A SIMPLE METHOD OF TEST FOR DETERMINING THE PERMEABILITY AND CAPILLARITY OF CONCRETE

by

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INTRODUCTION

The purpose of this study was:

1. To develop a simple, inexpensive test method for determining the permeability and capillarity of concrete.

2. To investigate the influence of gradation, cement content, and water-cement ratio on the permeability and capillarity of concrete.

3. To find out, if there is any, the relationship between those two properties.

4. The capillarity and permeability of concrete may be matters of very great economic importance in many classes of structures. Where concrete structures such as water tanks, grain bins, floor slabs, etc. are subjected to seepage water, it is economically advantageous to minimize the vulnerability of the concrete to seepage water by controlling the mixture or in some other way. For illustration, take the case of a water tank, eight inches thick, with both sides under approximately atmospheric pressure. Assume the permeability of concrete, K, equals 150×10^{-13} in/sec; capillary potential, h_c, equals six feet. The amount of water that will pass through one square foot of wall surface in twenty-four hours may be computed as follows:

$$Q = Avt = A\left[k\left(\frac{h_o + h_c}{L}\right)\right] \times t$$

$$= (144) \times \left[150 \times 10^{-13} \left(\frac{0 + 6 \times 12}{8}\right)\right] \times (60 \times 60 \times 24)$$

$$= .00167 \text{ cu. in. (or, .0274 c.c.)}$$

Assume the water tank has a diameter of 20 feet, and a height of 10 feet; the total surface area will be

$$20 \quad \times 10 = 628.32 \text{ ft}^2$$

The total seepage in 24 hours will be

$$628.32 \times .00167 = 1.05 \text{ in}^3$$

which is negligible.

For another case of the basement of a house having a floor of 24 feet wide, 36 feet long, and 8 inches thick, the total surface area will be

$$24 \times 36 + 2 \times (24 + 36) \times 4 = 1,344 \text{ ft}^2$$

Then the total amount of seepage water in twenty-four hours will be $.00167 \times 1,344 = 2.24 \text{ in.}^3$ which is negligible, also. But, if the concrete was made of lean mix and with poor workmanship, it might have a permeability $K = 333 \times 10^{-10}$ in./sec, (Some clays have this permeability); then, our water tank given above would have a daily seepage of

$$\frac{333 \times 10^{-10}}{150 \times 10^{-13}} \times 1.05 = 2,330 \text{ in.}^3$$

And our basement walls and floor given above would have a daily seepage of

$$\frac{333 \times 10^{-10}}{150 \times 10^{-13}} \times 2.24 = 4,970 \text{ in.}^3$$

Obviously, the daily seepage becomes significant.

PROCEDURES OF INVESTIGATION

Preparation of Specimen

Sixty 3 inches dia. x 6 inch cylinders were made using various combinations of gradation, water-cement ratio, and cement mortar ratio. Variation of gradation included sieve ratios of 0.7, 0.8 and 0.9; the water cement ratio varied from 0.6 to 0.8 at 0.05 intervals; and the cement aggregate ratios were 1/2.25, 1/2.5, 1/2.75 and 1/3.

Tensiometer Test

Each 3 inch x 6 inch cylinder is made with a hole of 1 inch dia. x 4 inches depth (Fig. 1, Plate 1). When tested, the hole is filled with water and plugged by a rubber stopper at the top and sealed with paraffin to secure air-tight

EXPLANATION OF PLATE I

Fig. 1. Schematic drawing of capillarity test apparatus.

A Concrete Cylinder
B Rubber Stopper
C Tube A
D Valve A
E Tube B
F Rubber Hose
G U-Tube
H Scale

Fig. 2. Schematic drawing of electric conductivity test apparatus.

