Permeability Tester
TORRENT

Subject to change

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A. Introduction

The TORRENT Permeability Tester is a measuring instrument which is suitable for the determination of the air permeability of cover concrete by a non-destructive method.

It operates under vacuum and can be used at the building site and also in the laboratory.
The essential features of the TORRENT method of measurement are a two-chamber vacuum cell and a pressure regulator which ensures an air flow at right angles to the surface and into the inner chamber. This permits the calculation of the permeability coefficient kT on the basis of a theoretical model.
In the case of dry concrete, the results are in good agreement with laboratory methods, such as oxygen permeability, capillary suction, chloride penetration and others. The quality class of the cover concrete is determined from kT using a table.
The humidity, a main influence on the permeability, is compensated by additionally measuring the electrical resistance ρ of the concrete. With kT and ρ, the quality class is obtained from a nomogram.

Diagram of the measuring equipment:

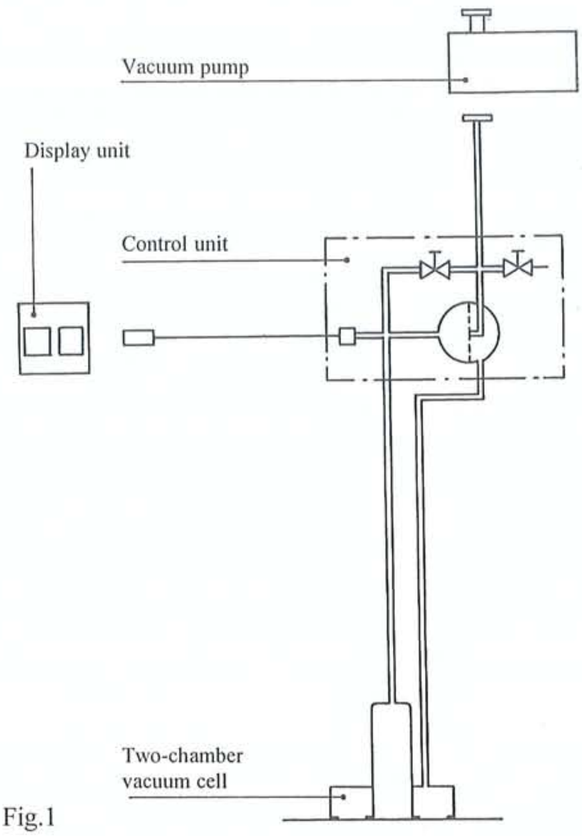
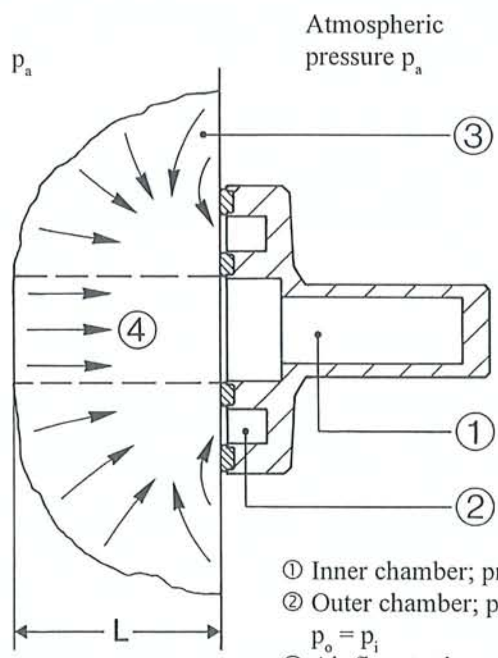


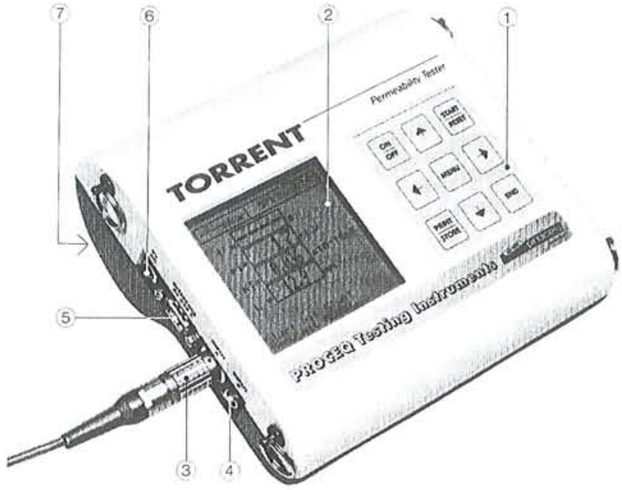
Fig.1

Two-chamber vacuum cell:



