IN-SITU STRENGTH EVALUATION OF CONCRETE BY THE LOK-TEST SYSTEM

by **Peter Kierkegaard-Hansen** and **John A. Bickley**

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SYNOPSIS

The development of the Lok-Test system and the method of test is discussed. Details are given of research programs carried out by various academic and research institutes.

The use of the system on three major projects is described. Site test data and experience is given together with discussion of practical aspects of the use of the test method.

The economics, problems and benefits are reviewed, and the technical questions solved and raised by in-place concrete testing are summarized.

CONTENTS

PART I SYSTEM DEVELOPMENT

In 1962 the development of a new control system started in Denmark. The purpose of the investigation was to find a method of measuring the strength of concrete placed and hardened in the structure. Our experience has shown that test specimens cast separately - such as cylinders - do not tell us very much about the concrete in the construction because of the difference in the four c's: carriage, casting, 'compression, and curing.

The investigation started at the Danish Engineering Academy. Research showed that the best method was to cast a test bolt on the inside of the form, as figures 1 to 4. The diameter of the disc is one inch (25.4 m).

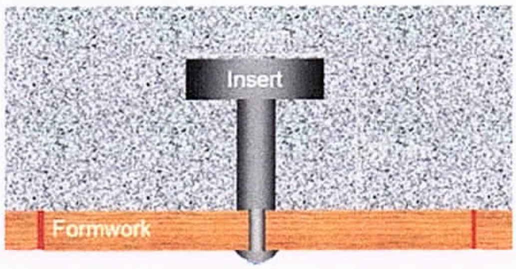


Figure 1. The test bolt (incl. disc and stem) is mounted on the inside of the form prior to placing concrete.

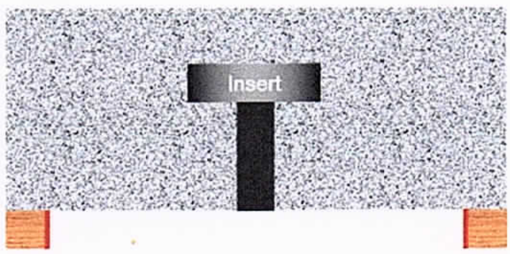


Figure 2. The formwork (or part of the formwork) and the stem of the test bolt are removed.

After the formwork has been stripped, the stem of the bolt is unscrewed, and a special traction apparatus is mounted. The force - the Lok-strength - required to drag the disc through the cylindrical counter-pressure member is then a measure of the compressive strength of the concrete.

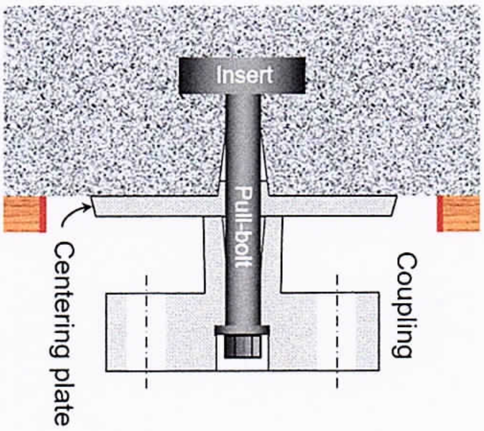


Figure 3. A pull bolt is screwed into the disc, and the instrument is mounted on the surface of the concrete.

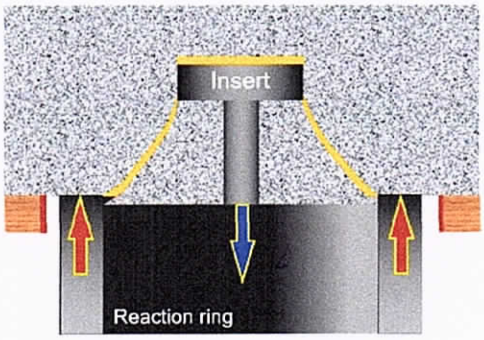


Figure 4. By applying a force with the instrument, a small piece of the concrete is dislodged. The force required to extract the disc through the cylinder counter-pressure device is called the Lok-strength.

