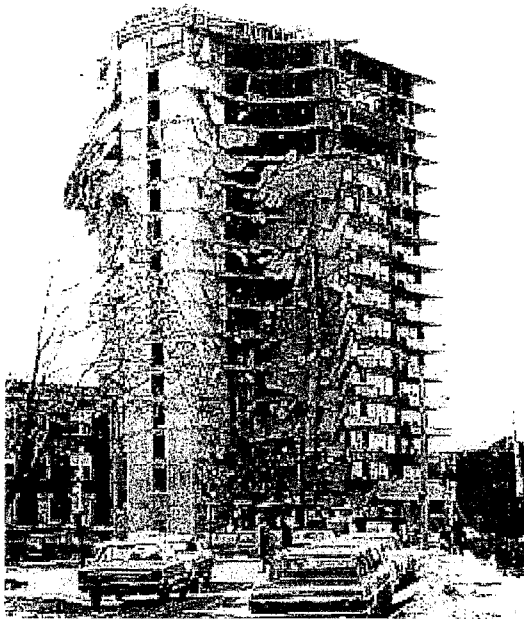


"Build Faster for Less" course completed successfully in Liverpool, UK

The one-day course December 5th, 2000, at The University of Liverpool attracted 20 persons from academia, control authorities, contractors and structural engineers in the UK.

The lecturers were Adjunct Professor John A. Bickley, Toronto, Canada and Professor John Bungey, The University of Liverpool. Mr. Claus Germann Petersen of Germann Instruments trained the attendees in the practical Lok-Testing.

Cases were presented illustrating how safety against collapse as well as large economic benefits can be achieved by implementing accelerated construction schedules using optimized concrete mixes tested in-place with Lok-Test before form stripping. The cases reported from Canada and the UK covered construction of multi-story buildings, cooling towers and beams in parking garage structures being post-tensioned.



Multi-story building collapse in Boston, USA. Standard cylinders tested had passed the requirement. Subsequent investigation showed the in-place strength to be 50% of the cylinders at the time of stripping of the forms



Canadian example of a completed high rise building where an accelerated construction schedule was implemented resulting in a net benefit of 375,000 \$



Lecturing in accelerated construction schedules at the Liverpool course



Training of the course attendees in Lok-Testing, supervised by Mr. John Bickley

BUILD FASTER FOR LESS

The Use of In-Situ Testing to Speed up Construction and Increase Profits.

A One-day Workshop was held in The Department of Civil Engineering and Foresight Centre of The University of Liverpool. The workshop included talks, demonstrations and practical sessions on the use of pullout testing, namely the LOK- and CAPO-tests, in combination with COMA maturity measurements, for accurately determining the early age strength of concrete to enable safe and early striking of formwork or tensioning. Speakers were Prof. J. H. Bungey of the University of Liverpool, and Mr. J. A. Bickley who is a Concrete Consultant in Toronto, Canada. Demonstrations and practical sessions were conducted by Mr. C. G. Petersen of Germann Instruments A/S, Copenhagen, Denmark.

Prof. J. H. Bungey gave an overview of test procedures to set the theme of the workshop and then concentrated on the use of the above methods on site for:

- The construction of cooling towers at Drax in North Yorkshire. The project demonstrated that use of the tests could enable the formwork to be removed with confidence, even in cold weather, and help construction schedules to be maintained.
- The European Concrete Building Project at the Cardington Laboratories of the Building Research Establishment in the UK, see Figure 1.



Fig. 2: Scotia Plaza – Toronto – Canada.