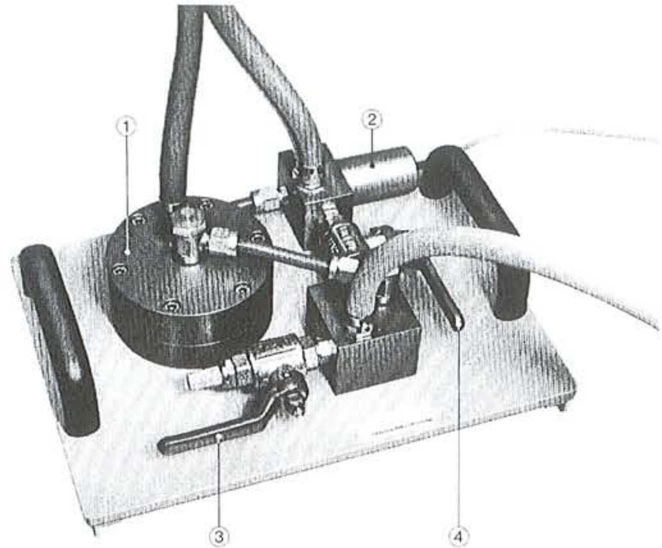
① Inner chamber; pressure p_i
② Outer chamber; pressure p_o
$p_o = p_i$
③ Air flow to the outer chamber
④ Air flow to the inner chamber
L = Depth of penetration of the vacuum

Electronic display unit:



① Operating panel
② Graphic LCD
③ Input A
④ Input B
⑤ Signal output RS 232 C
⑥ External battery-connection 9 VDC
⑦ Battery compartment

Control unit:



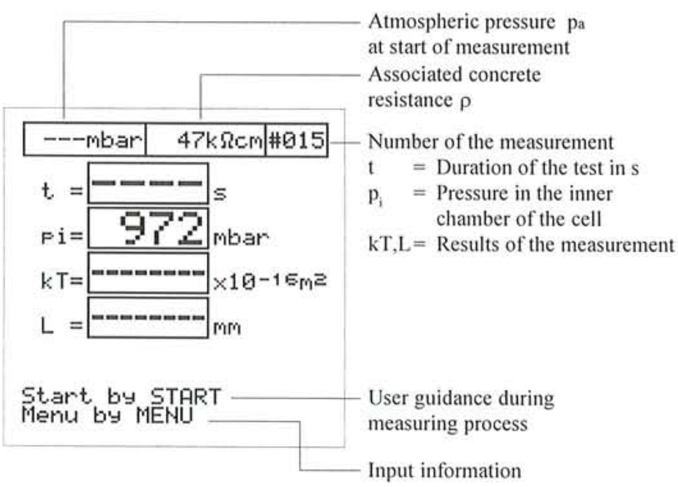
① Pressure regulator
② Pressure sensor
③ Red cock
④ Blue cock

B. Operation of the Instrument

1. Display Unit

Press the "ON" key. The serial no. of the unit, the installed software version, whether the automatic self-test is successful and the remaining battery life are displayed briefly. If no display appears, the batteries must be replaced.

The measurement display then appears:



2. Measurement of the Permeability

Measuring setup according to Fig. 1

Control unit:
- both cocks open (horizontal)
- connect small flange to vacuum pump
- connect plug of pressure sensor to Input A of display unit

To reach the operating conditions put the instrument under vacuum for 10 minutes, i.e.: let the pump run, the red cock closed, the vacuum cell on the concrete. To remove the vacuum cell: close the blue cock, then open the red and blue one.

A measurement is always carried out in the same sequence. Please follow the instructions on the display.

Start the vacuum pump.