In the initial test 50 standard cylinders (diameter 6 inches (150 mm), height 12 inches (300 mm)), with a test bolt embedded in the bottom, were used as test specimens and concrete was taken from 10 batches with different strengths, from 850 to 7700 psi (6 to 53 MPa).

After measurement of the Lok-strength the 50 cylinders were crushed to determine their compressive strength. Four cylinders broke during the Lok-strength measurement at the highest strength. The remaining 46 pairs of observations were analyzed showing a linear relation between the Lok-strength and the compressive strength in the whole range 850 to 7700 psi (6 to 53 MPa) [5]. The standard deviation based on deviations from the regression line, i.e. the residual standard deviation, was 2.4 KN.

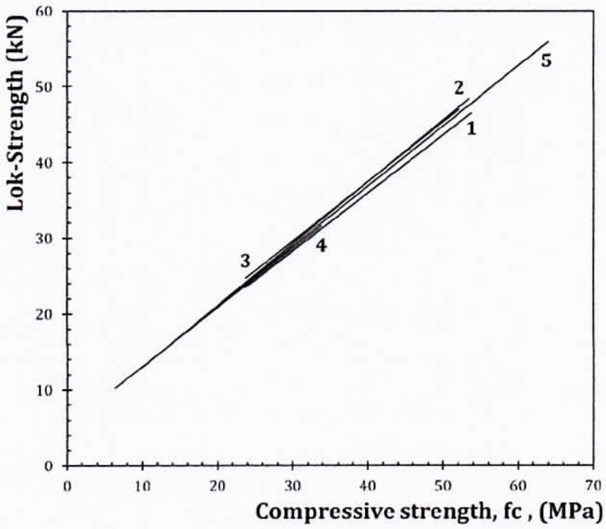
In 1970 the society of Danish Civil Engineers requested the Department of Structural Engineering at the Technical University of Denmark to verify the applicability of the method. For thi4 investigation Dr. Herbert Krenchel used 250 standard cylinders and 500, test bolts embedded in 250 cubes cast from 50 different batches [1]. The main point of this research was to investigate the consistency of the linear relation between the Lok-strength and the compressive strength for all relevant variations in size of aggregate, type of cement and curing time and curing conditions. There appeared to be a significant effect due to maximum aggregate particle size, but later experiments do not show this effect, and to-day we believe that the effect was due to variations in cylinder compressive strength because of variable compaction of concrete with 0.6 inch and 1.2 inch (16 mm and 32 mm) aggregate in a 6 inch (150 mm) cylinder.

In 1975 the Danish Road Department and Danish State Railway together investigated the Lok-Test system on site to verify the utility of the system in practice [8, 9, 10]. Six different constructions consisting in total of 30 control full size structural elements were investigated, containing 360 test bolts and with 240 associated cylinders. The relation between the Lok-strength and the cylinder strength was a straight line with no significant deviation from the earlier results.

Measurements by	Standard Deviation, Residual, MPa	Max. Deviation from line, MPa
Ultrasonic	8.0	-19.1, +12.6
Impact Hammer	4.5	-10.3, +12.3
Lok-Test	3.3	-7.7, +6.3
Cubes (Laboratory cast)	3.7	
Cubes (site cast)	5.7	-10.5, +11.0

In 1976-77 Dr. Bellander [7, 13] at the Swedish Cement and Concrete Research Institute at the Institute of Technology investigated the Lok-Test method among others. He too found a relation independent of compaction and curing conditions and size of aggregate. The regression of the compressive strength of drilled cores on the strength measured by each of the different methods was determined and the methods judged by the residual standard deviation and the maximum deviation of the observations from the regression line. The results are shown in the following table. Six inch (150 mm) cubes were used for these tests.

