

Expedient Permeability Measurement for Porous Pavement Surface

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The drainage capacity of porous surface course is one of the most important functional properties of a porous asphalt pavement. The ability to measure this property in the field is highly desirable. However, the flow measurement devices currently used for drainage testing of in-service porous pavements typically uses the time taken to discharge a given volume of water as the basis for assessment and comparison. Such empirical measurements are unsatisfactory, as they cannot be used to determine the actual drainage capacity and the flow properties of the material. Field equipment for non-destructive measurement of the *in situ* permeability of porous pavement surface materials has been developed. This paper describes the theoretical basis and operation of the equipment. A test on normal porous pavement materials with permeability of the order of 10 mm/s takes less than 2 min to complete. A demonstration project was performed to test two pieces of the equipment in a 14 km porous pavement expressway in Singapore. The project investigated the single-equipment reproducibility, and the between-equipment repeatability of test results. It was found that the coefficient of variation of measurements was of the order of 4%, and the results showed very good between-equipment repeatability at the 95% confidence level. The results suggest that the equipment provides a useful tool for expedient field measurement of the *in situ* permeability of porous pavements.

Keywords: Porous asphalt mixtures; Porous surface course; Permeability measurement; Field permeameter; Drainage capacity; In-situ testing

INTRODUCTION

Porous pavement surface course has been widely used to improve driving safety in wet weather. By allowing surface runoff to flow within the surface course, wet-

weather skid resistance of the pavement surface can be maintained at a relatively high level. Splashing and spraying can be effectively eliminated. Other benefits including cutting out of the reflection of street lights or vehicle headlights from pavement surface, noise

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abatement, and improved visibility of lane dividing lines and other pavement markings on rainy nights (Skvarka and Kumar, 1994; Kandhal and Mallick, 1998; Watson *et al.*, 1998).

To be able to maintain a high level of permeability over the intended design life is an important requirement of a porous pavement surface course. There is a need for an expedient means of measuring the permeability of in-service porous pavements in the field for the purpose of assessing and monitoring the functional performance of the pavements in terms of their effectiveness in discharging surface runoff. Some of the current methods are described by Skvarka and Kumar (1994), Kandhal and Mallick (1998) and Watson *et al.* (1998). Many highway agencies are relying on various forms of flow cylinders that empirically measure the time needed to discharge a certain volume of water through the porous surface course. This is unsatisfactory because such measurements only serve as empirical comparative tests of drainage performance of different pavement sections. They do not provide a basic flow property of the pavement material that can be related to its intended design conditions. Permeability, which is directly related to the drainage capacity of a material, is undoubtedly the most suitable flow property for a rational evaluation of the drainage performance of porous pavements. This paper describes the application of a newly developed apparatus for expedient field measurements of the permeability of in-service porous pavement surface courses. The theoretical basis and the procedure of measurement are presented. A reliability analysis of the procedure is made based on the data gathered from an actual network level pavement evaluation run.

THEORETICAL BASIS OF PERMEABILITY MEASUREMENT FOR POROUS MATERIALS

The conventional laboratory methods of permeability measurement, such as those described in the standard test methods AASHTO T215 (1982) and ASTM D2434 (1998), are typically constant-head tests that maintain a steady-state flow under a fixed hydraulic head. The

coefficient of permeability is computed from the measured flow rate by means of Darcy's law as follows:

$$v = ki \quad (1)$$

where v is the specific discharge (m/s), k is the coefficient of permeability (m/s) and i is the hydraulic gradient (m/m).

The same principle and method of measurement could theoretically be used to measure the permeability of a pavement surface course. However, this would require sufficient water to maintain a steady flow. For porous materials with permeability of the order of 10 mm/s or more, the volume of water required to maintain a constant flow rate would be so large as to render the method impractical for routine measurement. This problem has been overcome by the use of a falling-head test. In a falling-head test, both the hydraulic gradient i and the specific discharge v vary with time during the test. A practical way of obtaining the values of i and v as functions of time is by measuring the variation of inlet water level with time. If the difference between the inlet and outlet water levels, h , is recorded continuously as a function of time t , then v and i can be computed as follows,

$$v = \frac{dh}{dt} \quad (2)$$

$$i = \frac{h}{l} \quad (3)$$

where l is the flow path.