Action:	Function/Explanation:
Switch on display unit.	Owing to the open vacuum cell, the atmospheric pressure p_a is displayed as p_i.
Press START key.	The measurement no. is increased by 1 if measured values are already stored under the displayed number obtained on switching on. Atmospheric pressure p_a appears at top left. The unit requests: “Shut red cock”.

Action:	Function/Explanation:
Place vacuum cell on test area.	
Shut off red cock.	p_i begins to decrease. t begins to run. After t = 30 s, the unit requests: "Shut blue cock"; 5 s later: "Open blue cock".
Shut off and open the blue cock.	This is carried out to activate the pressure regulator.
	At t = 55 s, a beep sounds in preparation for shutting off the blue cock at t = 60 s.
Shut off the blue cock.	From this time onwards, Δp_i = measured pressure increase in mbar is displayed.
	The **measurement is automatically terminated** and kT and L are calculated if: effective pressure increase = measured pressure increase – calibrated pressure loss ≥ 20 mbar, or t = 720 s.
Pressing the END key discontinues the measurement.	No values are stored and no calculations made.
In order to remove the vacuum cell from the concrete surface, open first the **red** and then the **blue** cock.	This results in venting of both chambers.
Switch off the pump only after the cocks have been opened!	This prevents the pump oil from rising back into the intake line.

3. Menu Options

```
■ Data Output
□ Test No.
□ Electr. resistance
□ Calibration
□ Device Constants
□ Language

Select by ↑↓
Start by START
End by END
```

Pressing the MENU key causes the adjacent list to appear. Select with ⇧⇩ and START. Pressing END leads to the measurement display.

4. Test No.

Set according to the information at the bottom of the display. The number is automatically increased by 1 for the subsequent measurement.

5. Electrical Resistance ρ

```
Electr. resistance
□ Manual Input
  ρ= 047  kΩcm
□ Wenner Input
□ Delete Mean Value
  ρ=   27 kΩcm  100%
  ρ̄=   32  kΩcm
         3  samples

Store with STORE
End by END
```

The electrical resistance of the concrete in kΩcm as determined by the Wenner method is used.

5.1 If the electrical resistance is measured using a separate instrument, ρ can be input manually: position cursor at "Manual input" and press the START key. Enter the value and confirm by pressing the END key.

5.2 Measurement with resistance probe WENNER-PROCEQ:
- Deletion of an existing mean value is carried out by positioning the cursor at "Delete mean value" and pressing the START key.
- Connect probe to Input B of the display unit. Moisten the four foams with water to enable electrical contact with the concrete. Select "Wenner Input" and press START. Place the contact points of the probe on the concrete. The unit measures the resistance and displays it at ρ. To the right the percentage of the nominal current that flows under the present conditions through the concrete is indicated.
  Once the measured value is stable, it is saved by pressing STORE and displayed as new mean value $\bar{\rho}$. Respectively, it is added to the already stored values of a test area and the resulting $\bar{\rho}$ is displayed. Max. number of individual resistances = 24.

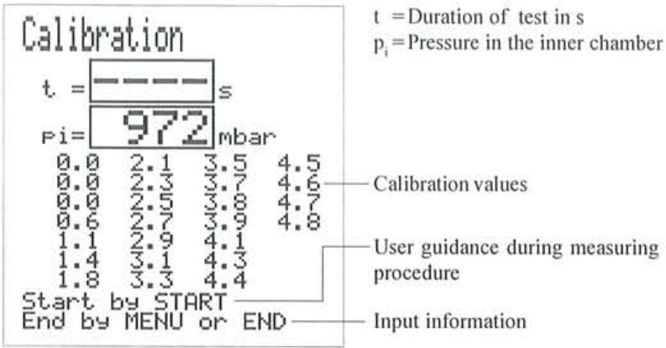
  The measurement of these resistance values is also completed by pressing the END key.

  If "Value not exact" appears, this means that the moistening of the four contact points of the probe is insufficient or the concrete is very dry and hence ρ is very large.

5.3 In the measurement display and with the stored data of a test area, the manually input resistance ρ or the resistance ρ measured with the Proceq probe appears, depending on the position of the cursor on exiting from the resistance measurement function.

Note:
The connected resistance probe consumes power even when no measurement is being performed. Disconnect the probe from the display unit when the probe is not in use.

