International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE) 26.-28.09.1995

A method for the rapid determination of the coefficient of permeability of the "covercrete"

R. Torrent, G. Frenzer
Management und Beratung AG "Holderbank", Holderbank (CH)

***Keywords:** Concrete, Durability, Permeability*

ABSTRACT

The permeability of the concrete cover ('covercrete') has been identified as the major factor that determines the potential durability of concrete structures. International bodies such as the CEB-FIP have stressed the importance of that property and the need to have means at our disposal for its reliable measurement, especially on site.

The object of the paper is to describe a new method that allows a fast and accurate non-destructive determination of the coefficient of permeability of the surface layer of concrete.

The method is based on creating a vacuum on the surface of the concrete and in monitoring the rate at which the pressure is raising in the test chamber after the vacuum pump has been disconnected. The distinctive features of the method are a double-chamber cell and a pressure regulator that balances the pressure in both chambers during the test. The equipment includes a microprocessor that processes and stores the information of up to 200 tests.

The special features of the apparatus create a controlled, uni-directional flow of air from the pores into the inner chamber, whilst the outer chamber acts as a guard-ring. Under these conditions it is possible to calculate the coefficient of permeability to air of the 'covercrete', as well as to estimate the depth of concrete affected by the test (normally between 10 and 50 mm, depending on the permeability).

The method has proved repeatable, accurate and reliable and correlates well with laboratory methods as well as with performance tests. A single determination takes between 1.5 to 12 minutes for completion, depending on the permeability of the concrete.

Another situation arose when trying to apply the method to concretes with a high moisture content because, as expected, very low permeabilities were measured even for relatively bad quality concretes. An approach is proposed that combines the gas-permeability test with a determination of the electrical resistivity of the 'covercrete', to compensate the effect of moisture.

1. INTRODUCTION

While the bearing capacity of a structural member depends on the integral behaviour of the element, its durability against environmental aggressive actions relies basically on the protective performance of a relatively thin superficial layer of concrete (20-50 mm thick), the 'covercrete' (see Fig. 1). Indeed, this layer should protect the reinforcing bars against corrosion - be it induced by carbonation or due to the ingress of chlorides - and it is also the most affected by chemical attack, frost, abrasion, etc.

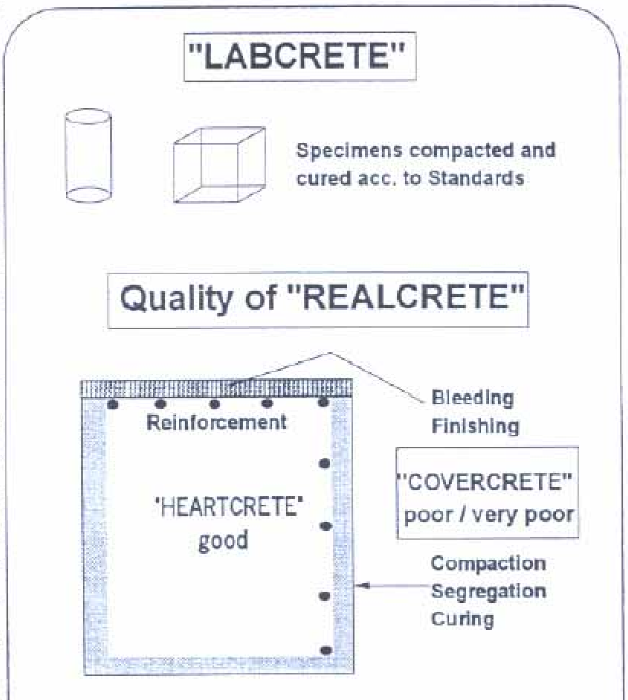


Fig. 1 : Concept of "Covercrete"

Currently, acceptance criteria for hardened concrete are based almost exclusively on the test results of moulded concrete specimens (essentially on their compressive strength). It is clear that these results can never represent the quality of the 'covercrete' because they assess the bulk behaviour of specimens that are, moreover, prepared and cured in a completely different manner as the real structure. Thus, the actual quality of this vital layer goes largely ignored, which may explain, at least partially, the unsatisfactory performance of many structures from the durability point of view.

