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PERMEABILITY OF EXISTING CONCRETE BRIDGES

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SUMMARY

On-going research at the EPF-Lausanne, Switzerland, is investigating the link between concrete permeability and the condition development of existing bridges. One area of this research is to determine a non-destructive testing method to evaluate the permeability of existing concrete structures. To achieve this objective a commercial permeability tester, designed for early age concrete, has been selected and a series of in-situ tests on 7 bridges near Lausanne have been conducted. A series of lab tests have been conducted to verify these in-situ values. It has been found that it is possible to measure the permeability of existing bridges using non-destructive methods.

Keywords: maintenance, rehabilitation, permeability, concrete, non-destructive testing, bridges, inspection

1. INTRODUCTION

As the world's infrastructure ages and increasing demands are placed on maintenance budgets, it is becoming increasingly important for engineers to make sound economical decisions pertaining to bridge rehabilitation. In order to make these sound decisions it is important to improve the predictions of future condition states of existing bridges. Improvement of these predictions requires improvement in the quality of data obtained during bridge inspections, as this is the data on which these predictions are based. Today, bridge maintenance inspections consist primarily of highly subjective qualitative observations. It is now necessary to go beyond these qualitative observations to more objective quantitative data.

On-going research at the EPF-Lausanne, Switzerland, is investigating new non-destructive testing methods that will improve the ability to predict the future condition states of existing bridges. One area of this research is to determine a link between the permeability of concrete cover and the vulnerability to corrosion of existing concrete bridges. By evaluating the permeability of existing bridges it may be possible to improve the estimation of the period of time before corrosion starts, the rate at which chlorides enter the existing structure and the life expectancy of the structure.

To achieve this objective a series of in-situ tests on 7 bridges near Lausanne have been conducted and to verify these in-situ values, a series of lab tests have been conducted.

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2. PERMEABILITY MEASURING DEVICE

The commercial permeability measuring device selected for this investigation was originally designed for the evaluation of the quality of early age concrete. The device measures permeability by creating a near vacuum on the concrete surface and measuring the flow of air from the existing concrete into the measuring device over a predetermined period of time.

The permeability tester has two chambers (Figure 1), an internal chamber (dia.- 32 mm) and an external chamber (dia. 86 mm). The permeability tester creates a near vacuum in the internal chamber, by use of a 1.5 m^3/h pump (Figure 2). Once this near vacuum has been created the permeability device measures the increase in pressure in the internal chamber, P_i, over a period of time (i.e. the flow of air through the concrete). To ensure that only air from directly below the internal chamber, and not from the surrounding concrete or the atmosphere, enters the internal chamber, an external chamber is used. The pressostat, shown in Figure 2, electronically controls the pressure in the external chamber, P_o, so it is equal to the pressure in the internal chamber, P_i. It is assumed that, by keeping the pressures equal, all air from the surrounding concrete or atmosphere that enters the measuring device will enter via the external chamber and have no effect on P_i.

