Non-Destructive Testing (Proc. 12th Wor[illegible] Conference), edited by
J. Boogaard and G.M. van Dijk
Elsevier Science Publishers B.V., Amste[illegible] – Printed in The Netherlands

MONITORING CONCRETE EARLY AGE STRENGTH DEVELOPMENT

J. H. BUNGEY

Civil Engineering Department, University of Liverpool, P.O. Box 147, Liverpool L69 3BX (United Kingdom)

SUMMARY

A range of non-destructive techniques are examined to assess their reliability and practicability for on-site concrete strength estimation within the first 24 hours from casting. Some commonly used methods are found to be unsuitable for the low strength levels sometimes encountered. Laboratory and site trials related to cooling tower construction are reported with particular attention to strength correlations and early age variability of concrete properties. Proposals relating to planning, interpretation and economic advantages are also provided with reference to other applications within civil engineering construction.

INTRODUCTION

A knowledge of the strength of in-place concrete during the first few days from casting may be of great importance for some critical types of structure. The reasons for this may include timing removal of formwork or supports, imposition of load, termination of curing, and application of prestress as well as quality control checking of the concrete mix. Detailed requirements will vary according to the nature of the structure, and testing techniques will be determined by practical factors including access.

Construction procedures for large cooling towers for example involve very tightly scheduled sequences of formwork stripping and load imposition. It is thus vital that the Engineer has total confidence in the results of testing upon which his decisions are based.

COOLING TOWERS

These are large-scale structures consisting of a thin reinforced concrete wall in the form of a shell. Thicknesses are typically about 175mm, thus concrete strength is critical if distortion or collapse is to be prevented when shutter panels are removed. Construction is typically in the form of $1^1/_2$m high lifts with a complete ring being formed on a 24 hour cycle. They are usually constructed in relatively exposed locations and access for testing is often very restricted as illustrated by Fig. 1.

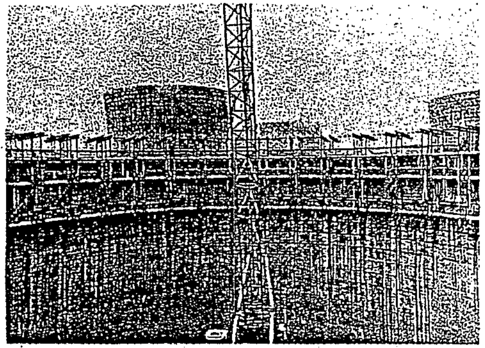

Fig. 1. Cooling tower under construction

TEST METHODS AVAILABLE

The range of relevant testing methods is outlined below. It is important to remember that the term 'non-destructive' when applied to concrete testing is often taken to include methods causing localised surface damage but not impairing future performance. Individual methods are described in detail in textbooks (ref. 1) and elsewhere (refs. 2, 3) but little information is available about their performance on very young or low strength concrete.

Rebound hammer

The measured surface hardness based on the rebound of an impacting mass may be related empirically to concrete strength. A low energy pendulum type of hammer is available for low strength materials.

Ultrasonic pulse velocity and pulse echo

Through transmission techniques involve the measurement of transit time between transducers on opposite faces of the member under test. The derived velocity may be related empirically to concrete strength. Simple equipment is available for comparative monitoring of the amplitude of internally reflected shock waves caused by a surface hammer blow.

Penetration resistance and pull-out

Either the depth of penetration of a probe fired at the concrete surface or the force required to 'pull-out' a small insert cast into the concrete surface are measured and may be related empirically to concrete strength.

Maturity and temperature-matched curing

Strength devel[illegible] is related to maturity which may be expressed as a function of tim[illegible] temperature, and may be computed by [illegible]itoring temperatures from the time of casting. Alternatively, test specimens in the form of cubes or cylinders may be cured in a water bath whose temperature is controlled by sensors located in the insitu concrete in the structure, and tested physically to determine strength.

