

Efficient Test Setup for Determining the Water-Permeability of Concrete

PRASIT SOONGSWANG, MANG TIA, DAVID G. BLOOMQUIST, CONSTANTINOS MELETIOU, AND LARRY M. SESSIONS

The permeability of concrete is one of the most important factors influencing the durability of a concrete structure, and is a property of great interest to designers of concrete structures. However, very little data on this property of concrete exist, and there is not any widely used standard procedure for determining the permeability of concrete. The major problems generally encountered in performing a water-permeability test on concrete include (a) the great amount of time required for each test; (b) the possible leakage of water through the sides of the test specimens; and (c) the extremely low water flow rate, which makes an accurate measurement difficult to obtain. This paper presents a test setup and procedure that have been developed through experimentation and that have proven effective in dealing with the above-listed problems. The developed test setup can test 20 concrete specimens simultaneously by using 20 permeability apparatuses, which are connected to the same regulated compressed air source. The concrete specimens can be placed into and removed from the permeability apparatuses with a minimal loss of time and with no disturbance to the other test specimens. The problem of the effects of water evaporation on the measured flow rate has also been effectively dealt with. Another major advantage of this test setup is that it can be duplicated easily and economically. This paper also presents the results of permeability tests on three different Florida concretes subjected to four different curing conditions. The test setup has been demonstrated to be both reliable and efficient for determining permeability on a large number of concrete specimens.

The permeability of concrete plays a very important role in influencing the durability of a concrete structure. First, it controls the rate of flow of water, which can cause disruption to the concrete upon freezing. Second, it controls the rate of flow of chemicals, such as chloride ions, which can reduce the pH of the concrete and increase the rate of corrosion of the steel rebars in the concrete structure. The work presented in this paper deals with the development of an efficient laboratory test setup for measuring the permeability of concrete and is part of an ongoing research project on the study of factors affecting the durability of concrete.

The permeability of concrete to water is a property of interest to nearly all designers of concrete structures (1). Very little test data are available on the permeability of concrete at present, especially for Florida concrete. Although a widely used standard procedure for determining the permeability of

concrete does not exist (2), quite a few different methods for measuring permeability have been used in the past. Researchers who have studied the permeability of concrete include McMillan and Lyse (3), Norton and Pletta of Wisconsin (4), Ruettggers, Vidal, and Wing (5), Tyler and Erlin (1), and Meulen and Dijk (6). The various apparatuses used by these researchers to measure permeability of concrete were similar in that all of them measured the flow rate of water under pressure through the concrete specimens after a steady flow condition had been reached. The sides of the concrete specimens were sealed so that water could flow through the specimens without leakage through the sides. The sealants used included asphalt (4, 5), epoxy (6), and paraffin and resin (3).

The major problems generally encountered in performing a permeability test on concrete include (a) the great amount of time required for each test, (b) the possible leakage of water through the sides of the specimens, and (c) the extremely low water flow rate that makes an accurate measurement difficult to obtain. This paper presents a test setup and procedure that have been developed through experimentation and that have proven to be effective in dealing with the above-listed problems.

PERMEABILITY APPARATUS

In the development of a suitable permeability apparatus, the following requirements and concerns were considered:

- The apparatus should be easily duplicated.
- The concrete specimens could be inserted and removed with a minimal loss of time.
- Concrete specimens cut from larger-size concrete specimens should be used.
- The small quantity of water flowing through the concrete specimen should be measured accurately.

Through months of experimentation, the permeability apparatus as shown in Figure 1 was developed. It consists of a 1-in.-thick acrylic top plate, a 1-in.-thick acrylic base plate, an acrylic tube (with an inside diameter of 4.5 in., a wall thickness of 0.5 in., and a height of 1 in.), four steel bolts (6.5 in. long and 0.375 in. in diameter) and four matching nuts. The top and bottom of the acrylic tube are provided with neoprene gaskets. One gasket is placed between the bottom of the acrylic tube and the top of the specimen; the other gasket is placed between the top of the acrylic tube and the acrylic top plate. A steel connection tube is inserted through

P. Soongswang, M. Tia, D. G. Bloomquist, and C. Meletiou, Department of Civil Engineering, University of Florida, Gainesville, 32611. L. M. Sessions, Bridge Inspection and Evaluation Engineer, Florida Department of Transportation, 605 Suwannee St., Tallahassee, 32301.

the center of the acrylic top plate to provide a connection between the water in the acrylic tube to the pressure source and the manometer tube, which measures the amount of water going into the specimen. A quick connection is installed on the top acrylic plate at 2 in. from the center. It is used for refilling water into the manometer tube.

