7.3	0.91
BICKLEY, J.A (12) 1982	②	340 cylinders, capped	340 on cylinder bottoms	age, w/c, aggr size, form source and c.t.	$P_L = 0.910 \cdot f_c - 0.32$	5.5-44.4	10 18, 38	1.0 3.1	4.1 8.2	.0.9 2.7	3.9 7.6	0.94
KRENCHEL, H. (13) 1982	③	75 cylinders	152 on vertical faces of 200 mm cubes, two in each	age, w/c, aggr size and source, curing and air	$P_L = 0.874 \cdot f_c - 1.91$	3.3-33.0	18, 38	3.3	9.1	1.6	4.0	0.90
KRENCHEL, H. (13) 1982	④	75 cylinders	146 on vertical faces of 200 mm cubes, two in each	age, w/c, aggr size and source, curing and air	$P_C = 0.904 \cdot f_c - 0.92$	3.3-33.0	18, 38	3.3	9.7	1.6	4.0	0.93
KRENCHEL, H. (14) 1970	⑤	250 cylinders	500 on vertical faces of 200 mm cubes, two in ea	age, w/c-ratio and curing condit.	$P_L = 0.981 \cdot f_c - 0.53$	5.0-50.0	16, 32	3.6	15.2	1.1	3.3	0.93
JENSEN, J.K.J. (15) 1978	⑥	96 cylinders	96 on one vertical face of 200 mm cubes	w/c-ratio	$P_L = 0.920 \cdot f_c - 0.03$	5.0-50.0	16	2.9	9.5	2.6	6.4	0.94
DRAKE, K.D. (16) 1981-82	⑦	69 cylinders, 3 in each set, capped	184 on vertical faces of 200 mm cubes, eight in each set	c.t., w/c, aggr. size, fly-ash and additive	$P_L = 1.04 \cdot f_c - 0.94$	12.0-36.0	10, 18 & 22	1.7	7.7	0.5	1.8	0.99
DRAKE, K.D. (16) 1981	⑧	15 cylinders, 3 in each set, capped	20 on vertical faces of 200 mm cubes, four in ea.	curing time	$P_L = 0.68 \cdot f_c + 11.3$	30.0-74	22	N/A	N/A	N/A	N/A	0.99
POULSEN, P.E. (17) 1975	⑨	36 columns (0.3×0.3×1m) IN-SITU	216 on vertical faces of another 36 columns	w/c-ratio	$P_L = 0.831 \cdot f_c + 5.50$	10.0-30	16	2.7	11.1	2.1	5.6	0.96
KIERKEGAARD-HANSEN, P. (18 and 19 p.4) 1975	⑩	100 cylinders	81 on cylinder bottoms	type of cement and aggr size	$P_L = 0.806 \cdot f_c + 5.10$	11.6-38.7	8, 16	1.8	6.0	1.8	5.6	0.99
LEKSOE, S. (20) 1976	⑪	240 cylinders	360 on panel bottoms	w/c-ratio, aggr size	$P_L = 0.800 \cdot f_c - 5.92$	20.0-55.0	25, 32	3.7	11.3	2.4	5.4	0.93
LEKSOE, S. (20) 1976	⑫	240 cylinders IN-SITU	360 on 30 structures, placed at random	w/c-ratio, aggr. size	$P_L = 0.710 \cdot f_c - 7.30$	20.0-55.0	25, 32	4.9	16.4	2.4	5.4	0.91
KRENCHEL, H. (21) 1982	⑬	116 cylinders	216 on vertical faces of 200 mm cubes, two in ea.	age, w/c, aggr. size and source, curing, air and admixt.	$P_L = 0.768 \cdot f_c - 4.70$	15.0-75.0	8, 16 and 32	2.2	7.9	1.1	3.6	0.95
KRENCHEL, H. (21) 1982	⑭	116 cylinders	214 on vertical faces of 200 mm cubes, two in ea.	age, w/c, aggr size and source, curing, air and admixt.	$P_C = 0.751 \cdot f_c - 5.30$	15.0-75.0	8, 16 and 32	2.1	7.8	1.1	3.6	0.95
MAGEE, R.L (22) 1982	⑮	36 cylinders, capped	42 total, 18 on cylinder bottoms and 24 on vertical faces (4) of 200 mm cubes	curing time and w/c-ratio	$P_L = 1.050 \cdot f_c - 1.00$	6.6-34.5	18	2.5	8.7	1.7	6.2	0.94
BICKLEY, J.A (23) 1984	⑯	472 cylinders, capped	472 on cylinder bottoms	age, w/c, aggr size, form, source and c.t	$P_L = 0.782 \cdot f_c - 3.53$	2.9-44.4	18	2.6	9.2	2.7	7.6	0.92

