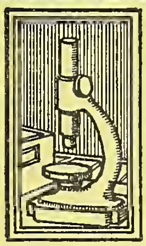
U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS76

Effect of Outdoor Exposure on the Water Permeability of Masonry Walls

by CYRUS C. FISHBURN,
DOUGLAS E. PARSONS,
and PERRY H. PETERSEN



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The Forest Products Laboratory of the Forest Service is cooperating with both committees on investigations of wood constructions.

[For list of BMS publications and directions for purchasing, see cover page III]

UNITED STATES DEPARTMENT OF COMMERCE · Jesse H. Jones, Secretary

NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

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by CYRUS C. FISHBURN, DOUGLAS E. PARSONS, *and* PERRY H. PETERSEN

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Foreword

Previous reports describe investigations of the factors affecting the water permeability of small masonry walls when first constructed and the effects of exposures in a dry condition to extremes of temperature and to wetting and drying at temperatures above freezing. This report gives data on the permeability of walls both before and after their exposure outdoors for three years at Washington, D. C. The weathering exposure was found to have had no great effect on the permeability of masonry walls of adequate thickness built of durable materials. The permeability of a few specimens, visibly damaged by the exposure, was found to have increased.

Lyman J. Briggs, *Director.*

Effect of Outdoor Exposure on the Water Permeability of Masonry Walls

By Cyrus C. Fishburn, Douglas E. Parsons, and Perry H. Petersen

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ABSTRACT

The water permeabilities of about 100 small masonry-wall specimens were measured before and after exposing them to the weather at Washington, D. C., for a maximum period of 3 years. Some of the more permeable walls had been waterproofed before exposure, and the durability of the waterproofing treatments, as well as the structural appearance or condition of the walls, was also determined.

The exposure did not have an important effect on the permeability of all-brick or brick-faced walls 8 in. or more in thickness. The permeability of stucco-faced walls was slightly increased. Repointing of the face joints was the most effective and durable of the waterproofing treatments.

I. INTRODUCTION

Although masonry building walls afford excellent protection from the weather and serve well the purpose for which they were built, they may occasionally be penetrated by wind-driven rains. In such cases it is sometimes difficult, by examination of the structure or of the walls, to determine whether the leakage of water is through openings originally present at the time of construction or through cracks developed during the life of the structure. It has been thought that differential movements between the masonry units and the mortar, caused by temperature fluctuations, changes of moisture content, or by freezing of contained water, may produce cracks and subsequent leakage. The effects of such weathering agents may be determined by measuring the change in the permeability of masonry-wall specimens that have been subjected to exposure.

Previous investigations were made on small masonry-wall specimens at the National Bureau of Standards to determine the effects on permeability of bathing dry walls in alternately hot and cold air,[1] and of alternately wetting and drying walls at temperatures above freezing.[2] This paper reports the effects of outdoor exposure on the water permeability of small masonry walls. Some of the specimens were waterproofed before the outdoor exposure, and the effects of weathering on the durability of these waterproofing treatments were determined.

II. THE WALL SPECIMENS

The 101 masonry walls were about 40 in. long and 50 in. high, and they included the 19 specimens described in BMS41 and BMS55. The walls were faced at the ends and top with a mortar parging ⅜ to ½ in. thick, which was applied to seal these areas so that a pressure gradient could be maintained within the masonry when pressure was applied to one face. A description of the materials and of the method or types of workmanship used in the construction of the walls is given in a previous publication [3] of the National Bureau of Standards. That report also contains data obtained from permeability tests made before the walls were placed outdoors. In this report only a brief description is given of the materials and methods of constructing the walls.

[1] C. C. Fishburn and P. Petersen, Effect of Heating and Cooling on the Permeability of Masonry Walls, Building Materials and Structures Report BMS41.

[2] C. C. Fishburn, Effect of Wetting and Drying on the Permeability of Masonry Walls, Building Materials and Structures Report BMS55.

[3] C. C. Fishburn, D. Watstein, D. E. Parsons, Water Permeability of Masonry Walls, Building Materials and Structures Report BMS7.

1. Materials Used in the Walls

The letters and numbers assigned the different masonry materials are given in the second columns of tables 3 and 4 and are the same as those assigned in BMS7.

Brick.—Brick *a* was a low-absorptive, side-cut, fire-clay brick having an average absorption during a 24-hour cold-water immersion of 0.4 percent by weight. Brick *b* was a side-cut shale brick having an absorption of about 8 percent. Brick *c* was a dry-press brick with an absorption of about 17 percent. The brick *c* were selected as underburned and contained a large percentage of salmon brick.

Stucco.—The stucco facings were mixed in the weight proportions of 1 part of portland cement to 3 parts of building sand. The stucco applied to the facings of four of the eight walls contained ammonium stearate in amount equal to 0.1 percent of the cement.

Hollow Units.—Structural clay tile *d*, double-shell, 8 by 12 by 10½ in., was a 6-cell end-bearing stretcher with bonding units. Tile *f*, Speed-a-backer, 8 by 8 by 12 in., was a side-construction stretcher or bonding unit. Tile *g*, Raritile, 8 by 12 by 8 in., was a 4-cell end-bearing stretcher with bonding units. Tile *h*, Techwood, 8 by 12 by 10 in., was a 6-cell end-bearing stretcher with bonding units.

Block *m*, 8 by 12 by 8 in., was a 2-cell stone-concrete block. Block *n* was a similar unit made with cinder concrete.

Mortars.—The proportions and the physical properties of the mortars are given in table 1.

TABLE 1.—*Physical properties of the mortars*

Properties of the mortars	Mortar numbers and proportions				
	1	2	3	4 [a]	5 [b]
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	1.0:0.85:7.7	1:0.42:5.1	1:0.42:5.1.
Average water content, percentage by weight of dry materials	19.3	22.6	23.7	22.7	19.8.
Water retentivity.[d] Initial flow 110 percent	77	86	88	86	30.
Compressive strength in 28 days, lb/in.^{2} [e]	2,850	640	250	530	950.
Tensile strength in 28 days, lb/in.^{2} [f]	310	130	50		155.

[a] Mortar 4 contained 0.2 percent of ammonium stearate by weight of cement plus dry hydrated lime in the putty.
[b] Mortar 5 contained a hydrated lime of low plasticity, which was added to the mortar in the dry state; all other mortars contained a 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] Percentage of flow after suction to that of initial flow of 110 percent. Federal Specification SS-C-181a.
[e] Cured according to Federal Specification SS-C-181.
[f] Cured in damp air at 70° F.

Mortar *1w*, not listed in table 1, was used only in wall A16, and it was similar to mortar 1 except that it contained 0.2 percent of ammonium stearate by weight of portland cement plus lime.