PLATE I

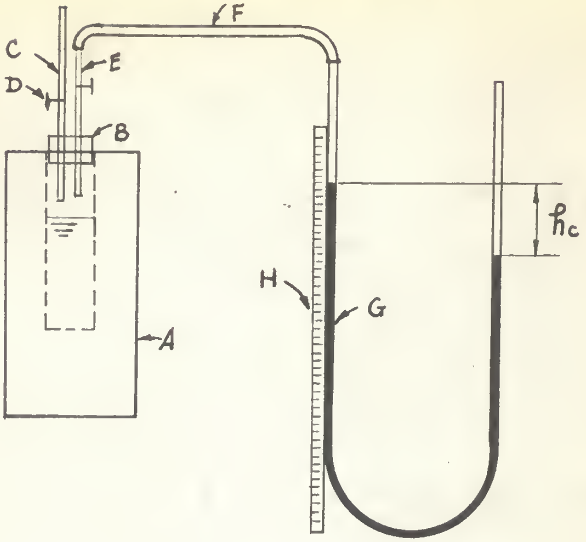

Fig. 1

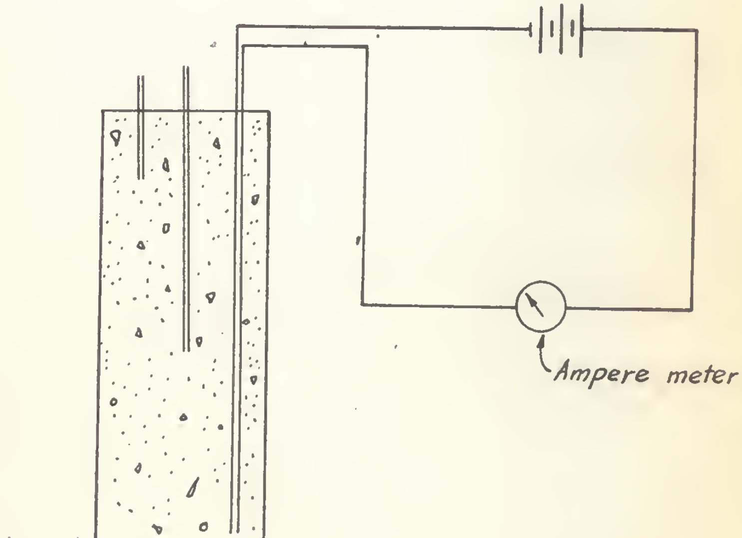

Fig. 2

condition. Tube A, with valve V_A on it, is for the purpose of adjusting air pressure when water is being filled from tube B. The rubber hose, F, is then connected after water has been filled and the specimen is ready for taking record.

The principle of this test implies that the starting pressures at either end of the liquid (mercury was tried first, then gasoline was used) in the U-tubes are both atmospheric. As capillarity develops, water is absorbed by the concrete and a pressure difference develops at the U-tube. The difference of pressure is then referred to as the capillary potential of the concrete, h_c.

The results indicate that this test method fails to measure the capillary potential of the specimens. It is believed that an absolutely air-tight condition was practically not obtained, and air leakage might have occurred at the connection between rubber hose and glass tube, or at the contact surface between paraffin and concrete. One specimen, No. 38, indicated a pressure difference of about 16½ inches height of water pressure, which, according to the writer's explanation, is the capillary potential of that specimen.

Electric Conductivity Method

An attempt was made to determine capillarity of concrete by the use of an electric circuit. Fig. 2 shows the general arrangement. A 3 inches dia. x 9 inches concrete cylinder was cast in a steel pipe with three pairs of copper wires embeded at points 1½ inches, 4½ inches, and 7½ inches from the bottom respectively. At the end points of each pair of wires, the distance between them was less than 1/8 inch so that when capillary water reaches the level where a pair of wire are embeded, more electric conductivity may be expected. At starting, the encased cylinder is put into a pan filled with water to ½ inch depth. The first pair of wires are then connected to dry cells to form a circuit (Fig. 2, Plate I). An ampere meter, sensitive to one micro-ampere, is put

Table 1. Tensiometer test record

Specimen No.	Pressure Difference	Duration	Equivalent water Pressure Head	Remarks
2	0.4cm	80min	5.4	Mercury
5	1.5	30	20.2	"
11	0.3	65	4.1	"
26	0.6	36	8.1	"
29	5.9	70	4.3	Gasoline (Sp. G.=.726)
32	1.0	60	.7	"
35	6.0	15	4.4	"
38	57.7	83	41.9	"
44	2.0	55	1.5	"
53	1.0	50	.7	"
62	1.3	75	.9	"
68	0	45	0	"
86	8.5	40	6.2	"

in the circuit to measure the current when capillary moisture reaches the wires.

