ANALYSIS OF PULL-OUT TEST DATA FROM CONSTRUCTION SITES

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ABSTRACT

The development of pull-out testing is reviewed briefly, with particular reference to published data on stress analysis and test variations. Test-data from eighteen construction sites, together with relevant calibration/correlation results, are analyzed. The data is further examined in the perspective of a. series of tests which attempt to determine the true in-test variation of the pull-out tests. It is shown that the pull-out 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 pour can be calculated to -a high degree of confidence

CONTENTS

INTRODUCTION

The purpose of this paper is to review pull-out test data from construction sites to illustrate the variations in test data and concrete strength obtained in the field.

Test data from eighteen construction sites, together with related correlation data, are analyzed. This testing was part of the construction testing programme on these sites.

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

DEVELOPMENT

While reference to pull-out testing occur 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 [6] 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 pull-out 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 authors carried out pull-out tests. These tests included some using apparatus to Richards' design and some using a Danish apparatus then just introduced to Canada - the LOK-TEST instrument.

All the experience described, and data given in this paper refers to the use of the latter system [9].

An analysis of the stresses which occur during a pull-out test was first published by Jensen and Braestrup [12], and recently a non-linear finite element analysis has been made by 0ttosen [29]. Some data on the variability of test results have been published [3], [4], [6], [21], but none are extensive. Very few refer to North American practice or give site test data.

TEST METHODS

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

NOTATION

Standard deviation	σ	MPa
Standard deviation of standard deviations	σ_1	MPa
Coefficient Of variation	V	%
Number of results in a set	n	
Average strength x	$\bar{x}$	MPa
Average of the standard deviations of a number of sets of test results	$\bar{x}_1$	MPa
Slope	a	
Intercept	b	
Correlation coefficient	r	

PROJECTS

Since July 1978, the authors have used pull-out testing on the sites listed in Table 1.

VARIABILITY OF SITE TEST RESULTS

A summary of standard deviations of sets of results of pull-out tests made on most of the sites listed in Table 1 is given in Table 2.

To see if the number of pull-out 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 3.

As will be seen, the standard deviation decreases slightly but not significantly the number of pull-out tests in a set increases from six to ten. The in-test variability of sets of tests of sets of six or more pull-outs appears.to be constant, which would be expected.

Table 1. Ontario Projects

	Site	Structure	Specified 28 Day Strength MPa	Specified form removal strength, MPa	Number of Pull-out Tests made on the structure
1	Ashbridges day	205 m Chimney	27.6	6.9	326
2	2900 Battleford	15 Storey Apartment	20.7	13.8	719
3	Continental Bank	33 Storey Apartment	27.6	20.7	700
4	Islington Ave. Bridge	Segmental Bridge	41.4	10.3 (stressing)	45
5	Warden and Passmore	20 Storey Apartment	20.7	15.5 mean 14.5 min	596
6	Dundas and Tomken	15 Storey Apartment	N/A	15.5 mean 13.8 min	316
7	Obelisk phase III	24 Storey Apartment	27.6	Not known	99
8	Consumers Gas, Hilton	Silo Base	27.6	20.7	15
9	Red Hill Creek	Trunk Sewer	276	6.9	30
10	Lockwood Park	12 Storey Office Building	20 25 30	14.5 13.8	368
11	110 Bloor Street	21 Storey Office Building	207	14.5	348
12	York-Durham Street	Sewer Pipe Cradles	25	20	63
13	Highway 427	Bridge Column	N/A	N/A	240
14	Senior Citizen Phillmore Building	15 Storey Apartment	20.7	13.8	301
15	Shipp Centre	20 Storey Office Building	24.1	17.2	88
16	Town of Vaugham	Trunk Sewer	N/A	Not known	19
17	Trinity Square	Office Building	27.6	20.7	28
18	Yukon	Trunk Sewer	Not known	Not known	---*

* Pre-construction correlation data only

Table 2. Standard deviations of sets of pull-out tests.