Using the relationship of Eqs. (2) and (3), Fwa *et al.* (1997) have developed a laboratory falling-head test apparatus and demonstrated that the procedure permitted the drainage properties of a porous test material at different hydraulic gradients to be determined in a single test run. In other words, performing a falling-head test over a given range of hydraulic gradients is equivalent to running many constant-head tests at different hydraulic gradients. This is of practical significance because it is known that in permeability measurements of porous media such as a granular material or a porous asphalt mixture, the assumption of laminar flow does not hold

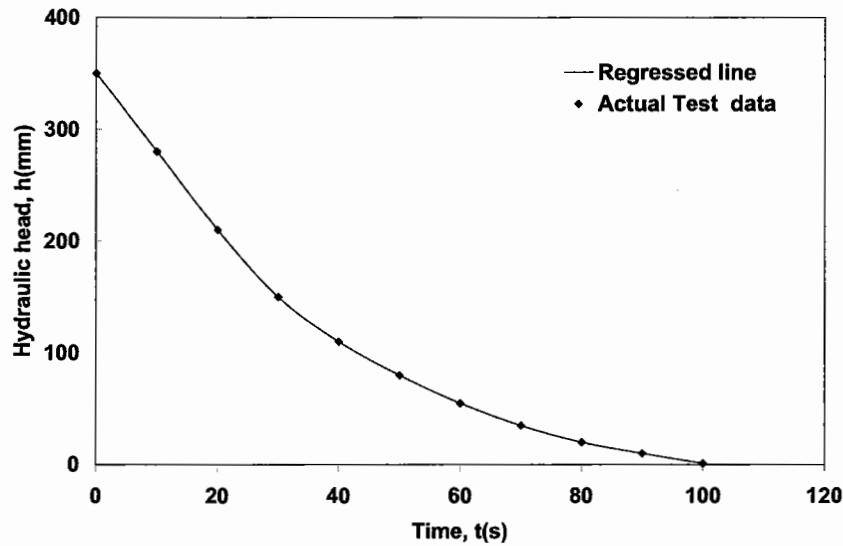


FIGURE 1 Typical results of falling head with time.

and Eq. (1) cannot be used directly (Muskat, 1937; Scheidegger, 1963; Jones and Jones, 1989). Instead, the following general relationship recommended by past researchers (Scheidegger, 1963; Bear, 1972) has been used to describe the non-laminar flow condition,

$$v = k_1 i^m \quad (4)$$

where k_1 and m are coefficients to be determined experimentally. For laminar flow, m is equal to 1, and for turbulent flow it has a value of 0.5.

To facilitate the computation of v from recorded data of time t and hydraulic head h , Fwa *et al.* (1997) expressed h as a polynomial equation of time t as follows,

$$h = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \quad (5)$$

where a_0 , a_1 , a_2 and a_3 are regression constants determined from experimental data. Figure 1 shows a typical plot of h as a function of time t . The specific discharge is computed from the following expression,

$$v = \frac{dh}{dt} = a_1 + 2a_2 t + 3a_3 t^2 \quad (6)$$

To determine the permeability coefficient k_1 and exponent n , a plot of $\log(v)$ against $\log(i)$ is prepared

as shown in Fig. 2. The slope of the plot gives the value of coefficient n , while the permeability coefficient k_1 is equal to the value of v at $i = 1$.

METHOD OF EXPEDIENT FIELD PERMEABILITY DETERMINATION

Field Permeameter

The falling-head test procedure described in the preceding section offers a feasible means for expedient non-destructive field permeability measurements of *in situ* pavement surface courses. Research by the authors has led to the development of a field permeameter, which can measure the permeability of a porous pavement surface course based on the theory presented.

Shown in Fig. 3 is a schematic diagram of the field permeameter, which has been registered under Singapore patent #9800747-9. It is a portable field apparatus that consists of a 150 mm diameter graduated perspex cylinder with a special trap door mechanism. An exterior circular metal guard fitted at the base of the cylinder has a rubber lining on its lower face to permit the permeameter to be seated firmly on the pavement surface and prevent water from leaking through the base

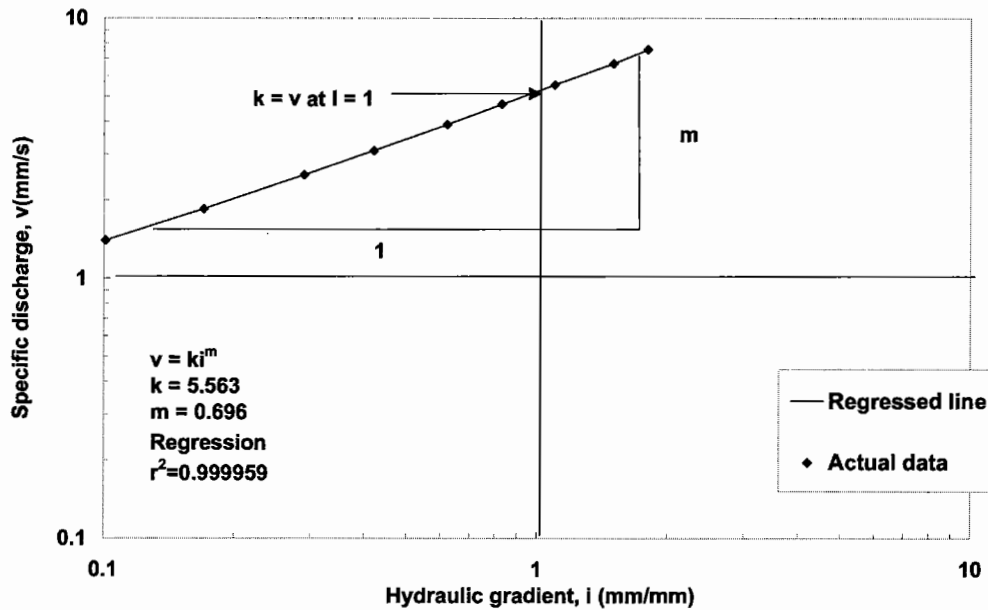


FIGURE 2 Example of a plot for determination of permeability coefficients.

