The Variability of Pullout Tests and In-Place Concrete Strength

by J. A. Bickley

The development of pullout testing is reviewed briefly. Test data from 18 construction sites, together with relevant correlation results are analyzed. The data are further examined in the perspective of a series of tests which attempt to determine the true in-test variation of the pullout tests. It is shown that the pullout test used has the same order of in-test variation as standard cylinders. It is, therefore, possible to measure the in-place strength of concrete and the variation of its strength. From this, the minimum strength of concrete in a placement can be calculated by standard statistical methods to a high degree of confidence.

Keywords: compressive strength; pullout tests; standard deviation; statistical analysis; tests.

INTRODUCTION

The purpose of this article is to review pullout test data from construction sites to illustrate the variations in test and in-place concrete strength obtained in the field.

Test data from 18 construction sites, together with related correlation data, are analyzed. The testing was part of the construction testing program on these sites.

The data are further examined in the perspective of a series of laboratory tests which attempt to determine the in-test variation of the pullout tests.

DEVELOPMENT

While reference to pullout testing occurs in North American technical literature as early as 1938, [1] it has only been seen as a potentially usable site test method for the last decade.

In the early 1970's, Richards* and Malhotra[4] published data on tests made with apparatus based on designs by Richards. In 1973 the North Carolina State Highway Department carried out some pullout tests. In 1977, as part of a National Research Council of Canada study on the field performance of various types of in situ tests, the author carried out pullout tests. These tests included some using apparatus to Richards' design and some using a Danish apparatus then just introduced to Canada.

All the experience described and data given in this paper refers to the use of the latter system.[8]

An analysis of the stresses which occur during a pullout test was first published by Jensen and Braestrup,[11] and recently a nonlinear finite element analysis has been made by Ottosen.[23] Some data on the variability of test results have been published,[3,4*,†] but none are extensive. Very few refer to North American practice or give site test data.

TEST METHODS

Pullout tests: ASTM C900-78T, Cylinder tests: ASTM C31-69, C39-72, C172-71, C192-76, and C617-76, Core tests: ASTM C42-77.

PROJECTS AND VARIABILITY OF CONCRETE SUPPLIED

Since July 1978, the author has used pullout testing on over 20 sites in Ontario. Most are multistory apartment or office buildings. One chimney, two bridges,

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*Richards, Owen, "Pull-Out Strength Tests of Concrete," Confidential Report, Research Session, ACI Annual Convention, Dallas, 1972.

†Kierkengaard-Hansen, P., and Bickley, J. A., "In-Situ Strength Evaluation of Concrete by the Lok-Test System," Paper presented at the ACI Fall Convention, Houston, Nov. 1978.

two sewers, and a silo base are included. Some 4300 in-place tests and 340 correlation tests from 18 sites comprise the data in this article.

On some of the sites the author was not involved in standard cylinder testing. On other sites, where an accelerated construction program was followed, a number of different mixtures were used to meet one specified 28-day strength but produce stripping strengths at different ages or in varying temperature conditions. For such sites an analysis of standard cylinder test results by ACI 214 procedures is inappropriate.

For sites where the same mixture was used for an extended period, typical ACI 214 data are given in Table 7.

VARIABILITY OF SITE TEST RESULTS

A summary of standard deviations of sets of results of pullout tests made on 15 of the sites is given in Table 1. Except where noted in Table 1, the tests were made at early ages, generally 1 to 7 days. The standard deviation of standard deviations (σ_1) is not a usual term. It was calculated by taking the standard deviation of each set of test results as a number, assuming normal distribution and calculating the standard deviation of those numbers.

Normally, at least 10 inserts are tested for a placement, (and this is recommended), but for small placements, fewer inserts have sometimes been used.

To see if the number of pullout tests in a set affected the variability of the test results, the data was further analyzed for several sites where there was an adequate number of tests using different numbers of inserts in a set. This analysis is summarized in Table 2.

As will be seen, the standard deviation decreases slightly but not significantly as the number of pullout tests in a set increases from 6 to 10. The in-test variability of sets of tests appears to be constant.