For years a common question was: Do you measure a tensile, a shear, or a compressive strength by Lok-Test? In 1976 two civil engineers, Ph.D.'s, at the Technical University of Denmark [6] proved by means of the theory of plasticity that it is indeed the compressive strength that is measured.



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 5.

In the latest paper produced jointly by the Technological Institute and the Danish Engineering Academy experiments with columns 40 inches (1000 mm) high and a cross section of 12 inches x 12 inches (300 mm x 300 mm) [6] are described. From each of 8 mixes with different strength in the range 3250 - 4750 psi (22 - 33 MPa) 6 columns were cast, 3 for crushing in full scale and 3 with test bolts embedded, 8 bolts in each column. On these columns some other methods of measurements were also used: ultrasonic, impact hammer, and drilled cores (diameter 4 inches (100 mm)), and 10 standard cylinders were cast from each mix. One of the main purposes of the investigation was to examine the correlation between the in-place strength of construction and the strength determined by the different methods. The results shown in Table 3 in the report are reproduced below.

Measurements by	Coefficient of Correlation
Ultrasonic	0.5
Impact Hammer	0.53
Lok-Test	0.96
Cylinders 6 in x 12 in (150 mm x 300 mm)	0.84
Cores 4 in x 8 in (100 mm x 200 mm)	0.92

The different relations between Lok-strength and the cylindrical compressive strength in the investigations described above are shown in figure 5.

PART II FIELD EXPERIENCE IN NORTH AMERICA

INTRODUCTION

The Lok-Test system has been in field use in Canada since July 1977, to date confined mainly to the Provinces of Ontario and Alberta. In this paper, details are given of its use on three major projects in the Toronto area.

Figure 6. Ashbridges Bay Chimney

ASHBRIDGES BAY CHIMNEY

This is a reinforced concrete chimney 675 feet'(205 m) high, (See figure 6). It was constructed using a single 8 foot (2.4 m) high steel jump form. This was the first significant project on which the system was used. It was used for two purposes.

Firstly, the Engineer had N type bolts installed in the side of the wall every 50 feet (15.2 m) to monitor the in-situ strength gain of the chimney. This was to ensure that the rate of rise did not exceed the developing strength capacity of the structure.

Secondly, during very cold weather the system was installed on behalf of the contractor who planned to pour an 8 foot (2.4 m) lift each day. F type bolts were installed in the top of each lift at the end of each pour, usually mid to late afternoon. Tests were made early next morning as early as 13 1/2 hours after completion of the pour. This work was done during a period of consistently below freezing temperature. The pours in question, while protected, were unheated, and were in an exposed lakefront location at heights above the ground of between 230 feet (70 m) and 375 feet (114 m).

The concrete mix used was specified to reach 4000 psi (28 MPa) at 28 days and the specified minimum in-situ strength for stripping and re-pouring was 1000 psi (7 MPa).

Because of the adverse conditions and the early stripping time, marginal strengths were indicated on a number of occasions. In retrospect, it appears that the standard curve we used for interpretation of results may be slightly conservative in the region of 1000 psi (7 MPa). However, other data showed that the results indicated were representative of the order of in-place strength. More data is obviously needed for very early low strength conditions and we are concentrating research efforts in this field.

The project demonstrated the need for effective communication and co-operation between all parties involved. Some problems in access difficulties, steel interference, dirty form faces, loose bolts, and premature installation caused problems. Despite the problems, the system performed satisfactorily. The need to install and operate the system in accordance with the high standards developed into it by its designers was effectively demonstrated.