of the device. A high-precision pressure transducer is installed on the interior wall of the cylinder at the base of the permeameter. This transducer can measure up to 0.3 mm change in water level, and the data are captured at a frequency of 100 Hz.

The trap door is held in its closed position and rested on the pavement surface inside the cylinder at the start of the test. Then about 4 l of water is added into the cylinder. This gives a water height of approximately 230 mm. The measurement of falling water head commences once the trap door is switched open. For a typical porous surface course with permeability of 10 mm/s or higher, the test will be completed in less than 2 min.

Determination of Three-dimensional Permeability

The determination of the *in situ* permeability from the measured data of the field permeameter applies to Eqs. (4–6). The permeability coefficients k_1 and m thus obtained describe the three-dimensional drainage properties that represent the combined effects of both the vertical and horizontal permeability of the

pavement surface course. Since the actual flow path and the depth of flow within the pavement surface course cannot be measured directly, additional analysis has to be performed before the permeability coefficients k_1 and m can be computed. In the present study, this additional information was obtained by means of a finite element simulation.

To facilitate the evaluation of the drainage capacity of a porous surface course, and the comparison of the drainage capacity of porous pavements of different geometric dimensions, the field permeability measurement results are reported in terms of effective permeability k . This effective permeability is defined as the permeability k of an isotropic material with uniform permeability in all flow directions.

In the finite element analysis, an axi-symmetric model was adopted to analyze the three-dimensional flow problem of isotropic medium. The finite element program available could only handle a steady-state flow condition. This, however, does not present any problem as explained earlier in the preceding section that a falling-head test is equivalent to many steady-state constant-head tests. In other words, a series of steady-state constant-head finite element analysis can be

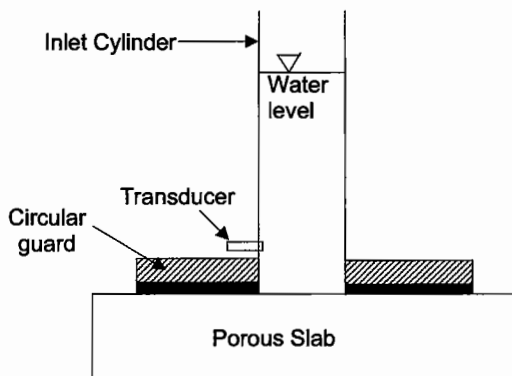


FIGURE 3 Schematic diagram of field permeameter.

performed and used to analyze the measured data of laboratory or field falling-head tests. Figure 4 shows a typical finite element mesh adopted for the analysis.

A large number of finite element analyses were performed to cover the practical ranges of permeability values and surface course layer thickness. This has led to the establishment of a relationship database that enables an expedient computation of three-dimensional field permeability based on the time history measurements of water level in the cylinder as recorded by the pressure transducer. The relationship database defines a pseudo three-dimensional permeability coefficient k_{3D} which is computed using Eqs. (4–6) by setting

- i) h as the height of water level within the cylinder measured by the pressure transducer, and
- ii) $i = (h + d)/d$ where d is the thickness of the surface course thickness.

A conversion is next derived to convert the pseudo three-dimensional permeability coefficient k_{3D} to the equivalent isotropic permeability k . The conversion relationship was found to be uniquely defined for a given thickness of the pavement surface layer. A laboratory verification program has been performed using seven sets of porous slabs of the following thicknesses: 25, 50, 75, 100, 125, 150 and 200 mm. The conversion relationship derived from the finite element analysis was found to be valid. This expedient determination of the equivalent isotropic permeability k from the *in situ* field measurement

permits the computation of the drainage capacity of a pavement, and directly compares to the drainage properties of different pavements.

Determination of Anisotropy in Permeability of Pavement Material

Pavement construction that involves compaction by rolling introduces some degree of preferential orientation of aggregate and hence anisotropy in drainage properties of the pavement layer. This has led to much higher horizontal permeability than vertical permeability in most pavements. Using the described apparatus to determine the effective permeability, it is possible to compute the anisotropy in permeability of field materials. This, however, requires core samples to be taken from the pavement.