The CEB-FIP Model Code 1990 states the following {Ref. 1}:

> "There is no generally accepted method to characterise the pore structure of concrete and to relate it to its durability. However, several investigations have indicated that concrete permeability both with respect to air and to water is an excellent measure for the resistance of concrete against the ingress of aggressive media in the gaseous or in the liquid state and thus is a measure of the potential durability of a particular concrete."

> "There are at present no generally accepted methods for a rapid determination of concrete permeability and of limiting values for the permeability of concrete exposed to different environmental conditions. However, it is likely that such methods will become available in the future allowing the classification of concrete on the basis of its permeability. Requirements for concrete permeability may then be postulated; they would depend on exposure classes i.e. environmental conditions to which the structure is exposed."

> "Though concrete of a high strength class is in most instances more durable than concrete of a lower strength class, compressive strength per se is not a complete measure of concrete durability,

because durability primarily depends on the properties of the surface layers of a concrete member which have only a limited effect on concrete compressive strength."

2. OBJECTIVE

The objective of this paper is to present an innovative method - Torrent Permeability Tester - and a concept which can constitute a basis for a performance-oriented specification and control criterion regarding concrete durability, in line with the CEB-FIP Model Code's concepts.

The test results mentioned in this paper are based on the compilation and analysis of test results from different projects that have been carried out at "Holderbank" Management and Consulting Ltd. since 1989. More detailed information on them can be found elsewhere {Ref. 2, 4}.

3. TORRENT PERMEABILITY TESTER

The main features of the so-called "Torrent Permeability Tester" method, developed at "Holderbank" {Ref. 2 - 4}, are a two-chamber vacuum cell and a regulator that balances the pressure in the inner (measuring) chamber and in the outer (guard-ring) chamber (see Fig. 2).

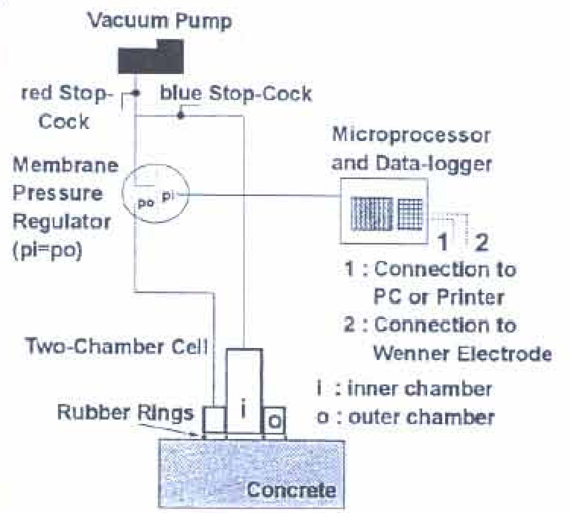


Fig 2 : Sketch of Torrent Permeability Tester

The operation is as follows: the cell is placed on the concrete surface and a vacuum is produced with the pump. Due to the external atmospheric pressure and the rubber rings the cell is pressed against the surface and thus both chambers are sealed. After 1 min. the blue stop-cock is closed and the rate at which the pressure raises in the inner chamber is recorded; this rate is related to the permeability of the underlying concrete.

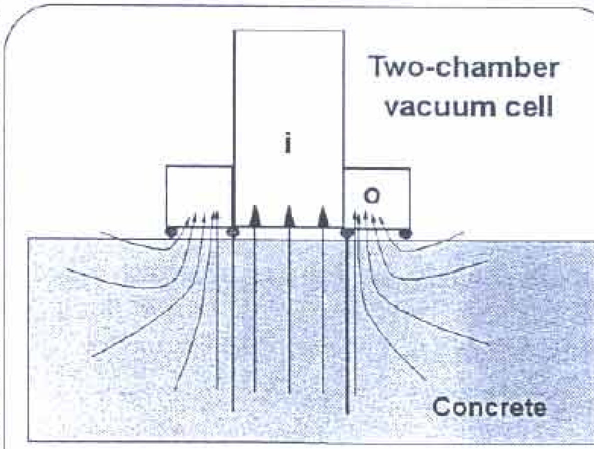


Fig. 3 : Air-flow into the two-chamber vacuum cell

The design of the apparatus ensures a unidirectional air flow into the inner chamber (see Fig. 3), which makes it possible to calculate the coefficient of permeability (kT [m²]), on the basis of a theoretical model {Ref. 3}, recently refined {4}.

