Permeability Tester
TORRENT
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 $\rho$ of the concrete. With $kT$ and $\rho$, the quality class is obtained from a nomogram.

Diagram of the measuring equipment:

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Two-chamber vacuum cell:

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

Fig. 1
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:

- Atmospheric pressure $p_a$ at start of measurement
- Associated concrete resistance $\rho$
- Number of the measurement $n$
- Duration of the test in s $t$
- Pressure in the inner chamber of the cell $p_i$
- Results of the measurement $kT$. $L$

Start by START Menu by MENU

User guidance during measuring process

Input information

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.

<table>
<thead>
<tr>
<th>Action:</th>
<th>Function/Explanation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch on display unit.</td>
<td>Owing to the open vacuum cell, the atmospheric pressure $p_a$ is displayed as $p_i$. The measurement no. is increased by 1 if measured values are already stored under the displayed number obtained on switching on. Atmospheric pressure $p_i$ appears at top left. The unit requests: &quot;Shut red cock&quot;.</td>
</tr>
<tr>
<td>Press START key.</td>
<td></td>
</tr>
</tbody>
</table>

Press START key.
**Action:**

Place vacuum cell on test area.
Shut off red cock.

Shut off and open the blue cock.

Shut off the blue cock.

Pressing the END key discontinues the measurement.

In order to remove the vacuum cell from the concrete surface, open first the red and then the blue cock.
Switch off the pump only after the cocks have been opened!

### 3. Menu Options

<table>
<thead>
<tr>
<th>Data Output</th>
<th>Test No.</th>
<th>Electr. resistance</th>
<th>Calibration</th>
<th>Device Constants</th>
<th>Language</th>
</tr>
</thead>
</table>

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

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### 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 $\rho$

The electrical resistance of the concrete in $\text{k}\Omega\text{cm}$ as determined by the Wenner method is used.

#### 5.1 If the electrical resistance is measured using a separate instrument, $\rho$ 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 $\rho$. 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 $\rho$ is very large.

#### 5.3 In the measurement display and with the stored data of a test area, the manually input resistance $\rho$ or the resistance $\rho$ 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
- Press START key

The further calibration procedure is the same as for the measurement.

Calibration values
User guidance during measuring procedure

7. Instrument Constants

The list shows the values of the constants which are used in the calculation of $k_T$ 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 $\Theta$ 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 $\Theta$ 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.

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 dialog box "Communications" set:

        | Connector   |
        | Baud Rate   |
        | Data Bits   |
        | Stop Bits   |
        | Parity      |
        | Flow Control |

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

        | Select directory |
        | Enter filename  |

    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 "Transfer" 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.

<table>
<thead>
<tr>
<th>Software version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test No.</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>G</td>
</tr>
</tbody>
</table>

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 craked.
   - 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 $\rho$ of the concrete and calculate the mean value.


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 $\rho$ from nomogram Fig. 2.

<table>
<thead>
<tr>
<th>Quality of cover concrete</th>
<th>Index</th>
<th>$kT \times 10^{-6} \text{ m}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>very bad</td>
<td>5</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>bad</td>
<td>4</td>
<td>1.0 - 10</td>
</tr>
<tr>
<td>normal</td>
<td>3</td>
<td>0.1 - 1.0</td>
</tr>
<tr>
<td>good</td>
<td>2</td>
<td>0.01 - 0.1</td>
</tr>
<tr>
<td>very good</td>
<td>1</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

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 $p_0$ 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.

A $\Delta p_{\text{eff. negative}}$ is displayed. If this difference is not more negative than -1 mbar, 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-PROCEDURE:
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 tolerance

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

F. Notes on Use and Interpretation

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).

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"Labcrete"

Specimens compacted and cured according to standards

Quality of „Realcrete“

Reinforcement

"Heartcrete“ good

"Covercrete“ poor

Bleeding

Finishing

Segregation

Compaction

Curing

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 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 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

<table>
<thead>
<tr>
<th>Quality of cover concrete</th>
<th>Index</th>
<th>KT (10^{-16} m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>very bad</td>
<td>5</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>bad</td>
<td>4</td>
<td>1.0 - 10</td>
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<tr>
<td>normal</td>
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<td>1</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>
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 \( \rho \) must be additionally measured as an aid:

**Correction by means of \( \rho \)**

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

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

![Nomogram for determining the quality classes of cover concrete](image)

Procedure for "moist" concretes:
- Measurement of \( kT \) (1 x per test area)
- Measurement of \( \rho \) (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 \( \rho \) values

**Remarks:**

☐ The determination of \( kT \) and \( \rho \) 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 (\( \rho \) 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

   Final Draft, Section d.5.3: "Classification by Durability", Bull. d'Information No. 205, Lausanne, July 1991

   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

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  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

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  Third CANMET/ACI International Conference on Durability of Concrete
  Nice, France 1994