2. Workmanship Used in the Walls

The wall constructions differed in the method of applying mortar to the units, in the amount of mortar placed in the interior of the wall joints, and in the treatment of the face joints. Nearly all of the walls were built of either workmanship *A* or *B*. In class *A* workmanship, all of the joints were solidly filled with mortar. The face joints were tooled. Workmanship *B* was similar to much commercial workmanship in that the collar joints and the interior of the head joints were not filled. The face joints were cut flush with the faces of the brick. Workmanship *C* was similar to workmanship *A* except that the facing joints were cut without subsequent tooling. Workmanship *D* was the same as class *B* except that the joints in the exposed face were tooled to form a concave surface, as in class *A* workmanship.

Most of the walls contained copper flashings so placed as to collect leakage passing through the wall or dropping between the wythes. During the tests on walls without flashings, it could not be determined if moisture appearing on the supporting channels at the back of the walls had penetrated the wall facing or had leaked through the bed joints between the walls and the supporting channels.

3. Walls With Waterproofed Faces

Thirty-three wall specimens, listed in table 4, were waterproofed on the exposed faces and tested for permeability before being placed outdoors. The waterproofing treatments and their immediate effects on the permeability of the walls are described in report BMS7.

Ten walls were treated with a solution containing 10 percent of paraffin and 5 percent of tung oil, by weight, in mineral spirits. The joints of six of these walls were then coated with a wax containing equal parts, by weight, of paraffin and tung oil. One wall, No. 37, was treated with a paraffin and tung-oil solution applied after the face joints were repointed. This solution contained 10 percent of paraffin and 10 percent of tung oil in mineral spirits. The total amount applied on this wall in two treatments was equivalent to about 22 sq. ft. of wall per gallon of solution.

The face joints of 12 walls were repointed with the same kind of mortar which was used in the original construction. The repointed joints were tooled with a rounded bar. The faces of 10 of these walls were treated with additional waterproofing materials, applied after the repointing operation. These additional waterproofings included aluminum-stearate solutions, a linseed-oil solution, melted paraffin, and both oil and cement-water paints.

The joints in the faces of four walls were treated with portland cement grouts applied with a brush.

One wall was painted with an oil paint mixed at the Bureau and designed for use on masonry walls (see p. 30 of BMS7). Three walls were painted with cement-water paints, and five were waterproofed with proprietary compounds. The treatments with proprietary materials are described in BMS7, with the exception of those applied to walls 88 and 34. Wall 88 was treated by grouting the face joints with a mixture of 60 percent by weight of Rocktite, 10 percent of sand passing No. 30 sieve, and 30 percent of water. This grout was applied in two treatments, the total amount of dry materials used being equivalent to 8.7 lb per 100 sq ft of wall area. The face of wall 34 was brushed with two applications of a grout mixture consisting of 50 percent by weight of Rocktite color coating (white), 8 percent of sand passing No. 30 sieve, and 44 percent of water. The total amount of dry materials used was about 30 lb per 100 sq ft of wall area. The face of this wall crazed within 1 day after making a permeability test of the waterproofing.

4. Walls Without Waterproofings

The plain walls (without waterproofings) included the least permeable of the specimens described in BMS7. This group of walls,

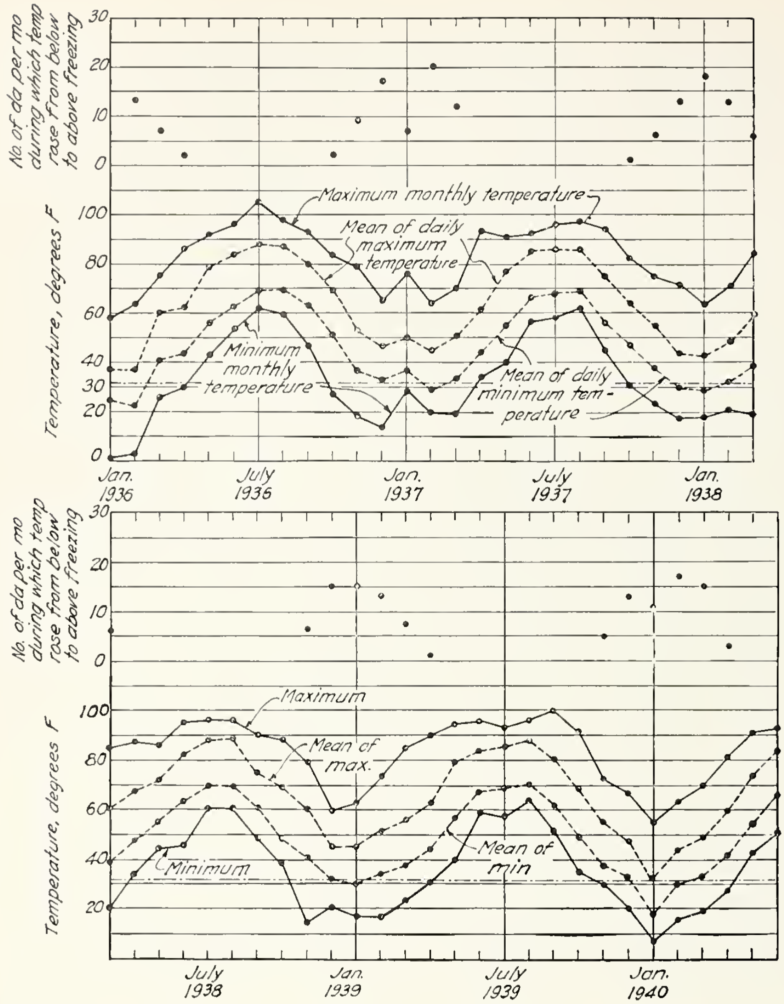

FIGURE 1.—*Temperature record.*

listed in table 3, contained 48 all-brick walls 8 or 12 in. thick, 9 walls faced with brick and backed with hollow units, 8 walls faced with stucco on hollow-unit backings, and 3 brick walls 4 in. thick with a backing of mortar parging.

III. METHOD OF TEST

1. OUTDOOR EXPOSURE

The walls were stored outdoors at Washington, D. C., during the time interval between January 1936 and May 1940. They were tested for permeability after being exposed outdoors for intervals of 1 to 3 years. During the storage periods they were placed end to end in parallel rows spaced 50 in. apart and facing east. The waterproofed walls that gave good performances after being treated, were partially protected from the weather by sheet-metal coverings on the tops, backs, and ends, so that only the treated faces were exposed to wind and rain. The top coverings were adjusted so that rain and snow water dripping from them would run down the exposed, waterproofed faces of the walls. All of the plain walls, without waterproofings, as well as those specimens in which the waterproofing treatments were ineffective, were placed outdoors without coverings.

The maximum and the minimum monthly air temperature and the mean for each month of the daily maximum and of the daily minimum air temperatures are shown in figure 1, for the period between January 1936 and May 1940.[4] It can be seen from figure 1 that the maximum annual air temperature approached or exceeded 100° F and that the minimum annual air temperature averaged about 12° F. The greatest monthly fluctuation in air temperature (about 60° F), occurred during the winter months and the least, during the summer months. The number of times each month that the air temperature fell below and then rose to above freezing is also shown in figure 1. The meteorological data indicated that the air temperature did not rise above freezing more than once in any one day. The monthly precipitation at Washington, D. C., for the period of outdoor exposure of the walls is given in table 2.

