

ACHIEVING SAFETY AND ECONOMY IN
HIGH RISE CONCRETE STRUCTURES THROUGH
THE USE OF IN-PLACE TESTING

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Presented at The Third International Conference
on Tall Buildings, Chicago, Illinois
January, 1986

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ABSTRACT

The paper discusses the use of pullout testing to achieve safety and economy in construction.

This test is more suitable as a construction tool than the traditional 28 day cylinder test. Collapses have resulted from unrecognised low in-place strength and this test solves this problem.

The procedure as per ASTM C900 is illustrated.

The development of specifications and interpretation are discussed. A model specification is presented and suitable interpretation criteria suggested.

Because of the possibility of excessive deflections in concrete structures loaded at an early age, creep and curing factors are reviewed. The stress-strength ratio is seen to be critical.

The benefits of accelerating construction schedules are reviewed and illustrated by an example showing the financial savings which can be achieved.

¹ Published under the title "The Use Of NDT In Construction"
Colloquim On Concrete In The Developing Countries, Lahore, Pakistan,
December 1985.

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INTRODUCTION

This paper discusses the use of one non-destructive test method, the pullout test, to achieve safety and economy in construction.

While reference to pullout testing occurs in North American technical literature as early as 1938 (Skramtajew 1938), it has only been seen as a potentially usable site test method for the last fifteen years.

In the early 1970's, (Richards 1972) and (Malhotra 1972) published data on tests made with apparatus based on designs by Richards. In 1973 the North Carolina State Highway 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 Richard's design and some using a Danish apparatus then just introduced in Canada. All the experience described and data given in this paper refers to the use of the latter system (Kierkegaard-Hansen 1975).

Since then the procedure has been legitimized by the publication of an ASTM Standard and the method is now in use worldwide.

BACKGROUND

The pace of construction today makes the use of the traditional 28 day cylinder test inappropriate as a construction tool. While it still has relevance as a measure of the quality of concrete delivered to a site, and is still the legal test for this purpose, it does not help the building process.

Indeed, when rapid construction schedules are used, form removal, post-tensioning, and the cessation of curing as soon after the placing of concrete as one day, make a reliable knowledge of the in-place strength prudent. In cold weather conditions such ~~data becomes an essential part of safety.~~

In January, 1971, a sixteen storey apartment building in Boston collapsed during construction with the loss of four lives. Investigation showed that while all relevant standard test cylinders met specification requirements, the in-place strength of the concrete at the time of collapse was not much more than 50 per cent of the specified 28 day strength. And it was by then two months old!

Since then there have been a number of spectacular collapses of structures during construction. A cooling tower collapsed in West Virginia in 1978, with the loss of fifty-one lives. New Civil Engineer International of December, 1979, quotes the U.S. National Bureau of Standards report as indicating that "all the evidence points to the concrete having been loaded before it gained sufficiently in strength". This factor has been cited in other failures.

As a result, the civil authorities are making a detailed study of in-place testing. It is anticipated that in the near future it will become mandatory to carry out in-place testing before form removal or other operations where safety is critical.

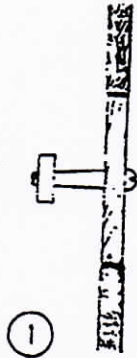
Insofar as standards are concerned, the American Society for Testing and Materials has published ASTM C 900-82 "Pullout Strength of Hardened Concrete". In Canada, the main concrete standard is Canadian Standards Association CAN 3-A23-M-77. In the latest edition this standard encourages the use of in-place testing and lists pullout testing as one of the recommended methods. ACI Committee 228 on Non-Destructive Testing of Concrete is currently drafting a State Of The Art Report On In-Place Methods For Determination Of Strength Of Concrete.

TEST PROCEDURES

ASTM C 900-82 "Pullout Strength Of Hardened Concrete" states:

"1.1 This method covers determination of the pullout strength of hardened concrete in test specimens or structures by measuring the force required to pull an embedded metal insert and the attached concrete fragment from a concrete mass."

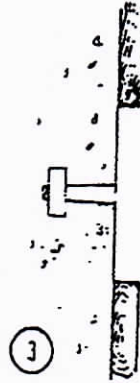
Figures 1 to 5 show the basic principles involved.