A summary of typical data is as follows:

a) Strength of monitoring for rate of rise	
Number of pour tests:	17
Average age at test:	8 to 9 days
Average in-place strength indicated:	3920 psi (27 MPa) Range: 2250 psi -5800 psi (15.5 MPa - 40 MPa)
Number of N type bolts per lift:	10 to 12
LOK-TEST results::	
X	25.3 KN
Average s:	3.0 KN
b) Strength for stripping and re-pouring -	
Number of pour tests:	19
Average ambient temperature at time of pours time of pours:	-3°C
Range of in-place strengths indicated:	350 - 3200 psi (2.4 MPa - 22.0 MPa)
Range of times from pour to final test before stripping:	13 1/2 hours -4 days
Number of Lok-Test bolts per lift:	10
Range of Lok-Test results:	4.5 - 23.0 KN
Average s:	1.61 KN

RICHMOND-ADELAIDE PHASE II

This is a 33 storey prestige office building in downtown Toronto, (See figure 7). Each floor is 25,000 square feet (2322 m2) and contains approximately 690 cubic yards (528 m3) of concrete.

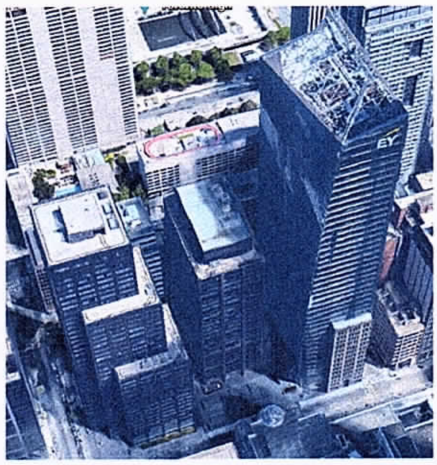


Figure 7. Richmond-Adelaide Phase II

Because of his interest in building as quickly as possible, the owner/builder was very co-operative in the proper installation of the system. The flying form system was modified with two circular portholes per bay to allow installation of N type bolts in the bottom of the slab. The method of installation and testing is shown in figures 8 to 13. Initially, each floor was poured in three pours, but was subsequently changed to two pours. To date, a rate of slightly better than one floor per week has been achieved.