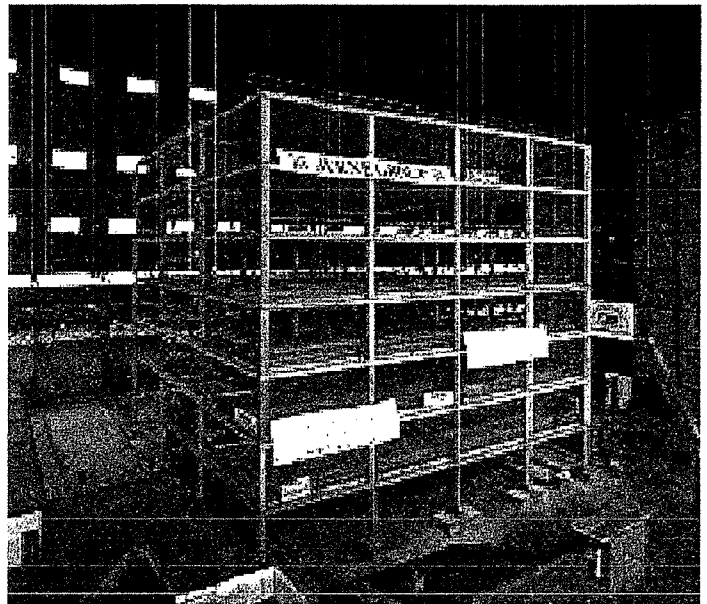


Fig. 1: The European Concrete Building Project.

This project involved the construction of a seven storey insitu reinforced flat slab building frame, utilising a range of construction methods with the aim of improving speed, reducing costs and improving the quality of such construction. See: <http://www.bre.co.uk/bre/cardington/cardlab1.html> for a virtual tour of the Cardington Testing Facility. The study⁽¹⁾ compared a range of different in-situ test methods and approaches, including pull-out testing with and without planned inserts, pull-off testing, maturity measurements and temperature-matched curing. A Best Practice guide⁽²⁾ on “Early age strength assessment of concrete on site” has been produced as a direct result of this work.

Mr. J. A. Bickley started his talk with his own experiences from the construction of the CN Tower in Toronto. Maturity measurements were used to enable the slip forming operations to be carried out safely even during adverse weather conditions. He also provided examples of the use of LOK-tests during the construction of cooling towers for electricity generating stations. However, the rest of his talk concentrated on multi-storey buildings in Toronto. These were:

- Scotia Plaza, fig.2. A multistorey building with most of the concrete containing ground granulated blast furnace slag (ggbs) as a cement replacement. Fast track construction schedules were maintained without any early age strength development problems despite construction starting in Summer and continuing throughout the Winter months. This was achieved by varying the level of cement replacement by ggbs according to the season of the year and the prevailing temperatures. Self-climbing forms were used on this project and were removed from vertical elements as early as 11 hours to be lifted to the next floor.
- The Trinity Square Head Office for Bell Canada⁽³⁾ and the 30 storey College Park Phase II office building. All floors in both buildings were tested in-situ to determine formwork removal times and the time to remove props.

Unique to these two projects was the fact that the City of Toronto waived standard cylinder test requirements; acceptance criteria relied solely on LOK-tests.

It was explained that the main incentive to build faster is financially driven as major cost savings can be achieved, see Table 1. The correct use of approved in-place tests make this fast-track construction safe and economical. Commitment from ALL the parties involved is however needed to realize the economic benefits. These include:

- Acceleration may involve the design and use of a wide range of *special mixes*, nicknamed "Super-Stripper", which achieve strengths to match the formwork sub-contractor's 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, see Table 2, and there would be no advantage in gaining strength faster. For the substructure and vertical elements where rapid strength gain is irrelevant, a different approach is used – A mix proportioned to meet design requirements at 91 days after casting is used. This mix may contain pozzolanic material to ensure good strength gain at ages later than 28 days.

Concrete Suitable for Stripping at:	Premium \$/yd ³
1-day (18 hours)	6.75
2 days (42 hours)	5.06
3 days (66 hours)	3.94
91 days	-6.50

Table 2: Premiums assumed to apply compared to the cost of normal 30MPa concrete.

COST TO OWNER	
Additional costs from the use of concrete mixes to meet early formwork removal time, down to 24 hours after casting. This allows a faster construction schedule.	\$20,000
Cost of in-place testing (900 LOK-test inserts were used)	\$15,000

SAVINGS TO OWNER	
Reduction of the interest charges because of a one month acceleration in the construction programme (accumulated savings derived from the difference in interest rates between the high-cost short term construction financing and the long term mortgage).	\$600,000
Saving from the use of concrete mixes for all vertical members to meet design requirements at 91 days instead of 28 days.	Not Applicable.
Rent income from earlier than anticipated tenant occupancy of the building	\$200,000
Construction cost reduction gained by using a modified drop panel floor section design.	\$120,000
Refund from Formwork Contractor.	\$120,000

Net savings to owner	\$1005,000
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Table 1: Financial benefits outweigh the additional cost of fast track construction, based on the Toronto Place Phase II National Bank building⁽⁴⁾. Total construction cost of \$21.5 million. 30 x 30ft column grid. Plan area of 480,000sq.ft. 8in. thick floor slabs, strengthened with modified drop panels at the columns.