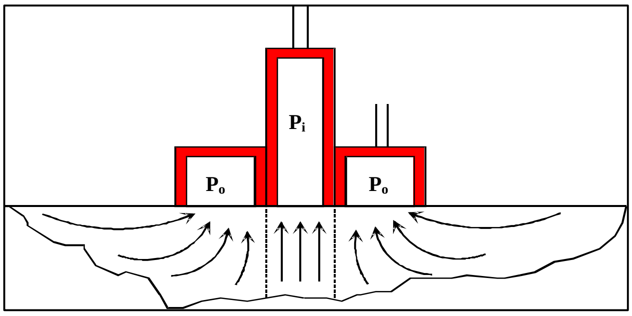


Figure 1. Air Flow through Concrete into the Permeability Tester

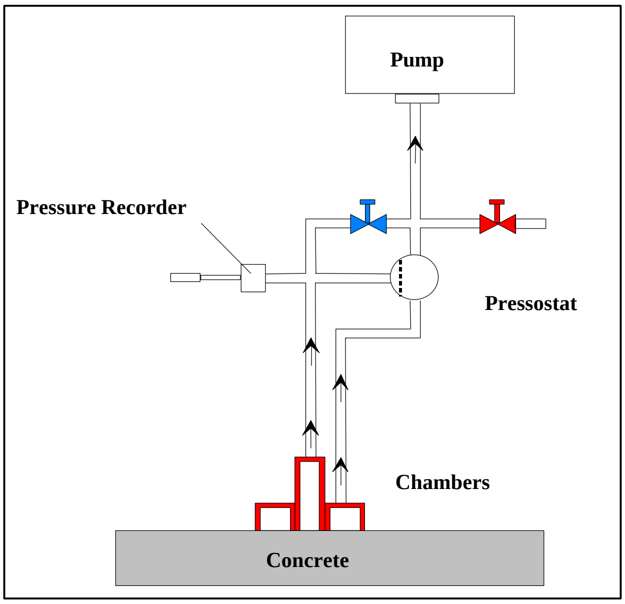


Figure 2. Schematic of the Permeability Measuring Device

By measuring the change in pressure in the internal chamber it is possible to rank the concrete into categories. The categories suggested for early age concrete are shown in Figure 3, with the permeability coefficient (kT) on the y-axis and the suggested concrete category on the x-axis (Torrent, 1993).

As concrete permeability changes with internal water content, the permeability measurements must be adjusted accordingly. Water content can be determined by measuring the resistivity of the concrete. This is done using the 4 point method of Wenner (Torrent, 1992).By categorising concrete into the five classes shown in Figure 3, assumptions can be made pertaining to the quantity of water carrying chlorides, and the quantity of oxygen, that can enter the concrete over time.

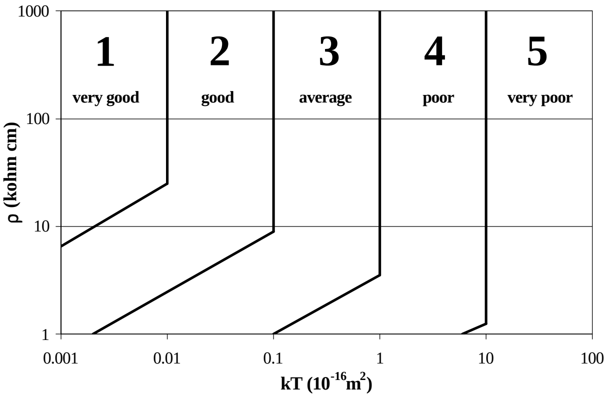


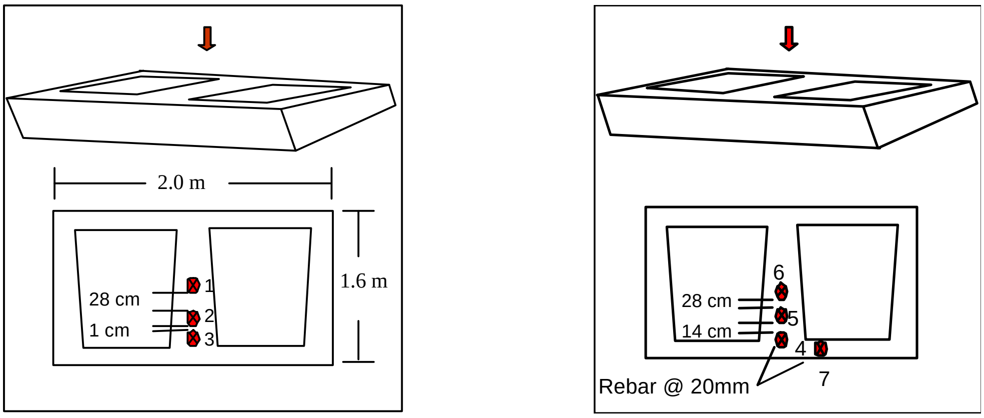
Figure 3. Nomograph to determine concrete class (Torrent, 1992)

3. TEST PROGRAM

In order to investigate the feasibility of measuring the permeability of in-situ concrete with this non-destructive method, both lab and field investigations were conducted.