The 20 permeability apparatuses described above were built and connected to 20 manometer tubes, which were held in a vertical position against two boards. All the manometer tubes were connected to a main pressure line, which runs along the top of the vertical boards. The pressure is held constant by a regulator and is indicated on a pressure gauge, which is attached to one side of the vertical board for ease of reading. Any line can be disconnected from the main pressure line at any time without interfering with the operation of the other lines by turning off the individual valves. A picture of the test setup is shown in Figure 2.

Another regulator and pressure gauge are used to regulate the pressure in the water reservoir. The water reservoir, which is used for refilling water into the manometer tube, consists of an acrylic tube 8 in. in diameter and 14 in. long, top and bottom steel plates, two quick connections (one on each end), eight 0.375-in. \times 18-in. threaded rods, and eight matching nuts. The water reservoir used is shown in Figure 3.

PREPARATION OF TEST SPECIMENS

The test specimens, cylindrical specimens 4 in. in diameter and 2 in. high, are made by cutting 8-in.-thick cast cylinders

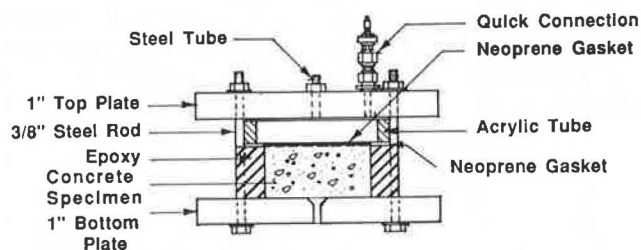
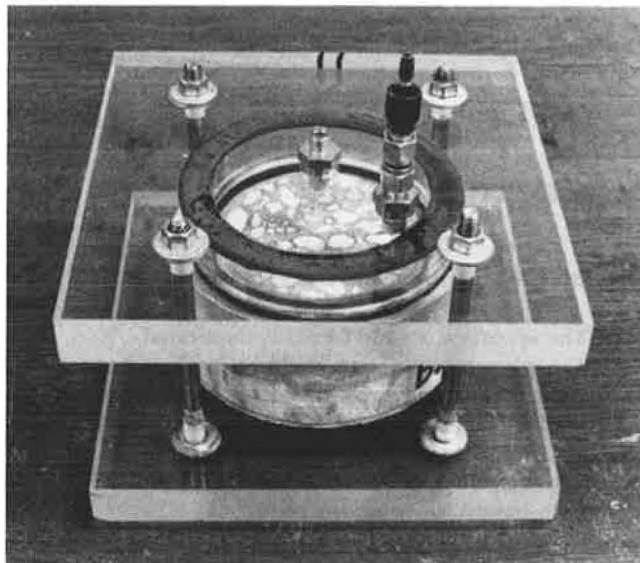


FIGURE 1 Permeability test apparatus.

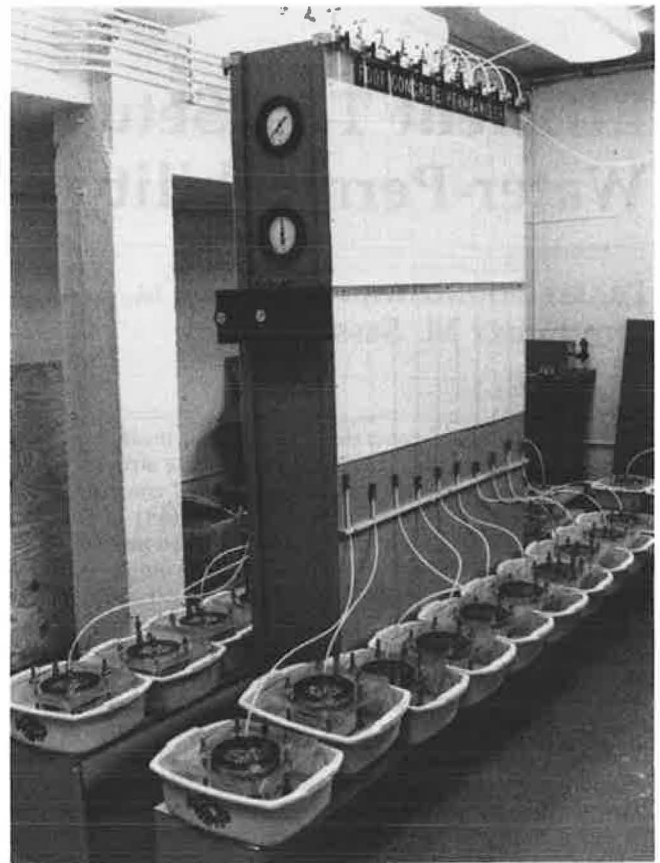


FIGURE 2 Permeability test setup.