P_L Pullout force as measured with Lok-Test, P_C Pullout force as measured with Capo-Test

Table 1
Correlation data for sixteen calibrations relating pullout force to standard cylinder compression strength, ref. 11 - 23.

AUTHOR (ref.) year of publishing	CORRELATION NO	NUMBER AND TYPE OF REFERENCE SPECIMENS	NUMBER AND PLACEMENT OF PULLOUT TESTS	PARAMETER INVESTIGATED	CORRELATION, Pullout-force P (kN) – Cube-strength f'_c (MPa)	RANGE (MPa)	MAX. AGGR. SIZE (mm)	STANDARD DEVIATION AND COEFFICIENT OF VARIATION				COEFFICIENT OF CORRELATION
								Pullout force		Cube strength		
								s (kN)	v (%)	s (MPa)	v (%)	
JOHANSEN, R. (24) 1979	⑰	65 cores/cubes	65 on topport of panels (floating inserts, type L-49)	w/c-ratio, curing cond.	$P_L = 0.780 \cdot f'_c + 1.70$	8.0-35.0	18	2.4	9.5	1.5	5.0	0.94
GELHARD, R. (25) 1979	⑱	140 cubes	140 on vertical face of 150 mm cubes (low range) and 200 mm cubes (high strength)	curing time	$P_L = 0.813 \cdot f'_c + 2.00$	12.0-64.0	32	3.3	8.0	3.2	6.6	0.95
van der WINDEN, N. (25) 1979	⑲	75 cubes	75 on vertical face of 150 mm cubes	w/c, curing time	$P_L = 0.792 \cdot f'_c + 1.50$	3.0-48.0	16, 32	3.5	8.5	3.4	8.0	0.95
van der WINDEN, N. (26) 1980	⑳	90 cubes	45 on vertical face of 150 mm cubes	curing time	$P_L = 0.758 \cdot f'_c + 2.23$	18.0-50.0	16	1.4	5.0	3.0	7.5	0.99
BELLANDER, U. (27) 1979	㉑	420 cores, 20 in each panel and 180 job cubes, IN-SITU	378 on faces of vertical cast panels in-situ, 18 in each	type of cement, age, curing time and condit., compac, freezing	$P_L = 0.746 \cdot f'_c + 2.76$	10.0-60.0	18, 38	4.7	11.0	6.0	13.5	N/A
BELLANDER, U. (27) 1979	㉒	340 cores 20 in each panel	612 on faces of vertical cast panels in lab., 18 in each	type of cement, age, curing time	$P_L = 0.725 \cdot f'_c + 3.31$	10.0-60.0	18, 38	2.6	6.3	1.6	6.0	N/A
BELLANDER, U. (28) 1983	㉓	75 cubes, 3 in each set	75 on vertical face of 150 mm cube, 3 in each set	w/c-ratio, aggr. size	$P_L = 0.705 \cdot f'_c + 1.80$ *)	3.0-85.0	18, 38	2.0	5.0	2.0	5.0	0.98
BELLANDER, U. (28) 1983	㉔	75 cubes, 3 in each set	75 on vertical face of 150 mm cube, 3 in each set	w/c-ratio, aggr. size	$P_C = 0.696 \cdot f'_c + 1.68$ *)	3.0-85.0	18, 38	2.0	5.5	2.0	5.0	0.98

*) Slope corrected 10% due to radial cracking as outlined in ref. 10.