DETAILS OF INVESTIGATION

A comprehensive programme of laboratory and site work has been undertaken to examine the suitability of these methods for use in this situation. Laboratory work was undertaken in the Civil Engineering Department at Liverpool University in conjunction with site trials at a power station construction site in northern England where several new cooling towers were being built.

Laboratory studies

These included the development of strength correlations for each of the methods using a range of standard specimens with compressive strengths ranging from about 1MPa to 20MPa with particular emphasis upon performance within the first 3 days from casting. Strengths were varied by testing at different ages as well as by varying the mix proportions, although the aggregates were confined to two types of gravel - one being the same as that used in subsequent site work.

A series of full size trial wall panels were also made to enable practical aspects of the testing to be examined. This included testing after shutter removal, but attention was primarily concentrated on assessment of concrete before that operation occurred. Temperatures and maturities were monitored at several locations within each panel and in companion specimens. The most promising strength test methods were also used to survey wall panel strength distributions for comparison with standard test specimens both cured alongside and subjected to temperature matched curing. Maturities were calculated from internal temperatures measured by re-usable thermistors as well as by disposable chemically-based COMA meters, and concrete surface temperatures were also monitored by a digital thermometer.

Site Studies

Temperatures were measured at varying depths within panels by means of thermistors lowered into stainless steel tubes cast into the concrete coupled to a multi-channel battery-operated recorder. Temperatures were also monitored in companion test cubes cured alongside the panels and in a temperature matched curin[illegible] ık mounted on the construction platform. Matur[illegible] s were additionally assessed by COMA meters inserted through small holes drilled through the plywood shutter panels, whilst pull-out testing was undertaken using Lok-test equipment through removable panels in the shutters as shown in Fig. 2.

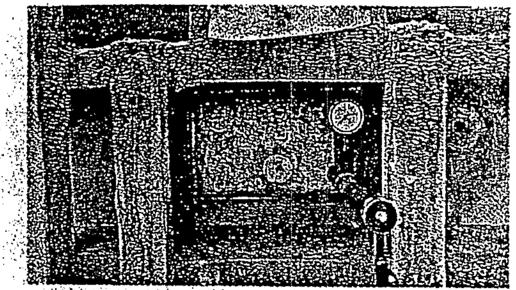

Fig. 2 Pull-out testing on site through removable shutter panel

RESULTS

Rebound hammer and penetration resistance tests were found to be unreliable at strengths below about 10MPa and sensible results could not be achieved with the simple pulse echo equipment available. Good correlations between ultrasonic pulse velocities and compressive strength were found for specific mixes (Fig. 3), but site application is limited by the need for access to opposite faces of the concrete element.

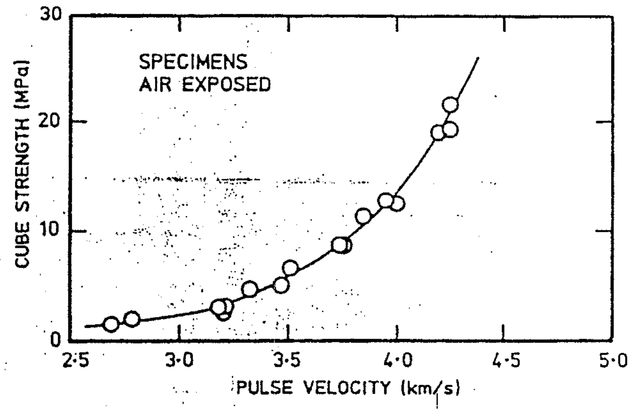

Fig. 3 Typical strength correlation for ultrasonic pulse velocity

Approximately li[illegible] strength/maturity relationships were shown t[illegible] st for periods of up to about 24 hours from casting for particular mixes but, as with UPV measurements, the risk of mix variations limits the value of the technique without some other form of back-up testing. It was also found, both in the laboratory and on site, that maturities from COMA meters gave poor correlation with values computed from temperature measurements at early ages.