Figure 8. Access porthole in flying form

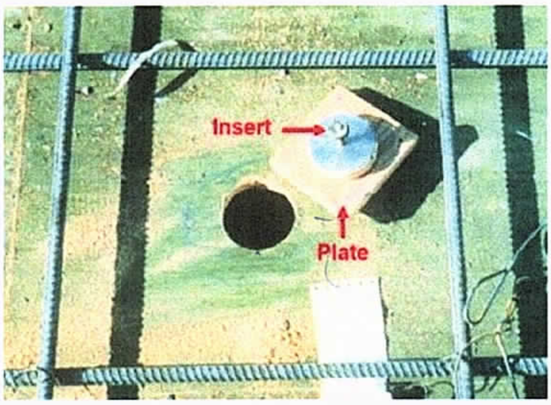


Figure 9. Removable plug

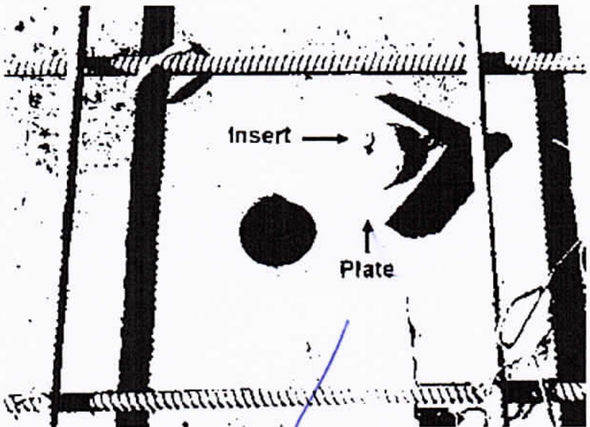


Figure 10. Plug in place in porthole

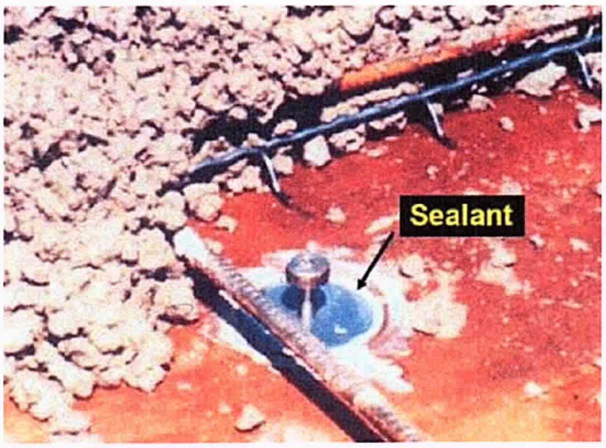


Figure 11. Lok bolt in place in floor form

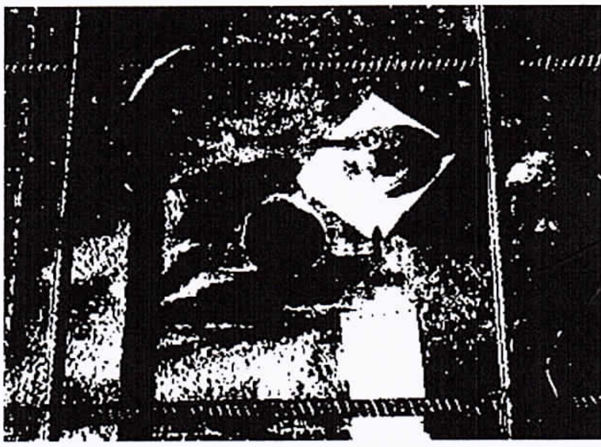


Figure 12. Connecting pull bolt to Lok bolt (NOTE: plug removed from porthole)

Figure 13. Testing

Stripping strength was established as 3000 psi (21 MPa) (4000 psi (28 MPa) concrete at 28 days specified. 5000 psi (35 MN) was used by the contractor to speed strength gain). We have interpreted this as an average equal or greater than 3000 psi(21 MPa) and statistically no concrete indicated as less than 2250 psi (15.5 MPa) (75 per cent of 3000 psi (21 MPa)

The normal programme is to test 48 hours after casting to allow stripping and flying to take place very early the next morning.

For correlation purposes, sets of 10 standard cylinders have been made each with a Lok-Test bolt cast into the bottom. The Lok-Tests are made and then the cylinders are capped and tested in the standard manner.

As a typical example: The tests done on the 7th floor are interesting to demonstrate the use of the system. The June 5th and 6th pours were stripped on schedule. The first test of the June 7th pour showed inadequate strength for stripping and further tests were scheduled for A.M. June 12th. The first 5 bolts tested showed the strength still low but a set of 10 bolts tested later the same day showed adequate strength. Examination of the data showed that, had 10 bolts been tested first on June 12th, adequate stripping strength would have been indicated.

A summary of typical data is as follows:

floors tested to date:	7
Total number of tests to date:	20 (including 4 retests two on one pour and two on another that did not reach specified strength as early as anticipated).
bolts per pour:	usually 10 (some 15, one 25)

Floor	7	7	7	7	7
Date of Pour	June 5	June 6	June 7	June 7	June 7
Date of Test	June 7	June 8	June 9	June 12	June 12
Proposed Time of Stripping	A.M.	A.M.	A.M.	A.M.	P.M.
	June 8	June 9	June 12	June 12	June 12
		LOK-TEST RESULTS			
No. of Tests Made	25	11	11	5	10
Mean In-Place Strength (psi) (MPa)	3040 (21.0)	3122 (21.5)	2818 (19.4)	2860 (19.7)	4590 (31.7)
Standard Deviation (psi) (MPa)	222 (1.5)	65 (0.5)	512 (3.5)	477 (3.3)	592 (4.1)
Minimum In-Place Strength (psi) (MPa)	2708 (18.7)	3015 (20.8)	1974 (13.6)	1926 (13.3)	3601 (24.8)
Decision	ok to strip	ok to strip	Retest AM- June 12	Retest PM-June 12	ok to strip

For all pours to date, average s for in-place tests of 10 or more bolts equals 564 psi (3.9 MPa). For the 15 sets of 10 cylinders made to date, to check calibrations s = 1.91 KN and V equals 9.9 per cent. For the cylinder tests s = 43 psi and V = 2.3 per cent.