TABLE 2.—*Monthly precipitation at Washington, D. C.*

Month	Year					
	1936	1937	1938	1939	1940	Normal
	in.	*in.*	*in.*	*in.*	*in.*	*in.*
January	5.9	7.8	2.6	3.4	2.1	3.6
February	3.8	3.3	2.4	5.7	2.8	3.4
March	4.5	1.5	2.2	2.9	3.4	3.8
April	2.0	6.9	1.7	3.8	6.2	3.3
May	5.3	4.0	3.5	.4	3.1	3.7
June	2.3	5.2	2.3	4.6	.9	4.1
July	4.1	3.7	5.0	2.0	-------	4.7
August	3.6	6.7	4.6	3.2	-------	4.0
September	2.0	1.8	4.3	6.9	-------	3.2
October	1.7	8.8	1.2	4.1	-------	2.8
November	.8	3.9	2.6	1.4	-------	2.4
December	5.2	.7	2.7	2.2	-------	3.3
Total	41.2	54.3	35.1	40.6	-------	42.3

2. Permeability Tests

A full description of the permeability testing apparatus and of the method of test is given in BMS7 (heavy-rain test). The walls were dried to nearly constant weight before the tests were made. Each wall was supported on metal skids and clamped into position so that the exposed face formed one side of a pressure chamber. An air pressure of 10 lb/ft^2 above atmospheric pressure was maintained within the chamber, and water from a perforated tube was applied to the upper portion of the exposed face at the rate of about 40 gal/hr. This air pressure, equivalent to that produced by a head of 2 in. of water, is about the maximum produced by a wind velocity of 50 mph. Permeability tests were made on the wall specimens at the ends of outdoor-exposure periods, and the tests extended for a period having a minimum of 1 to a maximum of 5 days.

The temperature of the water applied to the walls in the earlier tests was not observed, and although the water was warmed in a heater during the winter months, the water temperature may have been below the dew-point temperature of the testing room during some of these tests. Similarly, during some of the earlier tests, the rate of water application was adjusted by eye and may have sometimes exceeded 40 gal (152 liters) per hour, especially for tests made on walls faced with the high-absorptive brick *c*. However, during the later tests, the rate of water application was regulated by means of orifice meters, and the water temperature was maintained above the dew-point temperature of the testing room. During all tests the relative humidity in the testing room was usually between 80 and 90 percent.

3. Observations

The following observations were made during the permeability test:

Time for the appearance of moisture (dampness) on the backs of the walls.

Time for the appearance of visible water on the back of the walls.

Time for leakage to flow from the flashings.

Maximum rate of leakage, if any.

Extent of damp area on the back of the wall after an exposure of 1 day and at the end of the test.

Observations were made at frequent intervals daily. The backs of the walls had been painted with white-wash, and the appearance of moisture (dampness) on the back could be easily detected.

4. The Data

Data obtained from the permeability tests are given in tables 3 and 4. Column 2 in these tables designates the kind of masonry units used in the wall facing and backing, the wall thickness, the type of workmanship, and the kind of mortar. Column 3 indicates the kind of test or kind of waterproofing treatment given

[4] Data obtained from the meteorological summary, Weather Bureau, U. S. Department of Agriculture.

each wall before it was placed outdoors. Beneath these are shown the periods of outdoor exposure that preceded the permeability tests. Data obtained from the permeability tests and an arbitrary rating of wall performance are given in columns 4 to 9.

TABLE 3.—*Permeability of masonry walls exposed outdoors*

[The data in columns 4 to 9 are from permeability tests made before the walls were stored outdoors and after the outdoor exposure periods indicated in column 3]

[E, excellent; G, good; F, fair; P, poor; VP, very poor]

Wall No.	Designation [a]	Period of outdoor exposure, inclusive	Time to failure as indicated by—			Maximum rate of leakage	Area damp in 1 day	Rating
			Damp on back	Visible water	Leak			
1	2	3	4	5	6	7	8	9
		12-INCH BRICK WALLS OF COMMON AMERICAN BOND						
			hr	*hr*	*hr*	*Liters/hr*	*%*	
15	aa12A1	Before exposure				0	0	E
		Jan. 1936 to Feb. 1937				0	0	E
		Apr. 1937 to Apr. 1939				0	0	E
77	aa12A1	Before exposure [b]				0	0	E
		Sept. 1937 to Sept. 1939				0	0	E
65	aa12A2	Before exposure				0	0	E
		May 1936 to May 1937	161			0	0	E
		July 1937 to July 1939				0	0	E
84	aa12A2	Before exposure	26			0	0	G
		July 1936 to Aug. 1937	15 ±6			0	1	G
		Sept. 1937 to Sept. 1939	66 ±3			0	0	E
56	aa12A3	Before exposure	85 ±8			0	0	G
		May 1936 to May 1937	60 ±6			0	0	G
		July 1937 to July 1939	83 ±3			0	0	G
74	aa12A3	Before exposure [b]	39 ±6			0	0	G
		Aug. 1937 to Aug. 1939	66 ±3			0	0	G
42	aa12A4	Before exposure				0	0	E
		May 1936 to May 1937				0	0	E
		Aug. 1937 to Aug. 1939	10 ±2			0	0	E
68	aa12C2	Before exposure	42 ±3			0	0	E
		June 1936 to May 1937	38 ±5			0	0	E
		July 1937 to July 1939				0	0	E
69	aa12D2	Before exposure	4		0. 5	2. 5	25	P
		June 1936 to May 1937	15 ±5		2. 5	1. 0	8	P
		July 1937 to July 1939	19 ±3		1. 7	0. 6	1	F
18	bb12A1	Before exposure	4 ±1		0	0	15	G
		July 1936 to July 1937	0. 6	13 ±7	0	0	45	F
		Aug. 1937 to Aug. 1939	10 ±3	10 ±3	0	0	30	F
A1	bb12A1	Before exposure [b]	33 ±2		12	. 01	0	F
		Sept. 1937 to Sept. 1939	22 ±3			0	1	E
27	bb12A2	Before exposure	1	2	1	(c)	7	P
		Apr. 1936 to Apr. 1937	0. 2	1. 5		0	43	P
		Aug. 1937 to Aug. 1939	. 2	15 ±6		0	15	F
85	bb12A2	Before exposure	9 ±2			0	10	G
		July 1936 to Aug. 1937	9 ±2		1. 5	. 07	20	F
		Sept. 1937 to Sept. 1939	0. 6	14 ±6		0	30	F
A4	bb12A2	Before exposure [b]	31 ±4	42 ±3		0	0	G
		Nov. 1937 to Nov. 1939	18 ±3			0	3	G
73	bb12A3	Before exposure	12. 1			0	15	G
		Sept. 1936 to Sept. 1937	17 ±4			0	4	G
		Oct. 1937 to Oct. 1939	18 ±3			0	3	G
A2	bb12A3	Before exposure [b]	28			0	1	G
		Nov. 1937 to Nov. 1939	39 ±6			0	2	G
45	bb12A4	Before exposure	0. 6	0. 6		0	21	P
		July 1936 to July 1937	2. 3	15 ±6		0	33	F
		Oct. 1937 to Oct. 1939	2. 5	18 ±3		0	23	F
19	bb12B3	Before exposure	0. 03	0. 03	0. 03	23	90	VP
		Mar. 1936 to Aug. 1936 Sept. 1937 to Sept. 1939	. 1	. 13	. 22	17	93	VP
28	cc12A1	Before exposure	6. 5			0	6	G
		Aug. 1936 to Aug. 1937	5			0	8	G
		Oct. 1937 to Oct. 1939	10 ±2			0	3	G
76	cc12A1	Before exposure	1. 1	9 ±1		0	95	F
		Aug. 1936 to Aug. 1937	1. 9		(c)	0	[d] 45	(c)
		Oct. 1937 to Oct. 1939	3. 7	15 ±6		0	40	F
94	cc12A1	Before exposure [b]	14. 5			0	1	G
		Sept. 1937 to Sept. 1939	10 ±2			0	5	G
35	ec12A2	Before exposure	7 ±1			0	20	G
		June 1936 to Aug. 1936	9 ±2			0	18	G
		Oct. 1937 to Oct. 1939	10 ±2		10 ±2	. 20	8	F
66	cc12A2	Before exposure	0. 4	1. 3	2. 3	(c)	100	P
		July 1936 to Aug. 1937	. 7	15 ±6	15 ±6	. 4	100	F
		Oct. 1937 to Oct. 1939	. 8	15 ±6	15 ±6	. 1	85	F
33	ec12A3	Before exposure	8 ±1			0	16	G
		June 1936 to June 1937	0. 07	0. 07	15 ±6	. 1	80	P
		Sept. 1937 to Sept. 1939	. 3	. 7	6. 4	10. 0	90	VP
75	cc12A3	Before exposure [b]	18 ±3			0	10	G
		Dec. 1937 to Dec. 1939	10 ±2	26		0	15	G