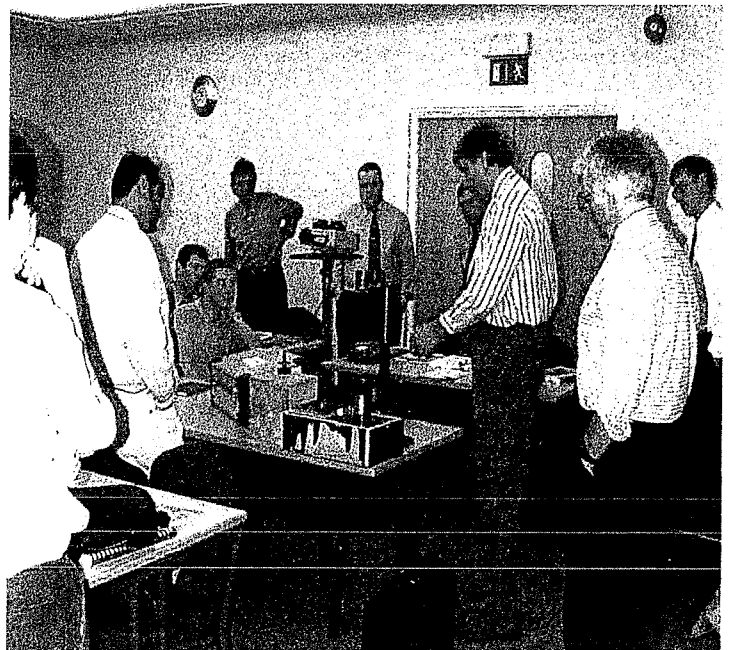


Fig. 3: Mr. Claus Germann Petersen demonstrating the use of LOK-Test at the lecture theater

- Control of formwork removal is achieved by the use of in-place testing. The use of special mixes in combination with in-place testing may require the approval of building officials. This approval should be obtained prior to the start of the project.
- 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 to 0.8 of the characteristic cylinder strength (f_c) are used. The example given in Table 3 assumes a factor of 0.75. The LOK-test system does not only provide 10 times as many tests as are made to meet standard cylinder testing specifications, but also the test is on the concrete in the element of the structure which is being stripped. Statistical methods provide valid evaluation techniques to determine the characteristic concrete strength.
- 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.

Discussion focused on identifying the differences in construction practices between Canada and the UK.

- The willingness of the ready mixed concrete suppliers in Canada to provide "Super-Stripper" mixes and modify these as necessary for warm- and cold-weather concreting has not yet become the norm in the UK.
- Testing ages of up to 91 days for conformity requirements appear to be a norm in Canada while not yet in the UK.
- The required strength at the time of stripping the formwork rely in Canada on the Danish 1976 Code rule, as explained above. A more detailed procedure for estimating the required strength for stripping the formwork is used in the UK. This procedure is described in the Guide for Flat Slab Formwork & Falsework⁽⁵⁾ that has recently been published by the Concrete Structures Group (CONSTRUCT).
- The statistical method used for converting in-situ test results into characteristic cylinder strengths in Canada can be described by the following equation:

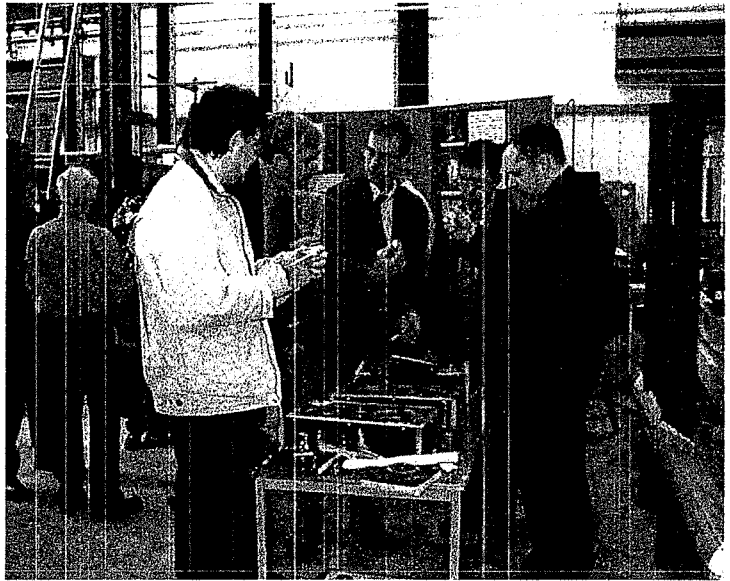


Fig. 4: Prof. John.H. Bungey being consulted on COMA maturity meter readings in the lab.