	Site	No. of sets of Pull-out tests made	$\bar{x}_1$ MPa	σ_1 MPa
1	Ashbridges day	# 14	3.0	1.2
		* 21	1.6	0.7
2	2900 Battleford	66	3.4	1.0
3	Continental Bank	65	3.8	-
5	Warden and Passmore	52	3.9	1.2
6	Dundas and Tomken	34	3.4	0.8
7	Obelisk phase III	12	2.3	0.9
8	Consumers Gas, Hilton	1	2.7	-
10	Lockwood Park	48	2.3	1.1
11	110 Bloor Street	42	2.9	1.3
12	York-Durham Street	7	2.6	0.8
13	Highway 427	8 (7 days)	3.2	1.4
		@ 8 (28 days)	4.2	0.9
		8 (64 days)	3.6	1.0
14	Senior Citizen Phillmore Building	20	2.6	1.1
15	Shipp Centre	9	3.2	1.1
16	Town of Vaugham	2	2.4	0.8
17	Trinity Square	2	3.6	0.4
		Average	3.1	

Most sets of tests consist of 10 or more pull-out inserts, but numbers vary.
\# Tests in the side of walls.
* Tests in the top of walls.
@ Test inside of circular columns.
All other tests in soffits of slabs.

CORRELLTION WITH COMPRESSIVE STRENGTH

On most sites it has been the author´s practice to cast sets of cylinders, each containing a pull-out insert. This has been done at the start of each project to check the relationship between pull-out force and compressive strength. Generally, ten specimens have comprised a set, but on occasion different numbers have been used, such as six.

Table 3. Effect of the number of pull-out tests in a set on the standard deviation of sets of tests.

	Site	Sets of 6 or more Tests, MPa		Sets of 10 or more Tests, MPa	
		$\bar{x}_1$	σ_1	$\bar{x}_1$	σ_1
6	Dundas and Tomken	3.5	0.8	3.4	0.7
7	Obelisk phase III	2.6	0.7	2.6	0.4
11	110 Bloor Street	3.1	1.2	3.1	1.2
14	Senior Citizen Phillmore Building	2.6	1.0	2.6	1.1
15	Shipp Centre	3.6	0.8	3.0	1.2
		3.1	0.9	3.0	0.9

At the time of test the pull-out test is made and the cylinder is then capped and tested in the usual manner. By testing the pull-out just to failure and tapping the top of the cylinder prior to capping when slight dislodging of the pull-out cone has _occurred, damage to the cylinder is almost always avoided.

Table 4 shows the data from a series of such tests made on laboratory cylinders. These were cast and tested in compression by the Ministry of Transportation and Communications. of Ontario. The pull-out tests were made for the Ministry by one of the authors.

Table 4. Effect of pull-out tests on the strength of cylinders

Age at test, days	Slump, mm	Compressive strength, MPa		
		Pull-out	Cylinder with Pull-out	Standard Cylinder
Crushed rock - 20.7 MPa mixes				
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

As will be seen from the results, this technique did not appear to have adverse effects on the strength of a cylinder containing a pull-out insert over the strength range tested.

Table 5 shows correlation data from a number of sites.

Table 5. Correlation data: Pull-out force to cylinder compressive strength

	Site	No. of tests	Range			a, intercept	b, slope	r
2	2900 Battleford	75	7.1	-	38.3	147.2	165.3	0.99
3	Continental Bank	119	12.7	-	28.8	275.7	138.3	0.81
9	Red Hill Creek	24	9.7	-	44.4	-405.8	171.4	0.92
10	Lockwood Park	23	5.0	-	32.6	-299.3	179.5	0.94
12	York-Durham Street	22	13.7	-	34.4	268.8	136.4	0.87
18	Yukon	28	8.8	-	25.2	-431.7	162.8	0.97
						Average		0.92
	Sites 2, 3, 9, 10, 12, 18 **	340	5.0	-	44.4	-52.9	158.0	0.94

** Those sites plus miscellaneous sets of tests

EFFECT OF INSERT LOCATION

On Site 3, comparative tests were made comparing the strength of the top and bottom of the 9-inch slab with the results shown in Table 6.

Further tests were made on Site 17 to see if the difference in strength related to the testing method or to actual differences in the strength of the concrete. During a pour, three sets of seven cylinders were cast. Each cylinder contained two pull-cut 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 no-occluded air was present under the flotation plates.

Table 6. Comparison between strength of top and bottom of slab measured with pull-out tests.

	Inserts in bottom of slab	Inserts in top of slab
Mean strength, $\bar{x}_1$ MPa	27.7	23.8
Standard deviation, σ_1 MPa	5.0	5.1

n= 10 for both sets of tests

Pull-out 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 one inch of such cylinders was cut off with a diamond saw before capping. Results are shown in Table 7. All tests were at an age of 5 days.