into 2-in.-thick cylinders. A 0.0625–0.125-in.-thick layer is removed by sawing from the bottom surface of the cast specimens. The circumference of the test specimens are wire-brushed until all loose particles have been removed. Care is taken to ensure that the surfaces of the test specimens are dry.

A 1-in.-thick layer of epoxy (Sikadur 32, Hi-Mod) is cast around the side of the test specimen by means of a casting mold. The casting mold is 6 in. in diameter and 2.25 in. high and is bolted down to a steel plate. The inner surface of the casting mold and the top surface of the steel plate are coated with a very thin layer of release agent. The side of the specimen is first coated with a thin layer of epoxy. The specimen is then placed in the center of the casting mold, and the remaining gap between the casting mold and the test specimen is filled with epoxy. The air bubbles are eliminated from the epoxy by using a small hand vibrator. When the epoxy has hardened, the test specimen is taken out of the casting mold. The small amount of epoxy that may adhere to the top surface of the test specimen is removed. Figure 4 shows a casting mold; a picture of the prepared concrete specimens coated with epoxy on the side is shown in Figure 5.

TESTING PROCEDURE

The prepared test specimen is placed into the permeability apparatus in the following steps:

1. The test specimen is placed on the center of the base plate.
2. A neoprene gasket is placed on the specimen.
3. The acrylic tube is placed on the neoprene gasket.
4. Another neoprene gasket is placed on the acrylic tube.
5. The top plate is placed on the neoprene gasket and bolted to the base plate with four 0.375-in.-diameter rods (Figure 1).

The permeability apparatus is then connected to the manometer tube in the following procedure:

1. The valve for the manometer tube is turned off.
2. The manometer tube is connected to the connection tube at the center of the top plate of the permeability apparatus.
3. Pressure is applied to the main pressure line and maintained at 100 psi by the regulating valve, which controls the pressure from the air compressor.
4. The water reservoir is connected to the other pressure regulator through one of the two quick connections of the water reservoir, and a pressure of 102 psi is maintained.
5. The other quick connection of the water reservoir is connected to the quick connection at the top plate of the permeability apparatus, and water is injected into the perme-

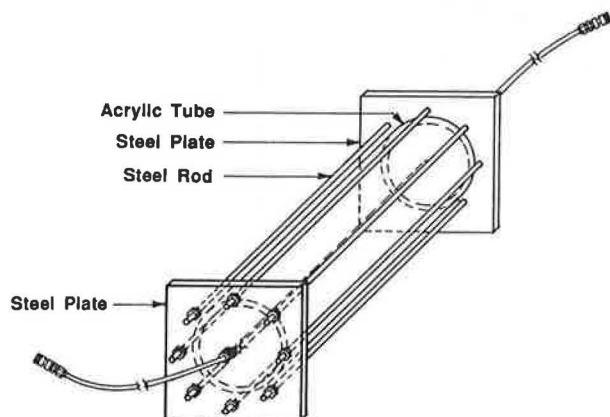
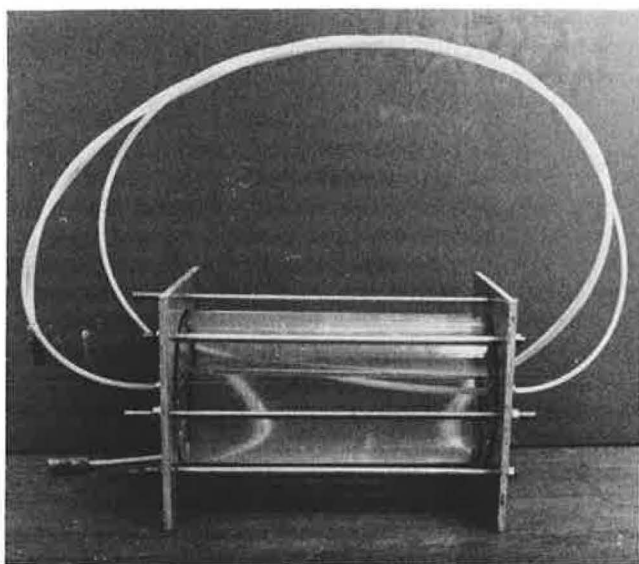


FIGURE 3 Water reservoir.