TABLE 1 — Standard deviations of sets of pullout tests

Site Number	Number of Sets of Pullout Inserts	Average Standard Deviation MPa	σ_1 MPa	Site Number	Number of Sets of Pullout Inserts	Average Standard Deviation MPa	σ_1 MPa
1	#14	3.0	1.2	11	42	2.9	1.3
	*21	1.6	0.7	12	7	2.6	0.8
2	66	3.4	1.0	13	x 8 (7 days)	3.2	1.4
3	65	3.8	—		x 8 (28 days)	4.2	0.9
5	52	3.9	1.2		x 8 (64 days)	3.6	1.0
6	34	3.4	0.8	14	20	2.6	1.1
7	12	2.3	0.9	15	9	3.2	1.1
8	1	2.7	—	16	2	2.4	0.8
10	48	2.3	1.1	17	2	3.6	0.4
					Average	3.1	

σ_1 Standard deviation of the standard deviations of sets of test results.
Most sets of tests consist of 10 or more pullout inserts, but numbers vary.
Tests in the side of walls.
* Tests in the top of walls.
x Tests in side of circular columns, (age at test).
All other tests in soffits or slabs.
1 MPa = 0.145 ksi

TABLE 2 — Effect of the number of pullout tests in a set on the standard deviation of sets of tests

Site	All Sets of 6 or More Tests MPa		All Sets of 10 or More Tests MPa	
	Average Standard Deviation	σ_1	Average Standard Deviation	σ_1
6	3.5	0.8	3.4	0.7
7	2.6	0.7	2.6	0.4
11	3.1	1.2	3.1	1.2
14	2.6	1.0	2.6	1.1
15	3.6	0.8	3.0	1.2
Average	3.1	0.9	3.0	0.9

σ_1 Standard deviation of the standard deviations of sets of test results.
1 MPa = 0.145 ksi

CORRELATION WITH COMPRESSIVE STRENGTH

On most sites it has been the author's practice to cast a number of sets of cylinders, each containing a pullout insert in the bottom. This has been done at the start of each project to check the relationship between pullout force and compressive strength. Generally, 10 specimens have comprised a set, but on occasion different numbers have been used, such as 6. Sets are tested at different ages to produce a range of strength for each mixture.

At the time of test the pullout test is made and the cylinder is then capped and tested in the usual manner. By testing the pullout just to failure and then tapping the top of the cylinder prior to capping, any slight dislodging of the pullout cone which has occurred is taken care of. Damage to the cylinder is almost always avoided.

Table 3 shows the data from a series of such tests made on laboratory cylinders. This technique did not appear to have adverse effects on the strength of a cylinder containing a pullout insert over the strength range tested.

Table 4 shows correlation data from a number of sites. Pullout force is plotted against cylinder compressive strength.

The data in Table 4 are shown graphically in Fig. 2. In Fig. 3 this

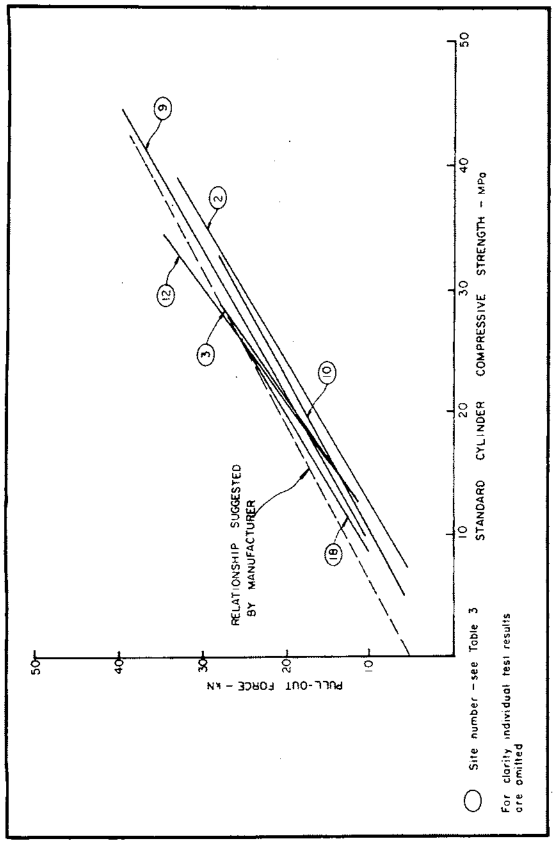

Fig. 2 — Correlation data for 6 sites (1 kN = 0.225 kip, 1 MPa = 0.145 ksi).