See footnote at end of table.

TABLE 3.—*Permeability of masonry walls exposed outdoors*—Continued

Wall No.	Designation	Period of outdoor exposure, inclusive	Time to failure as indicated by—			Maximum rate of leakage	Area damp in 1 day	Rating
			Damp on back	Visible water	Leak			
1	2	3	4	5	6	7	8	9
12-INCH BRICK WALLS OF COMMON AMERICAN BOND								
			hr.	*hr.*	*hr.*	*Liters/hr.*	%	
43	cc12A4	Before exposure	1	([e])	3 ±1	([e])	[d] 60	([c])
		June 1936 to July 1937	2	2.8	15 ±6	0.6	90	P
		Oct. 1937 to Oct. 1939	2.5	4.1	------	0	75	F
A17	cc12A5	Before exposure	0.2	([c])	------	0	80	([c])
		Sept. 1936 to Sept. 1937	.6	15 ±6	------	0	55	F
		Oct. 1937 to Oct. 1939	.9	2.5	------	0	40	P
A19	cc12A5	Before exposure	.4	0.7	15 ±6	.6	95	P
		Sept. 1936 to Sept. 1937	.35	15 ±6	14 ±6	.6	95	F
		Oct. 1937 to Oct. 1939	.5	2.7	6 ±2	.3	85	P
67	cc12B2	Before exposure	.25	0.5	0.07	130	75	VP
		Aug. 1936 to Aug. 1937	.35	2	.2	63	80	VP
		Oct. 1937 to Oct. 1939	.8	1.5	.4	28	75	VP
21	cc12B3	Before exposure	.4	1.8	.6	44	[d] 80	VP
		Apr. 1936 to Apr. 1937	.4	1.2	.8	80	100	VP
		Aug. 1937 to Aug. 1939	.1	0.9	2.3	0.4	80	P
A18	cc12B5	Before exposure	.08	.12	0.08	248	95	VP
		Sept. 1936 to Sept. 1937	.07	.1	.07	234	95	VP
		Oct. 1937 to Oct. 1939	.25	.5	.5	73	85	VP
A20	cc12B5	Before exposure	.05	.1	.1	249	100	VP
		Aug. 1936 to Aug. 1937	.05	.05	.09	283	94	VP
71	cc12C2	Before exposure	.4	([c])	.6	0.4	50	FP
		Sept. 1936 to Sept. 1937	.5	15 ±6	([c])	([c])	[d] 25	FP
		Oct. 1937 to Oct. 1939	1	2.6	------	0	60	P
70	cc12D2	Before exposure	0.25	14 ±6	.13	67	804	VP
		Aug. 1936 to Aug. 1937	1.1	15 ±6	.55	18	70	VP
		Oct. 1937 to Oct. 1939	1.9	13 ±6	.8	12	65	VP
8-INCH BRICK WALLS OF COMMON AMERICAN BOND								
14	aa8A1	Before exposure[e]	111 ±6	------	------	0	0	G
		Aug. 1937 to Aug. 1939	114 ±3	------	------	0	0	E
89	aa8A2	Before exposure	44 ±3	------	------	0	4	G
		July 1936 to July 1937	39 ±6	------	------	0	0	G
		Aug. 1937 to Aug. 1939	75 ±1	------	------	0	2	G
58	aa8A3	Before exposure[e]	18 ±4	------	------	0	48	G
		Oct. 1937 to Oct. 1939	24 ±1	------	------	0	3	G
51	aa8A4	Before exposure[e]	3	------	------	0	12	G
		Aug. 1937 to Aug. 1939	10 ±3	------	------	0	2	G
92	aa8A5	Before exposure	12 ±2	------	------	0	60	F
		July 1936 to Aug. 1937	18 ±3	------	------	0	17	G
		Oct. 1937 to Oct. 1939	18 ±3	------	------	0	10	G
47	aa8B4	Before exposure	0.03	0.03	0.03	25	[d] 9	VP
		Apr. 1936 to Apr. 1937	4.5	------	.02	19	20	VP
		May 1937 to Apr. 1939	0.30	------	.13	3.2	9	P
90	bb8A2	Before exposure	.03	([c])	------	0	90	FP
		Aug. 1936 to Aug. 1937	.05	14 ±6	------	0	80	F
		Oct. 1937 to Oct. 1939	.05	0.3	.5	.08	60	P
36	cc8A2	Before exposure	.2	.4	2.2	1.7	100	P
		July 1937 to Sept. 1939	.3	.4	2.5	1.3	100	P
38	cc8A2	Before exposure	.25	.4	1.5	3.2	100	P
		June 1936 to July 1937	.3	.5	1.8	6.6	100	VP
		Aug. 1937 to Aug. 1939	.3	.7	1.4	4.0	96,	P
20	cc8A3	Before exposure	.3	.5	([c])	([c])	[d] 70	P
		May 1936 to May 1937	.2	.3	2.0	1.8	100	P
		July 1937 to July 1939	.3	.4	0.8	0.7	96	P
40	cc8A4	Before exposure	.75	([c])	14 ±7	([c])	100	P
		June 1936 to July 1937	.6	([c])	4 ±2	2.2	100	P
		Aug. 1937 to Aug. 1939	.7	1.9	15 ±5	1.3	100	P
41	cc8B4	Before exposure	.05	0.1	0.1	146	100	VP
		June 1936 to June 1937	.03	.03	.05	157	100	VP
		July 1937 to July 1939	.15	.2	.2	41	100	VP
8-INCH BRICK WALLS OF COMMON AMERICAN BOND								
			hr	*hr*	*hr*	*Liters/hr*	%	
86	ac8A2	Before exposure	85 ±6	------	------	0	0	E
		July 1936 to Aug. 1937	111 ±6	------	------	0	0	G
		Sept. 1937 to Sept. 1939	114 ±4	------	------	0	0	E
87	ac8B2	Before exposure	0.05	0.8	0.3	20	100	VP
		Aug. 1936 to Aug. 1937	.1	16 ±4	1	16	92	VP
		Oct. 1937 to Oct. 1939	.1	0.6	1	10	85	VP