These cylinders confirm the standard Lok-Test line of Lok-strength (KN) = 5 + 0.8 f'c (MPa) for all values over 1750 psi (12.1 MPa).

2900 BATTLEFORD

This is a 15 storey apartment with 17,440 square feet (1620 m2) per floor, poured in three pours of approximately 9300, 4070, and 4070 square feet (864, 378 and 378 m2) and respectively 190, 85, and 85 cubic yards (145, 65 and 65 m3) of concrete. (See figure 14).

Figure 14. 2900 Battleford

The project is the first in a co-operative programme between Lok-Test Limited and Dufferin Concrete Products. The concrete supplier is marketing a controlled early stripping system called ACT (Advanced Concrete Technology System). Mixes are specially formulated for high early strength gain for stripping followed by more normal strength progression at 7 and 28 days. Proof of strength is by Lok-Test.

The project is planned for a maximum of 8 or 9 hours per week to average two floors per week. Stripping is planned for as early as 20 to 24 hours after the completion of each floor pour, which typically takes about three hours.

Age at test (hours)		6.5	7	8.5	14	24	24	96	96
LOK-TEST	xtes	7.1	9.3	11.1	15.9	18.9	23	31	32
	s	1.1	1.1	1.2	1.2	1.4	1.1	2	2
	V	15.5	11.8	10.8	7.5	7.2	4.8	6.5	6.3
Cylinders	xtes	1210	1330	1840	2520	3090	3590	4930	5360
	s	33	39	42	46	32	60	90	112
	V	2.7	2.9	2.3	1.8	1	1.7	1.8	2.1
Slump (inches)		5	5	3.5	3.5	5	3.5	5.25	3.5

Specified 28-day strength is 3000 psi (21 MPa) and minimum in-place stripping strength is 2000 psi (14 MPa). Because of the very early age being used for stripping, we are interpreting this requirement as a minimum of 2000 psi (14 MPa) as indicated by the statistical analysis of the results. This may be too conservative, but for the moment is easily achievable. For correlation purposes, a total of 8 sets of 10 standard cylinders containing N type bolts have been cast and tested. Results were as follows for slumps ranging from 3 inches (75 mm) to 5 1/4 inches (130 mm).

These cylinders give a Lok-strength relationship of:

Lok-strength (kN) = 0.5 + 0.00606 f′c (psi)

A summary of field data to the date of submission of this paper is as follows:

Number of pours:	28
Number of N type bolts per pour:	15 for first pour of each of these pours forming each pour, generally 10 thereafter. Number may be increased again if construction enters a cold weather period.
Age of test for in-place tests:	Average: 20 hours Range: 13 - 64 hours
Indicated in-place strength:	Average: 3150 psi (21.7 MPa) Range: 1690 - 4360 psi (11.7 - 30.1 MPa)

(19 pours stripped in 24 hours or less, remaining 9 poured Friday and stripped Monday)

SUMMARY OF FIELD EXPERIENCE

Experience to date shows the simplicity, flexibility and reliability of the system.

Like all new systems, however, there are inherent problems plus actual differences between construction practices in North America and Scandinavia which have practical implications.

The first requirement is that all parties involved take the use of the system seriously. It will probably tend to be used predominantly to monitor early strength gain for form stripping, post tensioning, and control of winter protection and heating costs. One is thus operating during the early age of the concrete when environmental and workmanship factors may have a critical effect on the safety of the structure.

Secondly, it is important that there is good communication between all parties involved to ensure that responsibilities for inspection of rebar placement, control of quality of concrete supplied, routine and Lok-Testing, and a procedure for releasing the pour as having achieved the strength specified are all clear and understood.

Thirdly, it is vital that the system be installed correctly. The system is designed so that improperly installed bolts cannot be tested, but an adequate number of tests is needed, and untestable bolts are not desirable.