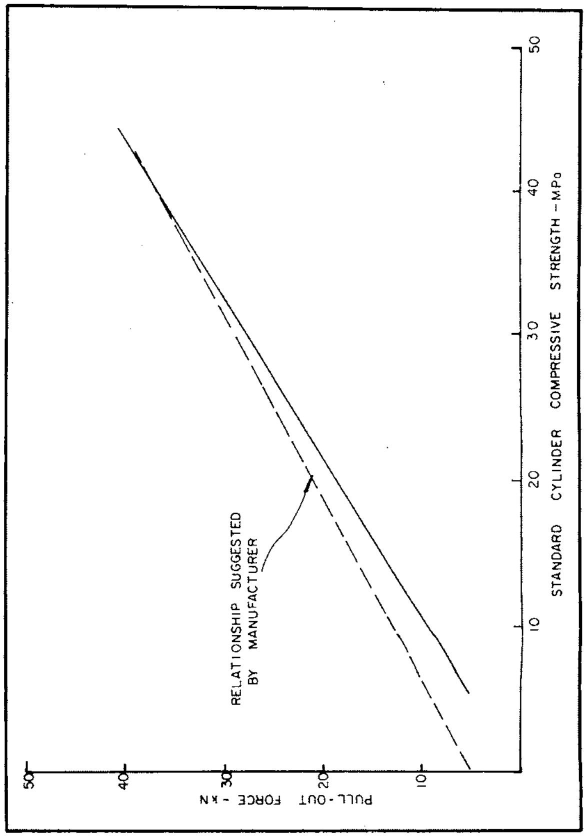

Fig. 3 — All correlation data combined (1 kN = 0.225 kip, 1 MPa = 0.145 ksi).

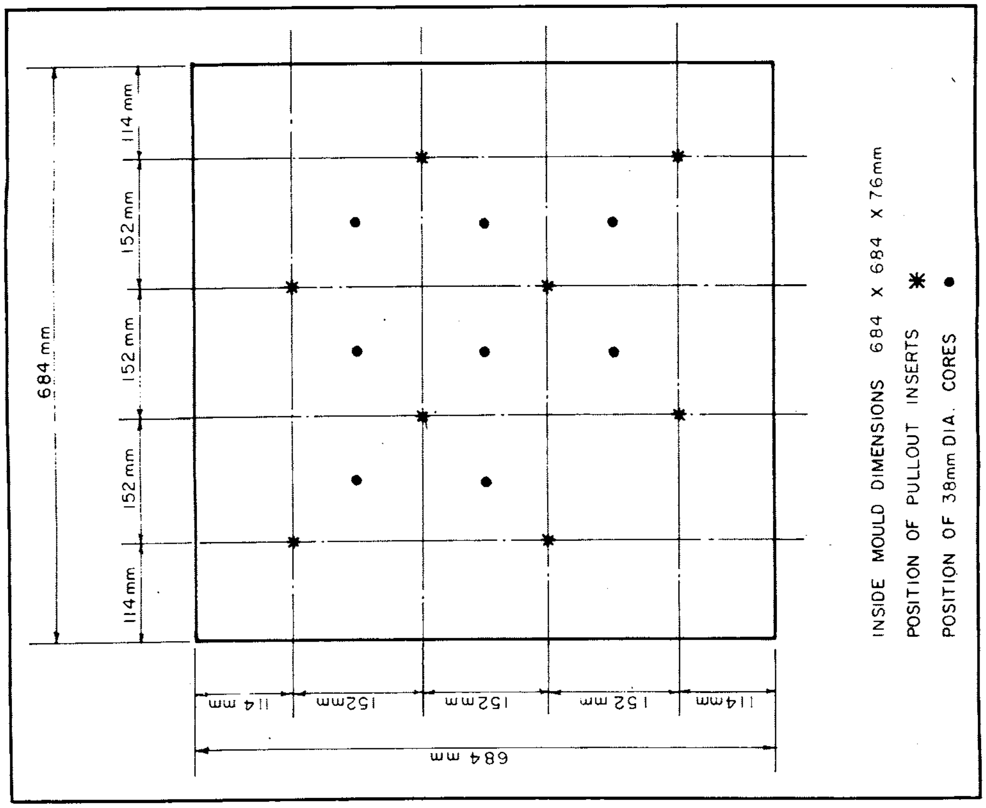

Fig. 1 — Laboratory test panels (1 mm = 0.0393 in.).

relationship is shown for all the data in Table 4 plus some miscellaneous sets of correlation data combined in one regression analysis. Each line is drawn from the lowest to the highest test result in each set of data.