The anisotropy of permeability in a pavement layer can be determined by the following procedure:

- (1) Measure the rate of discharge by the field permeameter.
- (2) Obtain core sample from the pavement layer, and measure the vertical permeability k_z by performing a laboratory one-dimensional permeability test using the falling-head method as described by Fwa *et al.* (1997).
- (3) With the known vertical permeability k_z , by means of the finite element analysis described in the preceding section, determine by trial and error the horizontal permeability k_x that produces the measured rate of discharge.

The isotropy ratio which is defined as the ratio (k_x/k_z) may thus be determined.

FIELD PROCEDURE OF IN SITU PERMEABILITY MEASUREMENT

A commercial equipment known as *k*-Tester is now available for *in situ* measurement of the equivalent isotropic permeability k of a porous pavement surface course. This equipment has been designed to apply the measurement theory presented in this paper (as shown in Fig. 3). Figure 5 shows a picture of the *k*-Tester.

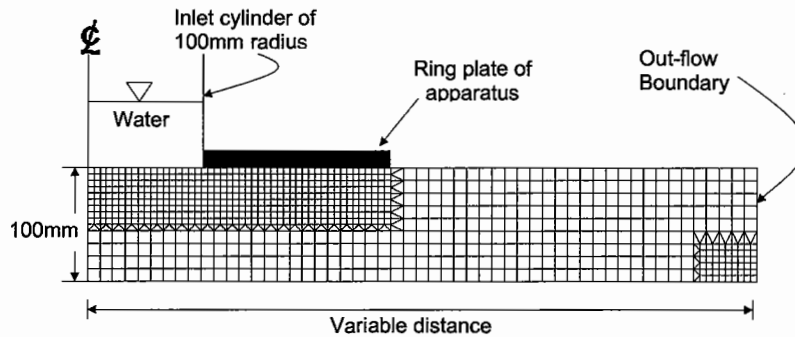


FIGURE 4 Typical mesh for finite element analysis.

The *k*-Tester is a portable falling-head test apparatus fitted with a pair of small wheels at the rear end of its base. It can be tilted to be supported on the two wheels and pushed to the next test point. It is equipped with a data recorder having a data acquisition rate higher than 100 Hz, and a micro-computer for processing the measured data.

To provide the mobility to cover a large road network, a light-weight short-wheelbase truck is needed for the field permeability measurement. It carries a water tank with a capacity of 500 l. As about 4 l of water is required for each measurement, the water provided is sufficient for 125 measurements. Each test, including setting up, can be completed within 4 min by a single operator. The amount of water is enough for 500 min (about 8.3 h) of non-stop testing, not including time for movement from point to point. Therefore, a full-tank of water is sufficient for one work of field measurement operation.

VALIDATION PROGRAM OF FIELD PERMEABILITY MEASUREMENT

Test Program

A validation program for field permeability measurement was undertaken to evaluate the permeability of a 14 km long expressway of porous asphalt pavement. The pavement had a porous asphalt surface layer of 50 mm thick. The demonstration project was conducted to determine the reliability of the field

permeameter. Two *k*-Testers were employed for the project work, one by the contractor awarded to carry out the field measurements, and another one by the project team engaged by the road authority. All measurements were made along the outer wheel path of the slow lane. The contractor randomly selected three points for testing in each kilometer and for the purpose of the demonstration project, three repeated measurements were made at each point. For each of the test points selected by the project team and tested by the contractor, the project team would perform another permeability test with their own equipment. The project team also had three repeated measurements at each test point.

One hundred and fifty millimeters diameter core samples of the porous surface course were obtained at selected test points for the purpose of determining the degree of permeability anisotropy in the porous pavement. The diameter of the cored specimens was selected so that they could be used directly for laboratory permeability determination. Some trimming and cleaning of the lower face of the cored samples were needed to remove the materials from the underlying dense-graded binder course.

Reliability of Field Permeability Measurements

The measured effective permeability *k* values are presented in Table I. There were a total 42 test points (14 km \times 3 points/km = 42 points). The data in the table are arranged sequentially. The following two aspects of the measured permeability values are of



FIGURE 5 Demonstration of *in situ* permeability measurement by field permeameter.

special interest in this demonstration project: the reproducibility of permeability measurements by a single permeameter, and the repeatability of permeability measurements of a permeameter by another permeameter. The reproducibility of a single permeameter can be assessed by examining the respective statistical coefficients of variation of the contractor's *k*-Tester and the project team's *k*-Tester. Since every test point was tested by the two *k*-Testers, the repeatability of the two equipment was assessed directly by means of a pair-wise comparison of the measurements.