From these tests it will be seen that no significant difference in the test data resulted, whether inserts were cast in the top or bottom of a cylinder. In practice, however, the tests from Site 3 confirm other findings that there is a real difference 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 inch) to be about 15 per cent weaker than the bottom 25 nun (1 inch).

VARIABILITY OF CONCRETE SUPPLIED

On some of the sites the authors were not involved in standard cylinder testing. On other sites, where an accelerated construction programme was followed, a number of different mixes were used to meet one specified 28-day strength but produce minimum 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 mix. was used for an extended period, typical ACI 214 data is given in Table 8.

Table 7. ...measured with pull-out tests.

Set	Cylinder	Pull-out force, kN		Cylinder compressive strength, MPa
		Top	Bottom	
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
	$\bar{x}$	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
	$\bar{x}$	34.2	33.2	34.7
	σ	2.5	3.4	1.2
	V	7.3	10.2	3.5
2	1	30.9	33.5	37.3
	2	32.4	31.9	34.1
	3	35.1	33.0	37.5
	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
	$\bar{x}$	32.5	33.3	35.7
	σ	1.8	2.5	1.5
	V	5.5	7.5	4.2
	Summary of all tests			
	$\bar{x}$	32.8	31.7	
	σ	2.0	2.4	
	V	6.1	7.5	
*	Cylinders trimmed prior to capping			

LABORATORY TEST PROGRAMME

To investigate the in-test variation of pull-out tests the following laboratory programme was carried out.

Three test panels, 686 mm x 686 mm x 76 mm (27 inches x 27 inches x 3 inches) thick were cast, one from each of three batches of concrete. Each of the three batches was designed to a different target strength, i.e. 15, 25 and 35 MPa (2180, 3630 and -5090 psi) at 28 days. Mixing was in a 0.09 m^3 (3 cu. ft.) Creatance multi-flow Type LE pan mixer.

Table 8. Statistical analysis of standard cylinder tests

Site	Specified 28-day compressive strength, MPa	No. Of sets of results		7-day MPa	28-day MPa
3.0	27.6	37.0	$\bar{x}$	-	37.7
			σ	-	2.9
			V	-	7.8
		47	$\bar{x}$	38.9	47.3
			σ	2.2	2.5
			V	6.7	5.3
		27	$\bar{x}$	37.8	-
			σ	2.5	-
			V	6.7	-
5.0	20.7	51 *	$\bar{x}$	28.6	35.4
	27.6 used	55 #	σ	3.3	3.5
			V	11.6	9.9
14.0	20.7	13.0	$\bar{x}$	-	33.9
	27.6 used		σ	-	2.2
			V	-	6.5
	*	7-day results			
	#	28-day results			

Eight pull-out and eight 38 MH (1 1/2 inch) core tests. were made on each panel. Two standard 150 mm x 300 mm (6-inch diameter by 12 inch) cylinders were cast from each batch of concrete. Figure 1 shows the test locations. The spacing between tests was based on Ottesen's [29] finite element analysis to ensure as far as possible that stress distributions in the panel during the testing of one specimen did not affect the concrete that would be stressed by the testing of any other specimens:

In the casting of each panel, every effort was made to place and compact the concrete so as to produce as uniform a panel of concrete as possible.

The standard cylinders were tested at 28 days and the pull-outs and cores at 7 days. Test results are shown in Table 9.

