How to Build Faster for Less - The Role of In-Place Testing in Fast Track Construction

by

John A. Bickley, P.Eng.
President, John A. Bickley Associates Ltd., Toronto, Ontario, Canada

Kal R. Hindo, P.E.
Sr. Vice President, NTH Consultants Ltd., Farmington Hills, Michigan, U.S.A.

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Abstract

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The economic needs of today dictate that many projects shall be built to a fast-track schedule. Recent developments in cementitious materials and admixtures have provided unlimited scope for the formulation of concrete mixes. Early age and later age high strength requirements can be met with the same mix. The safe removal of formwork from structural components can be accomplished at ages less than 24 hours. Post-tensioning, re-shoring, and curing in cold weather can be controlled to optimum economic cycles.

These economic benefits can be achieved by the use of selected in-place testing procedures which allow a fast track approach with safety.

Using a financial analysis, this paper demonstrates how the authors' approach can form part of a logical plan which facilitates speed of construction, ensures high quality, and results in significant cost savings.

Keywords

Non-Destructive Tests
Fast-Track Construction

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Introduction

For each month a construction schedule can be shortened, there will be reductions in overhead costs. In addition, with earlier occupancy, increases in revenue and reductions in interim financing costs can produce savings to the Owner.

A significant acceleration in the cast in-place concreting program will often enable the completion of a building within the time frame of an accelerated construction schedule.

Concrete mixes and in-place testing methods which make an accelerated programme practical are readily available.

Rationale for an Accelerated Construction Schedule

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:

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

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

Technical Considerations

Acceleration may involve the design and use of a wide range of special mixes in order to obtain technical or economic benefits. These range from mixes which allow the removal of forms from floor slabs as early as 24 hours after casting, and from columns as early as 11 hours, to the use of 56 and 91 days as the age for determining f'_c. Experience shows that with the right specification, pre-construction meetings, and effective supervision and testing, typical urban ready-mixed concrete suppliers can deliver these special concretes with consistency and reliability.

The use of special mixes and testing may involve the approval of building officials having jurisdiction. This approval should be obtained prior to the start of the project.

In-place pullout testing methods complying with ASTM C900 and maturity testing complying with ASTM C1074 were used. However the same principles could be met by the use of other approved in-place test methods. The use of a large number of pullout tests enables an accurate estimate of the strength of the concrete in the structure to be made using statistical procedures.

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. In the examples given in this paper 0.75 f'_c has been assumed in most cases.

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 have been met.

Concrete mixes can be formulated to meet any form removal Program. Depending on the formwork sub-contractor's program, the mixes can be designed to achieve strengths which match this program. If, for example, the program 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.

This approach has been reported on a number of projects in the technical literature [1,2,3].

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

The pullout system used provides about 10 times as many tests as are made to meet standard cylinder testing specifications. All tests are physical tests in-place. The test is on the concrete in the element of the structure which is being stripped. The test and the calculation of results are carried out on site, the apparatus being portable. By making a large number of tests, an accurate estimate of the in-place strength can be made using accepted statistical [5,6] procedures. The statistical methods provide valid evaluation techniques to determine the statistical concrete strength values. These methods are used to determine the minimum strength for use as the acceptance criteria.

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 by telephone with an authorized person at the head office. This review takes only two to 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 is obtained for record purposes on a standard form to confirm receipt of the data.

For rapid dissemination of the data on site a colour coded, multi-copy, self carbon form is used. This is completed in manuscript form. 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 form removal criteria, testing is stopped as soon as this becomes evident (usually after 5 tests) and re-testing is scheduled for a later date. Enough pullout inserts are installed to allow this to be accomplished.

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.[4]

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 28, 56 or 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, spare inserts, already in place in the slabs, may be used.

Specifications

The appropriate test of methods must be specified and in-place testing requirements detailed. One specification contained the following clause:

> "**Where In-Place Testing is Required**
>
> Install at least 15 pull-out inserts per 130 cu.yd. pour of concrete. For pours in excess of 130 cu.yd. provide at least an additional 1 insert per 26 cu.yd. Install 2 additional pull-out 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 test results on the approved form.
>
> 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."

Financial Analysis

To determine the costs and savings which will result from the acceleration of the construction program, a financial analysis is made. Where significant strength is required at an early age, the concrete costs will be somewhat higher. If the specified strength can be achieved at a later age than 28 days then the concrete needed will cost less.

There will be an additional cost for the in-place testing required.

In all accelerated programs on which the authors have used this approach, there has been a net saving in construction costs alone. When interest charges, overhead and earlier rental income is added, the savings can be somewhat significant.

The attached table summarises the costs and savings that were estimated for a number of projects in Canada, Michigan and Florida. The examples given are all of medium to high rise buildings. The same approach has achieved major savings on a large area, one-storey structure with multi-use forms for a standard layout.

In most cases all the savings were not determinable by the authors, since some owners preferred to keep the information confidential. In all the reported cases, the savings made possible by an accelerated programme convinced the owners to proceed.

Summary

The use of specially formulated concrete mixtures and modern form systems make fast track construction possible.

The correct use of approved in-place tests make this fast-track construction safe and economical. Without the application of the procedures described in this paper such programs would be hazardous.

The main incentive to build faster is financially driven as major cost savings can be achieved. In practice, the adoption of the criteria described results in the use of higher quality concretes than needed in the finished structure. The test procedures, properly applied, together with the high level of quality control needed to consistently meet the early formwork removal criteria, provide the high level of assurance needed for safety. The approach described in this paper should not be attempted unless all parties to the contract are as committed to the safety aspects as they are to the financial benefits that could result.

Summary of Savings

	20 Storey Office Building	15 Storey Utility Headquarters	30 Storey Office Headquarters	Twin Apartment Towers, 30 and 31 Storeys	14 Storey[5] Office Building	3 Storey Computer Center	9 Storey Condos
SAVINGS	(All Numbers are $/1000)						
Interest Charges	600	1750	188	NC	NC	533	43
Earlier Rental	200	NC	25	NC	NC	466	40
Formwork	120	25[4]	NC	75	NC	NC	NC
Re-Shoring	NC	NC	NC	NC	NC	NC	NC
Winter Heating	NC	NC	114	(0.3/Pour/Day)	NC	NC	NC
f'_c at 91 days	NA	50	38	62	23	NA	NA
Design	120	NA	NA	NA	NA	NA	NA
Overhead	NC	NC	20	NC	NC	NC	NC
Sub-Total	1040	1825	385	137	NC	999	83
COSTS							
Concrete	20[1]	320	152	56	93	20	0
Testing	15[2]	38	24	10	14	10	4
Sub-Total	35	358	176	66	107	30	4
NET SAVING	1005[3]	1467	209	71	NC	969	79

Notes:
- NC Not Calculated.
- NA Not Applicable
1. 0.04¢/Sq.Ft.
2. 0.03¢/Sq.Ft.
3. 5% of Total Cost
4. Refund From Formwork Contractor
5. Project Started Behind Schedule. Time Made Up by Acceleration.

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