Reproducibility of Measurements

The reproducibility of the permeability measurements by individual equipment is assessed statistically by

examining the coefficients of variation. Table I computes the standard deviation and the coefficient of variation for the three measurements at each test point. Figure 6 plots the frequency distribution of the coefficients of variation in the form of bar chart, Fig. 6(a) for the contractor's permeameter, and Fig. 6(b) for the project team's permeameter. For both permeameters, about 95% of the coefficients of variation were less than 5%. The results of the project team's permeameter appeared to have slightly smaller coefficients of variation. This could be due to the fact that the contractor's tests were performed by a technician who was new to the permeameter, while the project team's tests were by a research student who was familiar with the operation. However, by pair-wise comparison, the differences were statistically not significant at the 95% confidence level.

TABLE I Comparison of field permeability measurements

Test point	Contractor's <i>k</i> -Tester			Project team's <i>k</i> -Tester				
	Permeability, <i>k</i> (mm/s)		Std Dev. of <i>k</i> (mm/s)	Permeability, <i>k</i> (mm/s)		Std Dev. of <i>k</i> (mm/s)	COV (%)	
	Measured values	Mean		Measured values	Mean			
1	16.2, 15.9, 15.1	15.7	0.57	3.63	15.4, 15.8, 15.4	15.5	0.23	1.48
2	14.4, 13.2, 13.9	13.8	0.60	4.35	13.1, 13.9, 12.5	13.1	0.70	5.34
3	14.2, 14.3, 13.9	14.1	0.20	1.42	13.9, 13.1, 13.0	13.3	0.42	3.15
4	12.3, 11.8, 12.1	12.1	0.25	2.07	9.45, 10.0, 10.0	9.8	0.32	3.26
5	10.8, 10.7, 10.9	10.8	0.70	6.48	10.5, 10.8, 9.9	10.4	0.46	4.42
6	14.6, 14.3, 14.6	14.5	0.17	1.17	13.0, 12.8, 12.7	12.8	0.15	1.17
7	7.3, 7.5, 7.4	7.4	0.21	2.84	7.8, 8.0, 8.11	8.0	0.14	1.75
8	13.1, 13.1, 14.2	13.5	0.64	4.74	14.5, 14.5, 14.6	14.5	0.06	0.41
9	5.5, 5.6, 5.6	5.6	0.06	1.07	6.9, 6.7, 6.7	6.8	0.15	2.20
10	14.6, 14.5, 14.8	14.6	0.15	1.03	13.1, 12.6, 12.8	12.8	0.25	1.95
11	18.0, 18.2, 18.7	18.3	0.36	1.97	18.0, 17.5, 17.1	17.5	0.45	2.57
12	18.2, 17.9, 18.2	18.1	0.17	0.94	17.4, 17.8, 17.7	17.6	0.21	1.19
13	15.1, 14.6, 15.1	14.9	0.23	1.54	15.5, 16.5, 16.1	16.0	0.50	3.12
14	13.4, 13.9, 13.8	13.7	0.26	1.90	13.4, 13.5, 13.3	13.4	0.10	0.74
15	16.3, 15.3, 15.7	15.8	0.50	3.16	15.7, 15.3, 15.2	15.4	0.26	1.68
16	19.4, 20.2, 20.8	19.8	0.57	2.88	18.9, 20.1, 19.5	19.5	0.60	3.07
17	15.4, 15.4, 15.0	15.3	0.23	1.50	13.5, 13.5, 13.5	13.5	0.00	0
18	18.6, 19.9, 19.5	19.3	0.67	3.47	17.4, 17.6, 17.6	17.5	0.12	0.68
19	17.5, 15.2, 16.0	16.2	1.17	7.22	15.6, 15.6, 15.2	15.5	0.23	1.48
20	19.4, 20.2, 19.3	19.2	0.32	1.67	20.2, 21.5, 21.1	20.9	0.67	3.20
21	18.2, 17.2, 17.9	17.8	0.51	2.87	19.1, 19.1, 19.3	19.2	0.12	0.62
22	18.4, 18.5, 18.8	18.6	0.21	1.13	21.1, 20.5, 20.1	20.6	0.50	2.42
23	20.6, 20.4, 22.0	21.0	0.87	4.14	24.5, 24.7, 24.5	24.6	0.12	0.48
24	23.4, 23.8, 24.0	23.7	0.31	1.31	25.4, 25.2, 24.7	25.1	0.36	1.43
25	11.0, 11.9, 11.5	11.5	0.45	3.91	11.6, 10.9, 11.9	11.5	0.51	4.43
26	13.3, 13.7, 13.7	13.6	0.23	1.70	11.9, 12.0, 11.8	11.9	0.10	0.84
27	13.0, 12.1, 13.3	12.8	0.62	4.84	13.4, 12.8, 12.7	13.0	0.38	2.92
28	14.9, 15.0, 14.7	14.9	0.15	1.01	13.3, 12.4, 12.0	12.6	0.67	5.31
29	12.6, 12.3, 13.1	12.7	0.40	3.15	12.6, 12.7, 12.5	12.6	0.10	0.79
30	14.0, 14.5, 15.0	14.5	0.50	3.45	12.9, 13.0, 13.0	13.0	0.06	0.46
31	12.1, 12.1, 12.3	12.2	0.12	0.98	10.1, 10.1, 9.90	10.0	0.12	1.20
32	12.6, 12.3, 12.5	12.5	0.15	1.20	10.9, 10.0, 10.5	10.5	0.45	4.28
33	13.4, 14.0, 14.4	13.9	0.50	3.60	12.6, 12.3, 12.6	12.5	0.17	1.36
34	14.4, 15.0, 14.9	14.8	0.32	2.16	14.2, 14.4, 14.2	14.3	0.12	0.83
35	12.7, 12.9, 13.2	12.9	0.25	1.94	12.0, 11.5, 11.6	11.7	0.26	2.22
36	19.1, 18.8, 18.5	18.8	0.30	1.60	16.7, 17.1, 17.0	16.9	0.21	1.24
37	13.8, 14.7, 14.3	14.3	0.45	3.15	14.3, 14.6, 14.1	14.3	0.25	1.74
38	11.1, 11.6, 11.3	11.3	0.25	2.21	10.3, 11.2, 11.1	10.9	0.49	4.49
39	13.5, 13.7, 13.4	13.5	0.15	1.11	14.1, 13.7, 13.7	13.8	0.23	1.66
40	14.8, 14.2, 14.4	14.5	0.31	2.14	13.0, 12.8, 12.7	12.8	0.15	1.17
41	17.4, 17.4, 17.3	17.4	0.06	0.34	16.5, 15.6, 15.5	15.8	0.60	3.79
42	18.2, 17.7, 18.5	18.1	0.40	2.21	18.8, 18.1, 18.1	18.3	0.40	2.18