The method is fast (total duration between 1.5 and 12 min. for high and low permeability concrete, respectively), totally non-destructive and therefore suitable for both laboratory and site applications.

4. INFLUENCE OF MOISTURE ON THE kT-PERMEABILITY

The importance of the moisture content of the concrete on the measured gas-permeability is well known {Ref. 5}; hence the need to find measures to counteract it.

The possibility of combining "in-situ" test methods, whose readings are affected in an opposite sense by the moisture content, was considered as a means to neutralise the effect of the latter. The determination of the electrical resistivity ρ of the 'covercrete' complements, in that sense, that of the gas-permeability kT. The electrical resistivity ρ can be measured by applying four electrodes on the concrete, producing a current between the two exterior electrodes and measuring the potential drop between the two inner electrodes (method of Wenner).

By comparing the results of kT, ρ and kO - the latter is the coefficient for oxygen permeability (Cembureau method - a reliable, accurate and repeatable laboratory test method {Ref. 6}) - obtained on a series of slabs and specimens made of different concrete mixes and containing arbitrary and widely different moisture contents it was possible to establish a correlation between kO and kT for dry concrete (1) and a combination of kT and ρ for moist concrete (2) :

$$\mathbf{kO(T) = 2.5 * kT^{0.7}} \qquad (1)$$

$$\mathbf{kO(F) = 6 * kT^{0.4} / \rho^{0.7}} \qquad (2)$$

where

kO(T) : calculated oxygen permeability for dry concrete, [E-16 m^2]

kO(F) : calculated oxygen permeability for wet concrete, [E-16 m^2]

kT : gas permeability measured by the Torrent Permeability Tester, [E-16 m^2]

ρ : electrical resistivity measured by the Wenner method, [kohm cm]

As an explanation for equation (2) it can be mentioned that a bad quality 'covercrete' will have high gas permeability (kT) and low electrical resistivity (ρ), therefore $kT^{0.4} / \rho^{0.7}$ in (2) will potentate the effect of quality; if the 'covercrete' is moist this will lead to lower kT and also to lower ρ and, hence, $kT^{0.4} / \rho^{0.7}$ will be less influenced by the moisture content of the 'covercrete'.

The results indicate that this approach offers an interesting potential to neutralise the effect of the moisture content of the 'covercrete' on the estimation of its gas permeability by the Torrent Permeability Tester.

5. EVALUATION OF THE QUALITY OF THE 'COVERCRETE'

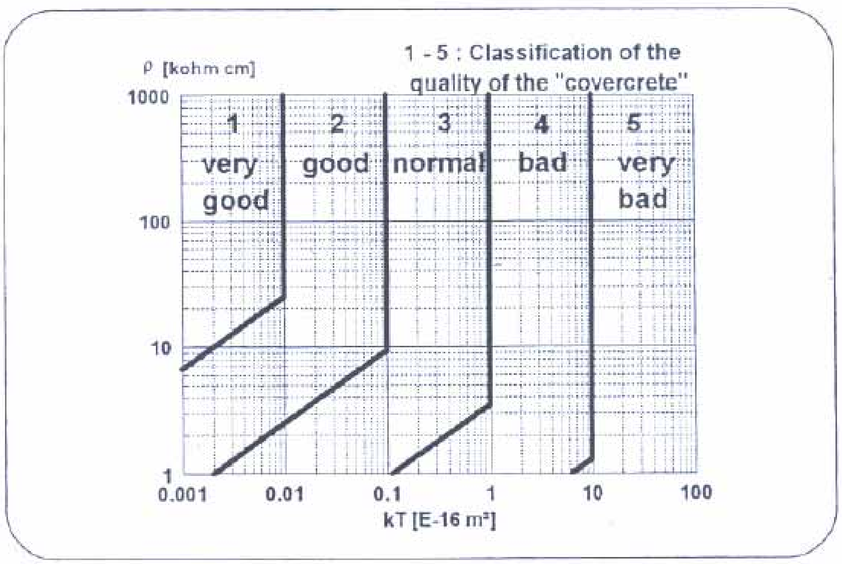
For dry concrete the quality of the 'covercrete' can directly be identified by entering the measured and indicated kT value of the Torrent Permeability Tester into table 1.