6. Calibration



In the calibration, the pressure loss of the unit is measured. The vacuum cell is placed on the polished steel plate glued in the large carrying case. The calibration is then carried out in the same way as the measurement (see B. 2). The pressure increase is measured at intervals of 30 s and stored. This pressure loss is automatically subtracted in every measurement.

Carrying out the calibration:

Connect unit	p_i is displayed
Press START key	Calibration values shown below disappear
The further calibration procedure is the same as for the measurement	The calibration values are deleted from the memory as soon as t begins to run. Duration of calibration t = 720 s.

7. Instrument Constants

The list shows the values of the constants which are used in the calculation of kT and L. They cannot be changed. Underneath there is the code of the resistance probe WENNER-PROCEQ. The setting **must be identical** with code on probe. Change according to information at bottom of display.

8. Data Output

8.1 Display Data:

The main data of a measurement are displayed on one page. The ⇧⇩ keys can be used for paging up or down to the preceding or subsequent measurement. The associated auxiliary data are to be found on the page to the right and appear when the ⇨ key is pressed. These data are the measuring time and effective pressure increase at intervals of 60 s.

8.2 Print Data:

Printing can be carried out on all commercial printers with a serial interface.
Printer cable: Art. No. 330 00 460

Set up the printer for operation according to separate operating instructions and connect to the display unit. When the START key is pressed at "Print Data", all objects are transmitted and printed in turn.

Printout of an object:

```
        #015
Rho   =   39   kOhmcm
pa    =  965.3 mbar
tmax  =  450    s
dpmax =   20.4 mbar
                 -16 2
kT    = 0.873*10    m
L     =   50.3 mm
```

Data format: 9600 Baud
8 Data Bits
1 Stop Bit
Parity none

8.3 Data to PC:

Data transmission from TORRENT display unit to PC under **WINDOWS 3.1** (WIN 95 see next page)

- Prepare Display Unit:
  Connect serial port (COM1) of the PC to the serial interface of the display unit with the transfer cable Art. No. 330 00 269. Switch on the display unit and select menu "Data Output".

- Prepare PC:
  - Start WINDOWS 3.1.
  - Create directory C:\TORRENT.
  - Start "Accessory" group.
  - Start "Terminal" utility program.
  - Select "Settings" in the menu strip.
  - Select "Communications".
  - In the dialogbox "Communications" set:

Connector	: COM1
Baud Rate	: 9600
Data Bits	: 8
Stop Bits	: 1
Parity	: None
Flow Control	: Xon / Xoff

    Confirm settings with "OK" and terminate.
  - In the menu list, select "Transfers".
  - Select "Receive Text File".
  - In the dialogbox "Receive Text File":

Select directory	: C:\TORRENT
Enter filename	: e.g. TORR1.TXT

    Confirm input with "OK".

  When the "OK" key is pressed, the PC is simultaneously switched to the receive mode and "Byte = 0" and "Receiving: TORR1.TXT" appear at the lower edge of the text window as a check.

- Start Transmission:
  In the display unit, position the cursor at the option "Data to PC" in the "Data Output" menu. Data transmission is started by the START key, and the total content of the memory is transmitted. The characters received are displayed on the screen.

- After transmission is finished:
  - In the menu "Transfers" select "Stop".
  - In the menu "File" select "Exit".
  - Confirm the question "Save current changes?" with "No".
  The data are now saved in the previously specified file TORR1.TXT and are ready for further processing in the form of a text file.

- Display Data:
  The transmitted data can be displayed by any text editor or word processing program.

Data transmission from TORRENT display unit to PC under **WINDOWS 95**

- Prepare Display Unit:
  Connect serial port (COM1) of the PC to the serial interface of the display unit with the transfer cable Art. No. 330 00 269. Switch on the display unit and select menu "Data Output".

- Prepare PC:
  - Start WINDOWS 95.
  - At the first time:
    Create directory C:\TORRENT.
    Open "Program" → "Accessories" → "HyperTerminal Connection".
    Start "Hyperterm".
    Do not install a modem.
    Insert name "TORRENT" and select an Icon.
    Confirm with "OK".
    Select menu "Direct to Com1". Confirm with "OK".
    Bits per second : 9600
    Data bits : 8
    Parity : None
    Stop bits : 1
    Flow control : Xon / Xoff
    Confirm with "OK".
  - In the menu "Transfer" select "Capture Text".
  - In the dialogbox "Receive Text File" enter:
    e.g. C:\TORRENT\TORR1.TXT
  - Confirm with "Start".
  Your PC is now ready to receive data.

