Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 57/1/57/2 (1989)

Artikel: Assessing surface properties of concrete by in-situ measurements
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DOI: https://doi.org/10.5169/seals-44315

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Assessing Surface Properties of Concrete by In-situ Measurements

Détermination des propriétés du béton à l'aide d'essais in situ

Bestimmung der Oberflächeneigenschaften von Beton

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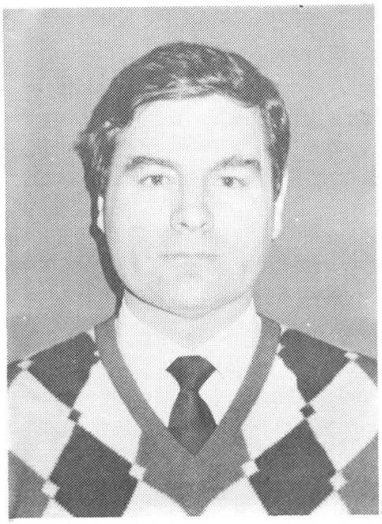

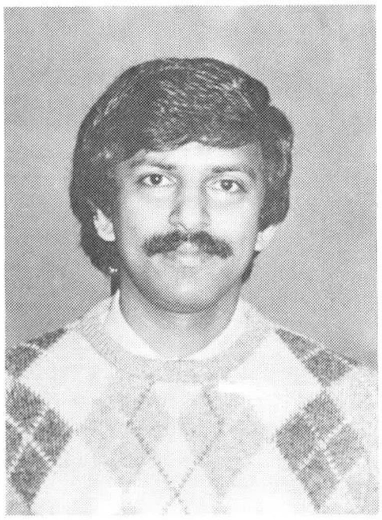

SUMMARY

This paper describes test methods which are employed for the assessment of surface strength, surface permeability and abrasion resistance of concrete on site. The successful application of these three methods in the laboratory and the details of the tests on site are described. By using them in combination, it should be possible to predict many of the problems related to durability of concrete structures before they reach serious proportions.

RÉSUMÉ

Cette communication décrit des méthodes d'essai employées pour l'évaluation de la résistance en surface, de la perméabilité et de la résistance à l'effritement superficiel du béton sur le chantier. Elle décrit l'application de ces trois méthodes en laboratoire ainsi que les modalités des essais sur chantier. En les combinant, il devrait être possible de prévoir de nombreux problèmes relatifs à la durabilité de structures en béton, avant que ceux-ci ne s'aggravent.

ZUSAMMENFASSUNG

Dieser Beitrag beschreibt Prüfverfahren, die zur Ermittlung der Oberflächenzugfestigkeit, der Wassereindringtiefe und des Abnutzwiderstandes von Beton am Bauwerk dienen. Die erfolgreiche Anwendung der drei Prüfverfahren im Labor und die Durchführung der Prüfungen am Bauwerk werden beschrieben. Die Kombination der drei Prüfverfahren soll das rechtzeitige Erkennen der durch äussere Einwirkungen verursachten Schäden am Beton ermöglichen, bevor diese grössere Ausmasse annehmen.

1. INTRODUCTION

As concrete is the most dominant structural material in many parts of the world, its strength and ability to protect reinforcement against corrosion has been the subject of much investigation. Research on durability of concrete has highlighted the importance of producing concrete with the ability to resist the ingress of deleterious agents from the surrounding environments. When testing and evaluating the quality of concrete structural elements, it is often presumed that the concrete within one member is uniform in composition and properties. However, during placing and compacting of the fresh concrete, the surface layer often contains more cement and water than the core concrete. Hence, the composition and properties of the surface layer of the concrete differ from those of the core. Furthermore, during the service life of the structure, the surface layer is usually subjected to more severe environmental attacks than the core concrete. The customary quality control for concrete using compressive strength tests on standard cubes and cylinders, or cores cut from the structure, do not measure the properties of the surface layer, instead they evaluate the properties of the mass. Hence, tests are required to evaluate the quality of the surface concrete, especially on site. In recent years, a wide range of methods have become available for estimating the strength of the in-situ concrete, which include the non-destructive methods and the more recently introduced partially destructive tests. The pull-off test using the LIMPET [1] comes under the latter category of tests which allows the compressive strength of the surface layer to be determined.