Table 1 : **Classification of the quality of the 'covercrete' according to kT**

Classification of the quality of the "covercrete"		kT measured at 28 days [E-16 m^2]
1	very good	kT < 0.01
2	good	0.01 < kT < 0.1
3	normal	0.1 < kT < 1.0
4	bad	1.0 < k T < 10
5	very bad	kT > 10

For wet concrete or whenever there are doubts if the concrete is wet or dry, additionally to kT, ρ needs to be measured and both values have to be entered into the nomogram (fig. 4) and the quality of the 'covercrete' can be identified. This nomogram is based on the two equations ((1) and (2)), the limits for kT (see table 1) and the concept that equation (2) and as such the influence of the moisture on the gas permeability measurement is only taken into consideration when the calculated value by equation (2) is higher than the one by equation (1). Or in other terms, the higher of both calculated values is representative for the permeability of the 'covercrete' - max of {kT(T) and kT(F)} = kO_{max} .

Fig. 4 : **Classification of the quality of the 'covercrete' according to kT and ρ**



6. CORRELATIONS BETWEEN kO_{max} AND OTHER RELEVANT PROPERTIES

A large number of concrete mixes has been systematically investigated in our laboratories. The comparison of kT in relation to several other methods and properties was carried out. The different concrete mixes produced standard cube strengths between 20 and 90 MPa. For each mix, slabs were cast as described in {Ref. 2} and subjected to either a moist curing of 7 days in the moist room (20°C, 95% R.H.) followed by 21 days storage in a dry room (20°C, 50% R.H.) until testing or a dry curing in which they were stored in the dry room for 28 days until testing.

Tests were also carried out on several jobsites (bridge constructions) in order to show that the approach is also applicable under jobsite conditions.

6.1 Correlation with kO

First the non-destructive tests (kT and ρ) were applied on the surface of the slabs or on the concrete surface at the jobsites and, later, cores were drilled at the same spots, cut to size (discs), pre-treated (50°C for 6 days) and tested for kO.

Fig. 5 shows that there is a good correlation between the calculated value kO_{max} and the measured value kO.

6.2 Relation with capillary suction

The capillary suction was determined on the same discs used for the determination of kO, after this test had been finished. It consists in placing the discs in contact with 2 - 3 mm of water on the surface which is to investigate and in monitoring the increase of weight due to capillary suction at prescribed intervals. The reported value is a_{24} [$g/m^2s^{0.5}$], the mass of water absorbed per unit exposed area after 24 h divided by the square root of the elapsed time (24*3600s).

Fig. 6 shows the relation between kO_{max} and the coefficient of capillary suction a_{24}.

6.3 Relation with carbonation depth

After their respective 28-day curing, companion specimens to the slabs where kT and ρ were measured,