3.1 Lab Investigation

The specific goals of the lab investigation were to verify the ability of the measuring device to accurately determine the permeability of existing concrete, and to determine the variability of the measurements. The variability was investigated with respect to location on the concrete surface, time and location of reinforcement.



Slab #12 *Slab #30*

Figure 4. Locations of Measurements on Slabs

Slabs were removed from an existing bridge, placed in the EPFL structures laboratory and allowed to dry over a 6 month period. Five sets of readings were taken on these slabs over a three week period from January 14th to February 2nd 1998, with a minimum of 24 hours between each reading. Each set consisted of one permeability reading at seven separate locations on two slabs (#12 and #30). The approximate locations are shown in Figure 4. Five of the locations were selected without reinforcement directly below the measuring device (#1,2,3,5 and 6). Two of the locations were selected with reinforcement directly below the measuring device and 20 mm of concrete cover (#4 and 7). The location of the reinforcement was determined using the Profometer 4 by Proceq.

3.2 Field Investigation

The specific goals of the field investigation were to determine the variability of the permeability of existing concrete structures, and to gain insight into the problems associated with permeability measurements on concrete exposed to continued wetting and drying.

To achieve these goals 7 bridges near Lausanne, Switzerland were selected for measurement. The bridges were built between 1960 and 1980, and had a wide variation in both design and use. The locations of the measurements on each bridge were selected to give an overall idea of the permeability of the bridge and to investigate as many different elements of the bridge as possible. Permeability measurements have been made on all bridges at least once. Measurements have been taken on Bridge #12, a dry bridge (one where no water content was detectable with the commercial resistivity meter), twice and on Bridge #15, a wet bridge (one where water content was detectable), three times. All measurements were taken at approximately the same location. The locations of the measurements on Bridge #12 and #15 are shown in Figure 6 and 7. At the time of the third measurement on Bridge #15 the precise locations of the measurements were marked so that future readings can be taken at exactly the same place.

4. TEST RESULTS

4.1 Lab Investigation

There was little variation in the permeability readings on the slabs when the measurements were taken at the same locations, with time as the only variable. This can be seen in Table 1 and Figure 5. The concrete class, as specified by Figure 3, did not change for any of the seven locations.

Table 1. kT values - Laboratory Tests.

	kT Values (Locations shown in Figure 5)						
Date	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7
14/01/98	3,468	0,349	7,236	3,186	56,250	7,089	5,033
15/01/98	3,381	0,451	1,226	6,166	57,300	6,732	4,471
16/01/98	3,717	0,600	7,060	7,765	55,240	7,709	5,516
19/01/98	3,573	0,518	6,552	6,081	53,130	8,073	5,795
02/02/98	3,487	0,429	2,829	6,394	55,590	4,068	5,614

Although there was little change in the measurements repeated at same location there were large differences in the measured values between locations. This can be seen by observing the proximity of the locations (Figure 4) and the widely differing kT values (Figure 5).

