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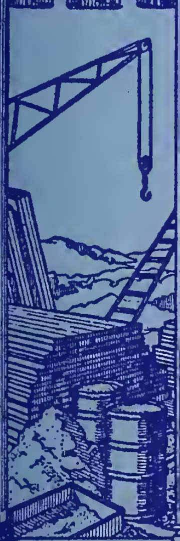

BUILDING MATERIALS AND STRUCTURES

REPORT BMS7

Water Permeability of Masonry Walls

by CYRUS C. FISHBURN
DAVID WATSTEIN, *and*
DOUGLAS E. PARSONS

NATIONAL
BUREAU OF STANDARDS

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ISSUED October 18, 1938

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be considered accordingly

UNITED STATES GOVERNMENT PRINTING OFFICE · WASHINGTON · 1938

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Foreword

When the wall of a house exposed to wind-driven rains allows dampness to penetrate to the interior, damage to the interior finish may be sufficient to require its replacement, a matter of considerable expense. Accordingly, there is great interest on the part of builder and owner in methods of constructing walls which will be resistant to the penetration of rain and in methods of "waterproofing" existing walls. An extensive investigation of the rain penetration of masonry construction is in progress at the request of and in cooperation with numerous Federal agencies. This paper gives the results obtained to date.

Because of the many kinds and qualities of masonry materials and varieties of design, and the lack of a definite measure of the performance of a wall with respect to rain penetration, the study must be very comprehensive, and the results cannot be adequately summarized in a few words. Of the many factors, workmanship is the most important single one. However, attention to many other factors will assist greatly in securing good results. Existing walls may be effectively "waterproofed", but the cost and success of the treatment depend on many factors discussed in detail in this paper.

Lyman J. Briggs, *Director.*

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ABSTRACT

Walls of brick, structural clay tile and hollow concrete unit masonry were tested under conditions resembling exposures to wind and rain and their resistance to the penetration of water determined. Five kinds of workmanship (method of filling joints), three kinds of brick, six kinds of structural clay tile, two kinds of hollow concrete units, and six different mortars were used in the construction of the walls. One group of 48 brick walls included specimens, both 8 and 12 inches thick, of three kinds of brick, four cement-lime mortars, and two classes of workmanship, in all possible combinations. The walls of structural clay tile were faced either with stucco or with brick of a single variety. Those of concrete units were faced either with the same brick or with cement paint. The effectiveness of several methods of "waterproofing" were compared by retesting some of the walls after they had been treated. The treatments for the walls included the filling of openings in the face joints with mortar, grout, or wax and the application to the exposed surfaces of colorless solutions or paints. Most of the walls were subjected to water penetration tests under two different conditions. Water was applied near the tops of the walls in a manner to produce a thin film of water over their exposed surfaces. In the "capillarity" test no pressure was applied to the exposed face, the water penetrating under the forces of capillarity and gravity only. In the "heavy-rain" test a static air pressure of 10 pounds per square foot was maintained against the exposed face.

The performances of the walls in the water penetration tests depended more upon the quality of the workmanship than upon any other factor. Walls of brick having the interior joints well filled with mortar usually gave excellent performances, whereas those with poorly filled joints leaked. Aids in obtaining walls resistant to moisture penetration were the use of mortars of medium or high water retentivity, the wetting of absorptive brick before use, and the application of a parging of mortar on the back of the facing wythe. The omission of two-thirds of the normal number of header brick, or the insertion of a limestone sill or belt course had no important effect on the permeability of the walls. On the average, walls with a brick facing and a backing of hollow masonry units were slightly less permeable than brick walls of equal thickness when the joints were not well filled. When the joints were well filled the performance of walls with hollow units was somewhat superior in the capillarity test but inferior in the heavy-rain test to that for otherwise similar all-brick walls. The performances of walls of structural clay tile faced with portland-cement stucco was somewhat better than the average for the walls of brick. The filling of openings in the joints with mortar, grout, or wax was effective in stopping leakage. Applications of colorless waterproofing solutions did not stop leakage through openings in the joints, but were effective in improving the performance of walls of absorptive brick when the openings in the joints had been sealed. Coatings of molten paraffin, oil paint, and cement paint were effective in reducing moisture penetration.

I. INTRODUCTION

Many exterior masonry walls of buildings are giving excellent protection against the penetration of water, and artisans are familiar with the technique of such construction. However, there is little published information on the relative effectiveness of walls differing as to design, materials, and workmanship which would serve as a basis for the preparation of technical specifications. Reported observations on the performance of walls in buildings have given but little specific information. Since many kinds of masonry materials and varieties of design are in use and as there are considerable differences in the severity of exposure even in a single locality, qualified observers have not always been in agreement as to the relative importance of factors contributing to watertight walls. With the object in view of determining the relative merits of several types of masonry construction by building and testing walls, the Bureau of Yards and Docks, Navy Department, with the cooperation of other governmental agencies, sponsored an investigation at the National Bureau of Standards.

The original program was prepared with the assistance of representatives of the Bureau of Yards and Docks, the Procurement Division, the Quartermaster Corps, War Department, and the Housing Division, Federal Emergency Administration of Public Works, and those agencies transferred funds to assist in defraying the cost of the work. When funds from the Emergency Relief Act were allotted to the National Bureau of Standards for research on the durability of materials for housing, members of the Subcommittee on Design and Construction of the Central Housing Committee sponsored a program of research requiring the construction and testing of additional walls. This program called for tests of types of construction not included in the original program. Investigations of waterproofing treatments for masonry walls were also included. Inasmuch as the materials and the methods of constructing and testing the walls were the same for both programs, and as the results are of most value when considered collectively, no distinction between the programs will be made in this report.

II. SCOPE OF INVESTIGATION

The investigation was planned to obtain information on the effects of the following factors on the permeability of masonry walls:

(a) Thickness, bonding of units, kind of brick or hollow unit, kind of mortar, and method of filling joints.

(b) Wind pressure on walls.

(c) Repointing and waterproofing treatments.

Five kinds of workmanship (method of filling joints), 3 kinds of brick, 6 types of structural clay tile, 2 kinds of concrete units, and 6 different mortars were used in the construction of 113 walls. One group of 48 brick walls included specimens both 8 and 12 in. thick of 3 kinds of brick, 4 cement-lime mortars, and 2 classes of workmanship in all possible combinations. The walls of structural clay tile were faced either with stucco or with brick of a single variety (brick *b*); those of concrete units were faced either with the same brick (brick *b*) or with cement paint. All walls of hollow masonry units were built with a single cement-lime mortar.

III. MASONRY WALLS

1. Materials

All of the materials used in the construction of the walls were representative of those commonly used in building construction and were purchased from either the makers or building supply dealers. The purchases were usually made on a noncompetitive basis in order that a selection of materials could be made to meet the special requirements of the investigation.

(*a*) *Bricks*

The bricks were selected to cover a wide range in both the rate and amount of absorption for bricks used in exposed structures. The physical properties of the bricks are given in table 1.

One type of brick had a very low, one a medium, and the third a very high and rapid absorption. The low-absorptive brick, designated as brick *a*, was a side-cut fire-clay brick, light in color with a slight fire gloss on edges and ends. The medium-absorptive brick, brick *b*, was a side-cut shale brick, selected hard-burned, dark brown in color, and somewhat irregular in shape. The high-absorptive brick, *c*, was red dry-press brick with a high rate of absorption, selected by eliminating the harder-burned specimens.

Table 1.—*Physical properties of bricks*

Properties of bricks			Types of brick		
			a	*b*	*c*
Average dimension (in.)	Width		3.75	3.60	3.95
	Length		8.00	7.75	8.20
	Depth		2.25	2.15	2.30
Average dry weight (lb.)			5.21	4.35	4.76
Absorption by total immersion (%)	5-hour cold		0.4	7.7	15.9
	48-hour cold, *C*		.6	9.1	16.8
	5-hour boil, *B*		1.6	11.4	18.8
C/*B* ratio			0.38	0.80	0.89
Absorption by partial immersion (g of water per cm ^{2} of brick surface)	Flat [1]	1 min	.01	.19	.61
		3 min	.02	.31	1.10
	Edge	1 min	.02	.14	.69
		3 min	.03	.23	1.18
	End	1 min	.03	.12	.70
		3 min	.06	.22	1.18
Time required for total penetration by capillary action (hr.)	Flat		------	.40	0.12
	Edge		------	1.9	.32
	End		------	12.5	1.8
Modulus of rupture (lb/in.^{2})			2,460	1,180	250
Compressive strength of half-bricks (lb./in.^{2})			16,900	7,580	2,370

[1] Absorption in grams per brick approximately 200 times these values.

The data of table 1 shows that brick *a* is dense, hard, and practically impermeable, with very little absorption or suction. Brick *c* had a very high rate of absorption. This brick absorbed 35 percent as much water when partially immersed on the flat face for 1 minute as it did when totally immersed for 48 hours. The absorptive properties of brick *b* were intermediate between those of *a* and *c*.

(*b*) *Structural Clay Tiles and Hollow Concrete Units*

The physical properties of the structural clay tiles and of the hollow concrete building units are given in table 2. Six different types of structural clay tile and one kind each of stone and cinder-concrete block are described in the table. The details of the units are illustrated in figure 1. The rate and total of absorption for tiles *g* and *h* are about double the average values for the other four structural clay tiles. Although the total absorption for the 24-hour cold-water immersion of the cinder-concrete units was nearly double that of the stone-concrete block, the rate of absorption was much less.

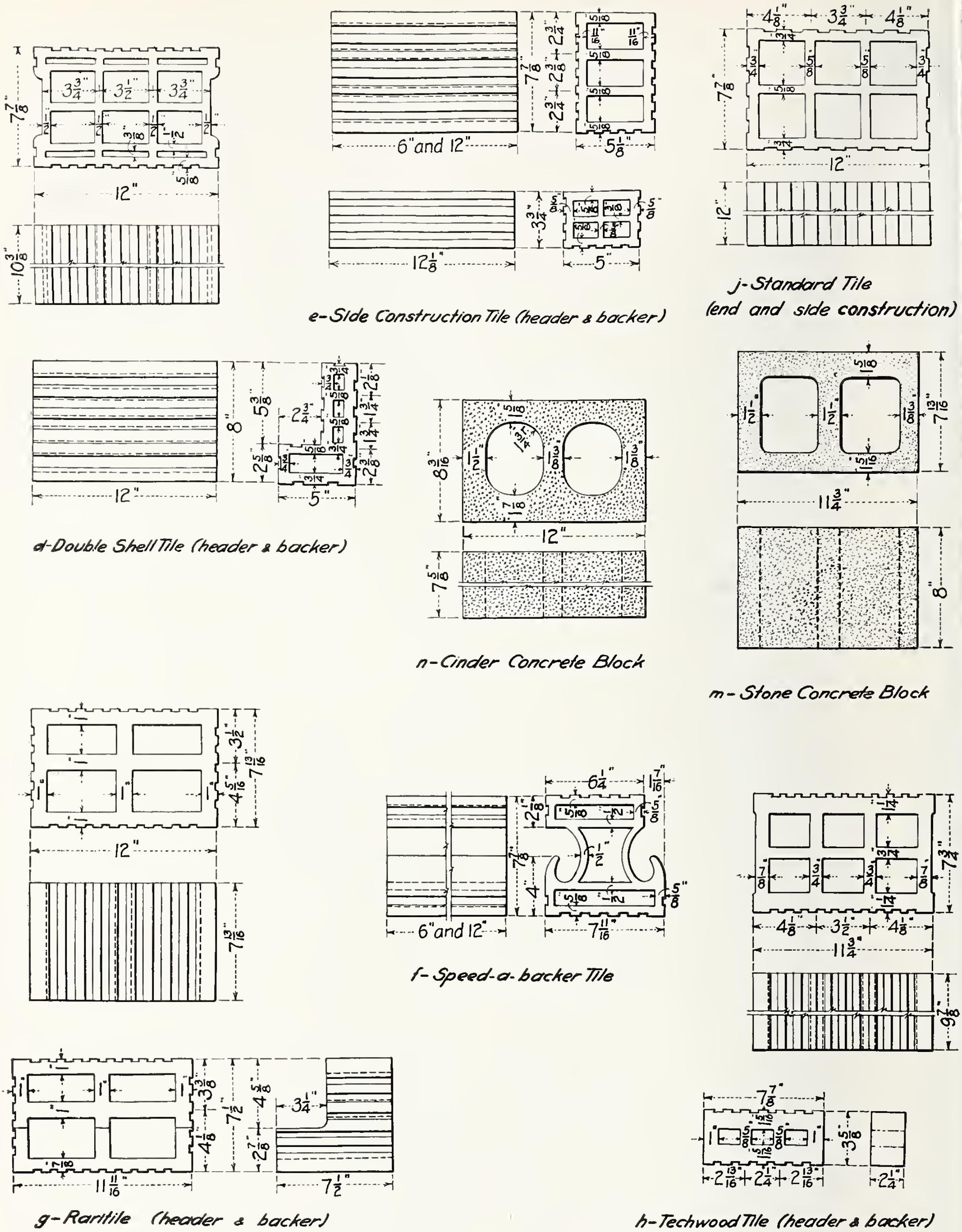

FIGURE 1.—*Details of structural clay tiles and hollow concrete units.*

TABLE 2.—*Physical properties of structural clay tiles and hollow concrete building units*

Masonry unit		Exterior dimensions			Thickness of face shell	Dry weight	Absorption by 24-hour cold immersion		Absorption by 1-hour boil	Weight per ft.^{3} of concrete	Weight per ft.^{2} of wall face area	Compressive strength		Face shell immersed in ⅛-inch of water			
Designation	Name	Thickness	Width	Length								Net area	Gross area	Absorption, g per cm^2 of surface (3 min)	Capillary rise of water in first hour	Time required for capillary rise through tile	
		in.	*in.*	*in.*	*in.*	*lb*	%	*lb/ft.*^{3}	%	*lb*	*lb*	*lb/in.*^{2}	*lb/in.*^{2}	%	*in.*	*in.*	*hr*
d	Double-shell, 6 cells	8.0	12.1	10.45	0.5	33.3	2.8	------	3.9	--------	37.9	11,970	4,830	0.01	1.7	8	23
e	Side construction, 3 cells.	7.9	5.0	12.0	.6	15.8	5.7	------	8.1	--------	38.0	--------	1,760	.05	1.0	6.5	168
f	Speed-a-backer	7.8	7.7	12.0	.65	22.5	4.1	------	7.1	--------	38.7	--------	1,820	(a)	1.0	4.4	168
g	Raritile, 4 cells	7.85	12.0	7.9	1.0	25.8	10.6	------	14.6	--------	39.4	8,010	3,290	.13	2.4	8	8.5
h	Techwood, 6 cells	7.75	11.85	9.9	1.25	33.7	10.4	------	13.3	--------	41.3	7,610	3,180	.11	1.9	8	12
j	Standard, 6 cells	8.0	12.1	12.0	0.75	34.1	4.1	------	6.3	--------	34.0	7,890	2,870	.03	2.3	------	------
m	Stone-concrete blocks, 2 cells.	7.8	11.75	7.85	1.5	29.9	8.9	10.8	-------	121.4	46.7	2,410	790	.75	3.1	8	86
n	Cinder-concrete blocks, 2 cells.	8.05	11.8	7.55	1.8	21.9	16.2	13.3	-------	82.2	35.2	2,430	870	.14	1.0	3.3	168

[a] Negligible.

(c) *Mortars*

The six mortars used in the construction of the walls were designed to determine the relative permeability of walls built with high-lime or high-cement mortars, the effect on permeability of integral waterproofing and of differences in water-retaining capacity. The physical properties of these mortars are given in table 3. Mortars 1 to 3 differ in the relative percentage of lime and portland cement. The lime used in these mortars was a fast-slaking pulverized quicklime with a plasticity [1] of over 600. Mortar 5 contained a selected lime hydrate with a plasticity of only 110. The water content of all the mortars was adjusted to the satisfaction of the mason, and it usually varied with the kind of brick used. A variation of 1 percent in the water contents given in table 3 for the first four mortars had apparently little effect on the workability so that mortar remaining after using one kind of brick was often used to start a similar wall of another kind of brick. All mortar materials were proportioned by weight and mixed in a batch mixer of about ⅔-cubic-foot capacity.