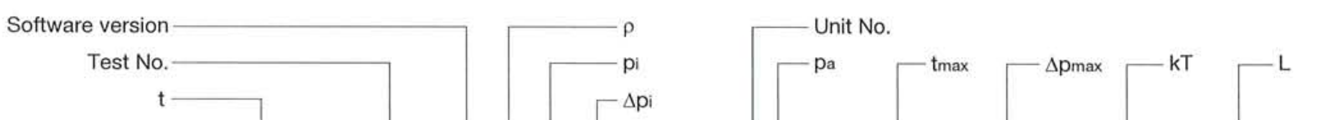
- Start Transmission:
  In the display unit, position the cursor at the option "Data to PC" in the "Data Output" menu. Data transmission is started by the START key, and the total content of the memory is transmitted. The characters received are displayed on the screen.

- After transmission is finished:
  - In the menu "Transfer" select "Capture Text" and "Stop".
  The data are now saved in the previously specified file TORR1.TXT and are ready for further processing in the form of a text file.

- Save settings from terminal program:
  - In the menu "File" select "Exit".
  - Confirm the question "Are you sure you want to disconnect now?" with "Yes".
  - At the first time:
    Confirm the question "Save session TORRENT?" with "Yes".
    Check: The new Icon with your settings appears on the screen.
  The next time you can start the TORRENT program easily by a double click on this Icon.

- Display Data:
  The transmitted data can be displayed by any text editor or word processing program.

8.4 Clear Memory:
Objects cannot be deleted individually.



	A	B	C	D	E	F	G
1	TORRENT Permeability Tester	1.43	11.014				
2	15	39	965.3	450	20.4	0.873	50.3
3	0	965.3					
4	30	5.3					
5	60	5.3					
6	90	2					
7	120	4					
8	150	5.8					
9	180	7.5					
10	210	9.1					
11	240	10.6					
12	270	12.1					
13	300	13.6					
14	330	15					
15	360	16.4					
16	390	17.8					
17	420	19.1					
18	450	20.4					

Data for a measured object in Windows file

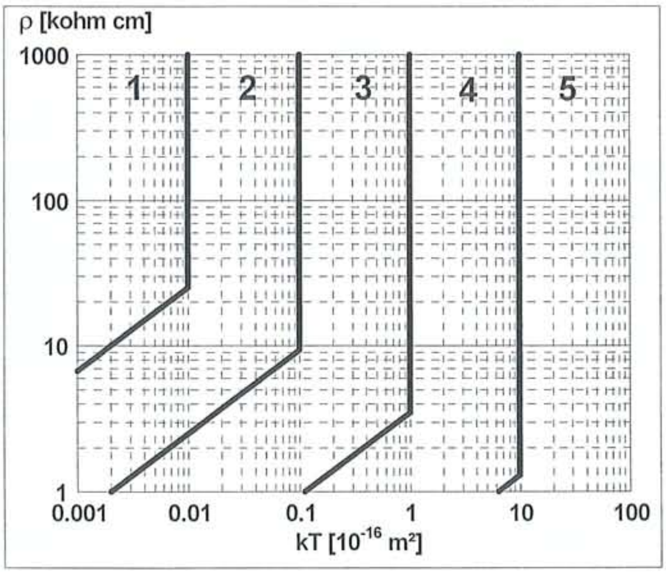
C. Practical Measurement Procedure

1. Nature of the test area:
   - Any desired position, surface **not** wet.
   - Sufficiently flat to enable the sealing rings to seal both chambers.
   - Concrete must not be cracked.
   - Distance between outer edge of the structural element and external diameter of the cell min. 20 mm.
   - The inner chamber should not be located above a reinforcement bar.
2. Calibrate the pressure loss from time to time and certainly after a large change in temperature and pressure.
3. Carry out three to six measurements of the electrical resistance ρ of the concrete and calculate the mean value.
4. Measurement of kT.
5. Determination of the quality class of the cover concrete: for dry concrete on the basis of kT from Table 1; for moist concrete on the basis of kT and ρ from nomogram Fig. 2.