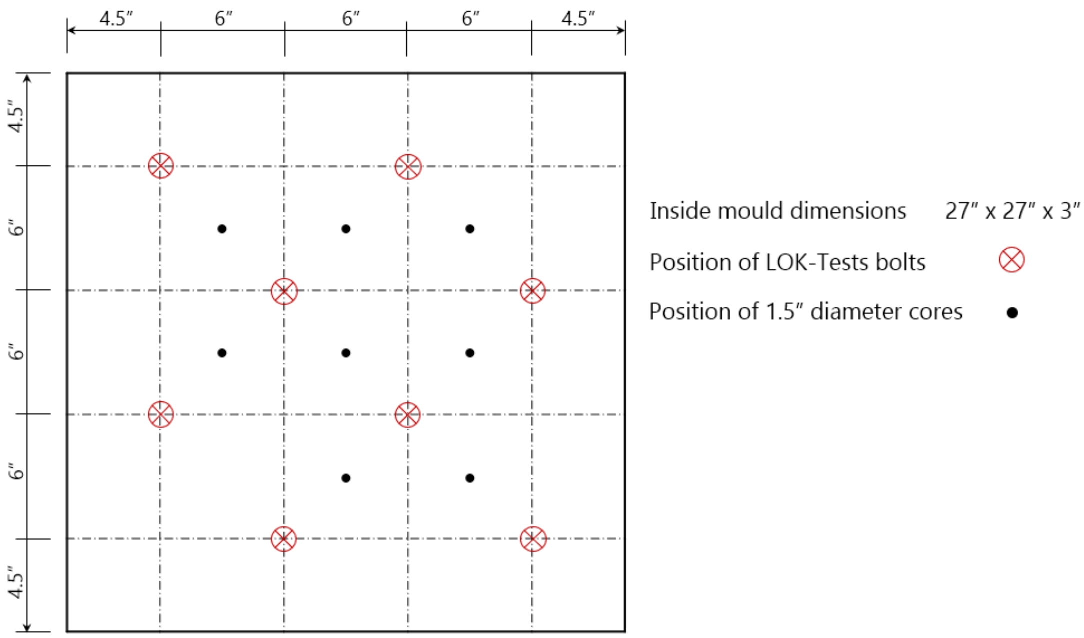

Figure 1. Laboratory test panels.

Table 9. Laboratory program test results

	Panel 1		Panel 2		Panel 3	
Target compressive. strength, MPa	15.0		25.0		35.1	
Slump, mm	50.8		57.2		88.9	
Air content, %	2.0		2.0		1.9	
28-day compressive strength (ASTM C 39), MPa	17.1		25.4		37.8	
Average	17.3		25.8		35.9	
	Pull-out force, kN	Core comp. strength, MPa	Pull-out force, kN	Core comp. strength, MPa	Pull-out force, kN	Core comp. strength, MPa
	17.1	10.1	21.5	19.5	25.4	29.2
	15.6	13.4	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	13.4	23.4	21.1	28.3	29.6
	15.6	12.6	22.9	20.8	28.8	26.4
	16.1	13.4	23.4	21.5	27.8	29.6
	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	1.1	0.9	0.6	1.5	1.4
V	3.2	9.1	3.9	3	5.3	5.1

EFFECT OF VARIATION OF TEST RESULTS ON CALCULATED IN-PLACE STRENGTH

It is the authors practice to calculate the minimum strength of a pour of concrete as follows:

Min. strength = Mean Value of Test Results – k * σ

Table 10. Constant k for different numbers of pull-out inserts tested in a pour

n	k	n	k
3	2.5	15	1.58
4	2.13	16	1.57
5	1.96	17	1.55
6	1.86	18	1.54
7	1.79	19	1.54
8	1.74	20	1.53
9	1.7	25	1.5
10	1.67	30	1.47
11	1.65	35	1.46
12	1.62	40	1.44
13	1.61	45	1.43
14	1.59	50	1.43

Where a is the standard deviation and k is taken from a table and is based on the number of tests performed on the particular pour of concrete. See Table 10

Generally, ten or More tests are used to determine the strength of a concrete pour.

If σ is the standard deviation of the test results, and σ_c and at 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 9 an appropriate in-test value for σ_t would be 1.0 MPa (145 psi).

Table 11 shows the effect of inherent testing variations. on the calculated minimum strength for sets of ten tests when the above values are used. As will be seen, the variation in the test only affects the minimum strength calculated by 0.3 MPa (40 psi).

Table 11. Effect of testing variation on calculated minimum strength

Average strength of concrete ($\bar{x}$) Mpa	Calculated minimum strength $\bar{x}$-$k\sigma$ 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.

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

∴ for a 6,9 MPa average strength and excluding testing variation

$$\bar{x} - k\sigma = 6.9 - 1.67(2.98) = 1.92$$

RELATIONSHIPS BETWEEN PULL-OUT FORCE AND COMPRESSIVE STRENGTH

The data in Table 5 is shown graphically in Figure 2. In Figure 3 this relationship is shown for all the data in Table 5 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 t - Figure 2 and Figure 3 lines. The only exception Would be some values derived from the line for Site 12 which used 38 mm (1 ½ inches) aggregate.

DISCUSSION

In applying the system to site use, the authors checked the manufacturer's recommended relationship by casting and testing sets of ten cylinders containing pull-out 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 pull-out tests. This may affect the values obtained at higher strengths. Perhaps the use of 203 mm (8 inch) cubes which is carman Danish practice, would be preferable for correlation purposes.