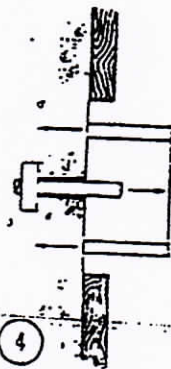
① THE TEST BOLT INCLUDING DISC AND STEM IS MOUNTED ON THE INSIDE OF THE FORM PRIOR TO PLACING CONCRETE.



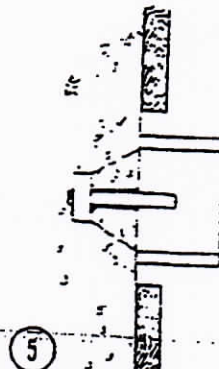
② CONCRETE IS PLACED.



③ THE FORM (OR PART OF THE FORM) AND THE STEM OF THE TEST BOLT ARE REMOVED.



④ A PULL BOLT IS SCREWED INTO THE DISC, AND THE INSTRUMENT IS MOUNTED ON THE SURFACE OF THE CONCRETE.



⑤ BY APPLYING A FORCE WITH THE INSTRUMENT A SMALL PIECE OF THE CONCRETE IS DISLODGED.

SPECIFICATIONS AND INTERPRETATION

The use of pullout testing has so far been predominately to determine form stripping times. This has invariably been part of an accelerated construction programme involving floor form stripping times as early as one day after casting. Since the introduction of the pullout test on a site has generally followed the issue of contract documents, specification requirements have been developed on each project by discussions with the structural engineer involved.

Generally it has been agreed that form removal can be made at about 75% of the specified 28 day strength for floor slabs, the range being 67% to 80%. For vertical elements form removal can be carried out at much lower strengths and on chimneys and cooling towers 1000 psi has been specified (7 MPa).

In interpretation, codes and specifications do not yet provide guidance in interpretation and structural engineers generally do not have experience. If a number of tests are made, is the average the strength required for form removal or is some calculated minimum the value that has to equal or exceed this strength? In practice, a number of approaches have been adopted, one of which follows.

A set of test results is expressed as a mean, a standard deviation, and a minimum calculated as follows:

Specified Strength = Mean Value of Test Results - k.s

where s is the standard deviation and k is taken from the following table based on the number of tests performed on the particular class of concrete.

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

Generally this procedure is followed, but it is thought to be conservative. On some projects this specified form stripping strength has been interpreted as the value the average of the pullout tests has to meet with no result less than 75 per cent of this value. When very early stripping times have been used, this minimum has been increased to 80 per cent of this value for a two day cycle and 90 per cent for one day cycle. Again, this approach is thought to be conservative. On most projects, however, the minimum strength calculated by the above procedure has been required to equal or exceed the specified strength for form removal. This is even more conservative.

If in-place testing is to become widely used it must be both safe and economic. Pullout testing provides an economic way of obtaining adequate numbers of tests from which statistically valid calculations can be made. With this number of tests a minimum strength can be calculated. In the past, where a small number of tests such as field cured cylinders determined form removal times at greater ages no statistically valid minimum was determined, or could be determined. As long as all the tests or their average exceeded a required value everyone was happy. With the more sophisticated approach possible with pullout testing a true minimum strength for a pour can be calculated.

The following clauses are from a contract specification. They worked well in practice and are recommended as a model for guidance.

"Issue reports of in-place testing to Structural Engineer, Resident Engineer and Construction Manager immediately after tests are made and checked. Keep file on site.

1. Concrete Tested with Pullouts

Until correlation between 28-day pullout tests and concrete cylinder tests is satisfactory to the Engineer, make 2 cylinders per 100 cubic meters or less of each pour for testing at 28 days.

2. Where In-Place Testing is Required

Install at least 15 pullout inserts per 100 M³ pour of concrete. For pours in excess of 100 M³ provide at least an additional 1 insert per 20 M³. Install 2 additional pullout inserts per pour for testing at 28 days.

In the substructure install inserts on the top of slabs at random locations agreed by the Engineer. In the superstructure, direct the installation of inserts in the soffit of slabs at random locations agreed by the Engineer.

Test inserts just prior to the time it is proposed to remove forms. Generally, at least 10 tests will be made. If the first five results indicate the concrete is below form removal strength, discontinue testing and reschedule. If a set of 10 tests indicates results marginally below the required values, recommend further tests then or additional curing time.