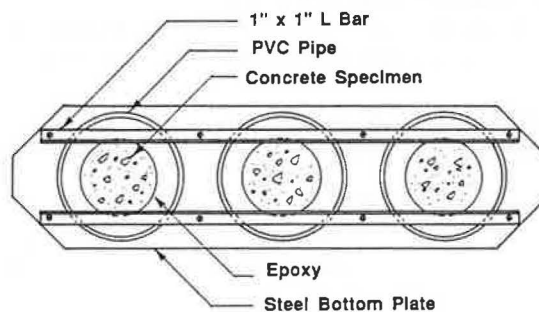
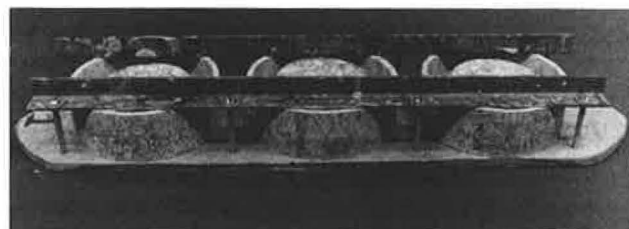


FIGURE 4 Casting molds.

ability apparatus and the manometer tube by opening the manometer valve slowly until the water in manometer tube reaches the top level. The valve is then turned off, and the permeability apparatus is disconnected from the water reservoir.

6. The air bubbles trapped inside the permeability apparatus are released through the quick connection at the top plate.

At this stage, the permeability test can be started by simply opening the manometer valve to connect the 100-psi air pressure line to the manometer. The water level in the manometer tube and the time at the start of the test are recorded. Possible leakage of water between the epoxy and the side of the test specimen is to be checked. If leakage occurs, the specimen must be discarded. However, leakage has occurred very infrequently. The test is continued if no leakage is found. When the water level in the manometer tube reaches a low level, additional water can be added to the manometer tube from the water reservoir. The process of refilling the manometer tube is the same as the initial filling as described earlier.

METHOD OF MEASURING RATE OF FLOW

The amount of water flowing into a test specimen is measured by reading the water level of the 0.125-in. manometer tube



FIGURE 5 Prepared concrete specimens.

at least once a day. A plot of the cumulative amount of water flowing into the test specimen vs. time is drawn for each test specimen to determine when a steady-state flow condition has been reached. The steady-state condition is usually reached within 10–14 days. The test is continued for about 5–7 days beyond the steady-flow condition. The average rate of inflow in the last 5–7 days is used as the rate of inflow for the test specimen. Two typical plots of cumulative amount of water flow vs. time are shown in Figure 6.

The evaporation of water introduces complications to the measurement of water inflow in the following two ways:

- The water in the manometer may evaporate into the compressed air line, resulting in a drop in the manometer water level.
- After water has flowed through the test specimen, the water at the bottom surface of the specimen may evaporate and produce a slight suction which can increase the rate of flow.

The amount of water evaporating into the air line is estimated by using a reference permeameter, which is connected to a manometer tube of the same size and the same main pressure line. The reference permeameter contains no test specimen and has a base plate with no hole, creating a condition of zero flow. The reference permeameter is filled with water and connected to a manometer tube and the main pressure line in a manner similar to that for the other permeameters. The water level in the reference manometer tube is read periodically to estimate the amount of water evaporating into the air line, which is then used to adjust the measured rate of inflow for the other permeameters.

The problem of the effects of evaporation of water from the bottom surface of the test specimen is dealt with by soaking the lower portion of the permeameter in water about 4–5 days after the test is started. The permeameter is not soaked in water immediately after the start of test to allow examination for leakage.

CALCULATION OF COEFFICIENT OF PERMEABILITY

The coefficient of permeability of a test specimen is computed from the net rate of inflow by using the following equation which is based on Darcy's Law:

$$K = \rho \frac{H Q}{P A} \quad (1)$$

where K = coefficient of permeability in in./sec or cm/sec.

ρ = density of water in lb/in.³ or kg/cm³.

H = length of test specimen in in. or cm.

P = water pressure in psi or kg/cm².

Q = net rate of inflow in in.³/sec or cm³/sec.