Results: No indication of any current was recorded long after the capillary rise was completed. The specimen was even soaked in water for three days, yet still there was no indication of any current passing through the circuit. The highest voltage tried was 110 volts from an A.C. source. No other fault of the technical device could be detected except that it is believed the conductivity of a saturated concrete is so low that it might need considerably high voltage to produce a measurable current passing from one wire to the other.

EXPLANATION OF PLATE II

Fig. 1. Preliminary permeability-capillarity test apparatus.

Fig. 2. Improved permeability-capillarity test apparatus.

PLATE II

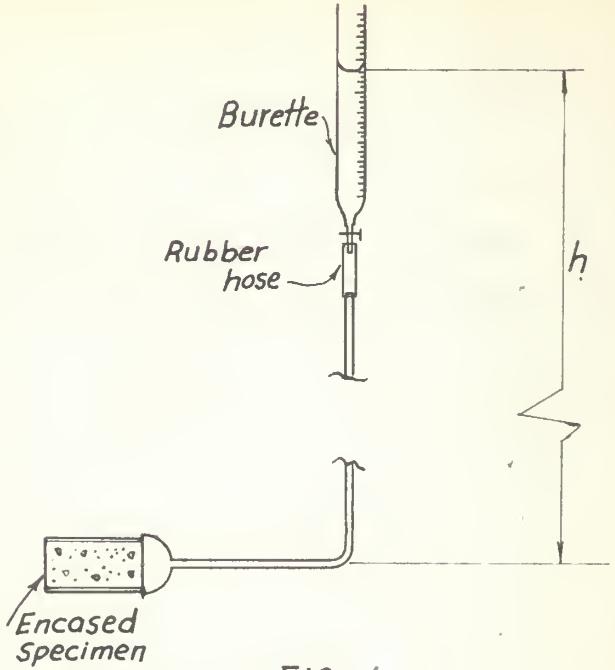

Fig. 1

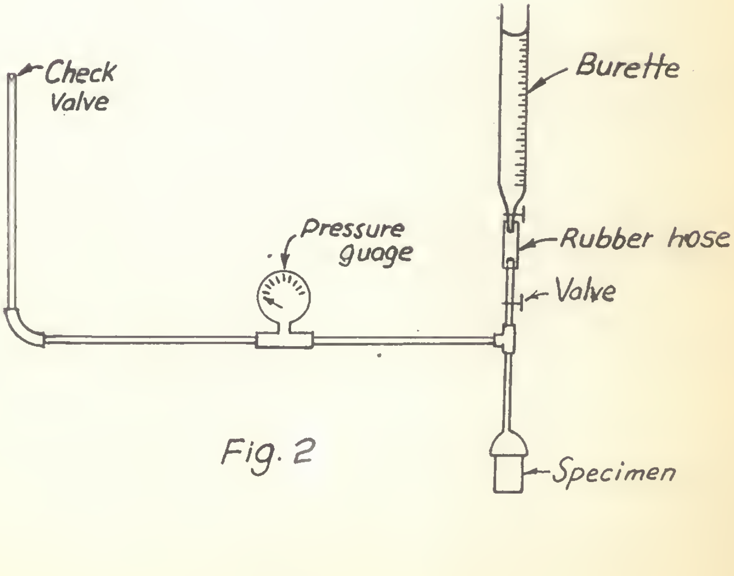

Fig. 2

Permeability-Capillarity Test

The apparatus consists of a horizontal specimen cast in a steel pipe, a brass tube of suitable length, and a burette (Fig. 1, Plate II). Since for a given concrete, the capillary potential, h_c, is a constant, the principle of this test can be simplified to the following expression:

$$v = v_s n = ki$$

$$\frac{Q}{At} = k\,\frac{h_o + h_c}{L}$$

where A = cross sectional area of the specimen

Q = amount of water passing through the specimen

h_o = pressure head

v = superficial velocity

v_s = Velocity of seepage water

k = hydrostatic permeability

n = porosity of concrete

h_c = capillary potential

In the above expression, h_c and k are the only two unknowns. The other elements can be measured or observed. By running the test for two different pressure heads, we have two simultaneous equations, which, when solved together, will yield the unknowns we desire.

The principle of this test is basically simple and advantageous, because it is a combination of two tests. Once the specimen is ready for test, all we have to do is just to take records of the amount of water passing through the specimen at different pressure heads. However, there existed some substantial difficulties that were hard to be overcome. It was found that air bubbles always accumulated on the wall of the slender tube, and when the room temperature changes, the bubbles expand or contract to so great an extent that it exceeds the amount of water passing through the specimen in 24 hours.

Table 2. Permeability-capillarity test data

Pressure head	Duration	Q (c.c.)	q (c.c./min.)	Remarks
100^{cm}	1,535 min.	.95	$.62 \times 10^{-3}$	
200^{cm}	1,088	2.40	2.2×10^{-3}	
312^{cm}	1,484	3.40	2.29×10^{-3}	
648^{cm}	261	2.00	7.66×10^{-3}	
648^{cm}	2,577	22.1	8.60×10^{-3}	

Since $$q = k \frac{A}{L} (h_e + h_c)$$

for a given specimen, A, L, K, and h_c are fixed quantities, therefore, q must be proportional to h_e. The inconsistancy of the observed data led to the discovery of air bubbles accumulated on the wall of the slender tube. Efforts were made to eliminate the tube connection for gaining pressure head. Compressed air was introduced to take the place of elevation head. The improved set-up is shown in Fig. 2, Plate II.

The performance of this test is principally the same as before except that compressed air is introduced. At starting, water is filled to the level of the check valve. Then the valve is shut and compressed air is forced into the check valve until the pressure gage reads the desired pressure, p_1. After a certain time interval, as the pressure drops down to p_2, it indicates that some amount of water must have passed through the specimen. To measure the amount of water, release the residual air pressure first; then open the valve to refill water to the check valve level. The amount of water needed for refilling is the quantity that has passed through the specimen during that time interval.

Test data:

Material used: cement-aggregate ratio = 1/6; W/c = 1/1.89 (6 gal./sack) sieve ratio = 0.7; A = 19.7 cm^2; L = 4 cm.

Table 3. Permeability-capillarity test

Initial Pressure	Final Pressure	Average Pressure	Duration (min.)	Q(c.c.)	q($\frac{c.c.}{min.}$)	Remarks
9.0#/in.^{2}	4.0#/in.^{2}	6.5#/in.^{2}	17	6.3	.370	
11.0	4.9	8.0	10	4.1	.410	
14.0	6.0	10.0	14	5.4	.386	
6.8	1.0	3.9	24	4.0	.166	
14.0	5.0	9.5	15	5.5	.367	
14.0	5.0	9.5	16	5.6	.35	
14.0	4.0	9.0	20	5.8	.29	
12.0	6.0	9.0	10	3.2	.32	
13.2	7.7	10.5	11	12.3	1.12	

The same test was applied on another specimen with the following specification: cement-aggregate ratio = 1:3, water-cement ratio = 0.65, and sieve ratio = 0.7; A = 13.2 cm^2; L = 5 cm.