Also shown on both figures is the relationship recommended by the manufacturer of the test equipment. As will be seen, this generally gives conservative values for compressive strength compared to those derived from the Fig. 2 and Fig. 3 lines. The only exception would be some values derived from the line for Site 12 which used 38 mm (1½ in.) aggregate.

EFFECT OF INSERT LOCATION

On Site 3, comparative tests were made comparing the strength of the top and bottom of a 230 mm (9 in.) slab with the results shown in Table 5.

Further tests were made on Site 17 to try to determine if the difference in strength related to the testing method or to actual differences in the strength of the concrete. During a placement, three sets of 7 cylinders were cast. Each cylinder contained two pullout inserts, one in the top and one in the bottom. Care was taken to ensure, as far as possible, that compaction throughout the depth of the cylinders was uniform. Care was also taken to ensure that the inserts in the tops of the cylinders were fully submerged and that minimal air was trapped under the flotation plates.

Pullout tests were made at both ends of the cylinders, which were then capped and tested. Where the inserts at the top and their supporting flotation plates penetrated the cylinder below the top surface, the top 1 in. (25.4 mm) of such cylinders was cut off with a diamond saw before capping.

Results are shown in Table 6. All tests were at an age of 5 days.

From these tests it will be seen that no significant difference in

TABLE 3 — Effect of pullout tests on the strength of cylinders

Age at Test Days	Slump mm	Compressive Strength: MPa Pullout	Compressive Strength: MPa Cylinder with Pullout	Standard Cylinder
3	83	24.0	23.3	23.6
7	83	28.0	27.2	27.4
3	32	27.2	24.9	25.7
7	32	27.0	25.8	25.8
		Crushed Rock — 34.5 MPa Mixes		
3	83	32.8	34.6	34.2
7	83	34.7	36.1	36.0
3	32	34.7	34.5	34.4
7	32	36.5	36.8	37.7
		Partly Crushed Gravel — 20.7 MPa Mixes		
3	83	26.4	23.5	25.4
7	83	26.2	22.9	25.1
3	32	25.4	25.0	26.1
7	32	28.3	29.0	29.3
		Partly Crushed Gravel — 34.5 MPa Mixes		
3	83	28.7	30.0	29.0
7	83	28.8	32.5	33.3
3	32	34.8	30.6	27.8
7	32	33.4	31.2	32.5
Averages:		29.8	29.3	29.6

1 mm = 0.0393 in.
1 MPa = 0.145 ksi

NOTE: Three and seven day tests are on different batches.
Results for pullout tests and cylinders containing pullouts are averages of six tests. Results for standard cylinders are averages of three tests. Pullout force converted to compressive strength to facilitate comparison.

TABLE 4 — Correlation data — Pullout force (kN) to cylinder compressive strength

Site	No. of Tests	Range MPa	a (Intercept)	b (Slope)	r
2	75	7.1-38.3	147.2	165.3	0.99
3	119	12.7-28.8	275.7	138.3	0.81
9	24	9.7-44.4	-405.8	171.4	0.92
10	23	5.9-32.5	-299.3	179.5	0.94
12	22	13.7-34.4	268.8	136.4	0.87
18	28	8.8-25.2	-431.7	162.8	0.97
				Average	0.92
Sites 2, 3, 9, 10, 12, 18, plus miscellaneous sets of tests.	340	5.0-44.4	-52.9	158.	0.94