TABLE 3.—*Physical properties of mortars*

Properties of mortars		Brick	Mortars numbers and proportions: 1	2	3	[a] 4	[b] 5
Proportions of cement, lime, and sand	by volume [c]	---------	1:0.25:3	1:1:6	1:2:9	1:1:6	1:1:6
	by dry weight	---------	1:0.11:2.6	1:0.42:5.1	1:0.85:7.7	1:0.42:5.1	1:0.42:5.1
Average water content, percentage by weight of dry materials		*a*	19.3	21.4	23.0	22.1	18.0
		b	19.3	22.9	23.8	22.6	19.8
		c	19.3	23.4	24.4	23.3	21.6
Average		---------	19.3	22.6	23.7	22.7	19.8
Compressive strength in 28 days (lb/in.^{2}) [d]		*a*	2,850	725	265	565	1,195
		b	2,850	625	250	495	885
		c	2,850	575	230	525	780
Average		---------	2,850	640	250	530	950
Flow after 1 min of suction on porous base (percentage) [e]	initial flow 130%	---------	87	104	109	105	49
	initial flow 110%	---------	86	95	97	95	30

[a] Mortar 4 contained 0.2 percent of ammonium stearate by weight of cement plus dry hydrated lime.
[b] Mortar 5 contained hydrated lime of low plasticity, which was added to the mortar in dry state; all other mortars contained highly plastic lime putty prepared from pulverized quicklime.
[c] Proportioning was by weight, assuming portland cement weighs 94 lb/ft^3, dry hydrated lime, 40 lb/ft^3, and that 1 ft^3 of loose damp sand contains 80 lb of dry sand.
[d] Cured according to Federal Specification SS-C-181.
[e] Test for initial flow of 130 percent; described in Rock Products, Septemher 10, 1932, "Rate of Stiffening of Mortars," by L. A. Palmer and D. A. Parsons; Test for initial flow of 110 percent. Federal Specification SS-C-181a.

[1] Plasticity determined according to Federal Specification SS-L-351. The lime used in mortars 1 to 4, inclusive, was lime *A* and that used in mortar 5 was lime *C*—described in J. Research NBS **17**, 895 (1936) RP952. (See fig. 7.)

The sieve analysis of the Potomac River building sand used in the mortars is given below:

Sieve number	Weight of sand passing
	Percent
4	100. 0
8	99. 4
16	94. 4
30	75. 2
50	14. 0
100	1. 0
200	0. 5

(*d*) *Stucco*

The stucco facing for the eight walls of tile *j* was mixed in the proportions by weight of 1 part of portland cement to 3 parts of dry sand; volume proportions were 1 part cement to about 3.5 parts of loose damp sand. The stucco applied to four of the eight walls contained a commerical ammonium stearate amounting to 0.2 percent by weight of the cement. The water added to each batch was suitable to the mason and amounted to about 18.7 percent by weight of the dry materials or 8.5 gallons per sack of cement. After the stucco was applied to the walls, they were thoroughly wetted each day for several days.

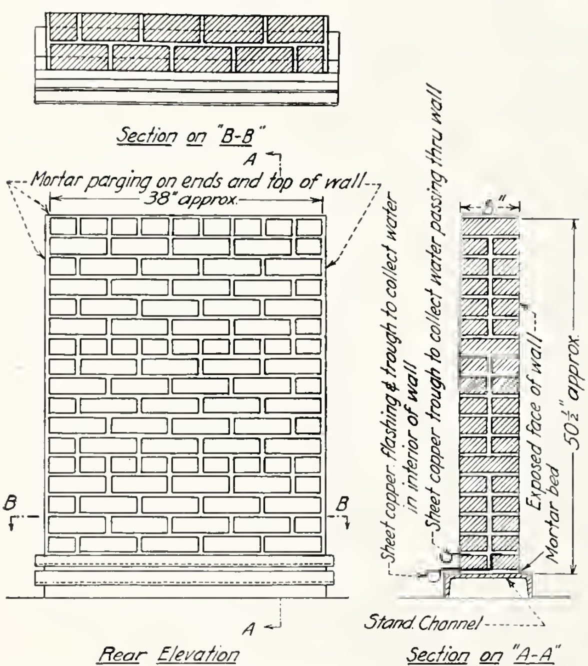

FIGURE 2.—*Rear elevation and sections of a typical brick masonry wall.*

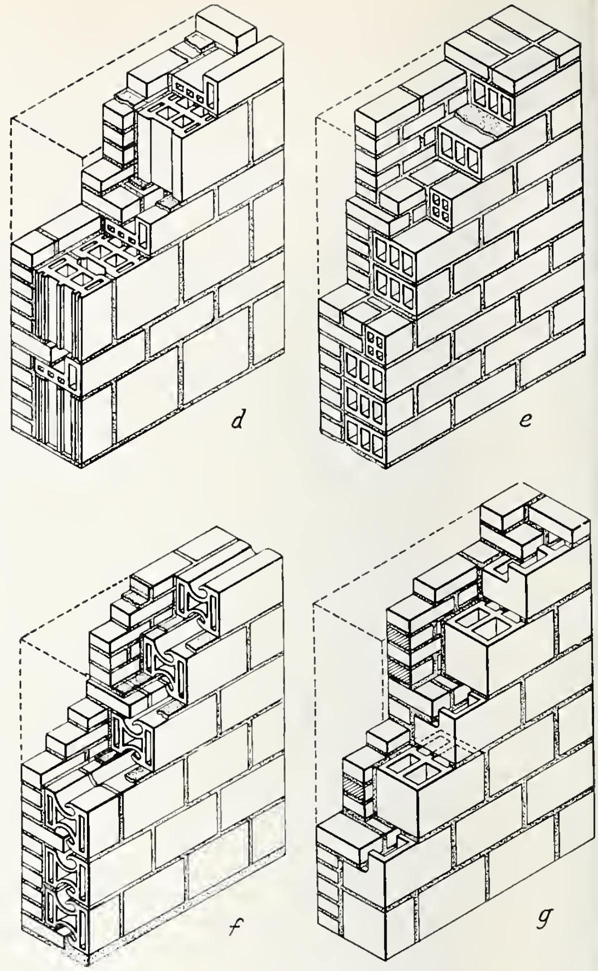

FIGURE 3.—*Isometric projections of walls with brick facings and backings of hollow units, workmanship A.*

d, double-shell tile; *e*, side construction tile; *f*, Speed-a-backer tile, and *g*, Raritile.

2. Types and Designations of Walls

The walls of all-brick masonry were of four different types of workmanship, described in section III (4) (pages 10, 11) and designated as *A*, *B*, *C*, and *D*. Walls containing other kinds of masonry units were constructed of workmanships *A*, *B*, or *E*. All of the walls are listed by number and described by designation in table 4 which also gives data showing performance under the tests. In the first column of table 4 the first number of the wall gives its serial location in the table. The second number, given the wall when it was constructed, is the number listed on all original data sheets. In the discussion of a wall in this report, both numbers will be given.

3. Method of Construction

Details of the construction of some of the walls are shown in figures 2, 3, and 4.

Separate bids were asked for the construction of the walls in two consecutive groups, and the same contractor was the successful bidder for both contracts. The work was performed by experienced masons and both the contractor and his workmen cooperated wholeheartedly in meeting the specification requirements.

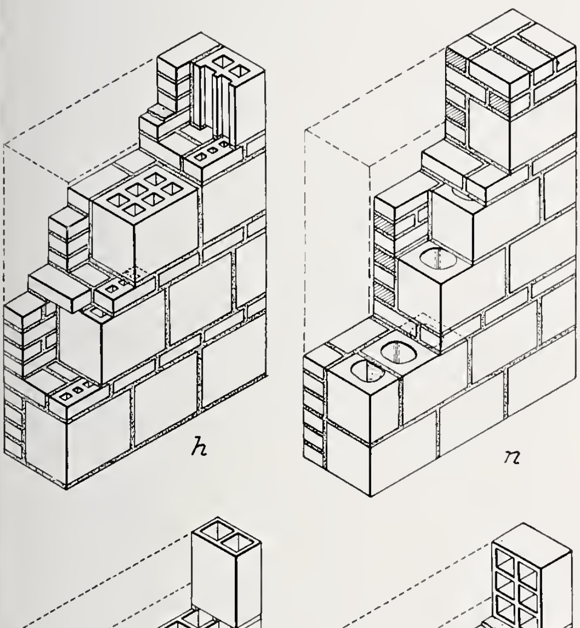

Figure 4.—*Isometric projections of walls with backings of hollow units, workmanship A.*

h, Techwood tile; *n*, cinder-concrete block; *j*, 8- by 12- by 12-in. tile showing end and side construction (stucco facing not shown).

Table 4.—*Performance of masonry walls in permeability tests*

KEY

Lower case letters denote brick or other structural unit.
The first letter in designation shows the material used in facing wythe.
Arabic numerals show either nominal wall thickness in inches, or the mortar number when used in later sequence.
Capital letters show workmanship.

a = Brick *a* (low absorptive).
b = Brick *b* (medium absorptive).
c = Brick *c* (high absorptive).
d = Double-shell tile.
e = Side construction tile.
f = Speed-a-backer tile.
g = Raritile.
h = Techwood tile.
j = 8×12×12″.
m = Stone concrete block.
n = Cinder-concrete block.
p = Mortar parging.
s = Stucco.

Wall	Designation [a]	Duration of test [b]	Time to fail as indicated by— Damp through wall [b]	Leak through wall [b]	Leak through facing [b]	Rating [b]
Walls of Common American Bond						
		Days	*Hours*	*Hours*	*Hours*	
1–15	aa12A1	14 14	-------- --------	-------- --------	-------- --------	*E* *E*
2–77	aa12A1	7 7	-------- --------	-------- --------	-------- --------	*E* *E*
3–65	aa12A2	7 8	-------- --------	-------- --------	-------- --------	*E* *E*
4–56	aa12A3	5 4	-------- 84	-------- --------	-------- --------	*E* *G*
5–74	aa12A3 [c]	-------- 4	-------- 65	-------- --------	-------- --------	-------- *E*
6–42	aa12A4	7 7	-------- --------	-------- --------	-------- --------	*E* *E*
7–16	aa12B1	1 1	0.9 .1	2.6 0.1	0.05 .15	*P* *VP*
8–64	aa12B2	1 1	1.9 2.2	-------- --------	.1 .03	*P* *P*
9–55	aa12B3	1 1 1	2.2 1 12	-------- 15 --------	.2 .07 5.5	*P* *P* *F*
10–48	aa12B4	2 1	2.6 0.17	-------- --------	0.05 .05	*P* *VP*
11–68	aa12C2	7 7	-------- 41	-------- --------	-------- --------	*E* *G*
12–69	aa12D2	1 1	2.8 4	-------- --------	2.8 0.45	*F* *P*
13–14	aa8A1	14 6	192 134	-------- --------	-------- --------	*E* *E*
14–60	aa8A2	3 3	67 58	-------- --------	-------- --------	*G* *G*
15–58	aa8A3	2 1	31 5	-------- --------	-------- --------	*G* *G*
16–51	aa8A4	2 1	18 0.37	-------- --------	-------- --------	*G* *G*
17–92	aa8A5	1 1	17 12.5	-------- --------	-------- --------	*G* *F*
18–17	aa8B1	1 1	0.08 .03	0.08 .03	0.03 .08	*VP* *VP*
19–61	aa8B2	1 1	.37 .05	.78 .32	.12 .04	*P* *VP*
20–57	aa8B3	0.8 1 1	.25 .1 9	.25 .1 18.1	.07 .03 9	*P* *VP* *F*
21–47	aa8B4	2 0.2	0.04 .04	0.04 .04	0.12 .04	*P* *VP*
22–18	bb12A1	4 0.8	50 4.5	-------- --------	-------- --------	*G* *G*
23–A1	bb12A1	2. 1	41 13.5	-------- --------	-------- --------	*G* *G*
24–A7	bb12A1	2 7	41 43	-------- --------	-------- --------	*E* *E*

See footnotes at end of table.

TABLE 4.—*Performance of masonry walls in permeability tests*—Continued

[For key see p. 7]

Wall	Designation [a]	Duration of test [b]	Time to fail as indicated by— Damp through wall [b]	Leak through wall [b]	Leak through facing [b]	Rating [b]
Walls of Common American Bond—Continued						
		Days	*Hours*	*Hours*	*Hours*	
25–27	bb12A2	5	26			*G*
		1	1			*G*
26–A4	bb12A2	1	10.5			*G*
		6	18			*G*
27–A6	bb12A2	1	15			*G*
		1	9.5			*G*
		1	19			*G*
28–73	bb12A3	1	17			*G*
		1	12.5			*G*
		1	20			*G*
29–A2	bb12A3	2	29			*G*
		2	41			*G*
30–45	bb12A4	5	36	82		*G*
		1	0.6			*G*
31–72	bb12B1	1	.33	13.5	0.07	*VP*
		1	.03	0.07	.02	*VP*
		1	6	15	15	*P*
32–50	bb12B2	1	0.45	2.5	0.8	*P*
		1	.10	0.13	.05	*VP*
33–19	bb12B3	1	.23	.35	1.5	*VP*
		0.2	.03	.03	0.03	*VP*
34–43	bb12B4	1	5.2	14	.03	*P*
		1	0.12	0.12	.02	*VP*
35–62	bb8A1	1	.03	.05	1.2	*F*
		1	.01	.01	0.25	*VP*
36–53	bb8A2	1	.20			*F*
		1	.02	.08		*F*
		1	1.5			*F*
37–59	bb8A3	1	0.03	18	18	*F*
		1	.02	0.05	4.5	*F*
		1	2.5	3.5		*F*
38–49	bb8A4	1	3.5			*F*
		1	0.05	0.05	0.38	*VP*
39–63	bb8B1	1	.05	.8	.03	*VP*
		1	.02	.05	.03	*VP*
40–22	bb8B2	0.8	.13	.42	.30	*VP*
		.2	.05	.05	.13	*VP*
		1	5.7			*F*
41–A9	bb8B2	1	0.02	.10	.37	*VP*
		1	.02	.02	.02	*VP*
42–A10	bb8B2	1	.03	.05	.10	*VP*
		1	.02	.02	.02	*VP*
		1	3	14.5	4.5	*F*
43–54	bb8B3	1	0.03	0.17	0.05	*VP*
		1	.03	.07	.05	*VP*
44–52	bb8B4	1	.03	.03	.17	*F*
		0.9	.01	.01	.03	*VP*
45–28	cc12A1	5	43			*E*
		1	6.5		15	*F*
		1	11			*G*
46–76	cc12A1	1	3.5			*G*
		1	0.08			*F*
		1	9			*F*
47–94 [f]	cc12A1	3	38			*G*
		1	11			*G*
48–A8	cc12A1	3	20			*G*
		1	9			*G*
49–35	cc12A2	3	21			*G*
		1	7.3			*G*
50–66	cc12A2 [e]	1	12			*G*
		0.6	0.43	1.3	2.3	*F*
51–33	cc12A3	2	20			*G*
		1	8			*G*
52–75	cc12A3	2	24			*G*
		1	4.6			*G*
		1	13.5			*G*
53–43	cc12A4	2	9			*G*
		1	1	4.5		*F*
54–A17	cc12A5	1	5.1			*G*
		1	0.23			*F*
55–A19	cc12A5 [e]	1	1.2		14.5	*F*
		1	0.42	0.75	3	*F*
56–29	cc12B1	0.9	.37		0.2	*VP*
		1	.17	.3	.13	*VP*
		1	19		19	*P*
57–37	cc12B2	1	0.53	14	0.13	*VP*
		1	.02	0.8	.13	*VP*
		1	13.7			*G*
58–67	cc12B2 [e]	0.9	0.97		.17	*VP*
		1	15	.7	.07	*VP*
		1	15		15	*F*
59–21	cc12B3	1	2	3.7	3.5	*VP*
		0.2	0.50	3	0.25	*VP*
60–44	cc12B4	1	1.9		.50	*P*
		1	0.27	0.35	.23	*VP*
61–A13	cc12B5	1	.32	1.6	.20	*VP*
		1	.08	0.12	.08	*VP*
62–A20	cc12B5 [e]	1	.42	1.1	.30	*VP*
		1	.05	0.10	.10	*VP*
63–71	cc12C2	1	2			*G*
		1	0.37		.58	*F*
		1	9			*G*
64–70	cc12D2	1	1.7		.50	*P*
		1	0.25	14.5	.13	*VP*
		1	18		18	*F*
65–31	cc8A1	1	0.9			*F*
		1	.47	15		*F*
		1	4			*F*
66–36	cc8A2	1	0.45	9		*F*
		1	.25	0.45	0.45	*F*
		1	7	7	7	*F*
67–20	cc8A3	2	0.68	2.8		*F*
		0.2	.30	0.48	2.3	*F*
68–40	cc8A4	1	1			*F*
		1	0.75	3.5		*F*
69–30	cc8B1	0.2	.17	1.5	0.22	*VP*
		.1	.10	0.11	.15	*VP*
		1	5.5		15	*F*
70–34	cc8B2	0.2	0.13	.50	3	*VP*
		.2	.03	.05	3.5	*VP*
71–32	cc8B3	1	.22	3.6	0.36	*P*
		0.1	.15	0.22	.28	*VP*
		1	5.5	14.5	14.5	*VP*
72–41	cc8B4	2	0.20	2	0.07	*VP*
		0.2	.05	0.05	.12	*VP*
Brick Walls With Two-Third "Blind" Headers						
73–89	aa8A2	3	60			*G*
		2	43			*G*
74–90	bb8A2	1	0.53			*F*
		1	.03			*F*
		1	4			*F*
75–38	cc8A2	0.8	0.92	5.8		*F*
		1	.25	0.38	4.5	*VP*
76–88	aa8B2	0.9	.07	.07	0.15	*VP*
		.1	.02	.02	.03	*VP*
77–91	bb8B2	1	.03	.07	.07	*VP*
		1	.03	.03	.03	*VP*
78–39	cc8B2	1	.22	15	.33	*P*
		0.2	.08	0.18	.18	*VP*

See footnotes at end of table.