Table 4. Permeability-capillarity test

Initial Pressure	Final Pressure	Ave. Pressure	Duration (min.)	Q(c.c.)	$q(\frac{c.c.}{min.})$	Remarks
14.0#/in.^{2}	8.5#/in.^{2}	11.3#/in.^{2}	1043	7.7	7.37×10^{-3}	
14.5	12.9	13.7	140	1.1	7.85×10^{-3}	
14.0	6.0	10.0	210	3.0	14.3×10^{-3}	
14.3	6.0	10.2	104	2.8	26.9×10^{-3}	
14.0	7.2	10.6	76	2.4	31.6×10^{-3}	
6.5	5.0	5.8	300	1.2	4.0×10^{-3}	
14.5	6.3	10.4	1128	2.2	1.95×10^{-3}	
14.4	12.2	13.3	324	6.8	21.0×10^{-3}	
15.4	9.0	12.2	1007	2.1	2.08×10^{-3}	

DISCUSSION

Since permeability is defined as that property of a material which permits passage of a liquid or a gas through its pores, the permeability of concrete to water may occur in three ways: 1) as a saturated or hydrostatic permeability, where water passes as a liquid; 2) as a vapour permeability, where the water passes as a gas; and 3) as an unsaturated permeability, where water enters as a liquid by capillarity and leaves as a gas by evaporation. Recent studies on the permeability of Portland cement paste, along with other information, have helped to identify the "ultimate particles" against which hydraulic forces inside the concrete can develop. With these particles identified and their wettable area measured, the order of magnitude of the area factor for computing hydrostatic up lift forces within concrete dams could be established. But the relationship of the permeability of the paste to that of concrete as a whole is still unknown. The paste of concrete is but a continuous body enveloping and isolating the individual aggregate particles. The over-all permeability is a function of the paste permeability and the relative function of the two. Fissures and cracks of concrete also play a part. Research works on concrete permeability find little generalized result because it depends upon so many factors.

Information obtained through simple tests in the study of the capillarity of concrete indicates that capillary movement of water through concrete may be of a greater magnitude than that of free liquids at ordinary heads (less than 10 feet); it is shown that for that reason permeability tests which operate at such heads measure mostly capillarity. Thus low-head tests may show concrete containing water repellent materials to be more resistant to capillarity than standard Portland cements because their surface tension characteristics have been altered. Such tests do not necessarily measure the ability of these concretes to resist the passage of liquid water.

What the writer has done here still presents a vague picture of these two properties of concrete. From

$$q = \frac{Q}{t} = AV = Ak\left(\frac{h_o + h_c}{L}\right) = \frac{Ak}{L} h_o + \frac{Akh_c}{L} ,$$

it is expected that q is proportional to h_o; or if plotted on a rectangular co-ordinates, the straight line vanishes at the abscissa of q (as Fig. 1, Plate III). In other words, when p is equal to zero, water still can pass through the concrete by capillary potential. Unfortunately the points plotted according to the present data are scattered rather than forming a straight line (as Figs. 2, 3, 4, Plate III).

EXPLANATION OF PLATE III

Fig. 1	Assumptive relationship between pressure head, p, and unit seepage water, q.
Figs. 2, 3, 4	Data from permeability-capillarity test shows erratic relationship between pressure head, p, and unit seepage water, q.