A fundamental problem arises in the need to relate pull-out 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 mixes, testing instruments and technicians, are subjected to regression analysis (Table 5.and Figure 3), a high degree of correlation is found to apply.

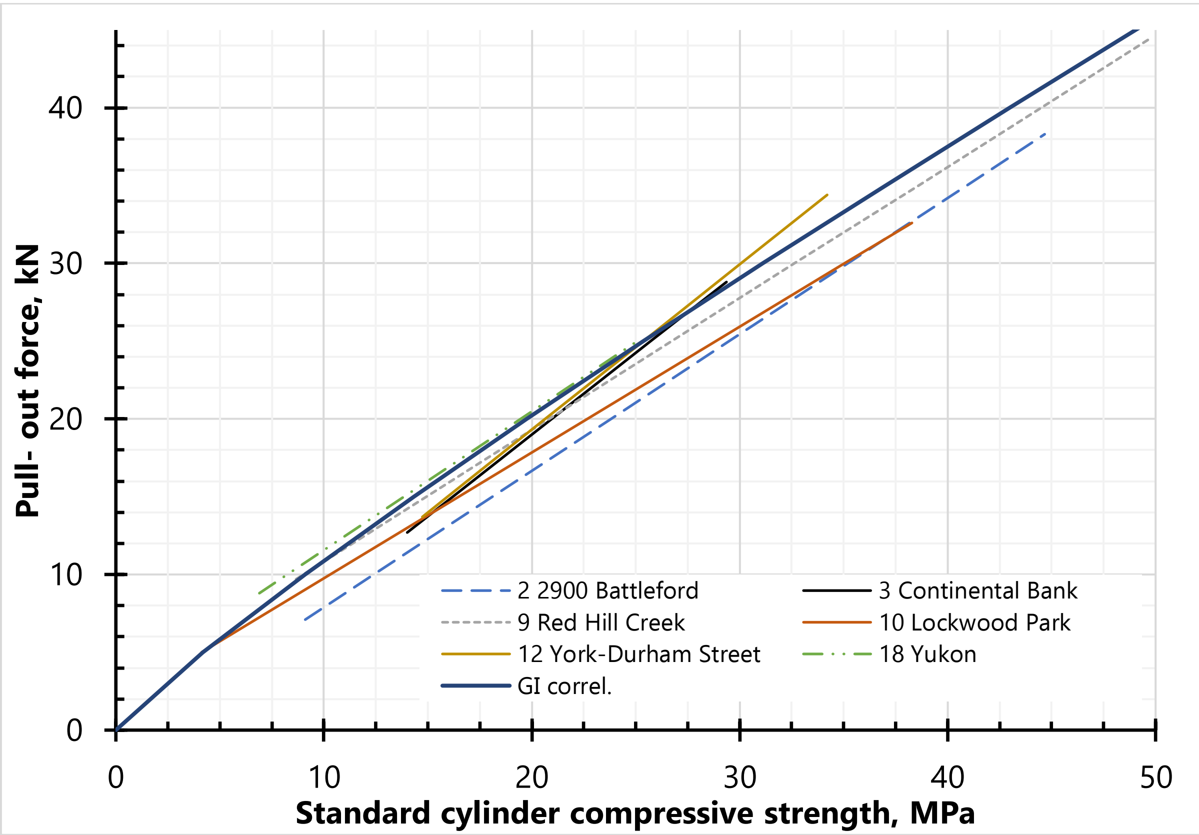

Figure 2. Correlation data for six sites.

The authors are therefore convinced that the pull-out test measures 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 confirms 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 5 having a coefficient of correlation less than 0.83 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 20.7 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 ten cylinders containing pull-out 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 per cent.

As shown by-the laboratory test programme, however, the in-test variation of the pull-out test is of the same order as that of the standard cylinder. Pairs of cylinders containing inserts would therefore probably suffice for each point on a correlation curve.

It is therefore clear that the variation- in the strength of in-place concrete is determined by the pull-out 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).