Table 1: Quality classes of cover concrete

Quality of cover concrete	Index	kT (10^{-16} m²)
very bad	5	> 10
bad	4	1.0 - 10
normal	3	0.1 - 1.0
good	2	0.01 - 0.1
very good	1	< 0.01

Fig. 2: Nomogram for determination of the quality class of cover concrete:



6. The thickness of the concrete element must be greater than the depth of penetration L of the vacuum. This is essential for using the formula for calculating kT.

D. Notes on Function, Check and Maintenance of the Unit

Repeatability of the permeability measurement:
The repeatability of a measurement at the same point is very good. However, it must be borne in mind that it takes about ½ hour for the atmospheric pressure p_a to be reached again everywhere in the interior of the concrete.

Calibration of pressure loss:
The pressure loss of the unit is usually a few mbar in 720 s. If the calibration is carried out several times in quick succession, the pressure loss values become slightly smaller.

If moisture is present in the inner chamber or in the hose, the measured pressure loss is much greater than usual. The moisture can be removed by pumping out for about ½ hour with the red cock shut.

A leak in the system is indicated by the unit 120 s after the start of the calibration, and the calibration is discontinued.

With very dense concrete, the effective pressure increase may be negative over a certain time, i.e. the calibrated pressure loss is greater than the measured pressure increase. "Δp_i eff. negative" is displayed. If this difference is not more negative than –1mbar, the deviation in the calculation of kT is very small and a recalibration is not necessary.

Control unit and vacuum cell:
The components require no special maintenance. It should be ensured that the sealing rings are not damaged. Only soapy water should be used for cleaning.

E. Technical Data

Display Unit:
- Nonvolatile memory for up to 200 measured objects.
- Display on 128 x 128 graphic LCD.
- RS 232 C interface.
- Integrated software for printout of measured objects and transmission to PC.
- Operation with 6 batteries LR6 1,5 V for about 60 h or commercial power unit 9 VDC/0.2 A.
- Temperature range -10° to +60°C.
- Carrying case 320/285/105 mm, total weight 2.1 kg.

Control unit and vacuum cell:
- The volume of inner chamber and hose and the cross-sectional area of the inner chamber are terms in the formula for calculating kT and L. They must therefore not be changed.
- Vacuum connection: small flange 16 KF.
- Carrying case 520/370/125 mm, total weight 6.3 kg.

Resistance probe WENNER-PROCEQ:
Electrode spacing 50 mm

Vacuum pump:
The instrument is operated with a commercial vacuum pump.
Technical Data according to DIN 28 400:

Suction capacity	1.5 m³/h
Final total pressure	approx. 10 mbar
Suction-side connection	Small flange 10 KF/16 KF

High water vapour toleration

Regarding operation and maintenance of the pump, please consult the relevant instructions.

F. Notes on Use and Interpretation

See Appendix: "The permeability of cover concrete" by R.J. Torrent and G. Frenzer, Holderbank Management & Consulting, Holderbank, Switzerland.

The Permeability of Cover Concrete

R.J. Torrent, G. Frenzer, Holderbank Management & Consulting, Switzerland

1. Principle and Significance of Cover Concrete

While the bearing capacity of a structural element in a concrete structure is based on the mechanical properties of the total element, its durability under aggressive environmental influences depends essentially on the quality of a relatively thin surface layer (20-50 mm). This layer is intended to protect the reinforcement from corrosion which may occur as a result of carbonation or due to ingress of chlorides or other chemical effects. The influences mentioned are enhanced by damage due to frost/thaw or frost/thaw/salt.

The fundamental significance of this layer (referred to briefly as "Covercrete") for the durability of concrete structures is attracting more and more attention among researchers and engineers since it has been recognized that, owing to the small distance between formwork and reinforcement, and as a result of processes such as segregation and bleeding, finishing and curing, the formation of microcracks, etc., the composition and properties of the "Covercrete" may differ very considerably from those of the „Heartcrete“ (Fig. 1). In addition, the concrete test specimens used for quality controls can never represent the quality and properties of the „Covercrete“ since they are produced and stored in a completely different manner ("Labcrete ").