See footnote at end of table.

TABLE 3.—*Permeability of masonry walls exposed outdoors*—Continued

Wall No.	Designation	Period of outdoor exposure, inclusive	Time to failure as indicated by— Damp on back	Visible water	Leak	Maximum rate of leakage	Area damp in 1 day	Rating
1	2	3	4	5	6	7	8	9
		12-INCH BRICK WALLS WITH HOLLOW UNIT BACKINGS						
		Before exposure	0.5		4 ±2	(c)	47	G
82	bg12A2	July 1936 to Aug. 1937	1.5		5.3	0.01	45	G
		Oct. 1937 to Oct. 1939	2.8			0	11	G
		Before exposure	0.2	(c)	0.6	6	100	VP
80	bm12A2	June 1936 to July 1937	.7	15 ±6	5 ±1	0.8	80	F
		Oct. 1937 to Oct. 1939	.08	0.2	2.8	2.5	95	P
A3	bm12A2	Before exposure [b]	3	15 ±6	15 ±6	0.1	20	F
		Sept. 1937 to Sept. 1939	1.8			0	15	G
A5	bm12A2	Before exposure [e]	18 ±4			0	1	E
		Dec. 1937 to Dec. 1939	18 ±4			0	1	G
		Before exposure	0.1	(c)	0.6	(c)	[d] 50	PF
78	bn12A2	June 1936 to July 1937	.1	0.75	5.7	.3	75	P
		Sept. 1937 to Sept. 1939	.6	15 ±6		0	15	F
		Before exposure	50 ±2			0	1	G
93	bn12A2	Aug. 1936 to Aug. 1937	17 ±3	157 ±7		0	1	G
		Nov. 1937 to Nov. 1939	43 ±3			0	0	E
		Before exposure	0.2		0.03	93	85	VP
83	bg12B2	July 1936 to July 1937	.7	15 ±6	.03	72	80	VP
		Oct. 1937 to Oct. 1939	.2	14 ±6	.1	27	70	VP
		Before exposure	.07		.03	93	85	VP
81	bm12B2	July 1936 to July 1937	.1	0.13	.3	71	90	VP
		Sept. 1937 to Sept. 1939	.16	.4	.2	36	85	VP
		Before exposure	.08	.08	.03	159	60	VP
79	bn12B2	June 1936 to July 1937	.05	.1	.09	101	40	VP
		Sept. 1937 to Sept. 1939	.07	.1	.08	36	30	VP
		4-INCH BRICK WALLS WITH PARGED BACKING						
		Before exposure	0.9			0	25	G
A13	ap4A1	July 1936 to Aug. 1937	5.7			0	15	G
		Oct. 1937 to Oct. 1939	0.2	1.1		0	25	P
		Before exposure	.2			0	35	G
A14	cp4A1	July 1936 to Aug. 1937	.3		1.2	.07	25	F
		Sept. 1937 to Sept. 1939	.5			0	70	F
		Before exposure	.4			0	15	G
A16	cp4A1w	July 1936 to Aug. 1937	.3	15 ±6	1.6	.1	90	F
		Oct. 1937 to Oct. 1939	.2	0.4	0.7	.9	85	P
		WALLS WITH STUCCO FACINGS [f]						
		Before exposure	87 ±6				0	G
1	sj9A2 (Eps) [g]	Jan. 1936 to Feb. 1937	23 ±1				4	E
		Mar. 1937 to Mar. 1939	19 ±3				4	G
		Before exposure	41 ±3			0	0	G
2	sj9A2 (Epr) [g]	Before exposure [b]	15 ±6			0	8	G
		Nov. 1937 to Nov. 1939	9 ±2			0	15	G
		Before exposure	207 ±6			0	0	E
3	sj9A2 (Ews) [g]	Before exposure [b]	25				10	G
		Sept. 1937 to Sept. 1939	18 ±3				20	G
		Before exposure	60 ±8				15	G
4	sj9A2 (Ewr) [g]	Jan. 1936 to Feb. 1937	15 ±3				10	G
		Apr. 1937 to Apr. 1939	2.7				30	G
		WALLS WITH STUCCO FACINGS [f]						
5	sj9A2 (Sps) [g]	Before exposure	108 ±7			0	0	E
		Jan. 1936 to Feb. 1937	64 ±6			0	0	E
		Mar. 1937 to Mar. 1939	4.4	10 ±3		(c)	8	F
		Before exposure	132 ±7				0	E
6	sj9A2 (Spr) [g]	Apr. 1936 to Apr. 1937	10 ±3				5	G
		May 1937 to May 1939	2.5				25	G
		Before exposure	132				0	E
7	sj9A2 (Sws) [g]	Before exposure [e]	111 ±6				3	G
		Oct. 1937 to Oct. 1939	58 ±2				0	E
		Before exposure					5	E
8	sj9A2 (Swr) [g]	May 1936 to May 1937	2				10	G
		Aug. 1937 to Aug. 1939	0.5	0.5			33	P

[a] Lower-case letters denote kind of masonry units in facing and backing. First numeral denotes nominal wall thickness in inches. Capital letters denote type of workmanship. Final number denotes kind of mortar.
[b] Tested after having been subjected to heating and cooling, see BMS41.
[c] Not determined.
[d] Duration of test exposure less than 24 hours.
[e] Tested after having been subjected to wetting and drying, see BMS55.
[f] Wall not flashed at bottom.
[g] For stucco-faced walls:
E, end-bearing tile backing.
S, side-bearing tile backing.
p, plain stucco.
w, waterproofed stucco.
s, smooth finish stucco.
r, rough finish stucco.