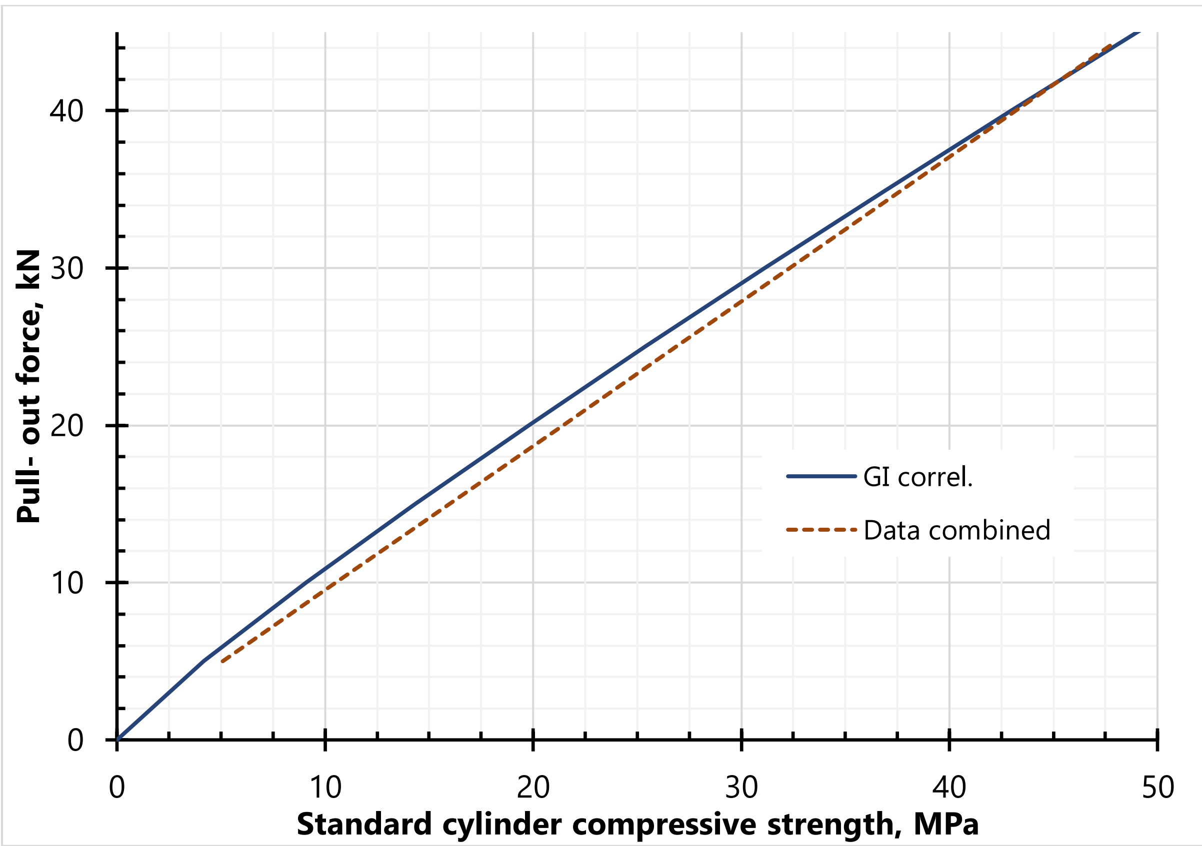

Figure 3. All correlation data combined

Examination of the data in Tables 2 and 3 shows there is only a crude relationship between age of test and standard deviation. Only at very early ages and low compressive strengths is a 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 2 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 also follows that the minimum strength, of a pour of concrete is accurately calculated by the procedure outlined.

As represented by Table 8, the supply to all the sites reported was from well controlled plants.

It is also clear from the test data that the. location of the insert does not affect the test result. If, for instance, tests in the upper part of a slab indicate lower strength than tests in the bottom of a slab, this is because of real differences in the strength of the concrete at the test location.

CONCLUSIONS

Standard cylinders containing pull-out inserts can be used for correlating pull-out force with compressive 'strength. Specimens with a greater distance from center to edge, such as 203 mm (8 inch) cubes, might be preferable.

The relationship between pull-cut 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 20.7 MPa (3000 psi) and preferably more.

The relationship between compressive strength and pull-out force should be calculated by regression analysis and for each point on the curve at least two specimens comprising a pair should be tested.

The 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 10a (1000 psi and 6000 psi). The in-test variation of the pull-out test is low and is of the same order as the standard cylinder test.

Variations in the strength of in-place concrete can there-fore be measured and calculations of average minimum strength in a pour made to high degrees of confidence by the use-of the pull-out test method reported.

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