Repeatability of Measurements

The repeatability of permeability measurements by the two permeameters is first evaluated indirectly by computing the statistical coefficient of correlation between the two sets of permeability measurements. For each of the test points selected by the contractor, there was a corresponding permeability test by the

project team at a point 2 m away. On the reasoning that the permeability values of two test points 2 m apart should be similar, one would expect the two sets of permeameter measurements would vary along the 14 km long expressway in a similar fashion. Figure 7 shows graphically the variations of the permeability measurements by the two permeameters. Very good agreement was found between the patterns of

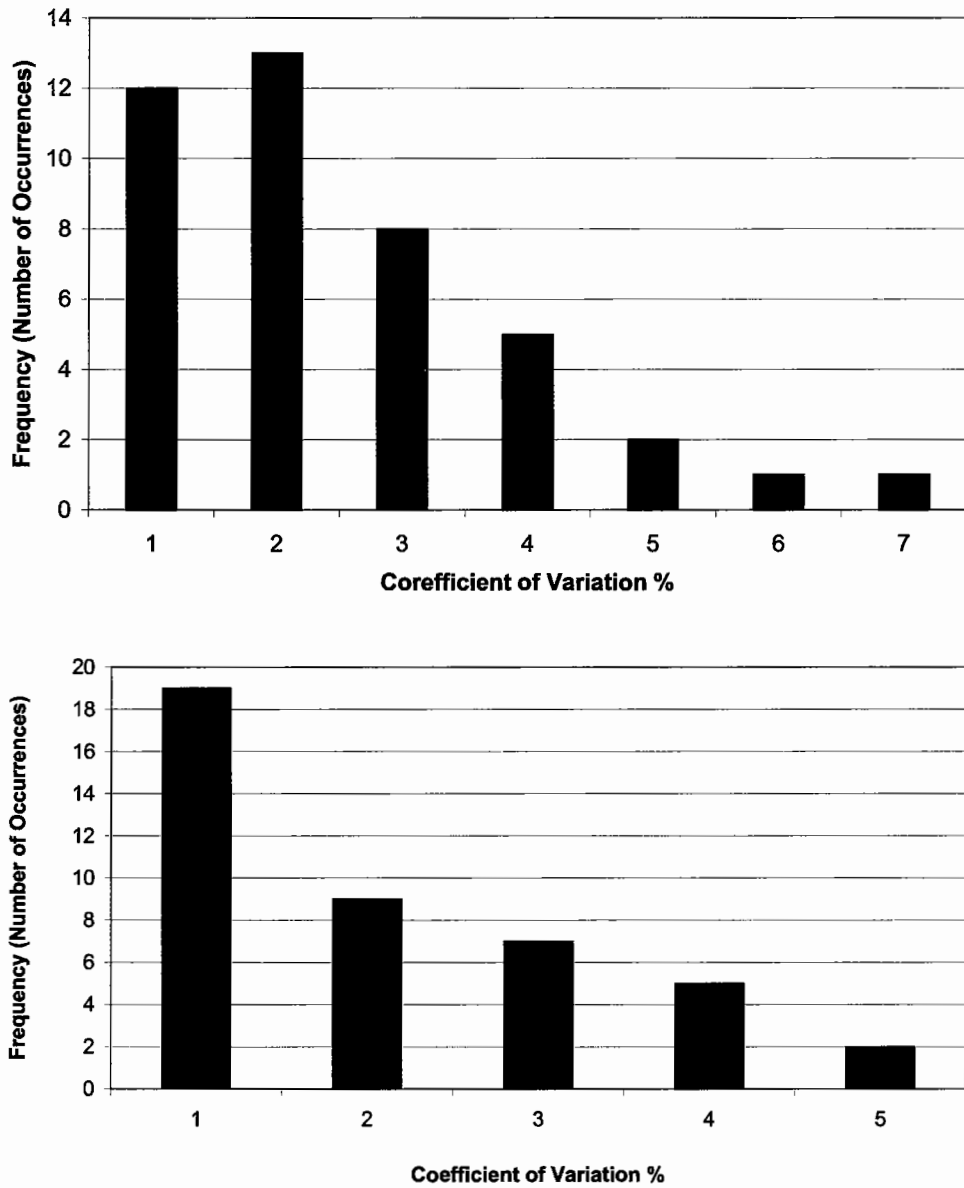


FIGURE 6 (a) Distribution of coefficients of variation of contractor's permeameter. (b) Distribution of coefficients of variation of project team's permeameter.

variation of the measurements by the two permeameters. The statistical coefficient of correlation is computed to be 0.945.

A direct test of measurement repeatability can be evaluated using a pair-wise comparison of the measured permeability by the two permeameters. The difference of each pair of the measurements was