It has been recognised over the past few decades that concrete is deteriorating not because of its low strength, but because of its other properties. When concrete is exposed to aggressive environments, its successful performance depends to a greater extent on its durability against the environment than its strength. Permeability has been widely accepted as a measure of the durability of concrete [2,3]. The permeability of the surface layer largely determines the vulnerability of concrete to external agencies, so that in order to be durable, the surface layer must be relatively impervious. The CLAM permeability test [4] enables the coefficient of permeability, as used in Darcy's equation to be determined for the surface layer of concrete.

Even though much work has been carried out in the general area of concrete durability, comparatively little research has been undertaken in one aspect of the subject, viz. the abrasion resistance. Isolated researches [5,6] have been undergoing in the past few years on the assessment of abrasion resistance and yet, there is no universal standard test method for the same. Hence, a research team at the Queen's University of Belfast developed the TEREDO [7] for the insitu use. The viability of the three apparatus has been established by means of extensive experimental work in the laboratory and on site.

2. ASSESSMENT OF SURFACE STRENGTH USING LIMPET

2.1 Procedure and Test Details

The pull-off test using the LIMPET [1] involves bonding a circular steel probe to the specimen under test by means of an epoxy resin adhesive. A slowly increasing tensile force is then applied to the probe until the specimen fails in tension. As the amount of overbreak is usually small, the area of failure can be taken as being equal to the area of the probe. This permits the calculation of the nominal tensile strength of the specimen from which the compressive strength of the surface layer can be estimated by the use of appropriate calibration graphs. The LIMPET is shown in Figure 1.

A correlation curve based on a large number of pull-off tests and corresponding cube compressive strengths is shown in Figure 2. The closeness of the fit between the tensile strength and the corresponding cube strength is indicated by the confidence limit of 95%. It was found from a series of laboratory tests that the test is sensitive to compaction and curing conditions which affect the strength.

2.2. Insitu Tests on Multi-storey Car Park

The accuracy and the reliability of the LIMPET test as a means of quality control was assessed [8] during the construction of a multi-storey car park for the Department of Environment (NI) in Ballymena. The structure involved large number of similar pours which offered an excellent opportunity to monitor the levels of accuracy and the reliability attained by the pull-off method on insitu concrete. The construction was that of insitu beams, slabs and columns resting on pad foundation.

The tests were performed on three different types of members (viz. columns, parapet walls and stair block walls) at both 7 and 28 days. The results of this investigation are summarised in Table 1 which indicates the closeness of the predicted values with the corresponding cube compressive strength. It was observed that there was an increase of strength of columns towards the bottom. The average strength of concrete at the top was 8% lower than that of concrete in the middle of the columns and 12% lower than that at the bottom.It was also noted that concrete at the top of columns was significantly more variable than that at the bottom.

Hence, the pull-off test using the LIMPET was found to be quite satisfactory as an insitu method and problems of variability of concrete can be investigated using it.

3. ASSESSMENT OF SURFACE PERMEABILITY USING CLAM

3.1 Procedure and Test Details

The CLAM (Figure 3) is a compact piece of equipment which is designed to measure the permeability of the surface layer without disturbing the concrete and over an area sufficiently large to rule out the exaggerated aggregate effects. The method involves bonding a steel ring of internal diameter 50mm on to the specimen under test. The body of the apparatus is bolted to this ring and sealed with an O-ring. Water is admitted into the pressure chamber by withdrawing the piston such that it rests above the level of the inlet nozzle. A syringe containing water is connected to this nozzle and the bleed valve is opened to allow air to escape. The pressure inside the chamber is increased to 25 psi using the syringe and is maintained by advancing the piston manually in to the pressure cylinder. A micrometer attached to the piston measures the travel from which the rate of flow into the specimen is determined. This in turn may be converted into coefficient of permeability, K, as used in Darcy's equation, in units of m/s, by multiplying with appropriate calibration factors which have been developed from a theoretical study of flow nets. The CLAM was also found to be useful in estimating the initial surface absorption of concrete.

Detailed laboratory investigation in the past five years or so indicated that the CLAM test is sensitive to the variations in properties of concrete as a result of the variation in mix parameters, age or curing. A modest change in water/cement ratio was found to have relatively little effect on the strength whereas the resulting surface permeability significantly differed.