TABLE 4.—*Permeability of waterproofed masonry walls exposed outdoors*

The data in columns 4 to 9 are from permeability tests made before the walls were waterproofed, after they were waterproofed, and after being stored outdoors, as is indicated in column 3]

[E, excellent; G, good; F, Fair; P, poor; VP, very poor]

Wall No.	Designation [a]	Waterproofing treatment or period of outdoor exposure [b]	Time to failure as indicated by— Damp on back	Visible water	Leak	Maximum rate of leakage	Area damp in 1 day	Rating
1	2	3	4	5	6	7	8	9
WALLS TREATED WITH PARAFFIN (PAR.) AND TUNG OIL SOLUTIONS AND WAXES								
			hr	*hr*	*hr*	*Liters/hr*	%	
A7	bb12A1	Before waterproofing	43 ±3			0	0	E
		Paraffin and tung oil				0	0	E
		Dec. 1936 to Dec. 1937	83 ±6			0	0	G
		Jan. 1938 to Mar. 1940				0	0	E
A8	cc12A1	Before waterproofing	9 ±2			0	16	G
		Paraffin and tung oil	19 ±4			0	11	G
		*Oct. 1936 to Nov. 1937	16 ±3				1	G
		*Dec. 1937 to Apr. 1940	38 ±6				0	G
31	cc8A1	Before waterproofing	0.5	( )	(c)	(c)	100	PF
		Paraffin and tung oil	3.5	4.1	15 ±6	0.3	80	F
		Nov. 1936 to Dec. 1937	1.3	5 ±1		0	55	F
		Dec. 1937 to Dec. 1939	1.3	4.4			55	F
16	aa12B1	Before waterproofing	0.1	0.1	0.1	21	70	VP
		Paraffin and tung oil	.35	1	1	14	55	VP
		Waxed joints	4.4	4.4	7.5	1.5	35	P
		Dec. 1936 to Dec. 1937	.03	0.03	.7	4	55	P
		Jan. 1938 to Mar. 1940	0.3	.3	.7	3	50	P
72	bb12B1	Before waterproofing	.03	.04	.02	158	70	VP
		Paraffin and tung oil	.5	4 ±1	.1	46	[d] 50	VP
		Waxed joints	7		15.0	0.4	18	F
		*Jan. 1937 to Jan. 1938	0.1	15 ±6	.3	11	85	VP
		Mar. 1938 to Mar. 1940	.1	0.3	.2	34	85	VP
29	cc12B1	Before waterproofing	.2	.3	.2	40	100	VP
		Paraffin and tung oil	1.3	15 ±6	.7	43	75	VP
		Sept. 1937 to Sept. 1939	0.7	0.8	.6	18	65	VP
17	aa8B1	Before waterproofing	.03	.03	.05	17	75	VP
		Paraffin and tung oil	.13	.13	.12	15	55	VP
		Waxed joints	24			0	0	G
		*Dec. 1936 to Dec. 1937	1.6	1.6	2	3	35	P
		Dec. 1937 to Dec. 1939	0.5	0.8	0.8	3	30	P
62	bb8A1	Before waterproofing	.01	.01	.3	16	100	VP
		Paraffin and tung oil	.05	.08	.4	4	100	P
		Waxed joints	3			0	55	F
		Paraffin and tung oil	12 ±1			0	10	G
		*Jan. 1937 to Jan. 1938	0.3	.3	10 ±3	.9	75	P
		Mar. 1938 to Mar. 1940	.05	.08	0.4	3	95	P
63	bb8B1	Before waterproofing	.02	.04	.03	120	100	VP
		Paraffin and tung oil	.03	.13	.05	80	100	VP
		Waxed joints	3.4	15 ±6	2.2	0.6	80	F
		Jan. 1937 to Jan. 1938	0.4	1.6	0.15	9	100	VP
		Feb. 1938 to Mar. 1940	.4	0.7	.25	13	95	VP
30	cc8B1	Before waterproofing	.1	.1	.1	88	100	VP
		Paraffin and tung oil	.3	.4	.5	50	100	VP
		Waxed joints	2.1	17 ±3	11 ±2	1.4	70	P
		Jan. 1937 to Jan. 1938	0.05	0.05	0.07	25	95	VP
		Mar. 1938 to Mar. 1940	.3	.5	.3	23	95	VP
WALLS WITH REPOINTED FACE JOINTS								
64	aa12B2	Before waterproofing	1.2		0.2	14	25	VP
		Repointed	19 ±3		8 ±2	0.3	8	F
		*Sept. 1936 to Sept. 1937	63 ±6			0	0	E
		*Oct. 1937 to Oct. 1939				0	0	E
48	aa12B4	Before waterproofing	0.6		0.05	15	15	VP
		Repointed	32 ±2			0	0	G
		*Aug. 1936 to Oct. 1937	65 ±3			0	0	E
		*Nov. 1937 to Nov. 1939				0	0	E
50	bb12B2	Before waterproofing	0.1	0.13	.05	36	100	VP
		Repointed	1.4	15 ±6	.7	1.7	42	P
			13		19 ±3	0.1	10	F
		Linseed oil solution	12 ±1		20	.1	12	F
		*Jan. 1937 to Jan. 1938	17 ±3		17 ±3	.2	1	F
		*Mar. 1938 to Mar. 1940	10 ±2		10 ±2	.2	15	F
46	bb12B4	Before waterproofing	0.12	0.12	0.03	38	100	VP
		Repointed	2.4	15 ±6	.5	2	55	P
			17 ±1		9 ±1	0.1	1	F
		Aluminum stearate solution	159 ±6			0	0	E
		*Feb. 1937 to Feb. 1938	78 ±1		18 ±3	.1	0	F
		*Mar. 1938 to Apr. 1940	9 ±2	99 ±2	18 ±4	.1	2	F

See footnote at end of table.