computed, which was the difference between a measured permeability by the contractor's permeameter and the project team's permeameter. The differences for the 42 pairs of measurements thus computed were tested against the hypothesis that there was no difference between the permeability measurements by the two permeameters. This pair-

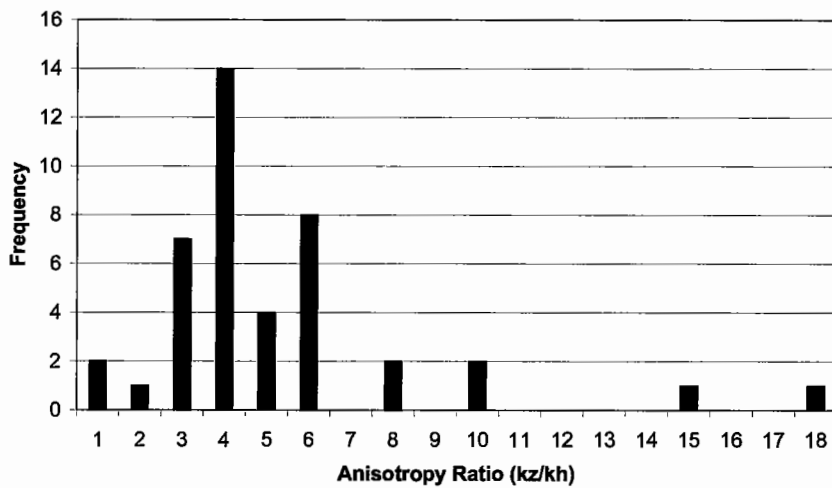


FIGURE 8 Frequency distribution of anisotropic ratios.

wise analysis showed no difference between the measurements by the two permeameters at the 95% confidence level. Therefore, it may be concluded that the field permeameters provided measurements with very good repeatability.

Permeability Anisotropy of Pavement Surface Course

Cored samples from selected test points were obtained from the demonstration project to provide some indication of the anisotropy in permeability of

the porous pavement surface course. By means of the procedure presented in an earlier section of this paper, the cored samples were tested for the vertical permeability k_z by means of the laboratory falling-head test, and the corresponding horizontal permeability k_x determined by means of finite element analysis. The anisotropy ratios (k_x/k_z) computed varied from 1.30 to 7.01. The frequency distribution plot presented in Fig. 8 shows that the majority of the anisotropy ratios lay within the range of 1.5–3.5. The mean anisotropy ratio was 2.68.

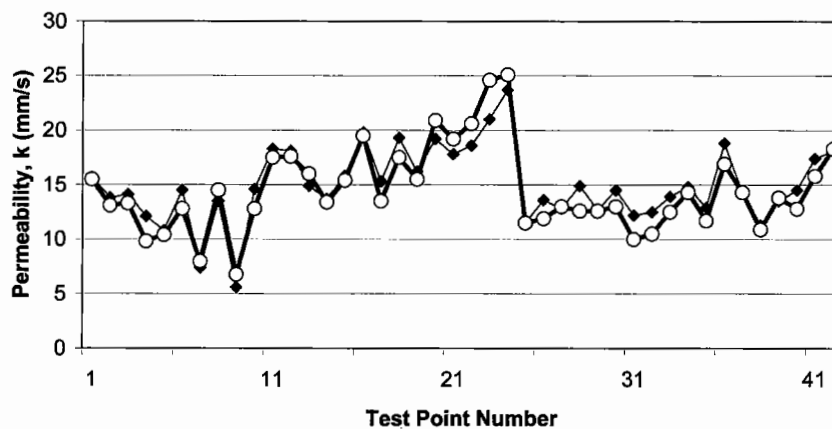


FIGURE 7 Permeability measurements by two permeameters.