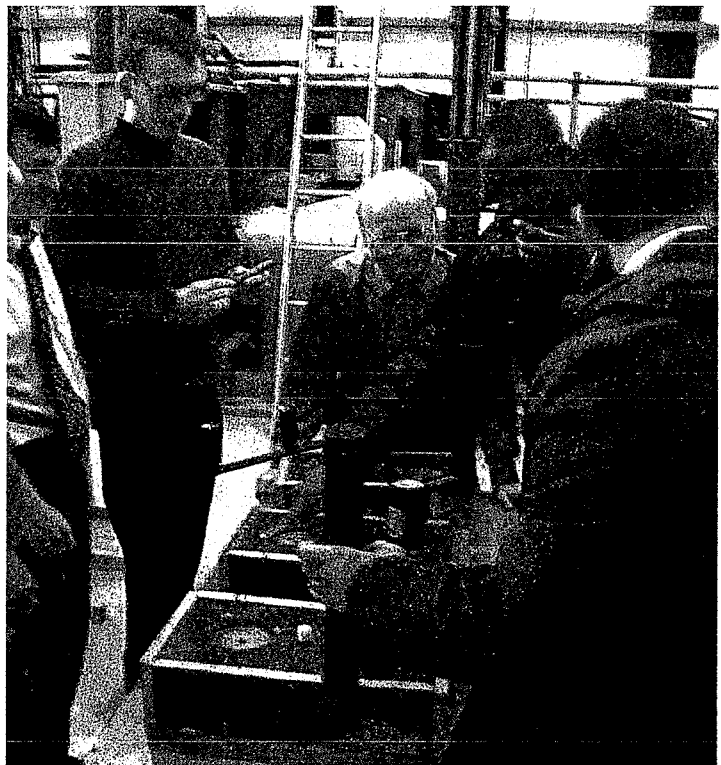


Fig.5. LOK-test being practiced in the lab by the delegates, supervised by Mr. John. A.Bickley

$$f_c = Y - kS$$

where:

f_c	=	characteristic strength (tenth percentile strength), MPa,
Y	=	the mean of the estimated in-situ concrete strengths from LOK- tests, MPa,
k	=	one-sided tolerance factor for ten percent defective level (based on a 75% confidence level)
S	=	standard deviation of in-situ test results.



Fig. 6: Mr. Claus Germann Petersen demonstrating in the lab that a CAPO-test takes only 4 minutes!

For 10 LOK-tests with a mean of 26.9 MPa and a standard deviation of 2.3 MPa, with k taken as 1.671, the tenth percentile strength will be 22.7 MPa. This in-situ strength would be sufficient to allow stripping of formwork, based on the $0.75 \cdot f_c$ criterion for a grade C30 concrete, as it exceeds $0.75 \cdot 30 \text{ MPa} = 22.5 \text{ MPa}$.

Table 3. Example of in-situ test results from a 100 m^3 deck pour

There is no generally accepted statistical method for use with non-destructive testing in the UK although similar approaches based on cube strength results (proportion of defectives less than 5%) have been proposed.

The lectures were followed by practical demonstrations in the lecture theatre, see Figure 3, and subsequently the delegates had the opportunity to try out the tests themselves in the laboratories, see Figure 4 and 5. LOK inserts were tested on specimens containing COMA maturity meters for comparison of values.

The CAPO-test was also demonstrated in the laboratory by Mr. C. G. Petersen, see Figure 6, who managed to complete a test just under four minutes – which is a significant improvement on the 30 minutes that is sometimes suggested to be allowed per CAPO-test on construction sites.

Further information about this subject, including test methods, may be obtained from Dr. M. N. Soutsos – Department of Civil Engineering, University of Liverpool, email: marios@liverpool.ac.uk

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