Table 4.—*Performance of masonry walls in permeability tests*—Continued

[For key see p. 7]

Wall	Designation [a]	Duration of test [b]	Time to fail as indicated by— Damp through wall [b]	Leak through wall [b]	Leak through facing [b]	Rating [b]
		Walls With Stone Belt Course				
		Days	*Hours*	*Hours*	*Hours*	
79-84	aa12A2	3 2	26 26	---- ----	---- ----	*G* *G*
80-85	hh12A2	2 1	24 9	---- ----	41 ----	*G* *G*
		Walls With High-Ahsorptive Brick Backing				
81-86	ac8A2	6 6	144 89	---- ----	---- ----	*E* *G*
82-87	ac8B2	1 1 1	0.17 .05 3.5	15 0.83 ----	0.90 .33 ----	*P* *VP* *G*
		4-inch Brick Walls With Parged Backing				
83-A13	ap4A1	2 1	9 0.88	---- ----	---- ----	*G* *G*
84-A15	ap4A1w	7 7	---- 2	---- ----	---- ----	*E* *G*
85-A14	cp4A1	3 1	1.2 0.22	---- 1.5	---- 1.5	*G* *F*
86-A16	cp4A1w	7 1	.35 .38	31 0.83	31 0.83	*F* *F*
		Walls With Structural Clay Tile Backing				
87-9	hd12A2 [d]	14 1 1	96 2.5 20	---- ---- ----	---- ---- ----	*E* *G* *G*
88-11	he12A2 [d]	6 1	65 9	---- ----	---- ----	*E* *G*
89-12	bf12A2 [d]	2 1	11.5 0.50	---- 0.75	---- 4	*G* *F*
90-82	bg12A2	1 1	9.5 0.05	---- ----	---- 7	*G* *F*
91-26	hh12B2 [d]	2 1	20 0.22	41 0.22	0.05 .07	*VP* *VP*
92-13	hd12B2 [d]	1 1	3 0.38	---- ----	.13 .12	*P* *P*
93-83	hg12B2	1 1	.92 .20	---- ----	.10 .03	*VP* *VP*
94-23	bh12E2 [d]	6 2	72 9	---- ----	---- 20	*G* *G*
95-25	hh12E2 [d]	4 2	96 17	---- ----	---- ----	*G* *G*
96-10	bd12E2 [d]	7 4	117 60	---- ----	---- ----	*E* *G*
		Stucco Walls With Clay Tile Backing				
97-1	sj9A2 [d]	8 5	168 89	---- ----	---- ----	*E* *G*
98-2	sj9A2 [d]	5 3	60 41	---- ----	---- ----	*G* *G*
99-3	sj9A2 [d]	14 14	---- 209	---- ----	---- ----	*E* *E*
100-4	sj9A2 [d]	14 6	---- 65	---- ----	---- ----	*E* *G*
101-5	sj9A2 [d]	14 6	---- 108	---- ----	---- ----	*E* *E*
102-6	sj9A2 [d]	5 7	65 132	---- ----	---- ----	*E* *E*
103-7	sj9A2 [d]	14 7	---- 132	---- ----	---- ----	*E* *E*

See footnotes at end of table.

Table 4.—*Performance of masonry walls in permeability tests*—Continued

[For key see p. 7]

Wall	Designation [a]	Duration of test [b]	Time to fail as indicated by— Damp through wall [b]	Leak through wall [b]	Leak through facing [b]	Rating [b]
		Stucco Walls With Clay Tile Backing—Continued				
		Days	*Hours*	*Hours*	*Hours*	
104-8	sj9A2 [d]	7 [c] 5	---- ([e])	---- ([e])	---- ([e])	*E* *G, E*
		Walls Containing Hollow Concrete Units				
105-80	bm12A2	1 1	0.85 .17	4 ----	5 0.77	*F* *P*
106-A3	bm12A2	2 1	5 2.3	---- ----	---- 5.5	*G* *F*
107-A5	bm12A2	1 1	6.5 1.3	---- ----	---- 8	*G* *F*
108-78	bn12A2	2 1	6 0.13	---- ----	---- 0.58	*G* *F*
109-93	bn12A2	7 3	---- 50	---- ----	---- ----	*E* *G*
110-A12	m8A2 [d]	1 1	0.03 .02	6.5 0.02	.08 .02	*VP* *VP*
111-A11	n8A2 [d]	1 1	.03 .05	---- ----	.08 .05	*VP* *VP*
112-81	bm12B2	0.2 1	.37 .07	---- ----	.05 .03	*VP* *VP*
113-79	bn12B2	0.2 1	.27 .08	---- .08	.08 .03	*VP* *VP*

[a] See "Key" at top of table.

[b] Results of capillarity, heavy-rain, and light-rain tests for each wall are given, respectively, in the first, second, and third lines.

[c] Brick were dry when laid. Capillarity test not completed after 2 days.

[d] Wall not flashed at bottom.

[e] Heavy-rain test on wall 104-8 not completed after 5 days.

[f] Constructed in place of wall 46-76.

The absorption of the bricks during a partial immersion for 1 minute on the flat side in ⅛ inch of water was limited to a maximum of 50 grams. It was necessary, therefore, to reduce the suction of brick *c* by totally immersing them in water for about 1 minute or more, depending upon their condition when received from the storage pile. Brick *a* were dried before laying. Figure 2 shows a rear elevation and two sections through a typical brick masonry wall. Common American bond consisting of five stretcher courses and a header course was used in the walls of brick masonry. The thickness of the joints ranged from ⅜ to ⅝ inch. The two flashings shown in figure 2 were placed at the bottom of the brick walls to catch leakage. Some of the walls of hollow building units were not flashed. Others contained a single flashing similar to the lower one shown in figure 2. A mortar parging ½ inch thick was applied on each end and on top of all walls in order to prevent the escape of appreciable quantities of air or water through these surfaces during a test; so that, when pressure was applied to the exposed face, a pressure gradient would be maintained through the thickness of the wall.

4. Workmanship

Of the five different kinds of workmanship used in the construction of the walls, the masons were most familiar with classes *B* and *D*. The other classes required more effort, but as the building of the walls continued, less time was required for satisfactory work. The different kinds of workmanship were as follows (not listed in sequence of quality):

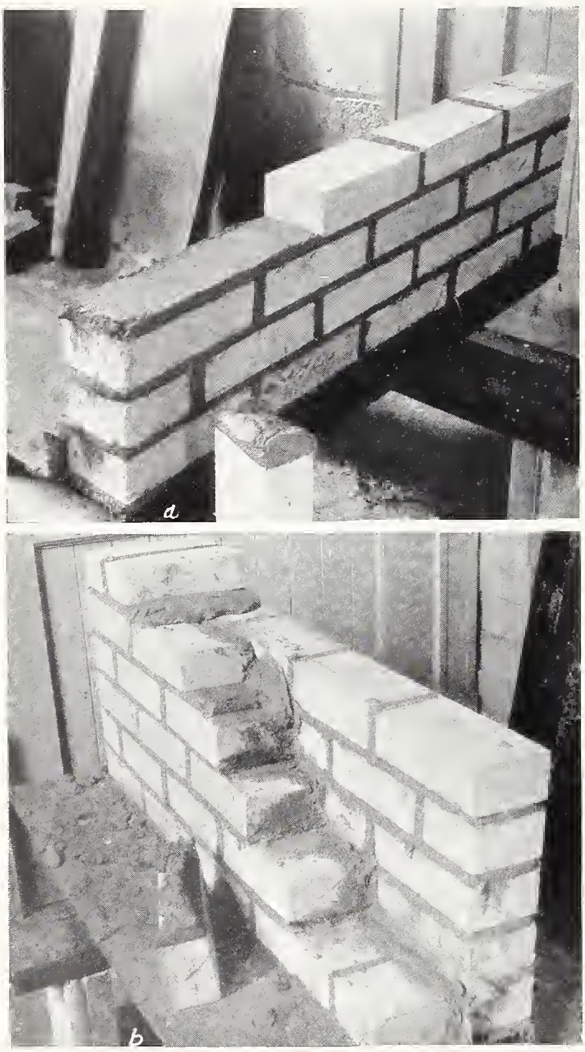

Figure 5.—*Wall 16–51 (aa8A4) during construction, illustrating workmanship A.*

a, front view before tooling face joints, and *b*, back view showing solidly filled cross and collar joints.

(a) Class A

Figure 5 illustrates class *A* workmanship. All joints were filled with mortar. The bed joints were spread to a uniform thickness (not furrowed). The cross or head joints were filled by applying mortar to the ends of stretchers and the sides of headers, the mortar being applied before the brick were laid by scraping the trowel on their lower edges. After laying the brick in each course, the filling of cross joints was completed by working in mortar from above. Stretcher brick in the facing wythe were laid to the elevation of the header course before the backing wythes were laid. In spreading the bed joints for the backing, the mortar was curled against the facing wythe to form a cove, filling the lower portion of the collar joint. The filling of the collar joint was then completed by working in mortar from above.

For the walls of hollow masonry units faced with brick, the joints in the brickwork were filled with mortar as described. The facing brick were laid to the elevation of a header course and the back of the facing wythe was then parged with at least ⅜ inch of mortar before the hollow units of the backing were set. Joints in the backing were completely filled.

The face joints on the exposed face of the wall were tooled to form a concave surface. A round metal bar of diameter slightly larger than the thickness of the joint was used to pack the mortar in the face joints forming a smooth hard surface.

(b) Class B

Figure 6 illustrates class *B* workmanship. As small an amount of mortar as was practicable was used. The mason was instructed to use a "light" trowel and to follow the technique usually employed in contract construction. The mortar beds were furrowed. The cross joints were made by buttering lightly the outer ends of the stretcher and outer edges of the header brick that lay in either face of the walls. The collar joints, between the wythes, and the interior of the cross joints were not filled. Only the face shells of hollow units were provided with mortar beds, and cross joints were made by buttering the edges of the unit that were exposed in the face of the wall. There was no

FIGURE 6.—*Wall 32–50 (bb12B2), illustrating workmanship B.*

a, front view, and *b*, back view, showing open cross and collar joints.

parging on the back of the facing wythe and the interiors of all vertical joints were left unfilled. The mortar joints in both faces of the wall were "cut" by drawing the edge of the trowel along the joint, cutting off excess or protruding mortar. The surface of the cut joints was rough in texture.

(*c*) *Class C*

This workmanship was the same as class *A* except that the mortar joints were cut without subsequent tooling.

(*d*) *Class D*

This workmanship was the same as class *B* except that the joints in the exposed face were tooled to form a concave surface in the same manner as for class *A* workmanship.

(*e*) *Class E*

This is according to the specification for the Techwood Slum Clearance Project, Atlanta, Ga. This class of workmanship was used for the construction of two of the walls built with a facing of brick *b* and a backing of Techwood tile. This workmanship is the same as class *A* except that no mortar was placed in the central 3-inch thickness of the tile backing except that for bedding the header bricks. The tile were set on end and only the two longitudinal face shells were provided with bed and cross joints.

5. AGING

After completion, the walls were allowed to stand in the laboratory for 2 or 3 days without being moved. The walls were then whitewashed on the ends and back and placed in the drying rooms. After 1 month or more, depending upon the time required for drying, the walls were given the first permeability test. They were also dried thoroughly between successive tests. The drying rooms were ventilated and heated to at least 30° or 40° F above mean outdoor temperature. The air inside the room was circulated around the walls by means of fans. The dryness of the walls was determined by weighing them on a platform scale. When a wall had lost less than about 0.2 percent of its weight in 7 days' time, it was considered dry enough for test.

IV. METHOD OF TESTING PERMEABILITY OF WALLS

A fixed testing procedure was followed and the tests on each wall were made in the same order. The tests were designated as the capillarity, heavy-rain, and light-rain tests. Only a limited number of walls were given the light-rain tests. Nearly all of the comparative data used in this report were obtained from the heavy-rain test, making it the most important as well as the most severe test given to the walls. The duration of the tests was for 1 day, or until failure, with the exception of a few tests made on walls that showed neither leakage nor dampness during exposures of 1 or 2 weeks.

1. Capillarity Test

In the capillarity test the water penetrated the walls under the forces of capillarity and gravity only. The wall was supported in a vertical position on the floor of the testing room and the water was applied near the top of the exposed face by means of a perforated metal pipe. The streams from the perforations were about 1 inch apart along the axis of the pipe and they merged into a thin sheet of water running down the face of the wall. The amount of water applied was about 10 gallons (38 liters) per hour per lineal foot of wall. Metal strips were supported at the ends and across the top of the wall so that the streams of water did not impinge against the masonry near the parging.

2. Heavy-Rain Test

This test was made after the capillarity test had been completed. The conditions of exposure simulated the effect of a windstorm accompanied by a heavy rain. The exposed face of the wall was subjected to an air pressure of 10 pounds per square foot above the atmospheric pressure on the back of the wall, so that a pressure gradient existed within the wall. The wall was supported on metal skids and clamped into position so as to form one side of an airtight pressure chamber, as illustrated in figure 7. Water was applied to the top of the wall through a perforated metal tube, so that the face of the wall was covered with a sheet of water, as in the capillarity test.* The joint between the wall and the chamber was made airtight by means of a sponge-rubber gasket. Since the opening in the chamber was 3 feet wide, no water was applied directly to the parging at the sides of the wall. The top of the wall was flashed with a combination of sponge-rubber and copper gaskets. The pressure chamber was equipped with observation windows, a manometer, a gooseneck water outlet, and a sensitive pressure-relief outlet.

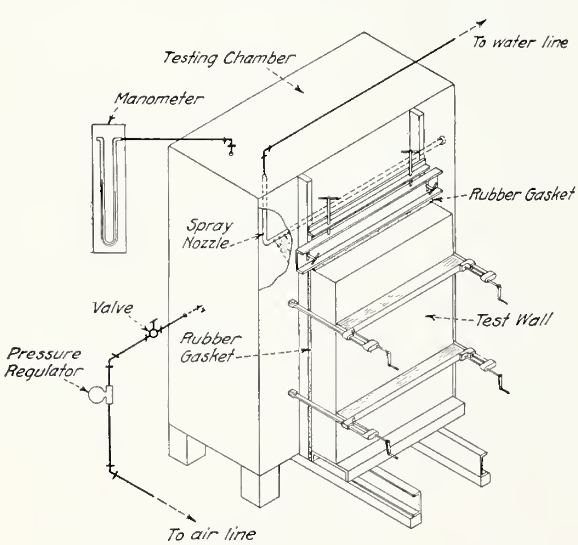

Figure 7.—*Isometric projection of testing chamber.*

3. Light-Rain Test

Light-rain tests were made only on some of the walls that had been found most permeable in the heavy-rain tests. The test differed from the heavy-rain test only in the amount of water applied and in the method of application. The wall was exposed to an air pressure of 10 pounds per square foot in the testing chamber (fig. 7) and water was applied to the face in small measured quantities by means of atomizers. Two atomizers, mounted one over the other on a carriage, moved horizontally back and forth in front of the wall. The sprays, elliptical in shape with the long axes vertical, were so adjusted that each covered one-half of the wall elevation with a slight overlap at mid-height. The amount of water applied per hour was about 0.5 gallon (about 2 liters) per lineal foot of wall, equivalent to a depth of approximately 0.2 inch per hour over the exposed surface.

