COST EFFECTIVENESS OF IN-SITU TESTING

by

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ABSTRACT

This paper illustrates by way of a case study how in-situ testing can be applied to accelerate a construction programme and summarises the cost benefits that result.

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INTRODUCTION

For each month a construction schedule can be shortened, there will be reductions in interest and 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 programme will 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 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.

It should be remembered that the maximum benefit will only be realized 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. 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, typical urban 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 in this example but the principles could be met by the use of other approved in-place test methods. The use of a large number of pullout tests gives a statistically valid determination of the strength of the concrete in the structure.

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 example given in this paper 0.75 f'_c has been assumed.

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 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 [1,2].

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 statistically valid result is therefore 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 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 [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 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.

COSTS

The prices used are based on typical prices in recent bids. The data used in this paper applied to a twin tower high-rise apartment project in Toronto.

Concrete Mixes

a) For early stripping:

The following are premiums assumed to apply compared to the cost of normal 30 MPa concrete.

Concrete suitable for stripping at		Premium $/m³
1 day	(24 hours)	11.45
2 days	(36 hours)	7.75
3 days	(60 hours)	3.40.

b) For 91 day strength:

Reduction assumed for determining f'_c at 91 days instead of 28 days - \$8.00/m³.

Concrete Quantities

			m^3
A.	Podium (from above the slab-on-grade to the 8th level)		
		Horizontal elements	3613
		Vertical elements	1768
B.	Apartment Towers		
	North Tower 31 Floors above 8th, South Tower 30 Floors above 8th.		
		Horizontal elements 263 m^3 x 61 floors	16043
		Vertical elements 124 m^3 x 61 floors	7564
C.	Roof of Towers		
		Horizontal elements	485
		Vertical elements	224
	Total excluding substructure and slab-on-grade		29697.

Concrete Costs

Accelerated Mixes

Assuming three day stripping for concrete which would be reasonable for this type of project, the additional cost of concrete would be:-

16,528 x \$3.40 = TOTAL: \$56,195.

91 Day Mixes

- Saving on 91 day concrete mixes:

7,788 x \$8.00 = TOTAL: \$62,304.

Concrete Testing Costs

Total quantity = 26,697 m^3.

Routine testing of cylinders including some field cured cylinders would require approximately 1,200 cylinders. A unit price of \$15.50 per cylinder is assumed. Adding in costs of air tests and some miscellaneous testing, the routine testing would cost approximately \$18,600.00.

In-place pullout testing systems carried out on a visiting basis cost approximately \$1.45 per m^3 of concrete. The normal cost of testing all horizontal elements of the superstructure for early stripping would therefore be \$23,965.00. For the additional in-place testing of columns and shearwalls if required, the estimated cost of testing would be approximately \$5,000.00.

It is also possible to eliminate about 90% of the routine testing of cylinders for horizontal elements of the superstructure because they are tested by pullouts.

The following is a summary of testing costs.

a)	Accelerated programme	
	In-place testing	$24,000.
	Cylinder testing	$ 1,050.
	Contingency	$ 1,000.
	Consulting	$ 3,000.
	Total cost of testing:	$28,050.
b)	Cost of normal testing	$18,600.
c)	Premium for accelerated programme.	$ 9,450.

Winter Heating Costs

Where the structural frame is constructed during cold weather, a change by acceleration from seven days heating per pour to three days heating per pour is assumed.

An average figure of $300. per day, per pour, is taken for heating costs. If 60 pours are made in cold weather the saving would be $300. x 4 days x 60 pours = $72,000.

Formwork Costs

The following slab pours have been assumed.

	Size of Pour m^3	Total Concrete m^3	No. of Pours	Approximate Area per pour m^2
Superstructure	130	16500	125	650

With a 3 day form removal period, assume 1 pour per set of forms per week and with a conventional 7 day form removal period, assume 1 pour per set of forms per 11 days. The increase in form rental time for a 7 day form removal period is therefore:-

$$\frac{11}{7} \times 125 - 125 = 71 \text{ weeks.}$$

Prices for form rental range from \$4.85 to \$8.07 per square metre per month. Taking a median value of \$6.46 the saving in formwork costs using a 3 day form stripping time would be:-

$$\frac{650 \times 6.46}{4} \times 71 = \$74,532.$$

Re-Shoring Costs

The use of pullout inserts surplus to form removal requirements can be used to determine the earliest permissable time to remove re-shores. Since accelerated mixes normally reach specified

28 day strength in much less than 28 days, an additional economy can be made in reduced re-shoring periods.

SUMMARY OF COSTS AND SAVINGS

Additional costs of accelerated concrete mixes	$ 56,195.	
Net additional cost of concrete testing	9,450.	
Total additional cost of accelerated concrete mixes and testing.		$ 65,645.
Saving on concretes meeting 91 day test requirements	62,304.	
Savings on winter heating costs .	72,000.	
Savings on formwork costs	74,532.	
TOTAL SAVINGS		$208,836.
NET SAVING		$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

Documents for the concrete supply and forming and placing contracts need amendments. Draft clauses have to be provided to ensure that the tenders clearly identify the base bid cost for standard concrete construction, and the cost of an alternative accelerated programme. Preliminary discussion on the alternative with one or more potential bidders is often advantageous.

The forming and placing contractor or sub-contractor is the key to an accelerated programme and has to be motivated. This needs discussion by the construction team.

At the appropriate times pre-tender and pre-construction meetings should be held.

Appropriate quality control of the concreting process is required.

Provided these procedures are followed, the use of in-place testing can result in significant economies.

REFERENCES

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