P_L : Pullout force as measured with Lok-Test, P_C : Pullout force as measured with Capo-Test

Table 2
Correlation data for eight calibrations relating pullout force to standard cube compressive strength, ref. 24 - 28

Specimens	PULLOUT TEST			REF. COMPRESSION TEST		
	s (kN)	v (%)	n -	s (kN)	v (%)	n -
1) Pullout vs. standard cylinder	1.9	7.5	957	1.7	6.4	994
2) Pullout vs. standard cylinder	2.8	9.9	2084	1.6	4.2	1073
3) Pullout vs. standard cube	2.5	6.8	1087	2.4	6.2	860
4) Pullout vs. cores (shotcrete)	1.3	4.5	125	4.4	8.9	36

1) Cylinders used for both pullout force and compression strength determination. Pullout test positioned in cylinder buttom. Reference: Table 5

2) Pullouts positioned centrally on two opposite vertical faces of 200mm cubes. Standard cylinders cast seperately without embedded inserts for pullout. Reference: Table 6.

3) Pullouts positioned centrally in one vertical face of 150mm cubes, if tested at higher strength levels 200mm cubes were used. Seperate 150mm cubes without pullout inserts were used for compressive strength determination. Ref.: Table 7

4) Pullout force measured on top-part of horisontal shot panels in the laboratory. 80mm x 160mm cores were used for compression tests. Reference: Table 8.

Table 3
In-test variability of concrete
specimens cast in the laboratory

Type of element	PULLOUT TEST		
	s (kN)	v (%)	n -
Beams and columns (table 9)	2.7	7.8	325
Slabs, buttom part (ref. 12)	3.1	9.7	4190
Walls and foundations (table 10)	3.2	10.0	753
Slabs, top part (table 11)	3.5	12.5	274
Shotcrete, walls (table 12)	4.0	13.4	150
Dubious structures (table 13)	4.5	14.7	1001

Table 4
In-place variability of concrete elements

Corr. no.	Pullout test		Cylinder test		Max. aggr. size
	s (kN)	v (%)	s (MPa)	v (%)	(mm)
1	0.5	9.0	0.5	7.3	18
2	1.0	4.1	0.9	3.9	10
2	3.1	8.2	2.7	7.6	18 & 38
10	1.8	6.0	1.8	5.6	8 & 16
15	2.5	8.7	1.7	6.2	18
16	2.6	9.2	2.7	7.6	18
Average	1.9	7.5	1.7	6.4	

Table 5
In-test variability of pullout tests and standard cylinder test.
Pullout test is placed in bottom cylinder, which is then compressed.

Corr. no.	Pullout test		Cylinder test		Max. aggr. size
	s (kN)	v (%)	s (MPa)	v (%)	(mm)
3	3.3	9.1	1.6	4.0	18 & 38
4	3.3	9.7	1.6	4.0	18 & 38
5	3.6	15.2	1.1	3.3	16 & 32
6	2.9	9.5	2.6	6.4	16
7	1.7	7.7	0.5	1.8	10, 18 & 22
9	2.7	11.1	2.1	5.6	16
11	3.7	11.3	2.4	5.4	25 & 32
13	2.2	7.9	1.1	3.6	8, 16 & 32
14	2.1	7.8	1.1	3.6	8, 16 & 32
Average	2.8	9.9	1.6	4.2	

Table 6
In-test variability of pullout tests and standard cylinder test.
Pullout tests are placed centrally on two opposite, vertical faces of 200 mm cubes. Cylinders are cast without pullout inserts.

Corr. no.	Pullout test		Cube test		Max. aggr. size
	s (kN)	v (%)	s (MPa)	v (%)	(mm)
17	2.4	9.5	1.5	5.0	18
18	3.3	8.0	3.2	6.6	32
19	3.5	8.5	3.4	8.0	16 & 32
20	1.4	5.0	3.0	7.5	16
22	2.6	6.3	1.6	6.0	18 & 38
23	2.0	5.0	2.0	5.0	18 & 38
24	2.0	5.5	2.0	5.0	18 & 38
Average	2.5	6.8	2.4	6.2	

Table 7
In-test variability of pullout tests and standard cube test. Pullout test is placed in vertical face of cube.