V. RATING OF PERFORMANCE

1. Observations

Three general types of observation or measurements were made to determine the performance of a wall. These were: (a) time for the penetration of moisture through the wall or the facing, (b) measurements of the maximum rate of leakage through the wall, and (c) the appearance of the wall during and after a test.

(*a*) *Time Required for Penetration*

Time measurements included the first appearance of a damp spot in the back of the

*When the leakage through the wall or facing was large, it was sometimes necessary to apply more than 10 gallons of water per lineal foot of wall.

wall, a leak through the wall, and the indication in the lower flashing of facing leakage that had penetrated downwards through the wall to the flashing. These observations are given for each wall in table 4. The designation "leak, through facing", of course, indicates the time for observation of a type of failure (leak from the lower flashing), rather than the actual time at which water first penetrated the facing wythe. The time values given in table 4 are usually correct within limits of plus or minus 10 percent. Although the times for the appearance and the location of subsequent damp spots and leaks were recorded, they are not included in this report.

(b) *Rate of Leakage*

The rate of leakage through the wall or the facing was determined by measuring the water caught in an interval of time on the upper or the lower flashing. The measurements were made at frequent intervals throughout a test or until a maximum rate of leakage was observed.

(c) *Appearance of Wall During and After Test*

The appearance of the walls under test was closely observed and recorded at the end of 1 day and at the end of the test. The location and extent of damp areas was drawn on mimeographed sketches representing the back of each wall. The intensity of saturation of damp areas was roughly determined by touching with the fingers, and the presence or absence of visible drops of water on the back of the wall was noted. The only data on the appearance of the wall that was used in establishing a criteria for performance was the percentage of damp area on the back of the wall. The degree of saturation of the damp areas was difficult to express in definite terms.

2. Arbitrary Ratings

A system of rating was established in order to classify the walls according to their comparative resistance to penetration by water. The method of rating was arbitrary because the exposures in tests continued for several hours were more severe than natural exposures for most building walls. The backs of the walls were not plastered and the high relative humidity in the testing room prevented the drying which would occur on the interior surface of walls in heated buildings. It is not known whether or not the permeation of moisture through the test walls, as evidenced by damp areas, would have produced visible dampness on plaster applied directly to the wall. When the amount of moisture penetration was sufficient to cause dampness on more than 50 percent of the wall area in 24 hours or less, it seems likely that the plaster would be damaged even though no visible dampness would appear. It is probable that damp areas on the plaster would have resulted in those cases where leaks penetrated the walls or where water could be plainly seen in the joints.

Measurements of the leakage through the walls indicated that the rate of leakage gradually increased to a maximum as the wall materials approached saturation, and then decreased very slowly with continued exposure. There was no correlation between the location of the leaks in the brick masonry walls and the kind of brick or workmanship. It appeared to be largely a matter of chance whether the leakage appeared on the back of the wall or on the lower flashing. However, it is probable that with increase in wall height, a relatively greater amount of the water that penetrated the facing would pass through the wall, especially if aided by a pressure gradient. For this reason the wall ratings were so classified as to give low ratings to all walls that leaked. The ratings of the walls are listed in table 4 and are as follows: Excellent (E), walls having no leaks through either the wall or the facing wythe, and less than 25 percent of the wall area damp in 7 days; good (G), walls having no leaks through either the wall or the facing wythe, and less than 50 percent of the wall area damp in 1 day; fair (F), walls having 50 percent or more of the wall area damp in 1 day, and/or having a leakage through the wall or facing of less than 1 liter per hour; poor (P), walls having a leakage of less than 1 liter of water per hour through the wall and less than 15 liters of water per hour through the facing during the first day; and very poor (VP), walls having a leakage of more than 1 liter of water per hour through the wall or more than 15 liters of water per hour through the facing.

VI. PERFORMANCE OF WALLS

1. Consistency of Results

The results of the wall tests have in general been consistent enough to indicate at least the relative advantages or disadvantages of different workmanships, kind or combination of brick, kind of mortar, and wall thickness. The lack of flashings in some of the earlier walls built with structural clay tile backing made it difficult to determine the exact reason for leakage at the bottom of these walls. Nearly all of the walls on which it was necessary to make repeated tests of the same kind showed a decrease in permeability in successive tests.

2. Effect of Variation in Methods of Testing

(*a*) *Comparison of Capillarity and Heavy-Rain Tests*

The only difference between the capillarity and the heavy-rain tests was in the air pressure applied. No pressure was used in the capillarity test, but 10 pounds per square foot was applied in the heavy-rain test. Some idea of the relative severity of these tests may be obtained from the data presented in table 5.

Table 5.—*Relative performance of all-brick walls under capillarity and heavy-rain tests*

[Performance under capillarity test taken as unity. Average of two to four walls, unless otherwise noted]

Thickness (in.)	Workmanship	Relative time for penetration as indicated by— Dampness	Relative time for penetration as indicated by— Leakage	Relative area damp after 1 day	Relative amount of leakage
		Brick *a*			
8	*A*	0.07	---------	1.4	---------
12	*A*	[a] .25	---------	1.0	---------
8	*B*	.29	0.45	1.1	3.1
12	*B*	.14	.13	1.1	2.7
		Brick *b*			
8	*A*	0.05	0.01	1.0	3.1
12	*A*	.04	---------	1.6	---------
8	*B*	.45	.21	1.0	3.6
12	*B*	.06	.02	1.3	5.9
		Brick *c*			
8	*A*	0.54	0.08	1.1	4.0
12	*A*	.18	---------	1.6	---------
8	*B*	.30	.03	1.0	2.9
12	*B*	.29	.05	1.1	4.1

[a] 1 wall only.

Most of the walls which leaked in the heavy-rain tests had leaked in the capillarity tests. The effect of the air pressure was to reduce greatly the time required for moisture penetration and to increase greatly the amount of leakage through the walls. The reduction in time required for moisture penetration in the heavy-rain test, as compared to that observed for the capillarity test, appeared to be slightly greater for walls of workmanship *A* than for those of workmanship *B*. The thickness of the walls did not greatly affect the relative times required for penetration, but it was found that pressure increased the permeabilities of walls of brick *b* relatively more than those of either brick *a* or *c*.

(*b*) *Comparison of Light- and Heavy-Rain Tests*

Since light-rain tests were made only on a small number of the more permeable walls, a proper comparison cannot be made on the relative severity of the light- and heavy-rain tests. By averaging the available data, it was found to take about 50 times as long for dampness to penetrate the wall during a light-rain test, and about 200 times as long for the appearance of leaks through the facing as was required for the heavy-rain tests.

VII. EFFECT OF KINDS OF WORKMANSHIP OR MATERIALS USED IN WALLS OF BRICK MASONRY

1. Comparison of Workmanship

The results of the tests have shown that workmanship was the most important factor affecting the permeability of brick walls of common American bond. A comparison of the performances of walls of workmanships *A*, *B*, *C*, and *D* is provided by the data in table 6 for individual walls of brick *a* and of brick *c*. This table gives the detailed results of the heavy-rain test on each wall. The data show that the resistances of walls with workmanship *A* were markedly greater than for the others. In order to illustrate more clearly the data in table 6 the salient features of each kind of

TABLE 6.—*Effect of workmanship on performance of brick walls based on results of heavy-rain tests*

Wall	Designation	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
					Walls of Brick *a* and Mortar 2, 12-inch Thick				
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
3–65	aa12A2	8	----------	----------	----------	0	0	0	*E*
8–64	aa12B2	1	2.2	----------	0.03	35	0	14	*P*
11–68	aa12C2	7	42 ±3	----------	----------	30	0	0	*G*
12–69	aa12D2	1	4	----------	.45	25	0	3	*P*
					Walls of Brick *c* and Mortar 2, 12-inch Thick				
49–35	cc12A2	1	7 ±1	----------	----------	30	0	0	*G*
57–37	cc12B2	1	0.20	0.55 ±0.2	0.13	95	1	100	*VP*
63–71	cc12C2	1	.37	----------	.58	50	0	0.5	*F*
64–70	cc12D2	1	.25	15 ±6	.13	75	.5	67	*VP*

workmanship are given below in the order of their least permeability.

Work-man-ship	Face joint treatment	Kind of joint inside of wall	Order of least per-meability
A	Tooled	Solid	1
C	Cut	do	2
D	Tooled	Open	3
B	Cut	do	4

It can be seen for walls of similar interior construction that tooled joints were more effective than cut joints. The effect of joint treatment was not, however, of sufficient magnitude to overcome the influence of the type of workmanship used inside the wall.

2. EFFECT OF WALL THICKNESS AND KIND OF BRICK

Data on the effects of wall thickness and kind of brick were obtained from tests on a group of 48 walls representing the four variables: workmanship, thickness, brick, and mortar. The specific variables in this group were workmanship *A* and *B*, wall thicknesses 8 and 12 inches, bricks *a*, *b*, and *c*, and mortars 1, 2, 3, and 4. Each workmanship and wall thickness was represented by 24 walls, each brick by 16 walls, and each mortar by 12 walls. As it was found that the effects of difference in the mortar were similar for each brick, the test data were averaged for groups of four walls of like brick, thickness, and workmanship. These averaged data are presented in table 7. Data which departed markedly from the average were not included in the values given in table 7; less than 10 determinations out of a total of over 900 were rejected.

Because of the relatively high permeability of walls of workmanship *B*, the effect of increasing the wall thickness from 8 to 12 inches was more noticeable for walls of class *A* than for those of class *B* workmanship. The length of time required in heavy-rain tests for the penetration of dampness through 12-inch walls (average of all brick) was usually more than 50 times as great as for the 8-inch walls of workmanship *A* and was about 6 times as great with workmanship *B*. This difference is probably because the penetration in class *A* construction walls was by capillarity, whereas it took place through interstices in the masonry of class *B* construction walls.

It is evident from the data of table 7 that for workmanship *A* the least permeable walls were those built of the least absorptive brick, whereas the data for the walls of workmanship *B* do not show a consistent relation between the performance of the walls and the absorptive properties of the bricks. As pointed out later, the performance of the walls of absorptive brick might have been better if these bricks had been wetted thoroughly before use in construction.

Table 7.—*Effect of wall thickness and kind of brick on performance of "typical" walls*

[Each value is the median for four or more walls which were alike except for the mortar]

Designation	Test	Duration of test	Time to fail, as indicated by—			Area damp in 1 day	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
aa12A	*C*	8	—	—	—	0	0	0	*E*
	HR	7	—	—	—	0	0	0	*E*
bb12A	*C*	3	29	—	—	0	0	0	*G*
	HR	3	24	—	—	9	0	0	*G*
	LR	1	19	—	—	3	0	0	*G*
cc12A	*C*	3	22	—	—	2	0	0	*G*
	HR	1	7	—	—	25	0	0	*G*
	LR	1	12	—	—	6	0	0	*G*
aa8A	*C*	6	72	—	—	0	0	0	*G*
	HR	3	48	—	—	0	0	0	*G*
bb8A	*C*	1	0.50	—	—	80	0	0	*F*
	HR	1	.03	0.05	1.3	100	4	.5	*VP*
	LR	1	2.8	—	—	100	0.3	.5	*F*
cc8A	*C*	1	0.75	—	—	75	0	0	*F*
	HR	0.8	.42	4	—	99	0.5	0	*F*
	LR	1	5	—	—	68	0	0	*F*
aa12B	*C*	1	1.9	—	0.10	35	0	5	*P*
	HR	1	0.83	—	.08	45	4	13	*VP*
	LR	1	12	—	5	5	0	0.1	*F*
bb12B	*C*	1	1	8	0.58	70	.5	10	*P*
	HR	0.8	0.07	0.03	.03	99	.5	60	*VP*
	LR	1	6	15	15	55	.02	1.4	*P*
cc12B	*C*	1	1.2	12	1.1	75	.5	24	*VP*
	HR	0.8	0.25	5	10	85	2	60	*VP*
	LR	1	16	—	—	20	0	0.5	*F*
aa8B	*C*	1	0.17	0.25	0.03	70	1	5	*VP*
	HR	0.8	.05	.12	.05	70	3	18	*VP*
	LR	1	9	12	.43	3	0.1	0.4	*F*
bb8B	*C*	1	0.05	0.27	.13	98	4	14	*VP*
	HR	0.8	.02	.03	.05	100	28	25	*VP*
	LR	1	3	15	4	87	0.2	0.3	*F*
cc8B	*C*	0.9	0.17	2	0.50	100	3	17	*VP*
	HR	.2	.08	0.10	.58	100	31	50	*VP*
	LR	1	6	15	—	100	1.6	0.7	*VP*

3. Effect of Absorptive Backing

The effect of combining a low-absorptive brick facing with a high-absorptive brick backing was determined from tests on two walls; 81–86, designation ac8A2; and 82–87, designation ac8B2. The performance of these walls in heavy- and light-rain tests is compared in table 8 with the performance of similar walls built entirely of brick *a* or of brick *c*.

From the data on the heavy-rain tests given in table 8, wall 81–86, of class *A* workmanship, gave the best performance and proved superior to wall 14–60 built entirely of low-absorptive brick. All of the walls of class *B* workmanship leaked badly. In the light-rain tests on walls of class *B* workmanship, wall 82–87 gave a slightly better performance than the other two. This wall was the only 8-inch wall of class *B* workmanship to be given a rating of good in the light-rain test.

The results of these tests indicate that when the amount of water penetrating the facing wythe was small, the relatively large absorptive capacity of the brick *c* backing was of some advantage in delaying penetration of dampness and in retarding leaks through either the wall or the facing. The impervious brick facings in walls 81–86 and 82–87 had, respectively, similar effects in the heavy- and light-rain tests inasmuch as they greatly reduced the amount of water passing into the backing. The walls of workmanship *B* built entirely of brick *c* were slightly more resistive than those built of brick *a*. Apparently the absorption of water by brick *c* delayed the penetration of leaks until the wall was nearly saturated.

TABLE 8.—*Effect of combining a high-absorptive brick backing with a low-absorptive brick facing*

Wall	Designation	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
		Heavy-Rain Tests							
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
14-60	aa8A2	3	57 ±1	----	----	70	0	0	*G*
81-86	ac8A2	6	84 ±5	----	----	100	0	0	*G*
66-36	cc8A2	1	0.25	0.45	0.45	100	.5	.5	*F*
19-61	aa8B2	1	.05	.32	.03	8	.5	20	*VP*
82-87	ac8B2	1	.05	.63	.33	100	5	20	*VP*
70-34	cc8B2	.2	.03	.05	1.8 ±.5	100	51	0.5	*VP*
		Light-Rain Tests							
20-57	aa8B3	1	9 ±2	18 ±4	9 ±2	83	0.2	0.4	*F*
82-87	ac8B2	1	3.5	----	----	45	0	0	*G*
69-30	cc8B1	1	5.5	----	15 ±5	30	0	.6	*F*

4. COMPARISON OF MORTARS

(*a*) *Effect of Varying Percentages of Lime and Cement in Mortars of High Water Retentivity*

The permeabilities of brick walls constructed with mortars 1, 2, 3, and 4 are given in table 9. The values in the table were computed in a manner similar to those given in table 7, using the data from tests on the same 48 walls. Each value is the average for the results of tests on the three walls which were similar except as to kind of brick.