3.2. Insitu Test Programme using CLAM

The viability of the CLAM as an insitu test device was assessed [9] on a multi-storey car park in Belfast. The tests for CLAM permeability were planned in the same way as that of the pull-off test which was explained earlier and the results were recorded at 7 and 28 days. The average permeability values from this comprehensive test are given in Table 2.

The variation in permeability within columns at different heights was investigated and the results are presented in Table 3. The variation in permeability was found to have followed an inverse relationship with that obtained from the pull-off results. There was a decrease of permeability from top to bottom of column height.
Both the laboratory and insitu test results confirm that the CLAM is a useful tool for measuring the surface permeability of concrete.

4. ASSESSMENT OF SURFACE ABRASION BY TEREDO

4.1 Procedure and Test Details

The TEREDO [7] is based on the principle of accelerated abrasion using rotating wheels and consists of three sets of spiked steel dressing wheels which are mounted on a central spindle (Figure 4). This is rotated at a constant speed of 50 rpm by means of a small DC electric motor with a variable speed control. The central shaft is attached to a hollow ram jack and hence, a force applied on to the spindle through the hollow ram jack enables the rotating wheels to abrade the surface. The machine is so designed that the dressing wheels will follow the contours of the test surface, including any peaks and troughs formed by its abrading action. The depths to which the test surface has been abraded is recorded at 8 points along the abraded annular path after 15 minutes of operation. This is used as a measure of the abrasion resistance of the surface. The machine is bolted on to the test specimens for laboratory tests. However, expanding bolts are used for insitu tests.

4.2. Early Results of the Laboratory Investigation

The investigation into the sensitivity of the apparatus to the concrete mix variables indicated that the TEREDO yields results which may be related to the strength of the concrete. The influence of water/cement ratio, curing regimes, and the method of surface finish on the abrasion resistance are given in Figure 5. The effect of water/cement ratio on the strength of concrete is also indicated for correlation purposes.

5. ASSESSMENT OF STRENGTH AND DURABILITY

The LIMPET, CALM, and the TEREDO have been successfully used in a study on the surface durability of ferrocement and the results are reported else where [10]. It was observed that where the LIMPET gave low values of strength, the CLAM and the TEREDO yielded high values of permeability and abrasion respectively. Hence, by using these three tests in combination, it should be possible to eliminate many of the current strength and durability problems which occur in concrete structures.

6. CONCLUSIONS

On the basis of the extensive experience which has been gained at the Queen's University over the past few years, the following concluding remarks can be made.

1. The LIMPET test for the determination of insitu surface strength of concrete is quick, accurate and gives results within reasonable confidence limits.

2. The CLAM permeability test enables the assessment of the durability of concrete as it measures the surface permeability of concrete. The test is quick and reliable.

3. The TEREDO is portable and allows easy measure of the surface abrasion of concrete floors.

4. As the three apparatus are designed for site use, it should be possible to reduce some of the strength and durability problems in concrete structures in future by employing them in combination.

7. ACKNOWLEDGEMENTS

The contribution made to the development of the LIMPET, CLAM, and TEREDO by Alastair Thompson, Jim Newell, Andrew Murray, Alison Adams and David Lau is gratefully acknowledged.

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Type of Member	Age (Days)	Size of Aggregate	Average Cube str.	Average LIMPET str	Cube str.x100 / LIMPET str.
Column	7	20mm	22.6N/mm^2	23.6N/mm^2	96%
	28	20mm	39.7N/mm^2	38.1N/mm^2	104%
	28	10mm	42.7N/mm^2	40.4N/mm^2	106%
Wall	7	20mm	20.8N/mm^2	21.3N/mm^2	95%
	28	20mm	38.3N/mm^2	35.5N/mm^2	108%

Table 1 Summary of Results from Insitu Tests Using LIMPET

Type of Member	Age (Days)	Average Coefficient of Permeability K(x10^{-13})
Column	7 28	2.96 1.07
Wall	7 28	3.13 3.10
Beam	7 28	2.28 1.74