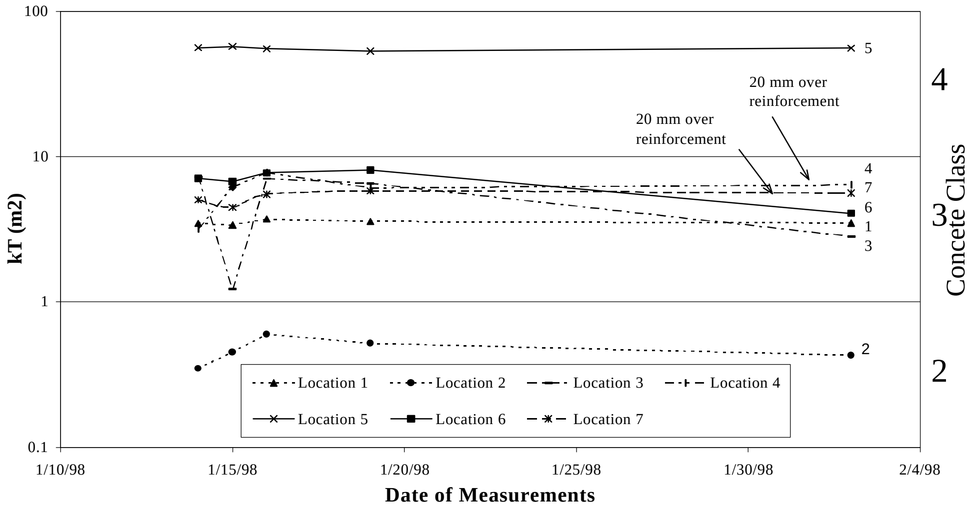


Figure 5. kT values - Laboratory Tests

The values obtained from Locations 4 and 7 showed no marked difference from the values of the other locations, indicating that reinforcement directly below the measuring device with 20 mm of concrete cover, has a negligible effect on the permeability measurements.

4.2 Field Investigation

The in-situ tests adequately predicted the permeability of dry concrete. Table 2 shows the consistency of the readings on Bridge #12 where no concrete humidity was detected.

Table 2. kT Values and Concrete Classes - Bridge #12.

Date of Measure	December 19th, 1997		March 20th, 1998	
Location	kT	Conc. Class	kT	Conc. Class.
1	0.709	3	0.204	3
2	0.186	3	0.112	3
3	0.553	3	0.007	2
4	0.942	3	0.343	3
5	0.717	3	0.322	3
6	0.395	3	0.308	3
7	0.12	3	0.059	3
8	39.7, 0.237, 0.04	5, 4, 2	43.16, 16.07, 0.071	5, 3, 2
9	0.004	1	0.017	2

Measurements at six of the nine separate locations resulted in the determination of the same concrete class both times. One of the nine locations showed improved concrete by one class, from average to good concrete and one of the nine locations showed decreased concrete quality by one class, from very good to good. The readings at the highly variable location, indicated as Location 8 in Figure 6, showed variation between very bad and good concrete (4 levels). Location 8 was the only one where humidity was detected in the concrete.

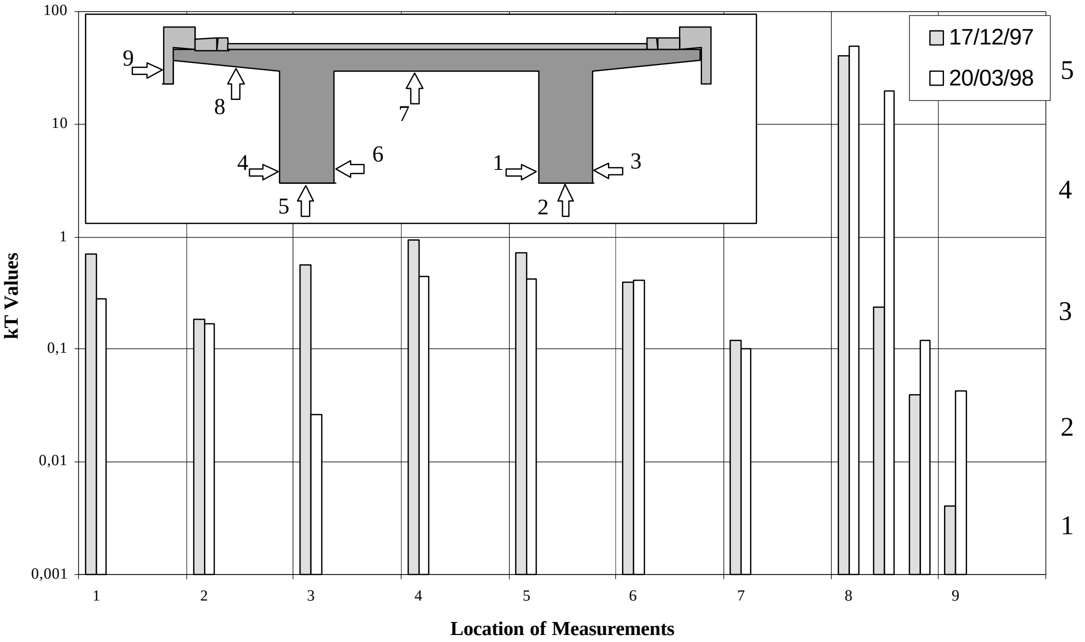


Figure 6. kT values and Concrete Classes - Bridge #12

Three sets of measurements were made on Bridge #15. All values are given in Table 3 and shown in Figure 6.