site/ref.	nos. of tests n	Pullout test		Core test		Max. aggr. size
		s (kN)	v (%)	s (MPa)	v (%)	(mm)
26	25	1.7	3.4	N/A	N/A	6
33	10	1.0	3.4	N/A	N/A	6
34	4	1.0	3.6	N/A	N/A	6
47	6	2.0	7.1	N/A	N/A	6
63	20	1.6	5.7	N/A	N/A	8
(21)	36	1.3	4.1	4.4	8.9	10
(12)	24	1.0	4.1	N/A	N/A	10
Average		1.3	4.5	4.4	8.9	

Table 8
In-test variability of pullout tests and cores (80 x 160 mm).
Pullout tests made on top part of horizontal, shotcrete panels.

site no	nos. of tests n	Pullout test	
		s (kN)	v (%)
1	216	2.7	11.1
32	5	1.3	3.6
46	18	3.9	9.8
50	10	2.5	4.2
55	10	2.4	12.0
56	6	2.5	6.2
65	36	3.1	6.2
66	6	2.0	5.1
75	18	3.6	12.2
Average		2.7	7.8

Table 9
In-place variability of beams and columns

site no (cal.)	nos. of tests n	Pullout test	
		s (kN)	v (%)
(21)	378	4.7	11.0
3	12	1.3	3.2
6	4	3.6	12.8
8	10	2.6	9.3
9	6	3.8	14.0
12	28	3.9	10.5
13	6	3.3	13.8
14	8	5.1	15.2
15	6	2.4	10.1
19	6	3.2	13.8
20	5	2.0	8.0
22	8	2.8	7.3
28	29	3.0	9.9
37	6	2.0	6.9
40	6	3.0	9.0
52	10	1.5	6.0
60	20	3.4	8.5
61	25	3.9	9.8
62	28	3.7	9.2
71	21	3.9	8.7
77	23	4.1	12.1
78	27	2.9	9.0
79	14	3.2	11.3
80	8	3.3	9.4
81	14	2.8	14.1
82	12	1.9	7.0
83	27	2.6	8.1
84	6	4.3	12.5
Average		3.2	10.0

Table 10

site no	nos. of tests n	Pullout test s (kN)	Pullout test v (%)
4	14	3.3	11.3
7	21	2.2	9.8
10	14	2.6	13.0
11	20	2.5	9.9
17	4	2.9	12.6
21	5	3.3	14.3
29	30	3.2	10.7
30	60	3.3	11.0
31	5	1.5	7.5
35	25	3.2	9.8
36	20	4.2	12.0
38	6	5.0	17.2
39	6	3.5	11.7
51	10	3.9	12.5
76	14	5.2	18.0
85	20	6.8	19.4
Average		3.5	12.5

Table 11
In-place variability of slabs, 25-40 mm top part

site no	nos.of tests	Pullout test s (kN)	Pullout test v (%)
16	54	3.4	12.5
64	32	3.9	15.2
86	64	4.8	12.6
Average		4.0	13.4

Table 12
In-place variability of shotcrete walls

site no	nos. of tests n	Pullout test		type of structure
		s (kN)	v (%)	
2	360	4.9	16.4	deteriorated bridge
5	130	5.5	9.2	deteriorated bridge
18	15	4.8	17.2	deteriorated slab
23	80	2.7	9.0	low maturity piles
24	14	5.2	18.1	firedamaged beam
25	20	4.8	16.2	firedamaged apartment
27	30	3.2	10.7	deteriorated beam
41	6	3.4	8.7	bad consolidated column
42	6	6.0	15.0	bad consolidated column
43	6	5.4	12.0	bad consolidated wall
44	6	3.6	9.0	miscured column
45	6	5.2	11.3	miscured pile
48	6	5.6	18.7	firedamaged wall
49	30	4.9	12.6	low maturity piles
53	20	3.8	7.6	low maturity piles
57	14	3.9	15.6	frozen slab
58	20	5.0	17.2	firedamaged apartment
59	16	6.1	25.5	deteriorated beam
67	14	4.8	18.0	firedamaged beam
68	14	1.7	17.0	deteriorated slab
70	12	4.2	12.7	fault-casted bridgeslab
72	8	5.9	11.0	miscured slab
73	28	0.7	15.2	bad consolidated beam
74	124	5.9	16.8	deteriorated bridge
87	16	6.3	20.3	deteriorated bridgedeck
Average		4.5	14.7	

Table 13
In-place variability of different types of dubious structure

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