Table 4.—*Permeability of waterproofed masonry walls exposed outdoors*—Continued

Wall No.	Designation	Waterproofing treatment or period of outdoor exposure	Time to failure as indicated by—			Maximum rate of leakage	Area damp in 1 day	Rating
			Damp on back	Visible water	Leak			
1	2	3	4	5	6	7	8	9
		WALLS WITH REPOINTED FACE JOINTS—Continued						
			hr	*hr*	*hr*	*Liters/hr*	*%*	
37	cc12B2	Before waterproofing	0.2	0.8	0.1	101	80	VP
		Repointed	8 ±1	-------	2.6	2.7	40	P
		1st, paraffin and tung oil	51 ±1	-------	38 ±6	0	0	G
		2nd, paraffin and tung oil	15 ±6	-------		0	4	G
		*Aug. 1937 to Oct. 1938	106 ±3	-------	67 ±3	0	0	G
		*Jan. 1939 to Apr. 1940	17 ±3	38 ±6	9 ±2	1.7	10	P
22	bb8B2	Before waterproofing	0.05	0.05	0.13	50	100	VP
		Repointed paraffin solution	4.8	15 ±6	-------	0	55	F
		*Oct. 1936 to Oct. 1937	1.5	15 ±6	-------	0	70	F
		Nov. 1937 to Nov. 1939	1.4	15 ±6	15 ±6	.3	85	F
91	bb8B2	Before waterproofing	0.03	0.03	0.03	69	100	VP
		Repointed; aluminum stearate 10 solution	10 ±2	-------	18 ±4	0.06	9	F
		*Oct. 1936 to Oct. 1937	8 ±1	-------	-------	0	1	E
		*Nov. 1937 to Nov. 1939	25 ±1	-------	-------	0	1	E
A9	bb8B2	Before waterproofing	0.02	.02	0.02	56	100	VP
		Repointed-linseed-oil solution	9 ±1	-------	-------	0	10	G
		*Nov. 1936 to Nov. 1937	39 ±6	-------	-------	0	1	E
		*Dec. 1937 to Dec. 1939	18 ±4	-------	-------	0	1	E
54	bb8B3	Before waterproofing	0.02	.07	.07	79	100	VP
		Repointed; aluminum stearate solution	2 ±1	19 ±4	-------	0	20	F
		*Oct. 1936 to Sept. 1937	3.8	-------	-------	0	10	G
		*Nov. 1937 to Nov. 1939	15 ±5	-------	51 ±14	0	10	G
52	bb8B4	Before waterproofing	0.01	0.01	0.02	59	100	VP
		Repointed	.5	9 ±2	9 ±2	0.8	75	F
		Molten paraffin	5	-------	-------	0	10	G
		*Dec. 1936 to Dec. 1937	38 ±6	-------	-------	0	0	E
		*Jan. 1938 to Mar. 1940	57 ±2	-------	-------	0	0	E
		WALLS WITH GROUTED FACE JOINTS						
55	aa12B3	Before waterproofing	1	15 ±6	0.08	14	65	VP
		Grouted joints	90 ±4	-------	-------	0	0	E
		*Dec. 1936 to Dec. 1937	106 ±2	-------	-------	0	0	E
		*Jan. 1938 to Mar. 1940	91 ±3	-------	-------	0	0	G
57	aa8B3	Before waterproofing	0.1	0.1	.03	19	90	VP
		Grouted joints	41 ±7	-------	-------	0	0	G
		*Dec. 1936 to Jan. 1938	39 ±3	-------	-------	0	0	G
		*Jan. 1938 to Mar. 1940	9 ±2	-------	-------	0	7	G
53	bb8A2	Before waterproofing	0.03	.08	.4	.9	100	P
		Grouted joints	2.4	-------	0	0	52	F
		Dec. 1936 to Dec. 1937	0.2	15 ±6	-------	0	90	F
		Jan. 1938 to Mar. 1940	.8	18 ±4	-------	0	75	F
59	bb8A3	Before waterproofing	.02	0.05	.2	.7	100	P
		Grouted joints	3.5	-------	-------	0	35	G
		*Dec. 1936 to Dec. 1937	3	-------	-------	0	30	G
		*Jan. 1938 to Mar. 1940	3.7	18 ±4	-------	0	35	F
		WALLS PAINTED WITH OIL OR CEMENT-WATER PAINTS						
44	cc12B4	Before waterproofing	0.3	0.35	.03	70	80	VP
		Repointed	2.6	15 ±6	1.4	3	35	P
		Cement-water paint	-------	-------	-------	0	0	E
		*Feb. 1937 to Feb. 1938	67 ±4	-------	-------	0	0	E
A10	bb8B2	Before waterproofing	0.02	0.02	0.02	49	100	VP
		Repointed—oil paint	7.8	-------	-------	0	22	G
		*Feb. 1937 to Feb. 1938	-------	-------	-------	0	0	E
		*Mar. 1938 to Mar. 1940	106 ±3	-------	-------	0	0	E
A12	m8A2[e]	Before waterproofing	0.02	.02	(c)	(c)	100	(c)
		Cement-water paint	161 ±10	-------	-------	0	0	E
		*Jan. 1937 to Jan. 1938	114 ±3	-------	-------	(c)	1	(c)
		*Jan. 1938 to Mar. 1940	91 ±4	-------	-------	(c)	6	(c)
A11	n8A2[e]	Before waterproofing	0.05	.05	(c)	(c)	70	(c)
		Cement-water paint	2.8	-------	(c)	(c)	16	(c)
		Repeated test	0.7	-------	(c)	(c)	30	(c)
		*Feb. 1937 to Feb. 1938	1.8	-------	(c)	(c)	15	(c)
		*Mar. 1938 to Apr. 1940	1.8	39 ±6	(c)	(c)	15	(c)

See footnote at end of table.

TABLE 4.—*Permeability of waterproofed masonry walls exposed outdoors*—Continued

Wall No.	Designation	Waterproofing treatment or period of outdoor exposure	Time to failure as indicated by—			Maximum rate of leakage	Area damp in 1 day	Rating
			Damp on back	Visible water	Leak			
1	2	3	4	5	6	7	8	9
WALLS WATERPROOFED WITH PROPRIETARY MATERIAL								
			hr	*hr*	*hr*	*Liters/hr*	%	
61	aa8B2	Before waterproofing	0.05	0.3	0.01	20	80	VP
		Grouted joints (Capsis)	25 ±2	----	----	0	1	G
		*Sept. 1936 to Sept. 1937	40 ±5	----	----	0	0	G
		*Nov. 1937 to Nov. 1939	34 ±2	----	0	0	0	G
88	aa8B2	Before waterproofing	0.02	.02	.03	10	[d] 50	VP
		June 1936 to June 1937	.03	.07	.4	4	85	P
		Rocktite grout joints	.3	6	.7	0.7	50	F
		Rocktite grout joints	.3	15 ±6	----	0	45	F
		July 1937 to July 1938	.7	11 ±3	----	0	40	F
		Sept. 1938 to Apr. 1940	.1	0.1	18 ±4	0.08	35	P
34	ee8B2	Before waterproofing	.03	.05	0.08	51	100	VP
		June 1936 to June 1937	.07	.1	.2	45	100	VP
		Rocktite color coat	2.1	----	----	0	35	G
		July 1937 to July 1938	29 ±1	----	----	0	0	E
		Sept. 1938 to Apr. 1940	9 ±2	----	----	0	3	G
39	ee8B2	Before waterproofing	0.08	.2	.4	67	100	VP
		Bldg. Chem. Corp. No. 1	9 ±1	----	----	0	12	G
		*Sept. 1936 to Sept. 1937	5.5	15 ±6	----	0	4	F
		*Nov. 1937 to Nov. 1939	5.1	----	----	0	8	G
49	bb8A4	Before waterproofing	0.05	0.05	.1	2	100	P
		Bldg. Chem. Corp. No. 2	.7	16 ±5	----	0	35	F
		*Sept. 1936 to Sept. 1937	4 ±1	15 ±6	----	0	60	F
		*Nov. 1937 to Nov. 1939	0.07	0.07	.07	----	85	P

[a] Lower case letters denote kind of masonry units in facing and backing.
First numeral denotes nominal wall thickness in inches.
Capital letters denote type of workmanship.
Final number denotes kind of mortar.
[b] Weathering exposure periods preceded by an asterisk indicate that wall was metal covered on back, top and sides during exposure.
[c] Data not determined.
[d] Duration of test exposure less than 24 hours.
[e] Wall not flashed at bottom.