After checking, report the results on the approved form as provided in the Terms of Reference.

Where necessary to check exposed areas, make additional tests either using additional inserts or maturity meters.

Test two inserts at 28 days.

During cold weather concreting make temperature checks within the heated or insulated areas and record."

CREEP AND CURING FACTORS IN THE EARLY STRIPPING OF FORMWORK

When early stripping of formwork is proposed there is concern about creep and the adequacy of curing. A review of the literature (Neville 1972) reveals the following:

- (1) For a constant stress-strength ratio creep increases as the age of loading increases. Creep is also greater the smaller the fractional strength increases. Creep is smaller at earlier ages than later ages given a constant stress-strength ratio.
- (2) Earlier investigation (e.g., Davis et al) had shown that creep increased with earlier age at loading but had failed to take into account the effect of stress-strength ratio. Since their load was constant the stress-strength ratio at earlier ages was higher. At early ages rate of creep is higher except for concrete loaded very early i.e. 1 - 2 days.

- (3) Recent work (Timusk and Ghosh) found that at a given stress-strength ratio creep decreases with the logarithm of the age of loading between 18 hours and 28 days. Attempts to relate creep to elastic deformation at time of loading have not been convincing.
- (4) It appears that the most critical factor affecting creep is stress-strength ratio. Therefore if the stress is reduced or the strength is increased creep will be reduced independent of the age of loading.
- (5) It is normal for the Engineer to require that concrete gain a certain minimum strength or maturity before
 - a) loading and
 - b) cessation of curing.
- (6) Criteria specified by Engineers vary, but values between 0.70 and 0.85 f'_c are typical of those specified by highly professional Engineering offices.
- (7) Curing equal to 5 days at 50°F or 3 days at 70°F are normally adopted. This approximates to a strength of 0.50 - 0.60 f'_c .
- (8) At present acceptable criteria for loading lie between 0.70 and 0.85 f'_c and for cessation of curing approximately 0.50 - 0.60 f'_c is acceptable.
- (9) It is therefore concluded that an acceptable stress-strength ratio at time of loading is obtained at between 0.70 and 0.85 f'_c . If, therefore, concretes are designed to reach these parameters at early ages creep should not be increased and may be reduced.

ACCELERATED PROGRAMMES

Historically, concrete test cylinders have been used to determine the potential quality of concrete delivered to a site. In addition, it has been assumed - with good reason - that if the concrete is installed in accordance with normal accepted practice, the structure will be safe. This procedure has been used since early in this century.

A number of factors now apply which make this standard practice no longer a valid approach in assisting in the construction process.

- (a) The speed of all forms of construction today makes 28 days far too long to wait for confirmation of the potential adequacy of the concrete. With slipforms 500 vertical feet (152.4 m) is possible in a month. Jumpforms can be poured an 8 foot lift (2.4 m) every day, and contractors are now achieving two to three floors per week with site-cast concrete on major commercial and residential structures using flying forms.
- (b) In cold weather, the safety to be of structure has to one of paramount concern.
- (c) To meet economic realities, early post-tensioning, form removal, and termination of cold weather curing as quickly as possible, are desirable.
- (d) Concrete mixes can now be formulated to give high percentages of f'_c within 1 to 3 days.
- (e) Reliable test procedures for the rapid determination of the in-place strength of concrete such as pullout tests are now available.
- (f) A.S.T.M. approved procedures for such tests now exist.

A policy decision to accelerate the construction programme is justified if significant savings can be achieved. With acceleration, savings can be realised in the following areas (Bickley 1982):

- Reduction in financing costs.
- Earlier rental of facilities.
- Overhead.
- Formwork costs.
- Re-shoring costs.
- Cold weather heating costs.
- Savings on concretes meeting 91 day requirements.

The maximum benefit will only be realized if all construction activities are re-scheduled to the accelerated programme.

Acceleration may involve the design and use of a wide range of special mixes. These range from mixes which allow the removal of forms from floor slabs at 24 hours after casting, to 9000 psi cast-in-place

concrete, and the use of 56 and 91 days for determining f'_c in order to obtain technical or economic benefits. Experience shows that with the right specification, pre-construction meetings, and effective supervision and testing, ready-mixed concrete suppliers can deliver these special concretes with consistency and reliability.