TABLE 9.—*Effect of composition of mortar on performance of "typical" brick walls*

[Each value is the median for three or more walls which were alike except for the brick]

Designation	Test	Duration of test	Time to fail, as indicated by—			Area damp in 1 day	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
--12A1	*C*	6	139	----	----	0	0	0	*E*
	HR	5	120	----	----	8	0	0	*G*
--12A2	*C*	6	125	----	----	4	0	0	*G*
	HR	6	115	----	----	12	0	0	*G*
--12A3	*C*	6	125	----	----	4	0	0	*G*
	HR	4	36	----	----	10	0	0	*G*
--12A4	*C*	7	127	----	----	20	0	0	*G*
	HR	5	117	----	----	33	0	0	*G*
--8A1	*C*	5	65	----	----	55	0	0	*F*
	HR	3	46	24	----	67	.5	0	*F*
--8A2	*C*	2	22	----	----	57	0	0	*F*
	HR	2	19	12	----	67	.5	0	*F*
--8A3	*C*	2	10.7	----	----	67	0	0	*F*
	HR	0.7	1.8	20	10	63	.5	.5	*F*
--8A4	*C*	1	7.5	----		32	0	0	*G*
	HR	1	0.38	9	----	70	.5	0	*F*
--12B1	*C*	1	.53	12	0.10	63	.5	15	*P*
	HR	1	.10	5	.10	80	6	69	*VP*
--12B2	*C*	1	.97	13	.42	52	0.5	14	*P*
	HR	1	.83	8	.07	77	.5	50	*VP*
--12B3	*C*	1	2	9	2	88	1	3	*VP*
	HR	0.5	0.52	6	0.12	82	9	18	*VP*
--12B4	*C*	1	3	----	.20	42	0	9	*P*
	HR	1	0.18	8	.12	60	.5	41	*VP*
--8B1	*C*	0.7	.10	0.80	.10	78	2	25	*VP*
	HR	.7	.05	.07	.08	95	7	68	*VP*
--8B2	*C*	.7	.17	.42	1	97	5	4	*VP*
	HR	.6	.03	.13	1	95	23	16	*VP*
--8B3	*C*	.9	.17	1	0.15	98	3	12	*VP*
	HR	.7	.07	0.13	.12	98	18	27	*VP*
--8B4	*C*	2	.08	.69	.12	78	1	12	*VP*
	HR	0.4	.03	.03	.07	80	29	47	*VP*

Table 9 shows an anomaly for the 12-inch walls of workmanship *A*. Although days are shown to be required for the penetration of moisture to the back of the wall, a definite damp area in 1 day is also given. The inconsistency is due to the fact that most of the walls of brick *a* were not penetrated by dampness, but the walls of bricks *b* and *c* were usually partly damp after exposure for 1 day.

The data in table 9 indicate that mortar 1 (high-cement-low-lime) was the least permeable. The addition of a metallic stearate to one of the mortars (No. 4) had little effect on the permeability. Variations in the proportion of cement to lime in the mortars did not affect the permeability of the brick walls as much as changes in the workmanship, the thickness of the wall, or the kind of brick. However, for walls of workmanship *A* the performances of those with mortar 1 were distinctly better than for those with the other mortars, and the permeabilities were slightly less with mortar 2 than with mortars 3 and 4. With workmanship *B*, the performance was about the same for mortars 1 to 4, inclusive.

Although the composition of the mortar had a measureable effect on the permeability of the walls, the data of tables 4 and 7 for walls of brick *a* and workmanship *A* show that the penetration of water through the mortar was very slow. Usually more than 1 day was required for dampness to penetrate the 8-inch walls and more than 1 week the 12-inch walls. These results indicate that the amount of water passing through the solid mortar joints was small in comparison to that flowing through openings in the walls which leaked early in the tests.

(*b*) *Effect of Using a Mortar of Low Water Retentivity*

Although mortars 1 to 4 were of a workability satisfactory to the masons, the bricklayers complained vociferously whenever using mortar 5, which was a cement-line mortar (1:1:6 by volume) and was the same as mortar 2 except for the quality of the lime. Five brick walls were constructed with this mortar. The numbers, designations, and performances of these walls are included in table 10, which gives data for comparing the performance of these walls with similar ones built with mortar 2.

The construction of wall 17–92, designation aa8A5, was marked by floating (settling and slipping) of the brick and excessive bleeding (separation of the water) of the joints. Although the low-absorptive brick *a* usually had some tendency to float with the other mortars, more of this difficulty was experienced in the construction of this wall. The construction of walls of brick *c* with mortar 5 was difficult because of the strong brick suction that immediately stiffened the mortar. The oven-dried brick, particularly, were hard to level after the completion of a course, and many brick were broken by the mason when attempting to hammer them into position.

All of the walls containing mortar 2 were less permeable than similar ones containing mortar 5. The superiority was most marked for workmanship *A*. For workmanship *B* the walls built with mortar 5 had nearly double the leakage of those built with mortar 2. The data are consistent in showing that the performance of walls with mortar 2 was better than those with mortar 5, whether judged by time for dampness to penetrate, time for leakage (if any) to start, or rate of leakage.

As pointed out previously, there was not a large difference in the performances of walls with mortars 1, 2, and 3, the permeabilities increasing only slightly with an increase in the ratios of lime to cement in the mortars. The water retentivites of these mortars were high; the values for flow after suction ranged from 87 to 109 percent (initial flow 130 percent). All were "fat" and all were so nearly alike in their working properties that the masons were unable to distinguish one from another with certainty. Both the performance of walls in the permeability tests and the testimony of the masons indicate, therefore, that the qualities of cement-lime mortars which are related either to permeability of walls or workability were not controlled by ratio of cement to lime in the mortars. Moreover, the performance of mortar 5 indicates that a mortar showing a low value for flow after suction is not satisfactory to the masons nor is it suitable for use in exterior walls of buildings where freedom from rain penetration is of importance.

5. Effect of Brick Suction

The maximum permissible absorption of brick when laid was limited in most of the walls (section III (3)) to 50 grams of water absorbed in 1 minute (brick laid flatwise in ⅛ in. of water). To meet this requirement it was necessary to wet the high-absorptive brick *c* before laying. In order to determine the effects of a high brick suction, four walls were constructed using brick *c* that had been oven-dried to constant weight. The results of tests on these walls are given in table 10. The effects of using dry or damp brick can be obtained by comparing the performance of walls 62–A20 with 61–A18, 58–67 with 57–37, 55–A19 with 54–A17, and 50–66 with 49–35. The effect of brick suction is most marked for walls of class *A* workmanship and mortar 2, and is least noticeable for class *B* workmanship and mortar 5. This is to be expected as nearly all walls of class *B* workmanship were very permeable. As all available data indicate that the permeability of walls increase with increases in the absorption of the brick at time of laying, it is probable that the performance of the walls built with damp brick would have been better if the brick had contained more water.[1] Even so, none of the walls of brick *a* or the dampened brick *c* with workmanship *A* leaked, whereas both of those of the high-absorptive brick *c* (set dry) leaked. Although the data are meager, they indicate that the wetter the bricks (less the absorption or brick suction) the less permeable the masonry.

Table 10.—*Effects of water retentivity of mortar, plasticity of lime, and suction of brick on performance of brick walls*

[Heavy-rain tests]

Wall	Designation	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
Brick Taken From Dry Storage									
		Days	*hr*	*hr*	*hr*	*%*	*Liters*	*Liters*	
14–60	aa8A2	3	57 ±1			70	0	0	*G*
17–92	aa8A5	1	12.5 ±2.5			50	0	0	*F*
Brick Damp When Laid									
49–35	cc12A2	1	7 ±1			30	0	0	*G*
54–A17	cc12A5	1	0.23			78	0	0	*F*
Brick Oven-Dry When Laid									
50–66	cc12A2	0.65	0.43	1.3	2.3	100	0.5	0.5	*F*
55–A19	cc12A5	1	.42	0.75	3	93	.2	.3	*F*
Brick Damp When Laid									
57–37	cc12B2	1	0.02	0.82	0.13	95	1	100	*VP*
61–A18	cc12B5	1	.08	.12	.08	95	5	244	*VP*
Brick Oven-Dry When Laid									
58–67	cc12B2	1	0.25	0.68	0.07	90	3	127	*VP*
62–A20	cc12B5	1	.05	.10	.10	100		249	*VP*

None of the data pertaining to the effects of kind of brick, absorption of brick when laid, or kind of mortar support an often expressed view that mortars should be adapted to the bricks. The best performance was shown by walls with mortars of high flow after suction, irrespective of the kind of brick used; and uniformly better results were obtained with brick of low absorption than with dry high-absorptive brick.

[1] *Permeability tests of 8-in. brick wallettes,* Proc. Am. Soc. Testing Materials 34, pt. II, 419 (1934).

6. Effect of Using Blind Headers

The effect of using two-third "blind" headers in 8-inch walls of common American bond is shown by the data in table 11. The walls containing blind headers were constructed in the usual manner except that two half brick were placed in the facing wythe between full headers in each of the header courses, leaving one-third of the headers full. The blind headers were placed with their ends outward and they were backed by stretcher brick in the second wythe.

Table 11.—*Effect of using two-thirds "blind" headers on performance of brick walls of common American bond*

[Heavy-rain tests]

Wall	Designation [1]	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
14–60	aa8A2–f	3	57 ±1	------	------	70	0	0	*G*
73–89	aa8A2–b	2	44 ±3	------	------	75	0	0	*G*
36–53	bb8A2–f	1	0.02	0.08	------	100	.5	0	*F*
74–90	bb8A2–b	1	.03	------	------	90	0	0	*F*
66–36	cc8A2–f	1	.25	.45	0.45	100	.5	.5	*F*
75–38	cc8A2–b	1	.25	.38	1 ±.5	100	3	.5	*VP*
19–61	aa8B2–f	1	.05	.32	0.03	80	0.5	20	*VP*
76–88	aa8B2–b	0.1	.02	.02	.03	50	5	5	*VP*
Avg [2]	bb8B2–f	.6	.03	.03	.07	100	30	23	*VP*
77–91	bb8B2–b	1	.03	.03	.03	100	6	67	*VP*
70–34	cc8B2–f	0.1	.03	.05	1.7 ±1	100	51	0.5	*VP*
78–39	cc8B2–b	.2	.10	.18	0.18	100	1	66	*VP*

[1] Letter f at end of designation indicates full headers; letter b indicates two-thirds "blind" headers.
[2] Average for walls 40–22 and 49–A9.

The use of blind headers had no significant effect on the performance of the walls of workmanship *A*. For those of workmanship *B* with bricks *b* and *c*, the use of blind headers caused the measured leakage through the facing to be greater and that through the wall to be less than for the walls with full headers. Although there may have been a tendency for water passing through the facing to drop down between the wythes in walls of workmanship *B* with blind headers, the data of table 7 show that most of the walls of workmanship *B* had much greater leakage from the facings than through the walls. It must be concluded, therefore, that the data obtained show neither a marked nor consistent effect resulting from using half brick for two-thirds of the units in the header courses.

7. Effect of Mortar Parging on Brick Facing

Four 4-inch brick walls were constructed with workmanship *A* with a ½-inch mortar parging on the back. To increase the stability of the walls, a 4- by 4-inch brick pilaster, 15 inches high, was built into the brick at each end of the wall. The pilasters contained a full header brick every other course and were covered with parging. The walls were flashed between the pilasters with a strip of copper inserted in the bed joint above the first course before the mortar had set and before the wall was parged. Mortar 1w used in two of the walls was the same as mortar 1, except that it contained 0.2 percent of ammonium stearate, by weight, of cement plus lime.

The data on performance of these walls are given in table 4 (wall 83–A13, 84–A15, 85–A14, 86–A16). The penetration of moisture through these walls was usually first indicated by a damp spot near the upper and inner corner of each pilaster. Although water penetrated under the wall and stood in a pool on the supporting channel, leakage from the flashings was less than 1 liter per hour. As the water leaking through the facing appeared to run down the back of the wall between the brick and the parging, it was difficult to determine how much, if any, water had penetrated the parging. Considering their thickness, the performance of these walls was exceptionally good, and about equal to the performance of the 8-inch walls of similar brick and workmanship. The absence of headers in these walls (except at the pilasters) might have been responsible for their good performance. The rating *E* of wall 84–A15 in the capillarity test indicates that the waterproofing in mortar 1w might have been more effective in the high-cement low-lime mortar than in mortar 4, which contained more lime.

8. Effect of a Stone Belt Course

Two 12-inch brick walls of workmanship *A* were built with a limestone belt course embedded in the two facing wythes. The courses were of Indiana limestone that had been stored outdoors for several years. The stones were thoroughly cleaned and scrubbed with sand and water before using in order to remove stains and organic materials from the surfaces. The courses (30 in. long, 9 in. deep, and 7 in. thick at the face edge, increasing to 7.5 in. at the back) were set on the fifth stretcher course with the faces projecting 1 inch from the face of the wall and were provided with a drip under the face edge. Three courses of half stretchers were placed at each end of the belt course with full mortar joints around the ends and back of the stone. The stretchers in the backing wythe were brought up to level with the top of the stone and covered with a rear header course over the collar joint between the stone and the backing wythe. The walls were of common American bond above the belt course.

Table 12.—*Effect of a stone belt course in a brick masonry wall*

[Heavy-rain tests]

Wall	Designation [1]	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
3–65	aa12A2	8				0	0	0	*E*
79–84	aa12A2–S	3	26			5	0	0	*E–G*
Avg [2]	bb12A2	2.7	29			40	0	0	*G*
8–85	bb12A2–S	1	9			10	0	0	*G*

[1] S at end of designation indicates stone sill.

[2] Average of tests on walls 25–37, 26–A4, 27–A6.

In table 12 the performance of walls with a stone belt course in the heavy-rain test is compared with that of the other brick walls. The walls containing stone belt courses were slightly more permeable than similar walls without belt courses. The first damp spots were usually noted opposite the lower corners of the stones. There was no leakage (measurable flow) from any of these walls.

The use of a belt course with brick backing did not increase greatly the permeability of brick masonry walls of class *A* workmanship.

VIII. EFFECT OF WORKMANSHIP AND MATERIALS IN WALLS CONTAINING HOLLOW MASONRY BUILDING UNITS

1. Walls With Structural Clay Tile Backing

The data on the performance of walls with a facing of brick and a backing of structural clay tile are given in table 4. Most of these walls were not provided with flashings, and, for this reason, rates of leakage were not measured. During the tests of walls without flashings, water sometimes flowed under the walls between the masonry and the supporting channel. The uncertainties resulting from the lack of flashing made difficult the determination of the time elapsing before failure. This difficulty was increased somewhat by the manner of failure of these walls. The amount of water passing through the brick facing seemed to be about the same as for the other walls of the same brick and workmanship, but a larger proportion of this water dropped down through the tile backing than through the backing in the 12-inch brick walls.

The performance of the walls with tile backing was affected more by the quality of the workmanship than by any other factor. The walls of workmanship *B* leaked considerably at the bottom and the cells in the lower courses were partially filled with water. However, on the average the performance of these walls was a little better than for typical 12-inch walls of brick *b* and workmanship *B*. The performances in the capillarity test of the tile walls of workmanships *A* and *E* were somewhat superior on the average to those of the 12-inch walls of brick *b* and workmanship *A*. In the heavy-rain test they were inferior. On account of the small number of specimens and their apparently erratic behavior, the data do not provide a positive indication as to the relative merits of end and side construction tiles.

2. Walls With Backing of Hollow Concrete Units

All of the walls with backing of hollow concrete units were furnished with lower flashings extending under the wall to the first bed joint in the facing wythe. Data on the performance of these walls during the heavy rain tests are given in table 13. It appears that consistent results were not obtained from walls built of the same workmanship and materials, possibly because of differences in the permeability of the facing wythes. For class *A* workmanship the walls with cinder-concrete backing were slightly less permeable than those with stone-concrete backing. The kind of concrete had little effect on the permeability of walls of class *B* workmanship.

Table 13.—*Performance of walls with backing of hollow concrete units*

[Heavy-rain tests]

Wall	Designation	Duration of test	Time to fail, as indicated by— Damp through wall	Time to fail, as indicated by— Leak through facing	Area damp at end of test	Maximum leakage per hour	Rating
		Days	*hr*	*hr*	%	*Liters*	
105–80	bm12A2	1	0.17	0.73	100	6	*P*
106–A3	bm12A2	1	2.3	5.5	30	0.5	*F*
107–A5	bm12A2	1	1.3	20 ±3	35	.01	*F*
Avg	bm12A2	1	1.3	8.7	55	.5	*F*
108–78	bn12A2	1	0.13	0.58	50	.5	*F*
109–93	bn12A2	3	50 ±1	63 ±5	17	.05	*G*
Avg	bn12A2	2	25	32	34	.5	*F*
112–81	bm12B2	1	0.07	0.03	90	93	*VP*
113–79	bn12B2	1	.08	.03	60	159	*VP*

The permeability of walls with backing of hollow units was dependent mostly upon the effectiveness of the brick facing. Since the performances of walls of brick *b* and workmanship *A* were found to be more erratic than those of walls built of bricks *a* or *c*, it follows that the permeability of the walls with hollow unit backings and brick *b* facings may have been influenced by irregularities in the performances of the facings. In general, it was found that the more absorbent the hollow-unit backing, the larger the damp area on the back of the wall. This would seemingly indicate a difference in the type of failure dependent upon the absorption of the backing. Because of the possible erratic behavior of the facings of brick *b*, the absence of flashings on many of the walls which made comparison difficult and the probable difference in the manner of failure of walls with units of high or low absorption, the relatively small differences in the performances of walls with backings of hollow units may not be significant.

Walls 110–A12 and 111–A11 were, respectively, of stone- and cinder-concrete units without brick facings. These walls offered little resistance to penetration of water (see table 4).