Table 3. kT Values and Concrete Classes - Bridge #15.

Date of Measure	December 17th, 1997		March 20th, 1998		April 1st, 1998	
Location #	kT	Conc. Cat.	KT	Conc. Cat.	kT	Conc. Cat.
1	-	1	-	1	-,-, 0.014	1,1,2
2	0.013	2	0.001	1	-,0.008, -	1,1,1
3	0.595	3	0.003	1	0.015,-, 0.009	1,1,1
4	-	1	0.008	1	-, -, 0.249	1,1,3
5	0.039	2	0.005	1	0.023, 0.026, 0.176	2,2,3
6	0.005	1	n/a	n/a	n/a	n/a
7	0.001, 0.587, 0.037	1,3,2	0.015	2	0.368, 0.215 0.031	3,3,2
8	0.77	3	0.002	1	0.100	3

Eight locations were measured during the first set of readings. Five of these measurements were repeated during the second set and eight of the measurements were repeated three times during the third set. The three sets of readings indicated either the same concrete class or fluctuations between one and two levels, when compared with the earlier readings. Many of the measurements taken during the third set of readings were of negative value and have been assigned a value of 0,0015 in Figure 7. Negative values may happen if no air can enter the internal chamber through the concrete, which may happen if the concrete is very wet. If no air can enter the internal chamber through the concrete it is possible that air from the internal chamber passes to the external chamber through a thin layer of the concrete surface. This decreases the pressure P_i and results in a negative value, at which point the tests were stopped.