A = cross-sectional area of test specimen in in.² or cm².

RESULTS OF PERMEABILITY TESTS ON FLORIDA CONCRETES

This section presents the results of permeability tests on three different Florida concretes using the developed test setup and procedure. The three concretes tested were Florida type II, type III, and type IV concretes made with a type II portland cement and Florida aggregates. Table 1 displays the physical properties of the coarse and fine aggregates used. All the concrete mixes had a target slump of 3 in., which was achieved by adding the appropriate amount of a superplasticizer. Table 2 displays the proportions of ingredients for these three concrete mixes. Table 3 displays the properties of the fresh concrete at the time of testing.

Four different curing conditions were used on each of the three concrete mixes: (a) 16-hr steam curing at 160°F, (b) 28-day moist-room curing, (c) 3-day moist-room curing followed by 25-day air curing, and (d) 1-day curing in form followed by stripping and applying curing compound and 27-day curing. Two replicate specimens were tested for each of the combinations of concrete type and curing condition.

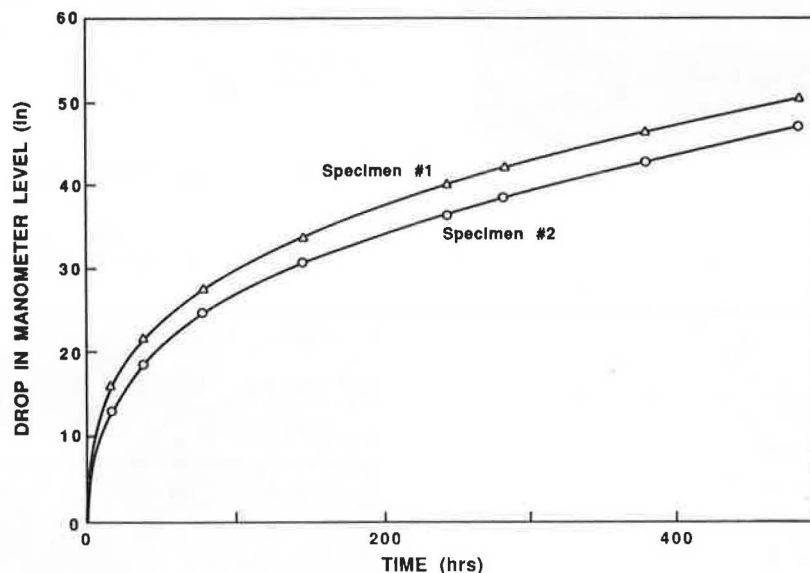


FIGURE 6 Typical plots of manometer readings in permeability tests.

TABLE 1 PHYSICAL PROPERTIES OF AGGREGATE

	Coarse Agg. (Brooksville Limestone)	Fine Agg. (Goldhead Sand)
Dry Bulk Specific Gravity	2.39	2.54
Saturated-Surface-Dry Specific Gravity	2.47	2.55
Absorption	3.16%	0.75%
Unit Weight (lb/ft ³)	92	-
Fineness Modulus	-	2.15

TABLE 2 MIX PROPORTIONS AND PROPERTIES OF FRESH CONCRETE

Concrete Type	II	III	IV
w/c	0.45	0.38	0.33
cement (lb/yd ³)	564	658	752
water (lb/yd ³)	253	250	248
Coarse Aggregate (lb/yd ³)	1702	1702	1702
Fine Aggregate (lb/yd ³)	1302	1238	1169
Superplasticizer (lb)	4.0	3.88	4.26
Unit Weight (lb/ft ³)	145.1	146.1	147.9
Slump (inches)	2 3/4	2 3/4	3 1/4
Air Content	3%	2 1/4%	2 1/4%

TABLE 3 RESULTS OF TESTS ON FLORIDA CONCRETE

Concrete Type	II w/c = 0.45				III w/c = 0.38				IV w/c = 0.33			
	A	B	C	D	A	B	C	D	A	B	C	D
Curing Condition*	A	B	C	D	A	B	C	D	A	B	C	D
Coefficient of Permeability (X10 ⁻¹² in/sec)	21 18	6.7 7.1	7.5 8.5	7.7 7.5	8.3 8.9	4.4 4.6	4.8 5.0	5.9 5.0	3.6 3.4	2.8 3.2	3.8 4.0	3.9 3.4
Mean Compressive Strength (psi)	4661	7114	6574	5982	5209	7761	7209	7225	6734	8582	7800	8196
Mean Splitting Tensile Strength (psi)	252	438	483	528	385	618	477	586	507	637	562	612
Mean Modulus of Rupture (psi)	599	543	590	602	681	666	496	613	638	709	637	643

Note: * Curing Conditions:

A = 16-hour steam curing
B = 28-day moist curing

C = 3-day moist & 25-day air curing
D = 1-day in form & 27-day with curing compound.