3. Stucco Facing on Structural Clay Tile

The walls constructed with two ½-inch facing coats of stucco on a backing of 6-cell 8- by 12- by 12-inch clay tile were the least permeable of all walls containing hollow masonry units. These walls were built with the tile either on end or on side and with plain or waterproofed stucco, either with smooth or rough textural finish. The numbers and structural details of these walls are listed below.

Wall	Kind of tile construction	Kind of stucco [1]	Texture of stucco finish coat
97–1	End	Plain	Smooth.
98–2	do	do	Rough.
99–3	do	Waterproofed	Smooth.
100–4	do	do	Rough.
101–5	Side	Plain	Smooth.
102–6	do	do	Rough.
103–7	do	Waterproofed	Smooth.
104–8	do	do	Rough.

[1] The plain stucco was mixed in the proportion by weight of 1 part of portland cement to 3 parts of dry sand. The waterproofed stucco contained 0.2 percent of ammonium stearate, by weight of cement.

The data on performance of the stucco walls in the heavy-rain tests are given in table 14. At the end of these tests all of the walls were more or less damp at the sides, top, or bottom because of the penetration of moisture through the parging, or under the wall. Dampness from this cause was not considered in determining the time to failure, but it was included in calculating the damp area on the back of the wall. Some of the walls were, therefore, unduly penalized in the calculation of the percentage of dampness at the end of the test.

TABLE 14.—*Performance of walls with stucco facings*

[Heavy-rain tests]

Wall	Construction of walls [a]	Duration of test	Time to fail, as indicated by—		Area damp at end of test	Maximum leakage per hour	Rating
			Damp through wall	Leak through wall			
		Days	*hr*	*hr*	%	*Liters*	
97–1	Eps	4	87 ±5	--------	55	0	*G*
98–2	Epr	3	41 ±4	--------	8	0	*G*
99–3	Ews	14	207 ±5	--------	33	0	*E*
100–4	Ewr	6	64 ±5	--------	33	0	*G*
101–5	Sps	6	108 ±7	--------	17	0	*E*
102–6	Spr	7	132 ±7	--------	25	0	*E*
103–7	Sws	7	142 ±14	--------	10	0	*E*
104–8	Swr	[b] 5.3	---------	--------	17	0	*E*

[a] The designation for all of these walls is sj9A2.
Key for construction symbols:
E=tile set on end.
S=tile set on side.
p=plain stucco.
w=waterproofed stucco.
s=smooth texture on finish coat.
r=rough texture on finish coat.

[b] Test on this wall interrupted by condensation on back of wall after 5.3 days of testing; no moisture penetration through the wall.

There was no great advantage in favor of any of the kinds of stucco or construction used in the walls, as is shown below by the average time for the penetration of moisture.

Type of wall	Damp through the wall—average time
	Days
Stucco (plain)	4.0
Stucco (waterproofed)	5.7
Texture of finish coat (smooth)	5.7
Texture of finish coat (rough)	4.0
Construction (tile on end)	4.2
Construction (tile on side)	5.5

The data show a slight advantage for the waterproofed over the plain stucco and the smooth over the rough finish. Although the data indicated a slightly greater average time for walls of side construction than for those of end construction, the results for the individual walls were not consistent and the least permeable wall (99–3) was of end construction.

The superiority of stucco on tile walls over similar walls faced with *b* brick is probably the result of the greater imperviousness of the stucco facing. In this connection it should be stated that because of their unfamiliarity with the application of stucco, the masons used a great deal of time and care in the application of the stucco coatings.

IX. SURFACE WATERPROOFING TREATMENTS

In order to determine the effectiveness of waterproofing methods for leaky masonry walls in existing structures, several of the walls which leaked in the permeability tests were treated and then retested. As the leakage through the walls usually was through openings in the masonry, most of the walls selected were of workmanship *B*. However, as dampness rapidly penetrated absorptive units, such as brick *c* and the concrete blocks, walls of workmanship *A* containing these units were also treated.

The waterproofing treatments may be divided into three classifications:

1. Raking of the face joints and repointing with mortar.

2. Filling of openings in the face of the wall (especially in the joints) with cement-grout or wax.

3. Painting the wall with colorless solution, oil paint, or cement paint.

Some of the treatments were combinations of 1, 2, and 3 above, and one was a molten-paraffin treatment. Each waterproofing method will be discussed together with a comparison of the performances of the walls in heavy rain tests before and after treatment. An outline of the waterproofing tests that have been made to date is contained in table 15, which gives the wall numbers, designations, treatments, and test ratings.

Table 15.—*Wall treatments and test ratings*

Wall	Designation [1]	Treatment	Rating	
			Before treatment	After treatment
42–A10	bb8B2	Repointed	*VP*	*G*
44–52	bb8B4	do	*VP*	*F*
8–64	aa12B2	do	*P*	*F*
10–48	aa12B4	do	*VP*	*G*
32–50	bb12B2	Repointed (2 tests made after repointing).	*VP*	*P,G*
34–46	bb12B4	do	*VP*	*P,G*
57–37	cc12B2	Repointed	*VP*	*P*
60–44	cc12B4	do	*VP*	*P*
92–13	bd12B2	do	*P*	*G*
40–22	bb8B2	Repointed and paraffin and tung-oil solution.	*VP*	*F*
77–91	bb8B2	Repointed and aluminum-stearate solution.	*VP*	*G*
43–54	bb8B3	do	*VP*	*G*
41–A9	bb8B2	Repointed and linseed-oil solution.	*VP*	*G*
35–62	bb8A1	Paraffin and tung oil solution.	*VP*	*VP*
65–31	cc8A1	do	*F*	*F*
18–17	aa8B1	do	*VP*	*VP*
39–63	bb8B1	do	*VP*	*VP*
69–30	cc8B1	do	*VP*	*VP*
24–A7	bb12A1	do	*E*	*E*
48–A8	cc12A1	do	*G*	*G*
7–16	aa12B1	do	*VP*	*VP*
31–72	bb12B1	do	*VP*	*VP*
56–29	cc12B1	do	*VP*	*VP*
89–12	bf12A2	do	*F*	*G*
91–26	bh12B2	do	*VP*	*P*
35–62	bb8A1	Waxed joints [2]	*VP*	*F,G*
18–17	aa8B1	do.[2]	*VP*	*G*
39–63	bb8B1	do.[2]	*VP*	*F*
69–30	cc8B1	do.[2]	*VP*	*P*
7–16	aa12B1	do.[2]	*VP*	*F*
31–72	bb12B1	do.[2]	*VP*	*F*
19–61	aa8B2	Grouted joints (*X* mixture).	*VP*	*G*
36–53	bb8A2	Grouted joints (flint mortar).	*F*	*F*
37–59	bb8A3	do	*F*	*G*
20–57	aa8B3	Grouted joints (high-early-strength cement mortar).	*VP*	*G*
71–32	cc8B3	do	*VP*	*P*
9–55	aa12B3	do	*P*	*G*
78–39	cc8B2	Proprietary, treatment 1	*VP*	*G*
38–49	bb8A4	Proprietary, treatment 2	*VP*	*G*
34–46	bb12B4–R	Aluminum-stearate solution.	*G*	*E*
32–50	bb12B2–R	Linseed-oil solution	*G*	*G*
41–A9	bb8B2	Repointed and linseed-oil solution.	*VP*	*G*
44–52	bb8B4–R	Molten paraffin	*F*	*G*
42–A10	bb8B2–R	Oil paint	*G*	*E*
110–A12	m8A2	Cement paint	*VP*	*E*
111–A11	n8A2	do	*VP*	*G*
60–44	cc12B4–R	do	*P*	*E*

[1] Letter R after designation indicates wall was repointed and tested before treatment.
[2] Walls treated with paraffin and tung-oil solution before waxing.

1. Repointing of Face Joints

Eliminating comparatively large openings in the walls by repointing of the face joints required more time and labor than any of the other treatments. The old joints were cut out carefully to a depth of ½ inch with the aid of an air hammer and then repointed with the same kind of mortar as was originally used. The new joints were tooled with a rounded bar and packed tightly in place so that the construction of the walls which were originally of workmanship *B* resembled class *D* workmanship. The entire operation required about one man hour per square foot of wall surface. After repointing the walls were wetted daily and kept in a damp location for 1 week. They were tested not less than 3 weeks after repointing. Data pertaining to the performance of the repointed walls are given in table 16.

Repointing of the face joints was successful in that the permeability of all of the walls was greatly reduced. The performance of the repointed walls was much better than that of walls built with the same kind of brick and workmanship *D*. The treatment was most effective on walls 8–64 and 10–48 built with the low-absorptive brick *a* and least effective on walls 57–37 and 60–44 constructed with the high-absorptive brick, *c*. The permeability of the brick *c* walls was not reduced as much because the repointing operation did not affect the absorptive properties of the brick.

The effect of continued exposure of the new face joints was markedly apparent in the tests on walls 32–50 and 34–46. These walls were tested twice after repointing and both were rated "Poor" and "Good", respectively, on the first and second tests. The performance of repointed walls was better in the second than in the first test. The 8-inch walls of brick *b* gave creditable performance on their first test after being repointed.

The application of two coats of aluminum stearate solution to walls 77–91 and 43–54 after repointing, slightly reduced the permeability of these walls. The effect can be seen by comparing these walls with the averages for walls 42–A10, 40–22, and 44–52. The proportion by weight of the aluminum stearate solution was 4 percent of aluminum stearate to 96 percent of mineral spirits. The addition of a small amount of paraffin to the solution applied to wall 77–91 made little difference in the performance of the wall.

2. Paraffin and Tung-Oil Solution

Experiments in the waterproofing of natural building stone [2] have shown that the applica-

[2] D. W. Kessler, *Experiments on exterior waterproofing material for masonry*, J. Research NBS **14**, 317 (1935), RP771. For sale by Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., price, 5 cents.

tion of a solution of paraffin and tung oil in a volatile solvent greatly reduced the effects of capillary attraction with very little discoloration. The solution applied to the masonry walls was mixed in the proportion of 10 percent of paraffin (mp 55° C) 5 percent of tung oil (Thermolyzed) and 85 percent of mineral spirits by weight. The solvent dissolved this amount of paraffin at temperatures above 75° F.

TABLE 16.—*Performance of walls before and after repointing the face joints*

[The data in the first line for each wall pertain to test made before treatment]

Wall	Designation	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
42-A10	bb8B2	1	0.02	0.02	0.02	100	17	34	*VP*
		1	7.8 ±.5	--------	--------	22	0	0	*G*
40-22	bb8B2 [a]	0.2	0.05	.05	.13	100	15	36	*VP*
		1	5.7	--------	--------	57	0	0	*F*
44-52	bb8B4	1	0.01	.01	.03	100	38	21	*VP*
		1	.50	9 ± 1	12	75	0.5	0.3	*F*
Avg	bb8B-	1	0.03	0.03	0.06	100	23	30	*VP*
		1	4.7	--------	--------	51	0	0	*F*
8-64	aa12B2	1	2.2	--------	0.03	35	0	14	*P*
		1	19 ±3	--------	10.3	8	0	0.3	*F*
10-48	aa12B4	1	0.17	--------	0.05	10	0	16	*VP*
		2	41 ±6	--------	--------	3	0	0	*G*
Avg	aa12B-	1	1.2	--------	0.04	22	0	15	*P*
		1.5	30	--------	--------	15	0	0	*G*
32-50	bb12B2	1	0.10	0.13	0.05	100	0.5	36	*VP*
		1	2.2	13 ±5	.67	43	.5	2	*P*
		[b] 1	13.1 ±.1	--------	18 ±3	10	0	0.1	*G*
34-46	bb12B4	1	0.12	0.12	0.02	100	--------	38	*VP*
		1	3	13 ±5	1.5	55	.5	2.0	*P*
		[b] 1	17.2 ±.3	--------	--------	1	0	0	*G*
Avg	bb12B-	1	0.10	1.5	0.03	100	--------	37	*VP*
		1	2.6	13	1.1	49	0.5	2	*P*
		[b] 1	15	--------	--------	6	0	0	*G*
57-37	ce12B2	1	0.20	0.82	0.13	95	1	100	*VP*
		1	8 ±1	--------	2.6 ±.4	40	0	3	*P*
60-44	ce12B4	1	0.27	4.5	0.23	70	.2	70	*VP*
		1	3.5	--------	2	35	0	3	*P*
Avg	ce12B-	1	0.23	2.6	0.18	82	0.6	85	*VP*
		1	6	--------	2.3	37	0	3	*P*
92-13	bd12B2	1	0.38	--------	0.12	[d] 25	--------	--------	*P*
		4	75 ±2	--------	--------	[d] 45	--------	--------	*G*
77-91	bb8B2 [c]	1	0.03	0.03	.03	100	6	67	*VP*
		2	10 ±2	--------	15 ±4	25	0	0.08	*G*
43-54	bb8B3 [c]	1	0.25	.07	0.05	100	42	44	*VP*
		1	4	--------	--------	18	0	0	*G*
Avg	bb8B- [c]	1	0.03	0.05	0.05	100	24	55	*VP*
		1.5	7	--------	--------	16	0	0	*G*

[a] Two coats of paraffin and tung-oil solution applied after repointing.
[b] Second test on repointed wall.
[c] Two coats of aluminum-stearate solution applied after repointing.
[d] Not flashed.

The walls were in a dry condition before the application of two coats of the solution on consecutive days. The liquid was applied liberally with a brush until the surface was wetted and the solution was no longer absorbed quickly. The high-absorptive brick *c* walls were not saturated, but the liquid was applied until the joints were wet. The walls absorbed about one-half as much of the solution on the second application as on the first. The approximate covering capacity of the solution for the different brick surfaces is given below.

Covering capacity of paraffin and tung-oil solution (square feet per gallon)		
Brick	One coat	Two coats
a	123	85
b	36	21
c	12	9

After the application of the solution, the walls were stored for at least 2 weeks before testing to permit the volatile spirits to evaporate and the tung oil to oxidize. Data on the performances of the walls before and after treatment with paraffin and tung-oil solution are given in table 17.

The application of a tung-oil and paraffin solution had little, if any, effect on the permeability of walls that leaked badly. The solution was somewhat effective when used on walls that had been penetrated by moisture through capillarity. All of the walls (both treated and untreated) gradually became less permeable as the number of tests increased and it is difficult to determine how much of the improvement noted for some walls in table 17 can be credited to the use of the paraffin and tung oil.

The application of the waterproofing to brick *c* and workmanship *A* (walls 65–31 and 48–A8) was beneficial, but it did not improve the rating of these walls. It is possible that if the brick had been saturated, or if more tung oil had been added to give the solution greater "body" the treatment would have been more effective.

TABLE 17.—*Performance of walls before and after treatment with paraffin and tung-oil solution*

[The data in the first line for each wall pertain to test made before treatment]

Wall	Designation	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
		Days	*hr*	*hr*	*hr*	*%*	*Liters*	*Liters*	
35–62	bb8A1	1	0.01	0.01	0.25	100	20	0.4	*VP*
		1	.05	.40	.52	100	4	.4	*VP*
65–31	cc8A1	1	.47	15 ±6	----------	100	0.9	0	*F*
		1	3.6	14 ±6	----------	81	.03	0	*F*
18–17	aa8B1	1	0.03	0.03	.08	85	11	9	*VP*
		1	.13	.13	.20	53	13	4	*VP*
39–63	bb8B1	1	.02	.05	.03	100	1	120	*VP*
		1	.93	.13	.02	100	2	78	*VP*
69–30	cc8B1	0.1	.10	.12	.15	100	11	77	*VP*
		1	.27	.38	.50	100	11	40	*VP*
24–A7	bb12A1	7	42 ±4	----------	----------	5	0	0	*E*
		7	----------	----------	----------	0	0	0	*E*
48–A8	cc12A1	1	9 ±2	----------	----------	16	0	0	*G*
		2	18 ±5	----------	----------	[a] 44	0	0	*G*
7–16	aa12B1	1	0.10	0.10	0.15	65	18	10	*VP*
		1	.36	1	1	53	13	1	*VP*
31–72	bb12B1	1	.03	0.07	0.02	75	0.3	158	*VP*
		0.3	.53	4	.10	[b] 50	.1	46	*VP*
56–29	cc12B1	1	.17	0.33	.13	100	.5	40	*VP*
		1	1.4	15 ±4	2.2	76	.3	43	*VP*
89–12 [c]	bf12A2	1	0.50	0.75	4	25	----------	----------	*F*
		1	5.5	----------	----------	20	----------	----------	*G*
91–26 [c]	bh12B1	1	0.22	.22	0.07	50	----------	----------	*VP*
		1	5.5	----------	.67	55	----------	----------	*P*

[a] 11 percent damp at end of first day. [b] 50 percent damp in 0.3 day. [c] Not flashed.