It is now believed that the partly unsatisfactory durability properties of non-prestressed and prestressed concrete structures could be improved if it were possible to specify the quality of the cover concrete with a view to the exposure conditions expected in each case and to test the completed structure (preferably by non-destructive test methods).

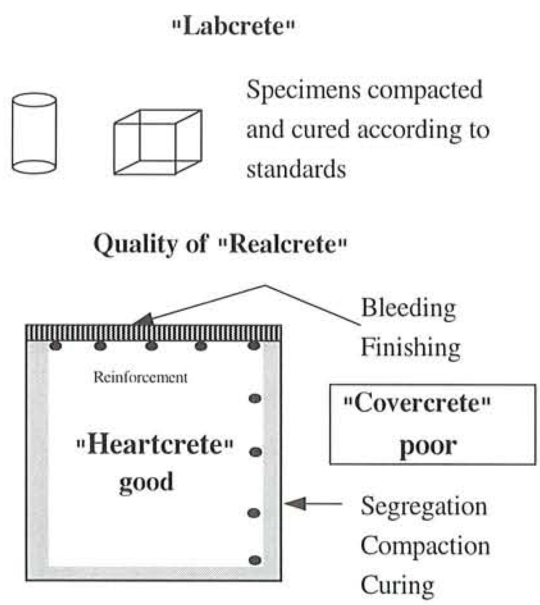


Fig. 1: Concept of „Covercrete"

The processes which cause damage to concrete structures are so varied and include so many different and often interlinked mechanisms (physical, chemical, physicochemical, electrochemical, mechanical) that it cannot be expected that only one or two parameters of the cover concrete quality will be sufficient for predicting the durability. This aside, there is general agreement that the permeability of the cover concrete is the most relevant property for measuring the potential durability of an individual concrete. This is also clearly expressed in the following paragraphs (from Section d.5.3 "Classification by Durability", Final Draft CEB-FIP Model Code 1990) [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 de-pend 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 alone 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."

The Torrent Permeability Tester permits a rapid and non-destructive measurement of the quality of the cover concrete with respect to its durability.

2. Evaluation of the Measured Values

On the basis of the results of various investigations into the durability of cover concrete [2], the following procedure was defined for evaluating the quality of cover concrete with respect to its durability:

2.1 For "Dry" Concretes

If the measurements are carried out on dry concrete (i.e. the concrete surface has not been in contact with water for about 2 weeks), the quality of the cover concrete can be determined directly from the measured kT values and Table 1:

Table 1: Quality Classes of Cover Concrete

Quality of cover concrete	Index	kT (10^{-16} m^2)
very bad	5	> 10
bad	4	1.0 - 10
normal	3	0.1 - 1.0
good	2	0.01 - 0.1
very good	1	< 0.01

These quality classes of cover concrete with regard to the permeability kT were defined by means of durability tests (carbonation, chloride penetration and frost/thaw cycling in the presence of salt) and on the basis of information from the literature.