Quality Control and Drainage Capacity Monitoring

The proposed procedure can be used as a quality control tool for new construction of porous asphalt pavement, and a means for monitoring of the drainage capacity of in-service porous pavement surfaces. This is because the measurements provide absolute values of permeability, which can be used for assessing the drainage capacity provided by the pavement surface tested. In other words, the results of the permeability measurements are able to differentiate between porous pavements of good and poor drainage capacity. This is illustrated in Table II in which permeability measurements made in two different highways are presented. Highway E4 being newly constructed had a very high permeability of the order of 30 mm/s, while Highway N1 generally had a permeability lower than 10 mm/s. A subsequent field inspection revealed that some degree of clogging had taken place in Highway N1 due to soil deposited by earth hauling trucks from a major construction project site nearby.

CONCLUSIONS

This paper has presented the theoretical basis and operation of a field permeameter developed for expedient determination of the *in situ* permeability of porous pavement surface course. The field permeability is a portable device that permits the *in situ* field permeability to be determined within a test duration of 2 min. Including setting up time, a single test can be completed by a single operator within 4 min. The amount of water required for each test is about 2l. A demonstration project has been carried out to evaluate the permeability of a 14 km long expressway porous pavement. The performance of two permeameters was studied in the demonstration project. The test results showed that the permeameters had good single-device reproducibility, giving a measurement coefficient of variation in the order of 4%. Two permeameters were found to display a high between-device repeatability. Even though the matching tests by the two permeameters were not performed

TABLE II Examples of field permeability measurements of in-service porous pavements.

Highway E4		Highway N1	
Chainage (m)	k (mm/s)	Chainage (m)	k (mm/s)
630-a	28.25	2000-a	6.07
630-b	28.83	2000-b	5.80
630-c	28.56	2000-c	5.57
680-a	47.15	2050-a	4.48
680-b	46.22	2050-b	3.94
680-c	46.94	2050-c	3.68
730-a	48.22	2100-a	4.36
730-b	47.95	2100-b	3.45
730-c	47.52	2100-c	3.33
780-a	21.76	2150-a	4.50
780-b	21.32	2150-b	5.07
780-c	21.52	2150-c	4.89
830-a	18.30	2200-a	7.85
830-b	18.35	2200-b	8.50
830-c	18.23	2200-c	7.90
880-a	17.84	2250-a	7.66
880-b	17.76	2250-b	6.72
880-c	18.28	2250-c	6.46
930-a	20.58	2300-a	6.14
930-b	20.68	2300-b	7.34
930-c	21.10	2300-c	7.04
980-a	20.73	2350-a	6.59
980-b	20.17	2350-b	8.28
980-c	20.33	2350-c	7.27
1030-a	23.31	2400-a	7.26
1030-b	23.33	2400-b	7.05
1030-c	23.43	2400-c	7.98
1080-a	38.05	2450-a	11.04
1080-b	38.83	2450-b	10.32
1080-c	37.78	2450-c	10.96
1130-a	33.21	2500-a	13.66
1130-b	33.35	2500-b	13.76
1130-c	33.14	2500-c	13.61
1180-a	29.23	2550-a	6.73
1180-b	28.56	2550-b	6.17
1180-c	28.23	2550-c	6.14
1230-a	33.71	2600-a	9.45
1230-b	34.69	2600-b	9.26
1230-c	34.62	2600-c	9.10
1280-a	43.59	2650-a	9.87
1280-b	43.83	2650-b	9.31
1280-c	44.45	2650-c	9.65
1330-a	29.98	2700-c	8.11
1330-b	30.88	2700-b	7.81
1330-c	30.83	2700-c	7.61

(Note: Three measurements were made at each test point, recorded respectively with suffix -a, -b and -c to the chainage)

at identical test points, but at about 2m apart, the measurement permeability values by the two permeameters yielded a high coefficient of correlation equal to 0.945. A further pair-wise statistical test indicated that the matching measurements made by the two

permeameters were statistically not different at 95% significance level. The measured data also gave information on the anisotropy of the porous asphalt pavement surface layer. The measured anisotropy ratio of horizontal to vertical permeability ranged from 1.30 to 7.01, with an average of 2.68. The positive results of the demonstration project suggest that the field permeameter can be used as an effective tool for expedient determination of *in situ* permeability of porous pavements.

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