3. Joint Filling

The time and labor required to repoint the face joints of a wall made it desirable to investigate the effects of filling the openings in joints that were otherwise structurally sound. Two kinds of filling materials were used, a wax, and finely divided cementitious mixtures. The tests on walls containing wax as a filler are described and referred to as tests on waxed joints; those containing cementitious mixtures, as grouted joints.

(a) *Waxed Joints*

The wax used on the walls was made by mixing equal parts by weight of paraffin and tung oil. It was applied to some of those walls that had been treated with the paraffin and tung-oil solution. After applying the wax with the finger tips the joints were wiped gently with a cloth in order to pack the wax in place and to remove the excess. The joints were made lighter in color and they were accentuated in jagged lines as though snow or ice was encrusted upon them, presenting a markedly altered appearance. The average amount of wax used was about 4.5 pounds per 100 square feet of wall surface. Data pertaining to the results of tests on walls with waxed joints are given in table 18.

TABLE 18.—*Performance of walls before and after joint treatment*

[The data in the first line for each wall pertain to test made before treatment]

Wall	Designation	Duration of test	Time to fail, as indicated by—		Leak through facing	Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall			Through wall	Through facing	
	Walls With Waxed Joints								
	[Walls treated with paraffin and tung-oil solution and tested before waxing]								
		Days	*hr*	*hr*	*hr*	*%*	*Liters*	*Liters*	
35–62	bb8A1	1	0.05	0.40	0.52	100	4	0.4	*VP*
		1	3	----	----	56	0	0	*F*
		[a] 1	12 ±1	----	----	10	0	0	*G*
18–17	aa8B1	1	0.13	.13	.20	53	13	4	*VP*
		2	24	----	----	7	0	0	*G*
39–63	bb8B1	1	0.03	.13	.02	100	2	78	*VP*
		1	3.5	----	2	78	0	0.6	*F*
69–30	cc8B1	1	0.27	.37	0.50	100	11	40	*VP*
		1	2.1 ±.1	----	10.7 ±1.7	67	0	1.4	*P*
7–16	aa12B1	1	0.35	1	1	53	13	1	*VP*
		1	4.4 ±.1	8.6 ±.9	7.5 ±.5	33	0.9	0.5	*F*
31–72	bb12B1	0.3	0.53	4	0.10	50	.1	46	*VP*
		1	7 ±.7	----	15	18	0	0.3	*F*
	Walls With Grouted Joints								
19–61 [b]	aa8B2	1	0.05	0.32	0.03	80	0.5	20	*VP*
		2	27 ±1	----	----	40	0	0	*G*
36–53 [c]	bb8A2	1	0.02	.08	----	100	.9	0	*F*
		1	3.4	----	----	52	0	0	*F*
37–59 [c]	bb8A3	1	0.02	.05	4.5	100	.7	.1	*F*
		1	4	----	----	35	0	0	*G*
20–57 [d]	aa8B3	1	0.10	.01	0.03	95	.8	19	*VP*
		3	40 ±6	----	----	[e] 100	0	0	*G*
71–32 [d]	cc8B3	0.1	0.15	.22	.28	100	12	17	*VP*
		1	.83	----	2	100	0	2	*P*
9–55 [d]	aa12B3	1	1	15±6	0.07	70	.5	14	*P*
		4	91 ±3	----	----	21	0	0	*G*

[a] Wall was repainted with 2 coats of paraffin and tung-oil solution after completion of test on waxed joints.
[b] Joints filled with mixture *X* by representatives of a contracting company.
[c] Joints filled with grout of cement and flint.
[d] Joints filled with grout of high-early-strength cement, flint, and sand.
[e] Some dampness probably caused by condensation.

The performance of the walls was improved by waxing the joints, the average rating being increased two grades from *VP* to *F*. Wall 69–30, built of the high-absorptive brick *c* was benefited less than walls built of brick *a* or *b*. The openings in the joints of wall 35–62, workmanship *A*, were closed by waxing, which changed the rating from *VP* to *F*. This wall was later treated with an additional coat of paraffin and tung-oil solution and the performance was raised from a rating from *F* to *G*. It appears, therefore, that the best method of applying paraffin and tung oil in the form of both a wax and a solution is to apply the first or second coat of the solution after application of wax to the joints. It is possible that suction of the solution into openings not perfectly sealed by the wax, followed by a brushing over of the wax, makes the wall less permeable.

(*b*) *Grouted Joints*

The cementitious joint filling materials used were a proprietary mixture of unknown composition and two mixtures prepared at the Bureau. The proprietary mixture designated as "*X*" was donated and applied to wall 19–61 by representatives of a contracting company. After wetting the face of the wall, the *X* mixture was mixed with water and vigorously brushed into the joints. The bricks were then cleansed with a damp sponge. The wall was cured by wetting daily for 1 week.

The joints of walls 36–53 and 37–59 were filled with a mortar composed of equal parts by weight of portland cement and powdered flint. The material later used on walls 20–57, 71–32, and 9–55 was mixed in the following proportions by weight: 40 percent of high-early-strength cement;[3] 15 percent of powdered flint, 96 percent passing a No. 200 sieve; and 45 percent of Potomac River building sand, passing a No. 30 sieve.

These materials were applied to the walls in much the same manner as in the application of the *X* mixture to wall 19–61. Water was added to the mixtures until they reached a thick creamy consistency. After wetting the wall surface, the mortar was applied to the joints with a typewriter cleaning brush. The weight of dry material required for 100 square feet of wall surface was about 5 pounds for the flint mortar (tooled joints, workmanship *A*) and 10.5 pounds for the high-early-strength cement, flint, and sand mortar (cut joints, workmanship *B*). The difference was largely a result of the rough texture of the joints in workmanship *B*. An average of 2 hours' time was required to apply the joint filling to a wall of workmanship *B* having an area of 13.5 square feet. The results of tests on walls with grouted joints are also given in table 18.

The grouting of the joints greatly reduced the permeability of the walls. The treatments given walls 19–61, 20–57, and 9–55 were exceptionally effective. The data in tables 16, 18, and 19 showed clearly that repointing or filling of the joints with wax or grout stopped large leaks, but did not prevent the penetration of moisture through walls of high-absorptive brick.

4. Special Proprietary Treatments

Representatives of one of the governmental agencies requested a contracting company specializing in waterproofing treatments to apply their treatments to two of the walls. Wall 78–39 (cc8B2) was given treatment 1 by representatives of the contracting company as follows: After testing the face joints of the wall with a sounding tool and judging them satisfactory, the joints were filled with mixture *X* as previously described. The next day a solution of 12 fluid ounces of paraffin in 108 fluid ounces of mineral spirits (Varsol) was prepared and applied to the wall. The first coat was applied with a brush. This was followed by a liberal application with a brush and an air blower. The air blast was directed upwards, spreading the liquid over the wall surface and preventing it from running down the face of the wall. The remainder of the solution was then brushed on the wall, and rough spots in the surface were then filled with a small quantity of paraffin and tung-oil wax. This wax was melted in place on the wall with a hot air blast. A block of paraffin wax was then rubbed over the brick and the adhering wax was melted with the hot blast. About 2 ounces of paraffin was applied in this manner and the total amount applied to the wall (area 13.5 ft.^{2}) was about 0.8 pound. Thus, there were three waterproofing operations made on this wall: filling of the joints, the application of a paraffin and tung-oil solution, and finally, the application and melting into place of cold paraffin wax. The appearance of the wall after these operations was not greatly altered although the film of paraffin on the brick could be scratched with the fingernail. The effect of treatment 1 on wall 78–39 was exceptionally good and the results indicate that it is possible to waterproof high-absorptive brick walls 8 inches thick and of class *B* workmanship.

[3] Donated by International Cement Co

TABLE 19.—*Performance of walls before and after treatment with various waterproofing materials*

[The data in the first line for each wall pertain to test made before treatment]

Wall	Designation	Duration of test	Time to fail, as indicated by—			Areadamp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
Special Proprietary Treatment 1									
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
78-39	cc8B2	0.2	0.08	0.18	0.18	100	1	66	*VP*
		2	9 ±1			[a] 26	0	0	G
Special Proprietary Treatment 2									
38-49	bb8A4	1	0.05	0.05	0.38	100	2	0.5	VP
		2	.75			[b] 67	0	0	G
Walls Treated With Aluminum-Stearate Solution									
34-46	[c] bb12B4-R	1	17.2 ±.3			1	0	0	G
		7	158 ±7			1	0	0	E
Walls Treated With Linseed-Oil Solution									
32-50	[c] bb12B2-R	1	13.1 ±.1		18 ±3	10	0	0.1	G
		2	12 ±.6		20	12	0	.1	G
41-A9	[d] bb8B2	1	0.02	0.02	0.08	100	45	11	VP
		1	8 ±1			10	0	0	G
Walls Treated With Molten Paraffin									
44-52	[c] bb8B4-R	1	0.58	9 ±1	12	75	0.5	0.3	F
		1	5.1			10	0	0	G

[a] 12 percent damp first day.
[b] 35 percent damp first day.
[c] Repointed and tested before treatment.
[d] Repointed and painted with 2 coats of linseed-oil solution before testing.

Treatment 2 of the contracting company was applied to wall 38–49 (bb8A4). The wall joints were sounded and judged to be satisfactory. A mixture was then prepared using 5 fluid ounces of molten paraffin, 5 fluid ounces of tung oil, and 70 fluid ounces of mineral spirits. All of this solution was applied to the wall with a brush and a "cold air" blast (air temperature about 80° F). The face of the wall appeared to be saturated. About 7 ounces of wax made of paraffin and tung oil was then rubbed into the joints and melted with a hot air blast. Excess of melted wax was distributed over the brick with a cloth. The wax altered the appearance of the wall considerably, the white paraffin outlining the joints in jagged lines. The results of tests on these treated walls are given in table 19.

Treatment 2 on wall 38–49 was effective in that the rating of the wall was raised from *VP* to *G*. The results are, however, about the same as those obtained on similar walls by either waxing or grouting the joints. Considering the kind of brick and workmanship together with the labor and materials used, this treatment was not as effective as that given to wall 78–39.

5. Aluminum-Stearate Solution

Data relative to the effectiveness of aluminum-stearate solutions are given in table 16 for walls 77–91 and 43–54, and in table 19 for wall 34–46. Walls 77–91 and 43–54 were repointed and treated with aluminum-stearate solutions and the data in table 16 shows that these walls were only slightly less permeable than similar ones which were repointed but not treated with aluminum stearate. Wall 34–46 was pointed and tested (see data in table 15) before treatment with a solution containing 4 percent of aluminum stearate and 96 percent of mineral spirits by weight. The results of the tests (see data in table 19) show that this wall gave a better performance after treatment with the solution than before, but, since repeated tests on repointed walls indicate a progressive decrease in permeability, it is not known how much of the improvement in performance resulted from the aluminum-stearate treatment.

The aluminum-stearate solution has been applied only to walls of low permeability (walls having a rating of *F* or *G*) and the performance of these walls has been improved, but it is not known whether the solution would be effective if applied to leaky walls having ratings of *P* or *VP*.

6. Linseed-Oil Solution

Two repointed walls were treated with linseed-oil solutions. The effects of the linseed-oil treatment alone were determined for one wall, and the combined effects of repointing and the oil treatment were determined on the other. The linseed-oil solution was mixed in the proportion by weight of 20 parts of kettle-bodied linseed oil, 20 parts of turpentine, and 1 part of paint drier. Two coats were applied to each wall, one coat on each of consecutive days. The covering capacity of the solution was 114 square feet per gallon for one coat and 67 square feet per gallon for two coats. The solution dried to a hard gloss, darkening the wall slightly and bringing out the colors of the bricks.

When first exposed in the heavy-rain tests the water ran off the wall in separate streams. After about 3 hours of exposure the face of the wall became wetted, the water ran down in even flowing sheets, and the appearance of the wall was lightened and clouded by a change in the condition of the waterproofing. At the end of the test the face of the wall was covered with a sticky opaque film. After drying, the face of the wall resumed its original color, but the gloss had disappeared from the oil coating. Data pertaining to the results of tests on walls with linseed-oil coatings are given in table 19.

The treating of wall 32–50 with linseed-oil solution did not change the performance of the wall. The results of these tests and those of walls treated by the contracting company indicate that treatment of the brick *b* is of little benefit after the face joints have been made watertight.

The combined repointing and linseed-oil treatment of walls 41–A9 was effective, however. This repointed wall gave a better performance than similar walls of the same brick and workmanship. It is probable that the linseed-oil solution reduced the permeability of the new face joints.

7. Molten Paraffin

Wall 44–52 (bb8B4–R) was coated with molten paraffin. The paraffin was heated and brushed on the face of the wall while at a smoking-hot temperature. The liquid was partly absorbed by the wall surface and cooled as a very thin, almost invisible coating. About 5 pounds of paraffin was applied per 100 square feet of wall surface. Very good results were obtained with the paraffin treatment as is shown by the data given in table 19. There was no leakage through the wall and the amount of damp wall area at the end of 1 day was only 10 percent.

8. Paints.

The effectiveness of one type of oil paint and one kind of cement paint was investigated.

(*a*) *Oil Paint*

An oil paint designed for use on masonry walls was ground and mixed at the Bureau from materials commonly used in paint manufacture. The proportions by weight of the materials used in this paint were as follows:

Pigment (68%)	Liquid (32%)
55% of basic carbonate white lead.	30% of "Thermolyzed" tung oil.
25% of acicular type zinc oxide.	20% of kettle-bodied linseed oil.
10% of titanium oxide	28% of mineral spirits.
10% of magnesium silicate	17% of turpentine, 5% of liquid paint drier.

Two coats of this paint were applied to wall 42–A10 (bb8B2 repointed). Two days were allowed between the application of the first and second coat. The covering capacity of the paint as applied on wall 42–A10 was 320 square feet per gallon for the first coat, 380 square feet per gallon for the second coat, and 170 square feet per gallon for the two coats.

Data on the results of the test given at the top of table 20 indicate that this paint was exceptionally effective. Before painting, dampness penetrated the wall in about 7.8 hours and 22 percent of the area of the back was damp after an exposure of 1 day in the heavy-rain test. After painting, the wall was exposed for 8 days without dampness appearing on the back. When the painted surface was first exposed it appeared to be water repellent, but after 3 days of exposure the face of the wall was wet over nearly the entire surface. At the conclusion of the test the paint dried quickly. It was hard and firm to the touch, but the paint had lost some of its "egg shell" gloss and there was some blistering at a few of the cross joints.

Table 20.—*Performance of walls before and after applying oil and cement paints*

[The data in the first line for each wall pertain to test made before treatment]

Wall	Designation	Duration of test	Time to fail, as indicated by—			Area damp at end of test	Maximum leakage per hour		Rating
			Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
Oil Paint									
		Days	*hr*	*hr*	*hr*	%	*Liters*	*Liters*	
42–A10	[a]bb8B2–R	1	7.8 ±0.5			22	0	0	*G*
		8				0	0	0	*E*
Cement Paint									
110–A12	[b] m8A2	1	0.02	0.02		[c] 100			*VP*
		7	161 ±10			3			*E*
111–A11	[b] n8A2	1	0.05	.05		70			*VP*
		1	2.9			16			*G*
		[d] 1	0.75			28			*G*
60–44	[a] cc12B4–R	1	3.5		2	35	0	3	*P*
		7				0	0	0	*E*

[a] Repointed and tested before treatment.
[b] Not flashed.
[c] 100 percent damp in 0.7 hour.
[d] Second test of painted wall.

Since the water was applied only to the exposed or painted face of the wall, the test is no criterion of the durability of an oil paint on a masonry wall in those cases where moisture penetrates behind the surface through faulty flashings or by other means.

(*b*) *Cement Paint*

The cement paint used on the walls was mixed in the proportion of 40 percent of white portland cement and 60 percent of water by weight. A commercial ammonium stearate was added in amount equal to 0.2 percent by weight of the cement. The wall surface was dampened to reduce the suction and two coats of paint were applied with an interval of 2 days between the application of the first and second coat.