PLATE III

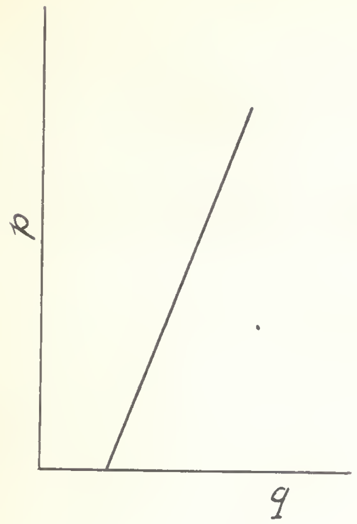

Fig. 1

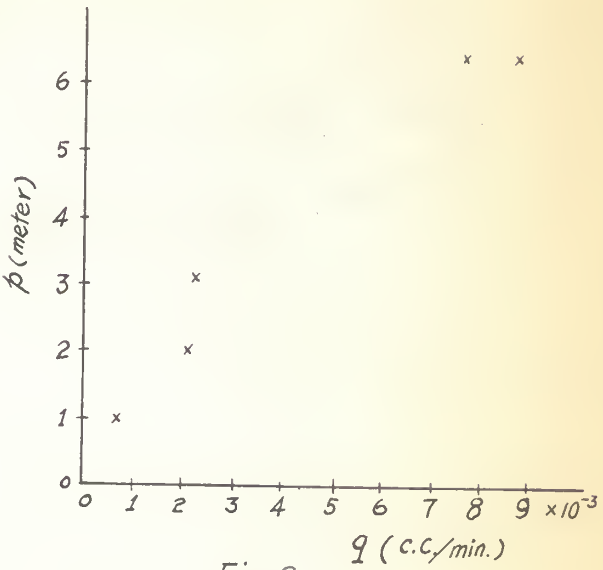

Fig. 2

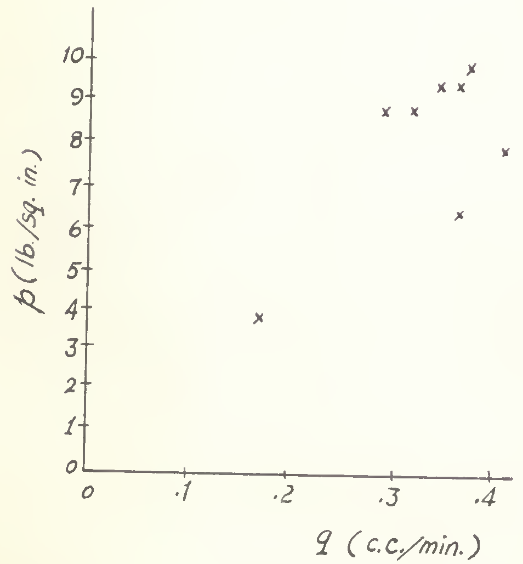

Fig. 3

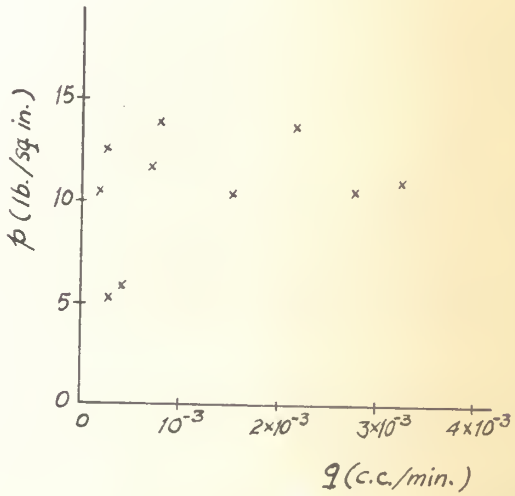

Fig. 4

CONCLUSIONS

The technical difficulty in the first test, i.e., the tensiometer test, is to maintain a high degree of air-tight condition at the contact between glass tube and rubber hose and at the contact surface between rubber stopper and the concrete. It is also possible that significant quantities of air passed through the wall of the rubber tube. However, the present data indicate that there exists a significant capillary potential in concrete. The inconsistancy due to technical flaws makes the present data questionable. Further efforts need to be devoted to obtain conformable results

In the permeability-capillarity test, owing to the fact that pressurized water absorbs more air, when water is passing the specimen, pressure being released, air bubbles may accumulate in the voids of the concrete.

The permeability-capillarity test has the following advantages:

a. It determines two properties in one test.

b. The specimen is cast in the steel case so that a perfect contact between concrete and the case can be secured; while in the conventional permeability test, the specimen is clamped between gaskets and the effective area of flow of water through the cross section (Fig. 1, Plate IV) is uncertain.

c. The apparatus can be constructed principally of standard pipe fittings and accessaries which are easily obtainable and moderate in cost.