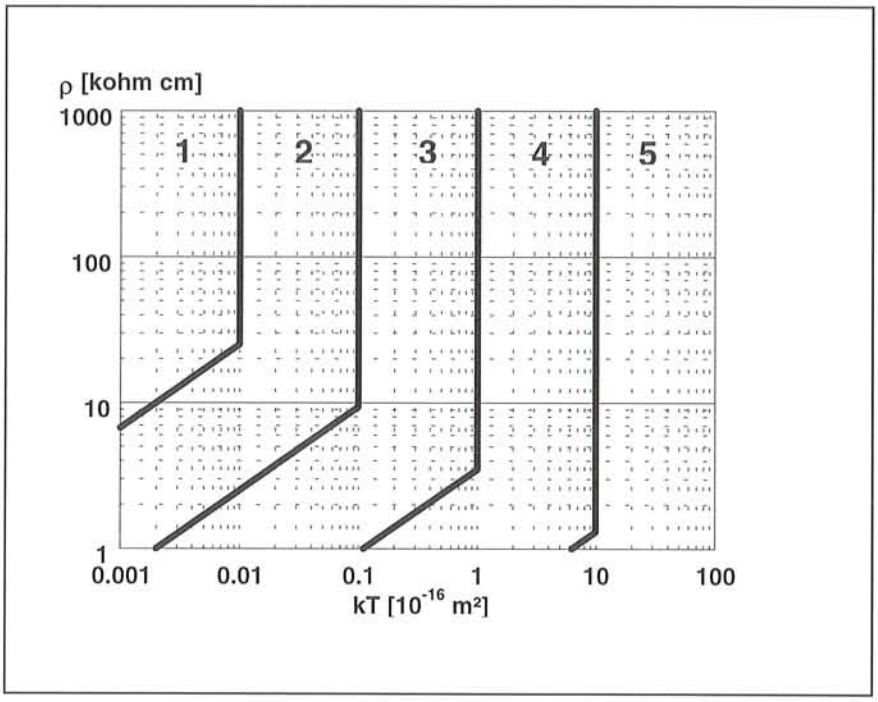
2.2 For "Moist" Concretes

If the requirement of appropriate dryness according to Section 2.1 is **not** fulfilled, the electrical resistance ρ must be additionally measured as an aid:

Correction by means of ρ

The quality classes of cover concrete can be determined from the measured kT and ρ values using the nomogram (Fig. 2).

Fig. 2: Nomogram for determining the quality classes of cover concrete



Procedure for "moist" concretes:

- Measurement of kT (1 x per test area)
- Measurement of ρ (3-6 times per test area and calculation of the mean value)
- Reading off the quality class of the cover concrete using the kT and the ρ values

Remarks:

- The determination of kT and ρ should not be carried out on wet surfaces (the moisture entering the unit could damage the membrane in the pressure regulator).
- The most accurate values are obtained for dry concrete (ρ measurement is superfluous).
- In order to obtain an exact idea of the quality of the cover concrete of a structure or of a finished component, several measurements must always be carried out.
- The quality classification of cover concrete (Table 1) and the nomogram (Fig. 2) relate to young concrete, i.e. concrete age about 1-3 months. Some measurements on concretes a few years old have shown that the classification in Table 1 and the nomogram cannot be directly applied.

- The moisture content of the concrete has a major effect on the gas permeability. The correction of this effect by the measurement of the electrical resistance generally leads to satisfactory results in the case of young concrete. For old concretes, further investigations must be carried out.

- The investigations were performed using a vacuum pump with a suction capacity of 1.5 m³/h and a motor power of 0.13 kW. This pump makes it possible to achieve a vacuum of a few mbar. Pumps of lower power do not reach the same vacuum and it is therefore advisable to use only pumps of similar power.

- There may be three further reasons why the desired vacuum (10-50 mbar) is not reached:

  - the concrete cover is too permeable (normal function of the unit)
  - the concrete surface is too uneven; the rubber seals can compensate only a certain degree of unevenness (abnormal function)
  - the unit has a leak (abnormal function)

3. References

[1] CEB-FIP Model 1990
Final Draft, Section d.5.3: "Classification by Durability", Bull. d'Information No. 205, Lausanne, July 1991

[2] Torrent R.J., Ebensberger L.
Studie über „Methoden zur Messung und Beurteilung der Kennwerte des Überdeckungsbetons auf der Baustelle", No. 506
Bundesamt für Strassenbau, Switzerland, Research Contract No. 89/89, January 1993

Further references:

- Continuation of Report No. 506 [2]:
  Torrent R.J., Frenzer G.
  Report No. 516, october 1995

- Torrent, R.J.
  A two-chamber vacuum cell for measuring the coefficient of permeability to air of the concrete cover on site
  Mater. & Struct., v.25, n. 150, July 1992, pp. 358-365

- R.J. Torrent und H. Braun
  Methoden zur Messung und Beurteilung der Kennwerte des Überdeckungsbetons auf der Baustelle
  SIA Documentation D 099
  Maintenance of bridges, current research results
  Lectures of the meeting of 11 March 1993 in Zürich and brief descriptions of other current research work

- R.J. Torrent, L. Ebensberger, J. Gebauer
  On site Evaluation of the permeability of the "Covercrete"
  Third CANMET/ACI International Conference on Durability of Concrete
  Nice, France 1994