The paint surface was cured by storing the wall in a damp room and wetting daily for 1 week. The covering capacity of the paint on the wall surfaces is given below:

Wall	Designation	Covering capacity					
		Cement (sq ft per sack)			Paint (sq ft per gal)		
		First coat	Second coat	Two coats	First coat	Second coat	Two coats
110–A12	m8A2	1,020	2,670	740	49	124	36
111–A11	n8A2	660	2,470	520	32	119	25
60–44	cc12B4–R	1,030	3,070	770	50	149	37

The rough texture of the cinder concrete block in wall 111–A11 made it necessary to apply nearly 50 percent more paint to this wall than was used on the surface of the stone concrete block (110–A12). Test data showing the results of treating the walls with cement paint are given in table 20.

The cement paint waterproofing was very effective on walls 110–A12 and wall 60–44, both walls being given a rating of excellent after painting. Although the rating of wall 111–A11 was improved from very poor to good, the wall was penetrated by moisture in 6 or 7 hours. It is probable that air holes were present in the paint film despite the fact that more paint was applied to this wall than on the others. A second test was made on wall 111–A11 and the performance, while rated as good, was inferior to that shown in the first test made after painting.

X. SUMMARY

1. Definitions

The definitions of some of the terms used in the conclusions are as follows:

Capillarity test.—Water was applied near the top of the wall in amount sufficient to cover the wall face with a thin unbroken sheet. This test was the first applied to each wall.

Heavy-rain test.—Same as capillarity tests except that face of wall was exposed to an air pressure of 10 pounds per square foot producing a pressure gradient within the wall from face to back.

Light-rain test.—Same as heavy-rain test except that the water was applied to the wall by means of atomizers in amounts equivalent to 0.2 inch per square foot of wall surface per hour.

Class A workmanship.—All interior joints of the wall filled with mortar. Face joints tooled with rounded steel bar.

Class B workmanship.—Workmanship commonly used for contract construction. Interior joints of the wall were open and a minimum amount of mortar was used. Face joints were cut.

2. Conclusions

Most of the new walls given repeated permeability tests of the same kind showed a slight decrease in permeability with successive tests.

With an air pressure of 10 pounds per square foot (heavy-rain test) the average time required for moisture to penetrate the brick walls of workmanship *A* was one-eleventh of that without pressure (capillarity test); for brick walls of workmanship *B*, it was one-sixth. The time for leakage to start was reduced more, averaging only one-twentieth for brick walls of workmanship *B*.

The average time for dampness to penetrate brick walls of workmanship *B* with the light-rain tests was about 50 times as great as in the heavy-rain tests; the time for leakage to start was about 200 times as great. The number of light-rain tests was relatively small and they were made only on the more permeable walls.

Workmanship affected the permeability of the walls more than any other factor. Walls with tooled joints were less permeable than similar wall with cut joints; but the quality of the workmanship inside the walls had a greater influence than the kind of surface finish on the joint.

The effect of wall thickness on the relative permeability of 8- and 12-inch brick walls was such that it usually required more than 50 times as long for moisture to penetrate the thicker walls of workmanship *A*, and six times as long for the penetration of 12-inch walls of workmanship *B*.

The absorptive properties of the brick had a greater effect on the permeability of walls of workmanship *A* than on walls of workmanship *B*. The least permeable walls of workmanship *A* were those built with the low-absorptive brick. The kind of brick had little effect on the permeability of walls of workmanship *B*, but walls of this type built of the high-absorptive brick required a slightly longer period of time before penetration. The low-absorptive brick had a tendency to "float" (settle and slip) during construction of walls, particularly those walls of workmanship *A*. The excessive brick suction between dry high-absorptive brick and the mortar made it difficult to align or level the facing courses.

The permeability of similar walls built with mortars having a high water retentivity (flow after suction ranging from 87 to 109%) was not greatly affected by differences in the relative amounts of cement and lime. Although the workability of all of these mortars were equally acceptable to the masons, walls built with the high-cement, low-lime mortars were slightly less permeable.

The use of a lime of low plasticity producing a mortar with low water retentivity greatly increased the permeability of the walls. This effect was more pronounced when the mortar was used with high-absorptive brick.

A high brick suction resulting from the use of absorptive brick in a dry condition increased the permeability of the walls; in general, the lower the absorption of the bricks at time of laying, the less permeable the masonry.

The use of two-thirds blind headers had little effect on the permeability of the walls.

Walls with a high-absorptive brick backing and a low-absorptive brick facing were less permeable than walls of either all high- or all low-absorptive brick for: Class *A* workmanship in the heavy-rain test and class *B* workmanship in the light-rain test.

Walls with limestone sills or belt courses of workmanship *A* and a backing wythe of brick were only slightly more permeable than walls without limestone sills.

Brick walls 4 inches thick with a ½-inch mortar parging on the back were about equally as permeable as 8-inch brick walls of workmanship *A*.

Walls with a brick facing and a backing of structural clay tile were slightly less permeable than all-brick walls for workmanship *B*. For workmanship *A* the walls with the tile backing were somewhat superior in the capillarity test and inferior in the heavy-rain test to otherwise similar all-brick walls.

Walls of concrete masonry units without brick facings and of class *A* workmanship were very permeable.

Walls with a structural clay tile backing and a stucco facing were less permeable than walls faced with a medium-absorptive brick.

All of the joint treatments such as repointing, grouting, or filling the joints with a paraffin wax were effective in stopping leakage through openings in the face joints.

The application of colorless waterproofings was ineffective in stopping leakage through openings in the joints.

Although joint treatments reduced the leakage through walls of high-absorptive brick, the penetration of moisture through the header brick of walls 8 inches thick, made it necessary to waterproof these brick for satisfactory wall performance.

Molten paraffin, oil paint, and cement paint were effective waterproof coatings.

XI. APPENDIX

Review of Previous Investigations

Although the problem of dampness in masonry walls and the related subjects of efflorescence, bond of mortar with masonry units, and durability of masonry have been discussed by many authors, only a few of these have presented data showing the results of water-penetration tests of masonry panels. In the following review of the literature pertaining to water penetration in masonry, only those publications are cited which describe investigations of the permeability of walls of several different materials and constructions.

1. Tests at Mellon Institute [1]

The investigation included permeability tests of about 300 masonry panels. The panels were erected outdoors under conditions simulating those which exist in actual construction, and were built under careful supervision. The absorption of the brick when immersed flatwise in water to a depth of ⅛ inch for 10 minutes varied from 0.6 to 12.0 percent by weight. More than 20 different mortar mixtures were used, including masonry cement mortars as well as those containing mixtures of cement and lime. After aging, the panels were tested for permeability by spraying water over the exposed faces. Although no results of the permeability tests are tabulated, it was reported that walls one brick in thickness leaked during ½ hour of exposure to the spray. Panels having an air space between the brick facing and the backing did not permit leakage completely through the wall. The papers include a comprehensive discussion of the effects of design, qualities of materials, and workmanship on the permeability of masonry walls.

2. Tests at the National Bureau of Standards

In two investigations at the National Bureau of Standards some of the factors affecting the rate of travel of moisture through brick and mortar and the permeability of masonry were studied. In the first investigation [2] the rates of water penetration through solid brick and mortar, both singly and in combination, were studied. It was found that the penetration of water was much slower in the brick-mortar assemblages than in either of the two materials singly, there being a retardation in the rate as the moisture traveled from one material to the other.

[1] F. O. Anderegg, *Construction of watertight brick masonry*, J. Am. Ceram. Soc. **13**, 351 (1930); F. O. Anderegg, *Watertight brick masonry*, Archt. Record **70**, 201 (1931).

[2] L. A. Palmer, *Water penetration through brick-mortar assembages*. J. Clay Prod. Inst. **1**, 19 (1931).

In the second investigation,[3] permeability tests were made on 240 wallettes of brick masonry 8 inches thick, 4 courses high, and about 17 inches long. Eighty groups of these specimens were made, using 10 different mortars and 5 makes of brick. The two bricks of lowest absorption were laid without wetting. The other three types were used both in the dry condition and after immersion in water.

All joints were filled solidly with mortar. The exteriors of the joints were cut flush with the sides of the wallettes. When the specimens were 3 months old, they were turned to cause the vertical faces, as constructed, to be uppermost and horizontal. They were tested for permeability by confining a pond of water 1 inch deep on the upper surfaces. The number of leaks, their location, the elapsed time before they appeared and the rate of leakage were observed.

The observations indicated that the leakage occurred through the joints rather than through either the solid brick or the mortar. Seventy-three percent of the total number of leaks in the wallettes appeared at the junctures of the vertical and horizontal mortar joints. The time for leakage and the rate of leakage were controlled largely by both the rate of absorption of the brick at the time of laying and the water retentivity of the mortar. In general, specimens built with high-absorptive brick laid dry were more permeable than those constructed with the same brick after wetting. The leakage through specimens of brick containing cracks was considerably greater than that through specimens of other bricks having similar physical properties.

3. Tests of the Louisville Cement Company [4]

Permeability tests were made on about 50 small reservoirs of brick masonry, each six courses high and about 25 inches square on the outside and having walls 8 inches thick. The water absorption by the 24-hour immersion method of the eight makes of brick used ranged between 3.4 and 14.0 percent. Four different cement-lime mortars, one lime mortar, and one masonry cement mortar were used. At least one specimen of each combination of brick and mortar was constructed. The joints in the specimens were slushed full of mortar so that all cross and collar joints were well filled. Face joints on the inside of the tanks were struck and those on the outside were cut flush with the brick surfaces. When 30 days old, the reservoirs were filled with water and observations of leakage were made for 48 hours.

The reservoirs which leaked did so almost immediately, indicating that the water passed through openings rather than through solid portions of the bricks or mortars. Although there was a tendency for the leakage to be greater for the reservoirs built with the more absorptive brick (presumably dry when laid), some of the specimens of highly absorbent brick gave good performance. The kind of mortar used did not affect the permeability of the masonry.

4. Tests of the Alton Brick Company [5]

Small tanks, 21 inches square on the outside, six courses high, and with walls 4 inches thick, were tested for water permeability. Six makes of brick and 9 mortars were used in the construction of about 30 specimens, each representing a combination of 1 kind of brick and mortar. The absorption of the bricks ranged between 2.6 and 10.8 percent by the 48-hour cold-water immersion test. All bricks were laid dry except two varieties of dry-press brick used in the construction of two tanks. The bed joints were furrowed and the cross joints were completely filled by slushing. The joints on the inner surfaces of the tanks were tooled, while those on the outside were cut flush. After the tanks had aged for 1 month they were tested by filling with water.

The performance of the tanks during the tests was rated according to the number and approximate size of the leaks. The leaks were through openings in the joints and not through the bricks or solid mortar. The permeability of the tanks was found to be dependent upon the absorptive properties of the bricks, irrespective of the kind of mortar used. Specimens containing dry-press brick laid wet gave better performance than similar ones of the same brick in which the brick were laid dry. The kind of mortar used did not affect the permeability of the specimens. The paper includes an excellent digest of the literature on the factors affecting the permeability of brick masonry and includes a bibliography.

5. Tests of the Portland Cement Association [6]

Walls 32 inches wide by 48 inches high were constructed and tested under conditions simulating wind-driven rains. The 45 specimens contained various types of concrete masonry units and mortars. They were tested in a vertical position by exposing them to a wind of 25.3 miles per hour and a water spray equivalent to a rain intensity of 2½ to 3 inches per square foot of wall surface per hour during the first 12 hours of the test, after which the intensity was increased to a rate of 12 to 14 inches per square foot per hour. The performance of the specimens during exposure was judged by visual examinations supplemented by electrical resistance measurements.

Leakage in the base walls of concrete units took place through the mortar, through the joints between mortar and masonry unit, and through the concrete of the masonry units. The penetration through the face shells was caused largely by the dynamic action of the wind and rain, while that through the interior and back was by capillary absorption. The initial penetration of the face shells usually occurred in 5 minutes or less and proceeded with such rapidity that pools of water soon formed in the cores at the base. Dampness on

[3] L. A. Palmer and D. A. Parsons, *Permeability tests of 8-in. brick wallettes*, Proc. Am. Soc. Testing Materials **34**, pt. II, 419 (1934).

[4] J. H. Mallon, *Leaky brick walls*, Archt. Record **72**, 412 (1932).

[5] *Impervious brick masonry*, Pamphlet, Alton Brick Co., St. Louis, Mo. (1933).

[6] R. E. Copeland, C. C. Carlson, *Tests of the resistance of concrete masonry walls to the penetration of rain*, Proc. Am. Concrete Inst. **32**, 485 (1936).

the back face was noted in from 10 minutes to 1 hour. Usually the leaks occurred first at the joints, but these were followed closely by dampness on the shells, especially with the more porous concretes.

After the walls had been tested for permeability, some were given a facing treatment of either portland-cement paint or stucco. The paint consisted of a mixture of white portland cement, a small amount of water repellent, and water. The paint was applied by means of stiff brushes except for one wall which was given spray coatings. None of the 8-inch walls which had been given two brush coats of cement paint showed leakage through the back face. The minimum time for initial penetration of the face shell for these was 2 hours and 45 minutes and usually 4 hours or longer was required. The wall with two coats of sprayed-on paint developed face-shell penetration in 25 minutes and showed dampness on the back face at 45 minutes. One wall with three coats of portland cement stucco showed no sign of face-shell penetration after 219 hours of continuous testing.

WASHINGTON, July 12, 1938.

The *National Bureau of Standards* was established by act of Congress, approved March 3, 1901, continuing the duties of the old Office of Standard Weights and Measures of the United States Coast and Geodetic Survey. In addition, new scientific functions were assigned to the new Bureau. Originally under the Treasury Department, the Bureau was transferred in 1903 to the Department of Commerce and Labor (now the United States Department of Commerce). It is charged with the development, construction, custody, and maintenance of reference and working standards, and their intercomparison, improvement, and application in science, engineering, industry, and commerce.

SUBJECTS OF BUREAU ACTIVITIES

Electricity
- Resistance Measurements
- Inductance and Capacitance
- Electrical Instruments
- Magnetic Measurements
- Photometry
- Radio
- Underground Corrosion
- Electrochemistry
- Telephone Standards

Weights and Measures
- Length
- Mass
- Time
- Capacity and Density
- Gas Measuring Instruments
- Thermal Expansivity, Dental Materials, and Identification
- Weights and Measures Laws and Administration
- Large-Capacity Scale Testing
- Limit Gages

Heat and Power
- Thermometry
- Pyrometry
- Heat Measurements
- Heat Transfer
- Cryogenics
- Fire Resistance
- Automotive Power Plants
- Lubrication and Liquid Fuels

Optics
- Spectroscopy
- Polarimetry
- Colorimetry and Spectrophotometry
- Optical Instruments
- Radiometry
- Atomic Physics, Radium, and X-Rays
- Photographic Technology
- Interferometry

Chemistry
- Paints, Varnishes, and Bituminous Materials

Chemistry—Continued.
- Detergents, Cements, Corrosion, Etc.
- Organic Chemistry
- Metal and Ore Analysis, and Standard Samples
- Reagents and Platinum Metals
- Electrochemistry (Plating)
- Gas Chemistry
- Physical Chemistry
- Thermochemistry and Constitution of Petroleum

Mechanics and Sound
- Engineering Instruments and Mechanical Appliances
- Sound
- Aeronautic Instruments
- Aerodynamics
- Engineering Mechanics
- Hydraulics

Organic and Fibrous Materials
- Rubber
- Textiles
- Paper
- Leather
- Testing and Specifications
- Fiber Structure
- Organic Plastics

Metallurgy
- Optical Metallurgy
- Thermal Metallurgy
- Mechanical Metallurgy
- Chemical Metallurgy
- Experimental Foundry

Clay and Silicate Products
- Whiteware
- Glass
- Refractories
- Enameled Metals
- Heavy Clay Products
- Cement and Concreting Materials
- Masonry Construction
- Lime and Gypsum
- Stone

Simplified Practice
- Wood, Textiles, and Paper
- Metal Products and Construction Materials
- Containers and Miscellaneous Products
- Materials-Handling Equipment and Ceramics

Trade Standards
- Wood, Wood Products, Paper, Leather, and Rubber
- Metal Products
- Textiles
- Apparel
- Petroleum, Chemical, and Miscellaneous Products

Codes and Specifications
- Safety Codes
- Building Codes
- Building Practice and Specifications
- Producer Contacts and Certification
- Consumer Contacts and Labeling

Office
- Finance
- Personnel
- Purchase and Stores
- Property and Transportation
- Mail and Files
- Library
- Information

Shops
- Instrument
- Woodworking
- Glassblowing
- Construction Stores and Tool Room

Operation of Plant
- Power Plant
- Electrical
- Piping
- Grounds
- Construction
- Guard
- Janitorial