1 kN = 0.225 kip
1 MPa = 0.145 ksi

TABLE 5 — Comparison between top and bottom of slab

			Inserts in Bottom of Slab	Inserts in Top of Slab
Mean Strength	$\overline{X}$	MPa	27.7	23.8
Standard Deviation	σ	MPa	5.0	5.1
Coefficient of variation	v	%	18.1	21.4

n = 10 for both sets of tests.
1 MPa = 0.145 ksi

TABLE 6 – Pullout tests on top and bottom of cylinders

Set	Cylinder	Pullout Force (kN) Top	Pullout Force (kN) Bottom	Cylinder Compressive Strength MPa
1.	1	33.0	27.2	30.3
	2	30.3	30.3	30.3
	3	33.5	29.3	29.5
	4	29.3	29.3	30.5
	5	32.4	29.3	30.8
	6	33.0	26.1	31.7
	7	31.4	28.8	30.8
	$\overline{X}$	31.8	28.6	30.6
	σ	1.6	1.4	0.7
	v	5.0	4.9	2.2
2.	1	34.5	34.5	36.8*
	2	30.3	36.6	34.6
	3	35.6	30.3	33.4
	4	37.7	36.6	34.4*
	5	35.1	27.7	35.4*
	6	31.4	31.9	33.4
	7	34.5	35.1	35.4*
	$\overline{X}$	34.2	33.2	34.7
	σ	2.5	3.4	1.2
	v	7.3	10.2	3.5
3.	1	30.9	33.5	37.3*
	2	32.4	31.9	34.1*
	3	35.1	33.0	37.6*
	4	33.0	31.4	36.6*
	5	31.4	30.3	35.4
	6	34.5	37.7	35.1
	7	30.3	35.1	33.9
	$\overline{X}$	32.5	33.3	35.7
	σ	1.8	2.5	1.5
	v	5.5	7.5	4.2
Summary Of All Tests:	$\overline{X}$	32.8	31.7	–
	σ	2.0	2.4	–
	v	6.1	7.6	–

*Cylinders trimmed prior to capping.
1 kN = 0.225 kip
1 MPa = 0.145 ksi

TABLE 7 – Statistical analysis of standard cylinder tests

Site	Specified 28 Day Compressive Strength MPa	No. of Sets of Results		7 Day MPa	28 Day MPa
3	27.6	37	$\overline{X}$	–	37.7
			σ	–	2.9
			v	–	7.8
		47	$\overline{X}$	38.9	47.3
			σ	2.2	2.5
			v	5.7	5.3
		27	$\overline{X}$	37.8	–
			σ	2.5	–
			v	6.7	
5	20.7 27.6 used	51* 55†	$\overline{X}$	28.6	35.4
			σ	3.3	3.5
			v	11.6	9.9
14	20.7 27.6 used	13	$\overline{X}$	–	33.9
			σ	–	2.2
			v	–	6.5

*7-Day Results.
†28-Day Results.
1 MPa = 0.145 ksi

the test data resulted, whether inserts were cast in the top or bottom of a cylinder. Since this is surprising, it may be that the manual insertion of the insert in the top of the fresh concrete has a localized effect on the compaction and hence the strength of the concrete surrounding it. This needs further investigation.

The tests from Site 3 confirm other findings that there may be real differences between the strength of concrete in the top and bottom of a slab, presumably due to differences in compaction and curing. The tests from Site 3 show the top 25 mm (1 in.) to be about 15 percent weaker than the bottom 25 mm (1 in.).

LABORATORY TEST PROGRAM

To investigate the in-test variation of pullout tests the following laboratory program was carried out.

Three test slabs, 685 mm x 685 mm x 76 mm (27 in. x 27 in. x 3 in.) thick were cast horizontally, one from each of three batches, designed to a different target strength, i.e., 15, 25, and 35 MPa (2180, 3630, and 5910 psi) at 28 days. Mixing was in a 0.09 m^3 (3 cu ft) pan mixer. Maximum aggregate size was 10 mm (3/8 in.).

Eight pullout and eight 38 mm (1½ in.) core tests were made on each slab. Two standard 152 mm x 305 mm (6 in. by 12 in.) cylinders were cast from each batch of concrete. Fig. 1 shows the test locations. The spacing between tests was based on Ottosen's [23] finite element analysis to ensure, as far as possible, that stress distributions in the slab during the testing of one specimen did not affect the concrete that would be stressed by the testing of any other specimen. The pullout inserts were placed in the bottom of the slabs.

In the casting of each slab, every effort was made to produce as uniform a panel of concrete as possible.

The standard cylinders were tested at 28 days and the pullouts and cores at 7 days. Test results are shown in Table 8.