The use of special mixes will involve the agreement of the building officials having jurisdiction. This agreement should be obtained prior to the start of the project.

In-place pullout testing methods complying with ASTM C900 are used but the principles could be met by the use of other approved in-place test methods.

The criteria for the removal of forms has to be decided by the Structural Engineer for the project. Generally values in the range of $0.7 - 0.8 f'_c$ are used.

The Contractor is responsible for deciding when to remove forms and the Inspection and Testing company is responsible for determining that the Engineer's criteria for form removal has been met.

Concrete mixes can be formulated to meet any form removal programme. Depending on the formwork sub-contractor's programme, the mixes can be designed to achieve strengths which match this programme. If, for example, the programme calls for a five-day work week with form stripping at one day, concrete placed Monday to Thursday could be a mix suitable for one day stripping. On Friday, however, a mix suitable for three day stripping would be used since it is cheaper and there would be no advantage in gaining strength faster.

The use of this approach on a number of projects has been reported in the technical literature (Bickley 1982).

Control of formwork stripping is achieved by the use of the ~~in-place testing.~~

The pullout system used provides about ten times as many tests as are made to meet standard cylinder testing specifications. All tests are physical tests in place (i.e. the test is on the concrete in the element of structure being stripped). A result

that is statistically valid can therefore be obtained. The test and the calculation of results are carried out on site, the apparatus being portable.

A control system is exercised which involves the following steps:

1. Testing on site.
2. Calculation of results on site.
3. Checking arithmetic and results with an authorized person at head office by telephone. This takes only two or three minutes as all authorized personnel have a suitably programmed calculator on their desk.
4. Confirmation in writing to the Contractor's authorized representative giving:
 - a) Mean strength, standard deviation, and minimum strength.
 - b) Levels and limits of the part of the structure tested.
 - c) Whether the area tested meets or does not meet the Structural Engineer's requirements for stripping.
5. A signature of the Owner's authorized site representative on a standard form to confirm receipt of the data is obtained for record purposes.

For rapid dissemination of the data on site a colour coded, multi-copy, self carbon form is used. This is completed in manuscript. Its distribution is limited to those who need it. In the event that a problem arises, the Structural Engineer is notified as soon as possible.

For a typical pour the above procedure takes approximately 30 minutes. If results fail to meet stripping criteria, testing is stopped as soon as this is obvious (usually after 5 tests) and re-testing is scheduled for later. Enough pullout inserts are installed to allow this to be done.

For vertical elements where rapid strength gain is irrelevant, a different approach is used.

~~The design strength of columns is not required until long after~~
they are cast. Therefore a mix proportioned to meet design requirements 91 days after casting is used. This has been done on a number of major projects and the results have been reported in the technical literature (Bickley 1982).

The type of mix used for this purpose might contain pozzolanic material to ensure good strength gain at ages later than 28 days.

Adequate curing of the vertical elements is required to ensure strength gain with age. This is easily achieved by spraying all vertical elements, designated by the Structural Engineer, immediately after stripping with a colourless and fugitive curing compound complying with ASTM C309-74.

For confirmation of specified strength at 91 days, and of appropriate strength gain earlier, additional pullout inserts may be specified in columns and walls where designated by the Structural Engineer.

For confirmation that re-shores may be removed, specified spare inserts, already in place in the slabs may be used.

A summary of costs and savings taken from a medium sized apartment project was as follows:

Additional costs of accelerated concrete mixes	\$ 55,195.
Net additional cost of concrete resting	9,450.
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Total additional cost of accelerated concrete mixes and testing	\$ 65,645.
Savings on concretes meeting 91 day test requirements	62,304.
Savings on curing costs	72,000.
Savings on formwork costs	74,532.
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TOTAL SAVINGS	\$208,836.
NET SAVINGS	\$143,191.

Potential savings in financing costs, overhead, and re-shoring costs, resulting from earlier completion of facilities due to a shortened construction period are not included in the above amounts.

SUMMARY

The use of a non-destructive in-place test procedure such as the pullout test can provide greater safety in construction. Relatively large numbers of tests can be made on the actual concrete in the structure. Statistical interpretations are made possible.

Combined with suitable concrete mix designs, the use of such testing can also make possible accelerated construction schedules resulting in significant cost savings.

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