For an improved apparatus, it is suggested that an air reservoir be installed, of a size sufficient to maintain a practically constant pressure, so as to eliminate errors due to continuously changing pressure. It is also suggested that a U-tube filled with mercury be installed between the pressure

EXPLANATION OF PLATE IV

Fig. 1 Schematic drawing of conventional permeameter showing cause of uncertainty of effective area of flow-path through specimen.

Fig. 2 Schematic drawing of suggested permeability-capillarity apparatus.

PLATE IV

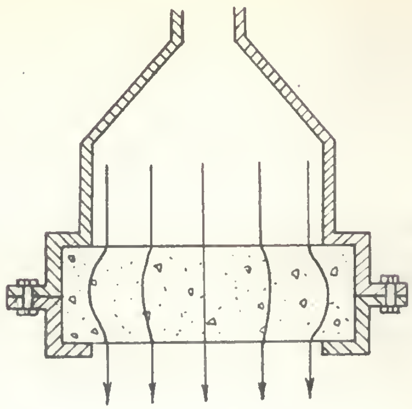

Fig. 1

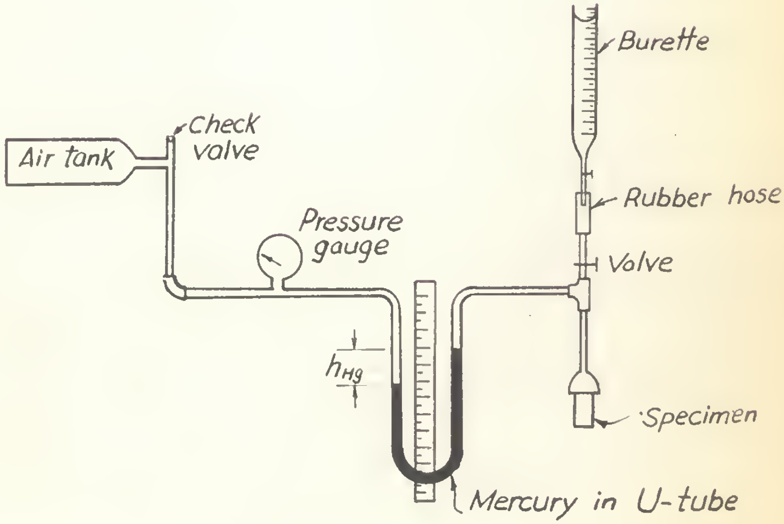

Fig. 2

gage and the specimen (Fig. 2, Plate IV) so as to eliminate absorption of air by the water which causes air bubbles to accumulate in the specimen.

Owing to existing technical flaws, the present data are vague and ambiguous. However, the writer has great confidence in its eventual success. Because of the limited time available that could be devoted to the development of this test, the writer is compelled to leave to the future efforts to perfect the apparatus.

ACKNOWLEDGMENT

The writer wishes to express his gratitude to his advisor, Professor Harold H. Munger, whose valuable guide and suggestion as well as whose evermore enthusiastic help made the devotion to this paper materialized.

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Where concrete structures such as water tanks, grain bins, floor slabs, etc. are subjected to seepage water, it is economically advantageous to minimize the vulnerability of the concrete to seepage water by controlling the mixture or in some other way. The purpose of this study was to establish a simple, inexpensive test method for determining the permeability and capillarity of concrete as well as the relationship between these two properties.

Three methods of test were tried. Technical difficulties were encountered and finally a simple satisfactory apparatus is suggested for further interest.

Much time was spent in improving the apparatus, and the test data obtained are not sufficient to show any definite relationship between the two properties under research. Failures due to the technical flaws are discussed and the writer comes to the conclusions that a simple method of test is believed to have been obtained because the suggested apparatus has the following three advantages:

a) It determines two properties in one test.

b) The specimen is cast in the steel case so that a perfect contact between concrete and the case can be secured; while in the conventional permeability test, the specimen is clamped between gaskets and the effective area of flow of water through the cross section is uncertain.

c) The apparatus can be constructed principally of standard pipe fittings and accessaries which are easily obtainable and moderate in cost.