TABLE 8 — Laboratory program test results

	Slab 1	Slab 2	Slab 3
Target Compressive Strength MPa	15.0	25.0	35.0
Slump mm	51	57	89
Air Content %	2.0	2.0	1.9
28 Day Compressive	17.1	26.1	37.8
Strength (ASTM C 39) MPa	17.2	25.4	35.9
Average	17.2	25.8	36.9

1 MPa = 0.145 ksi
1 mm = 0.0393 in.

TABLE 8 — Laboratory program test results (continued)

	Slab 1		Slab 2		Slab 3	
	Pullout Force kN	Core Compressive Strength MPa	Pullout Force kN	Core Compressive Strength MPa	Pullout Force kN	Core Compressive Strength MPa
	17.1	10.1	21.5	19.5	25.4	29.2
	15.6	13.5	23.4	21.1	30.3	29.2
	16.6	12.6	24.4	21.1	28.3	29.2
	16.6	13.0	23.4	21.1	26.4	31.7
	16.6	13.5	23.4	21.1	28.3	29.7
	15.6	12.6	22.9	20.8	28.8	26.4
	16.1	13.5	23.4	21.5	27.8	29.7
	16.6	13.8	24.4	20.3	27.8	28.4
$\bar{X}$	16.4	12.8	23.4	20.8	27.9	29.2
σ	0.53	1.2	0.91	0.6	1.48	1.5
v	3.2	9.1 (Note)	3.9	3.0	5.3	5.1

Note: If first core result is ignored the values become:

$\bar{X}$	13.2
σ	0.5
v	3.6

1 kN = 0.225 kip
1 MPa = 0.145 ksi

EFFECT OF VARIATION OF TEST RESULTS ON CALCULATED IN PLACE STRENGTH

It is the author's practice to calculate the minimum strength of a placement of concrete as follows:

Minimum strength = Mean Value of Test results − $k\sigma$ where σ is the standard deviation and k is taken from a table and is based on the number of tests performed on the particular placement of concrete. See Table 9. This table is one given in a Danish code but similar values could be derived from ACI 214.

Generally 10 or more tests are used to determine the strength of a concrete placement.

If σ is the standard deviation of the test results, and σ_c and σ_t the true standard deviations of the concrete strength and the test method respectively, then:

$$\sigma = \sqrt{\sigma_c^2 + \sigma_t^2}$$ [*]

From Table 2 it will be seen that a typical average value for σ_c would be 3.1 MPa (456 psi). From Table 8 an appropriate in-test value for σ_t would be about 1 kn pullout force which is about 1.0 MPa (145 psi).

Table 10 shows the effect of testing variations on the calculated minimum strength for sets of 10 tests when the above values are used. As will be seen, the variation in the test only affects the minimum strength calculated by about 0.3 MPa (40 psi).

DISCUSSION

In applying the system to site use, the author checked the manufacturer's recommended relationship by casting and testing sets of 10 cylinders containing pullout inserts. The averages of each set were plotted graphically and the best fitting straight line drawn.

In retrospect, some problems are seen in this procedure. At higher strengths there is a tendency for radial cracks to appear in the ends of the cylinders during pullout tests. This may affect the values obtained at higher strengths. Perhaps the use of 200 mm (8 in.) cubes, which is common Danish practice, would be preferable for correlation purposes.

A fundamental problem arises in the need to relate pullout tests to the standard *cylinder.* It is felt that this may be confusing the issue. When tests from a large number of sites, involving different mixtures, testing instruments, and technicians, are subjected to regression analysis (Table 4 and Fig. 3), a high degree of correlation is found.

The author is therefore convinced that the pullout test mea-

TABLE 9 — Constants *k* for different numbers of pullout inserts tested in a placement

n	3	4	5	6	7	8	9	10	11	12	13	14
k	2.50	2.13	1.96	1.86	1.79	1.74	1.70	1.67	1.65	1.62	1.61	1.59
n	15	16	17	18	19	20	25	30	35	40	45	50
k	1.58	1.57	1.55	1.54	1.54	1.53	1.50	1.47	1.46	1.44	1.43	1.43

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[*] The Application of Statistics to Concrete Quality, F. K. Himsworth, 1955.