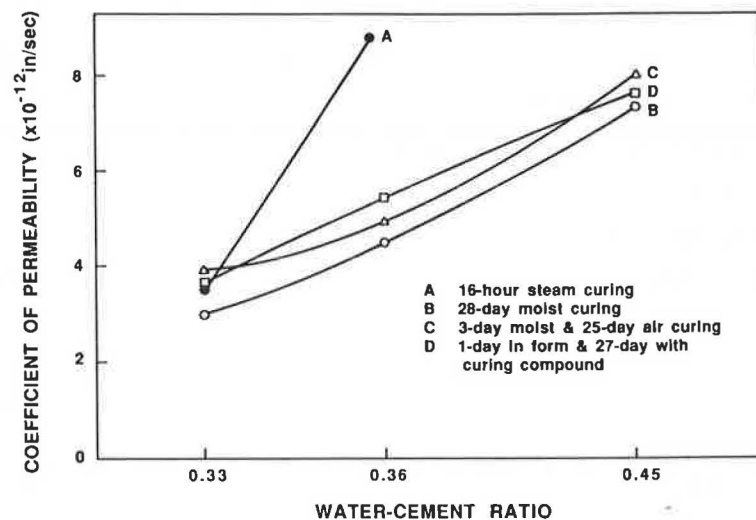


FIGURE 7 Effects of water-cement ratio on the coefficient of permeability of concrete.

The results of the permeability tests on these test specimens are displayed in Table 3. For references, the mean compressive, splitting tensile, and flexural strengths of these mixes are also displayed in Table 3. From the permeability test results, it can be noted that the coefficients of permeability of the replicate specimens (of the same mix and curing condition) are very close to one another, while the effects of concrete types (or w/c) and curing conditions on concrete permeability are fairly significant. This indicates that the test setup and procedure were able to produce precise and consistent results. Figure 7 shows plots of the mean coefficient of permeability as functions of water-cement ratio for three curing conditions. It can be seen clearly that the permeability of concrete decreases as the water-cement ratio decreases. Of the four curing conditions studied, the 28-day moist-room curing condition gave the best result.

CONCLUSION

The test setup and procedure as presented in this paper have been developed through experimentation and have been demonstrated to be both efficient and reliable for determining the permeability of concrete, especially when a large number of specimens have to be tested. One major advantage of this test setup is that it can be duplicated easily and economically.

Water-cement ratio had a significant effect on the water permeabilities of all the concretes in this study, regardless of the curing conditions. The lower water-cement ratio mixes yielded lower permeabilities.

ACKNOWLEDGMENTS

The work presented in this paper is part of a research project supported by the Florida Department of Transportation. The authors also wish to extend their appreciation to Ed Dobson and Danny Richardson for their technical support and to Pat Cribbs for typing and correcting the manuscript.

REFERENCES

1. I. L. Tyler and B. Erlin. A Proposed Simple Test Method for Determining the Permeability of Concrete. *Journal of the PCA Research and Development Laboratories*, Sept. 1961, pp. 2-7.
2. A. M. Neville and J. J. Brooks. *Concrete Technology*. Longman Scientific & Technical, 1987.
3. F. R. McMillan and I. Lyse. Some Permeability Studies of Concrete. *Journal of the American Concrete Institute*, Vol. 25, Dec. 1929, pp. 101-142.
4. P. T. Norton and D. H. Pletta. The Permeability of Gravel Concrete. *Journal of the American Concrete Institute*, Vol. 27, May 1931, pp. 1093-1131.
5. A. Ruettgers, E. N. Vidal, and S. P. Wing. An Investigation of the Permeability of Mass Concrete with Particular Reference to Boulder Dam. *Journal of the American Concrete Institute*, Vol. 31, March-April 1935, pp. 382-416.
6. G. J. R. Von der Meulen and J. van Dijk. A Permeability-Testing Apparatus for Concrete. *Magazine of Concrete Research*, Vol. 21, No. 67, June 1969, pp. 121-123.

Publication of this paper sponsored by Committee on Mechanical Properties of Concrete.