Bolts must be tightly and axially fixed to the form. We have adopted the addition of a circular 0 plate for all bolts, not just f type, whatever the form material since this assures a flat area for load application normal to the direction of loading. Additional cost is less than 10(f per bolt.

Bolts should be installed as late as possible in vertical forms to minimize hardened mortar splatter.

The number of bolts per test should be 10 per 100 cubic yards (76 m3) of concrete per element. For quantities over 100 cubic yards (76 m3) per pour, we feel that the number can be decreased to say, 5 per additional 100 cubic yards (76 m3) but 10 is preferable and judgement should be exercised.

Where a flying form system is used, we prefer, as for all floor pours, to have the bolts in the bottom of the form, as shown in figures 6 to 11. The access ports are simple to provide and once placed are re-usable for the whole project. We prefer to put in 50 per cent more ports than 10 per 100 cubic yards (76 m3). This provides for extra tests at the beginning of the job when persons new to the system need confidence. It also provides for more tests to check out the mix if it is in any way special, i.e. high early strength. Finally, in cold weather it allows for testing at more than one age if strength gain is lower.

We prefer to avoid F type bolts when N type can be used. While F type bolts can be successfully used, they require a, higher standard of care in installation, particularly in ensuring that no air is trapped under the supporting plate and flotation cup.

COSTS

Equipment costs are currently about $4500 in the United States and $5000 in Canada for each instrument depending on options. Quantity discounts can reduce the prices slightly.

N type bolts are currently about $25 for a set of 10 but North American production of these is imminent and should reduce costs by at least 1/3.

Costs for the use of the system are best separated into initial installation costs and operating costs. With a flying form system for a typical apartment building, about 45 ports will have to be installed. We find it necessary to supervise and sometimes take part in this procedure and, of course, we decide the location of each bolt to ensure representation throughout the pour.

Depending on the attitude and competence of site personnel, bolts can either be installed by them or the testing company. If the former, then the only subsequent involvement of the testing company is to make, interpret, and report the tests.

Assuming the latter, a reasonable cost for supplying bolts and carrying out the testing is probably 75t/cubic yard ($1.00/cubic m).

Cost effectiveness is, of course, a more complex subject and data is not as yet easy to obtain. Obviously, reductions in formwork quantities, shorter construction schedule with decreased overheads, control of winter protection and earlier post-tensioning can lead to savings many times the cost of extra testing. Reduction in interest charges, earlier mortgage draws, and increases in rental income due to earlier occupancy can achieve significant savings.

And who knows, eventually we might catch up to the Danes and use such a test instead of cylinders. Just don't hold your breath!

INTERPRETATION

The largest area of possible dispute and difficulty in using such a test system arises in the evaluation and application of results. Of necessity, the system will be used in situations where the results of the tests are urgently awaited.

Increasingly, Engineers are aware that in-place strength may be both significantly different to and lower than the strength of standard cylinders.

Recognition of this is spreading in codes. North American standards accept that cores averaging 85 per cent of f'c and individual

cores down to 75 per cent of f'c indicate structurally acceptable concrete. But, is this true at all strength levels? Is the Engineer happy with a 7500 psi

(51.7 MPa) core out of 10,000 psi (69 MPa) concrete? If concrete is stripped at very early ages, is the strength specified for stripping the minimum or mean, and can 85 per cent or 75 per cent of that value be accepted for individual results where the concrete pour is represented by 10 or more tests on the actual concrete and the mean strength is satisfactory? If the lowest strength in a pour the lowest test result or the statistically determined minimum? What is the comparative reliability between a physical test on the actual structure and a standard cylinder test?

While data to solve these problems is now being accumulated rapidly with the spread of in-situ testing, some of the above questions may remain controversial for some time to come.

CONCLUSION

The Lok-Test system of pull out tests offers a simple, reliable, economic, and non-destructive way of determining the actual in-place strength of concrete at all strength levels in a practical statistically valid manner.

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