Table 2 Summary of Results from Insitu Tests Using CLAM

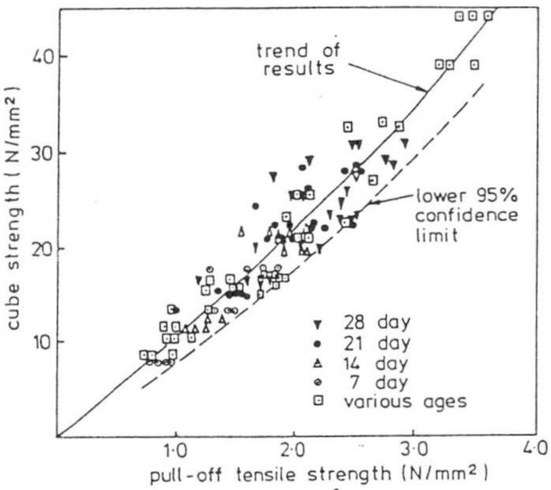

Figure 2 Typical Correlation Curve for LIMPET for concrete of Different Ages

Height up Column	Average Coefficient of Permeability K(x10^{-13} m/s)
1800mm	1.52
1470mm	0.91
815mm	0.87
280mm	0.68

Table 3 Variations of Permeability Within Column

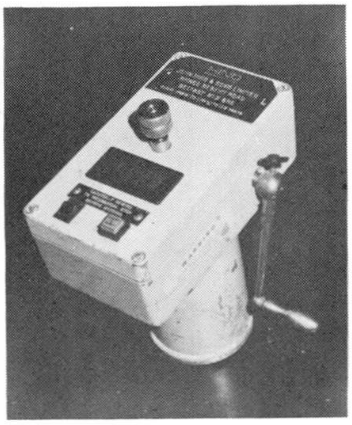

Figure 1 The LIMPET

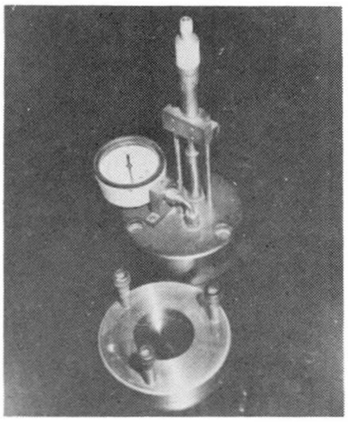

Figure 3 The CLAM

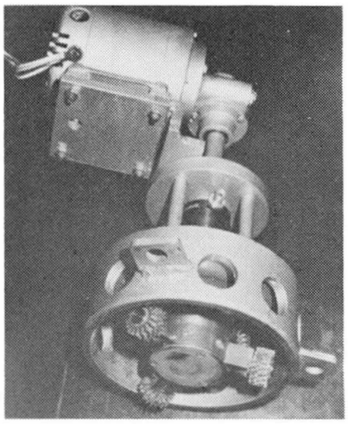

Figure 4 The TEREDO

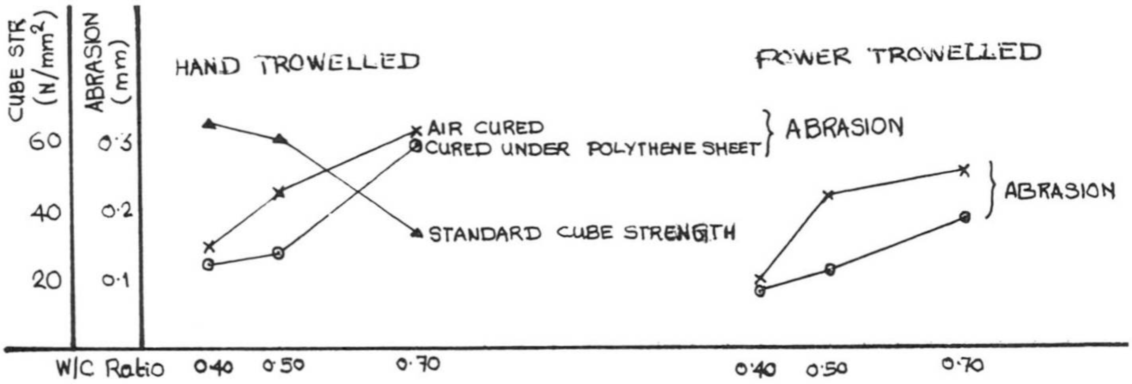

Figure 5 Results of TEREDO Abrasion Test