Pull-out tests were found to give a reliable direct measurement of concrete strength even at very low values as shown in Fig. 4 and showed that a lower acceptance limiting value can be established with confidence based on the mean of 6 test results. Tests on wall panels agreed closely with correlations based on test specimens.

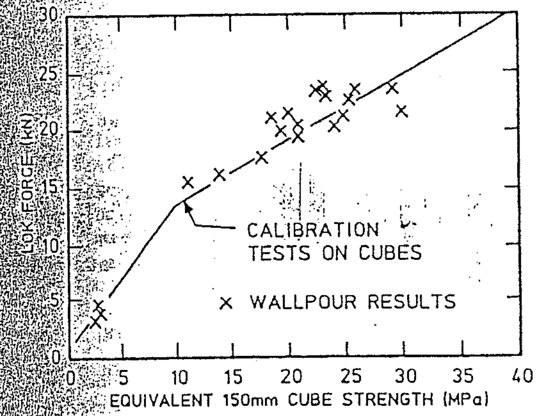

Fig 4 Pull-out test results

It was found in both laboratory and site trials that considerable temperature differentials existed across the depth of each wall panel during the first 24 hours from casting, whilst test specimens in steel moulds closely followed the air temperature unless placed in a temperature matched curing tank. The resulting maturity at 24 hours at the top of the panel was found to be as much as 40% below that at a depth of 600mm with consequent significant strength differences. Internal temperatures up to 30°C above ambient were encountered in the walls with plywood shuttering.

GENERAL OBSERVATIONS

Temperature matched curing has been discussed in detail in ref. 3. It requires a high initial investment whilst operation relies upon an uninterrupted power supply near the point of placing with continuous monitoring of temperatures. The equipment is particularly vulnerable to accidental damage and disruption. Pull-out testing before shutter removal requires simple modifications to some shutter panels but can be performed easily under difficult working conditions. Laboratory results confirm the validity of proposals to use this in combination with maturity values (ref. 4).

The savings in time which can be achieved from maintaining construction schedules during cold weather apply not only to cooling towers but to most types of concrete structure. Particular care must, however, be taken to ensure good curing following shutter removal if durability problems are to be avoided. Testing of concrete after placing is, at present, uncommon and there is a tendency towards suspicion by the workforce but experience on this project suggests that this is short lived.

CONCLUSIONS

Of the methods examined maturity measurements, temperature matched curing, and pull-out testing proved to be the most reliable and practicable at very low strengths. As outlined above, strength assessment based on maturity measurements alone cannot be relied upon. Temperature matched curing is reliable provided that practical difficulties can be overcome. Pull-out testing is quick and simple to perform and is reliable at very low strengths with low risk of damage to test assemblies during casting.

Insitu strengths are not adequately reflected by companion specimens cured near the pour, especially in cold weather, and considerable economic benefits can be obtained from testing the insitu concrete directly. Internal early age strength variations must, however, be considered carefully when deciding the location of these tests.

ACKNOWLEDGEMENTS

The assistance provided by the Science and Engineering Research Council in funding this work, and the provision of site facilities by the Central Electricity Generating Board are both gratefully acknowledged.

REFERENCES

1 J.H. Bungey, The Testing of Concrete in Structures, 2nd edn., Surrey Univ Press, Glasgow, 1989.

2 T.J. Parsons and T.R. Naik; Early age concrete strength determination by maturity, Concrete International 7(2) (1985) 37 - 43.

3 J.H. Bungey, Temperature matched curing of concrete, Proc. 1988 Conf. Brit Inst. NDT, Pergamon, Oxford, 1988.

4 R.L. Dilly and W.B. Ledbetter, Concrete strength based on maturity and pull-out, Jnl. Struct. Eng., 110(2) Am.Soc.Civ.Eng., (1984) 354 - 369.