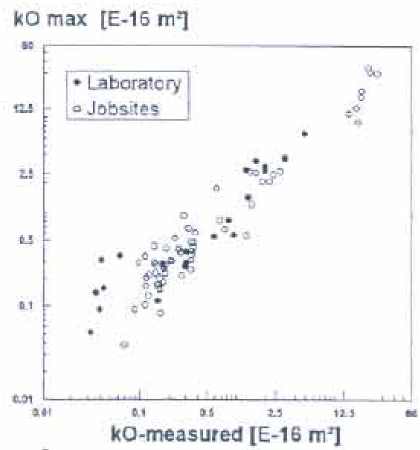


Fig. 5 : Correlation between kO max and kO measured

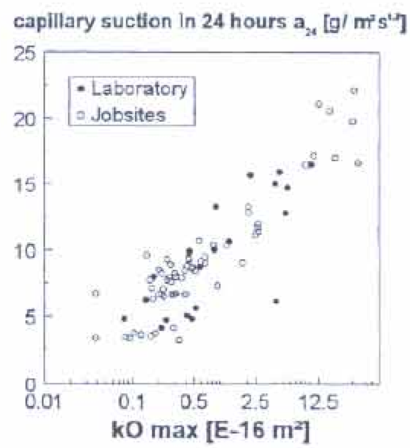


Fig. 6 : Relation beteen kO max and rate of capillary suction

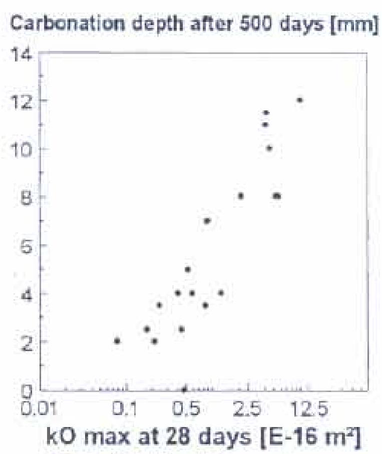


Fig 7 : Relation between ko max and carbonation depth were stored in the dry room and the carbonation depth was measured by the phenolphthalein method.

Fig 7 : shows the relation between kO_{max} measured at 28 days and the carbonation depth after 500 days for different laboratory concretes.

6.4 Correlation with chloride penetration

After their respective 28-day curing, companion slabs were pounded with NaCl solution for 90 days and the Total Chloride Penetration (total amount of chlorides ions that passed into the 'covercrete' per unit area) was measured, on the basis of the AASHTO T 259-80 method. The result of the test is the total amount of Cl^- that penetrated the 'covercrete' per unit exposed area [g/m^2]

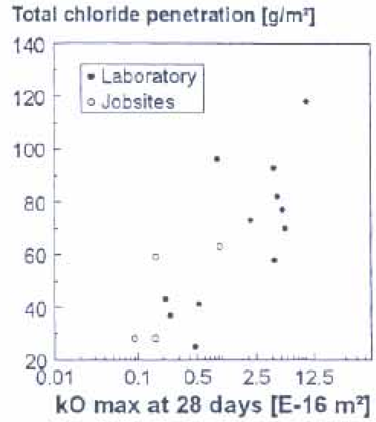


Fig 8 : Relation between ko max and Total Chloride Penetration

Fig. 8 shows the relation between kO_{max} at 28 days (before exposure to NaCl) and the Chloride Penetration (after 90 days of "pounding" with NaCl solution).

7. CONCLUSIONS

- The Torrent Permeability Tester constitutes a fast, repeatable and entirely non-destructive means to measure the air permeability of the 'covercrete' under both site and laboratory conditions.
- It correlates very well with the Cembureau method for oxygen permeability and other properties relevant for the durability of concrete structures.
- When the Torrent Permeability Tester has to be applied on moist concrete, it should be complemented with the non-destructive determination of the electrical resistivity.
- The concepts proposed in this paper have been applied to real concrete structures in Switzerland, mainly to bridges, both new and old; the results hitherto obtained indicate that the procedures are basically sound for actual on-site application.
- These concepts can be useful for the following purposes :
  - Quality control of the 'covercrete' in new buildings
  - Checking the permeability of the 'covercrete' on existing buildings for maintenance and repairs strategies
  - Support in the development of new products

- ➢ Non-destructive quality control of precast concrete elements
- ➢ Evaluation of the suitability of the placing, compacting and curing technique on the quality of the 'covercrete'
- ➢ Evaluation of the efficiency of surface treatments

Remark :

A commercial version of the Torrent Permeability Tester has been recently launched by Proceq SA, Zurich. The system is equipped with a microprocessor that calculates and displays the kT value immediately after the termination of the test (which takes between 1.5 to 12 min., for high- and low-permeability concrete, respectively) and stores the data of up to 200 tests. A Wenner electrode for the measurement of the electrical resistivity ρ can be purchased in connection with the Torrent Permeability Tester. The electrode can directly be connected to the microprocessor which calculates and displays the ρ value in kohm cm.

The Torrent Permeability Tester is presented by the exhibiting company "Ingenieurbüro DERENDA (IBD)" in the Equipment Exhibition.

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