TABLE 10 — Effect of testing variation on calculated minimum strength

Average Strength of Concrete ($\overline{X}$) MPa	Calculated Minimum Strength ($\overline{X} - k\sigma$)* Including Testing Variation σ_t	Excluding Testing Variation σ_t
6.9	1.6	1.9
13.8	8.5	8.8
20.7	15.4	15.7
27.6	22.3	22.6

e.g.,

$$\begin{aligned} \sigma &= \sqrt{\sigma_c^2 + \sigma_t^2} \\ \sigma^2 &= \sigma_c^2 + \sigma_t^2 \\ \sigma^2 - \sigma_t^2 &= \sigma_c^2 \\ 3.14^2 - 1.0^2 &= \sigma_c^2 \\ 2.98 &= \sigma_c \end{aligned}$$

*For a 6.9 MPa average strength and excluding testing variation $\overline{X} - k\sigma = 6.9 - 1.67\ (2.98) = 1.92$.
1 MPa = 0.145 ksi

sures a property of concrete, and that this is either compressive strength or has a constant relationship to compressive strength.

Data obtained from two cooling tower contractors confirm the high correlation, viz:

Site	*Test Series*	*n*	*r*
Susquehanna	1	46	0.91
	2	127	0.90
Arkansas		120	0.92
Grand Gulf	1	54	0.88
	2	52	0.93
	1 and 2	106	0.91

The only site reported in Table 4 having a coefficient of correlation less than 0.87 was Site 3. In this case it is seen that the compressive strength range of the correlation data is only 16.6 MPa (2400 psi). It is felt that a set of correlation tests should span a compressive strength range of at least 21 MPa (3000 psi) and preferably more. The greater the range the truer the slope appears to be. Regression analysis is considered preferable to graphical plotting as a means of determining the correlation given by the test data. The analysis should be made using individual results, not the average of sets of results.

The use of sets of 10 cylinders containing pullout inserts was based on procedures used during the development of the system and the feeling that this was necessary to take in-test variations into account. Correlations using inserts cast into cylinders tended to confirm this, showing a coefficient of variation of about 10 percent. As shown by the laboratory test program, however, the in-test variation of the pullout test is of the same order as that of the standard cylinder. Pairs of cylinders containing inserts would, therefore, probably suffice for each strength level on a correlation curve.

It is therefore clear that the variation in the strength of in-place concrete is determined by the pullout test, the effect of in-test variations being insignificant. For practical purposes the effect of this variation can be ignored. The variation of the in-place strength of concrete over a wide range of ages is shown to average a standard deviation of about 2.8 MPa (400 psi). It should be noted that much of the data is for tests at early ages when the difference in age between concrete placed at the start and end of a placement has a measurable effect on its strength.

Examination of the data in Table 1 shows there is only a crude relationship between age of test and standard deviation. Only at very early ages and low compressive strengths is it consistently lower than average, i.e., Site 1 tests on the top of the wall for form removal at 6.9 MPa (1000 psi). Most of the data in Table 1 is for tests between 1 and 7 days after casting, but for Site 13 where tests were made up to 64 days, there is no consistent or significant age-strength relationship variation in standard deviation.

It follows that the minimum strength of a placement of concrete is accurately calculated by the procedure outlined.

As represented by Table 7, the supply to all the sites reported was from well controlled plants.

The results of tests obtained from inserts placed in the top surface of fresh concrete may be affected by the process of insertion. The author, therefore, prefers inserts cast into the bottom or sides of a structural element, until this issue has been resolved by further research.

CONCLUSIONS

Standard cylinders containing pullout inserts in the bottom of the mold can be used for correlating pullout force with compressive strength. Specimens with a greater distance from center to edge, such as 200 mm (8 in.) cubes, might be preferable.

The relationship between pullout force and compressive strength should be determined for each site and for each type of concrete and aggregate size. The range of compressive strengths in a correlation test should be at least 21 MPa (3000 psi) and preferably more.

The relationship between compressive strength and pullout force should be calculated by regression analysis and for each strength level on the curve at least two specimens comprising a pair should be tested and the analysis made using individual results.

The average standard deviation of the in-place compressive strength of well controlled concrete is about 2.8 MPa (400 psi) and this does not vary significantly over a range of age up to 2 months and strengths between 6.9 and 41.4 MPa (1000 psi and 6000 psi).

The in-test variation of the pullout test is low and is of the same order as the standard cylinder test.

By the use of the pullout test method, variations in the strength of in-place concrete can be measured and the minimum strength in a placement calculated by standard statistical methods to high degrees of confidence.

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