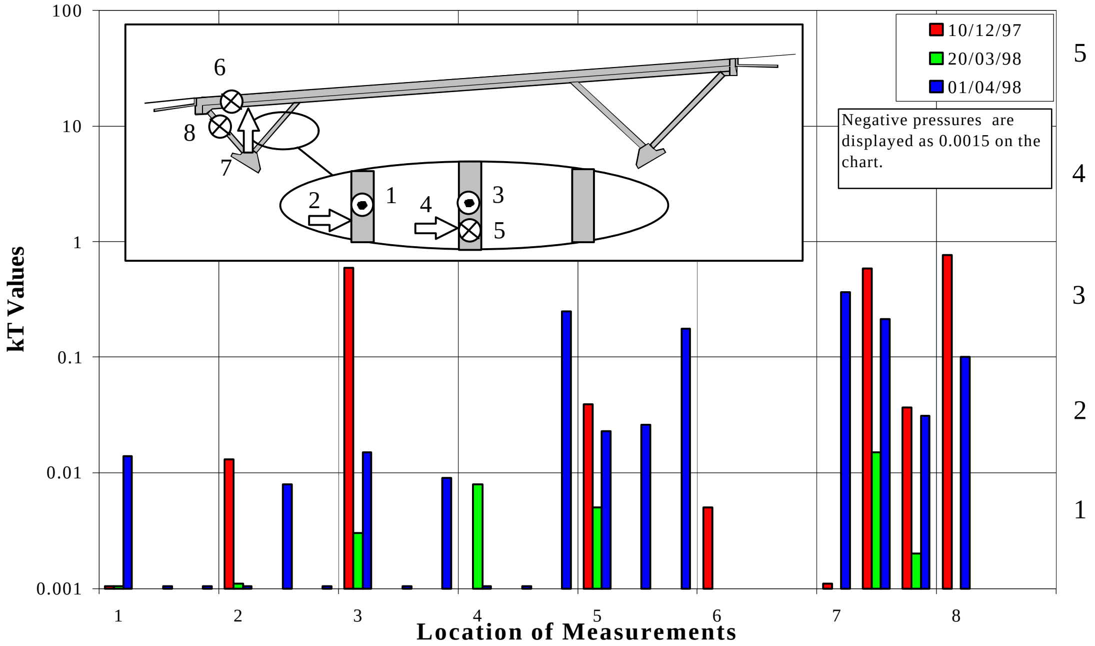


Figure 7. kT values and Concrete Classes - Bridge #15

During the first set of readings, humidity was detected by the resistivity measurements in the concrete at locations 2, 4, 6 and 7. During the third set of readings, humidity was detected in the concrete at all locations. None of the values however, were significant enough to change the level of concrete indicated by the kT measurements according to Figure 3. No humidity was detectable for the second set of readings. The exact locations of the third set of measurements were marked on the bridge to enable duplicate measurements in the future. One set of measurements, marked Location 3 in Figure 7, was duplicated during the third set of readings with approximately 45 minutes between readings. The permeability values in this case were closely reproduced (Table 4).

Table 4. The kT Values at Location 3 on Bridge #15 (April 1st, 1998).

1st kT Value	2nd kT Value
0.015	0.014
Negative	Negative
0.009	0.013

5 DISCUSSION

5.1 Lab Investigation

The test results of the lab investigation indicate that permeability measurements, when taken in exactly the same location, vary little. Due to this small variation, it is adequate to take only one measurement per location in the field if the permeability of the structure is to be monitored with time.

The wide variation in concrete of poor quality, means that, at least the first time the permeability of a bridge is measured, readings should be taken in a number of locations in close proximity to one another in order to obtain the overall condition of the bridge elements. This will be time consuming but is essential to a complete bridge evaluation.

As the location of the reinforcement with 20 mm of concrete cover showed no marked effect on the permeability measurements there is no need to locate the reinforcement precisely when there is more than 20 mm of cover. When there is less concrete cover the exact location of the reinforcement should be known and the permeability readings should be made away from the reinforcement.

5.2 Field Investigation

The test results of the field investigation indicate that with dry, good quality concrete the permeability can be accurately measured and the type of concrete of existing bridges determined even with small variations in location. The measurements taken on Bridge #12, with good concrete, using only approximate locations yielded virtually the same results (with changes of less than one class) both times, in 8 of 9 places. The one location where measurements showed a variation in the type of concrete by more than one class was located near a moist area of the underside of the bridge deck.

There is concern about the validity of the permeability measurements when there is moisture in the concrete. The measurements on Bridge #15 indicate changes in the concrete class between average concrete and very good concrete in all measured locations except one, over the three days that measurements were taken. These differences were also evident in the concrete during the same day with small changes in location. These differences may be attributed to the presence of water in the concrete and poor quality concrete. The presence of water in the concrete may cause differences in the permeability that cannot be adjusted using the resistivity measurements as originally intended (Torrent, 1992). Poor quality concrete may have large variations in permeability due to inconsistent composition, curing or compaction.

The two sets of measurements taken at Location 3 on Bridge #15 (Table 4) showed that if the exact location of the permeability measurements was the same and there was no change in water content that the permeability measurements are reproducible.

6 CONCLUSIONS

Permeability measurements are repeatable, on existing concrete bridges, when taken in exactly the same location and there has been no change in internal water content. By using permeability measurements it is possible to obtain quantitative data that will lead to better assumptions on the ability of water carrying chlorides and oxygen to enter an existing structure. (Further research correlating the relationship between air and water permeability is being conducted at the EPF- Lausanne). These assumptions with the assistance of deterioration models can then be used to obtain better approximations of the life expectancy of a structure.

7 REFERENCES

Torrent, R.J. (1992), “A two-chamber vacuum cell for measuring the coefficient of permeability to air of the concrete cover on site”, *Materials and Structures*, Vol.25, No.150, July 1992, pp. 358-365.

Torrent, R.J. (1993), “Studie über “Methoden zur Messung und Beurteilung der Kennwerte des Überdeckungsbetons auf der Baustelle” No.516 ”, Bundeamt für Strassebau, Schweiz, Forschungsauftrag Nr. 95/92 und Nr. 90/94.