5. Performance Ratings

The permeability test is a more severe exposure than the natural wind and rain storms to which most building walls may be subjected. Nearly all information of a practical value on the permeability of masonry test walls may therefore be obtained during an exposure period of 1 day in the test chamber. However, to determine possible slight changes in permeability, produced by outdoor exposure, the tests on some of the less permeable specimens have been continued for 5 days. The arbitrary ratings of wall performance given below are similar, except for some slight revision, to those given in report BMS7, page 12, and are based on the assumption that visible water, extensive damp areas on the back, or leakage through a wall would damage plaster applied directly to the back of a wall or would injure the finished interior of a building.

Wall Performance Ratings

Excellent (E):

No visible water on back of wall in 1 day. Not more than 25 percent of wall area damp in 5 days. No leaks [5] through either the wall or the facing wythe in 5 days.

Good (G):

No visible water in 1 day. Less than 50 percent of the wall area damp in 1 day. No leaks [6] through either the wall or the facing wythe in 1 day.

Fair (F):

Visible water on back of wall in not less than 3 or more than 24 hours. Total leakage rate (both flashings) less than 1 liter/hr in 1 day.

[5] Leaks are defined as follows: A leak is a flow of water from either flashing having a rate of flow equal to or greater than 0.05 liter/hr. Water ponded on a flashing having no flow is not considered a leak.
[6] See footnote 5.

Poor (P):

Visible water on back of wall in 3 hr or less. Total leakage rate not more than 5 liters/hr in 1 day.

Very Poor (VP):

Total leakage rate greater than 5 liters/hr in 1 day.

IV. EFFECTS OF THE OUTDOOR EXPOSURE

1. Structural Condition of the Walls After Exposure

(a) *All-Brick Masonry Walls, Not Waterproofed*

The walls were inspected when they were brought indoors to be tested, and the effects of weathering were noted. Although all of the mortar pargings were crazed, the effects of weathering were most apparent in the top pargings and in the top courses of the walls. It was observed that face joints that had been tooled were eroded sufficiently to remove the film of cement and fines brought to the surface by the tooling iron, so that the joint surface was roughened, exposing particles of the sand contained in the mortar. The joint structure of very few walls was damaged or cracked, but the top pargings on many were so badly cracked as to become loose or spalled. Structural damage to the walls or pargings probably resulted from the freezing of water absorbed by the brick or accumulated in the joints between the pargings and the masonry. The most severe structural failures in the masonry were characterized by an upward heaving of the top courses of brick with extensive horizontal cracking in the bed joints, and, in some cases, by spalling of the faces of the brick and their adjacent mortar joints.

A measure of the resistance to damage by weathering of a group of 48 all-brick walls is given in table 5. The data show the general structural condition of the walls before the final permeability test and also give a measure of the relative resistances of the different kinds of brick and of mortars to weathering. Neither the thickness of the walls (8 or 12 in.) or the kind of workmanship used appeared to have a significant effect on their structural condition. The arbitrary ratings of structural condition are given in table 5.

Table 5.—*Structural condition, after outdoor exposure, of 48 all-brick walls 8 or 12 inches thick*

Kind of brick in facing	Rating of structural condition [1]	Number of walls of— Mortar 1	Mortar 2	Mortar 3	Mortar 4	Mortar 5	Total number of walls, all mortars
a	*A*	2	6	1	2	0	11
	B	1	1	2	1	1	6
	C	0	0	0	0	0	0
b	*A*	2	3	1	1	0	7
	B	0	1	2	0	0	3
	C	0	0	0	0	0	0
c	*A*	2	5	0	1	3	11
	B	0	2	1	0	1	4
	C	1	0	3	2	0	6

[1] The ratings of structural condition are arbitrary and are defined as follows:

Rating *A*: Pargings crazed only, none loose. No cracks in mortar joints.

Rating *B*: Portions of pargings are loose or spalled. No cracks in mortar joints.

Rating *C*: Mortar joints in masonry cracked, loose or spalled.

The joint structure of the masonry in all walls containing the low- or medium-absorptive bricks (bricks *a* and *b*, table 5) was undamaged. The mortar joints in only 3 of 17 walls built of brick *c* with mortars 1, 2, 4, or 5 were cracked or spalled, whereas the joints in 3 of 4 walls built of these brick with mortar 3 were damaged.

The pargings applied to the ends and tops of 16 of 21 of the walls built of brick *a* or *b* and mortars 1, 2, 4, or 5 were crazed, but not badly damaged, whereas those in 4 of 6 walls built of these brick with mortar 3 were loose or spalled. Although the condition of the pargings had little or no effect on the permeability of the walls, it is indicated (table 5) from the appearance of the walls and pargings that mortars containing not more than an equal proportion of lime hydrate to portland cement were more resistant to weathering than was the low-cement mortar 3.

FIGURE 2.—*Top portion of wall 33–cc12A3 after 3 years' outdoor exposure.*

The walls rated *C* in table 5 are listed below, those sustaining the greatest damage being given first:

Wall No.	Designation
33	cc12A3
21	cc12B3
20	cc8A3
40	cc8A4
43	cc12A4
94	cc12A1

The upper facing portion of wall 33 (worse damaged) is shown in figure 2. The bed joints in both faces of the top three courses of this wall were badly cracked, and there were several spalled brick and head joints in the rear facing. The bed joint under the top course of wall 21 was severely cracked and spalled in both faces. Damage sustained by walls 20, 40, 43, and 94 was comparatively small. In walls 20 and 40 a few isolated brick were spalled with cracking or spalling in the adjacent mortar joints and in the pargings. The top parging on wall 43 was loose, and there were about 6 small vertical cracks in the upper two bed joints. Damage to the face of wall 94 was limited to about 10 small vertical cracks in the bed joints of the upper 3 courses. These cracks usually occurred near the end of a stretcher brick. There were no spalled brick or horizontal cracks in the bed joints, and the head joints appeared to be undamaged.

Since the interior of the joints in five of the six walls rated *C* in table 5 were solidly filled with mortar (workmanship *A*) and since the brick were more absorptive than the mortars, it is probable that the primary cause of damage to the joints was the expansion of the brick produced by the freezing of absorbed water.

The bricks for the walls were selected to provide a wide range in absorptive properties without regard to their probable resistance to weathering. Brick *c* was chosen as one type because of the high rate of absorption and relatively high total absorption, and was sold by

Figure 3.—*Stucco-faced wall 3–sj9A2, with tile on end, after 2 years' outdoor exposure.*

the manufacturer with the understanding that they were not suitable for exposed masonry. Moreover, investigations [7] indicate that a poor resistance to frost action would be expected for brick *c* because of the high saturation coefficient (*C/B* ratio 0.89—table 1, BMS7) and the low compressive strength (2,370 lb/in.^{2}). Conversely, from the data in table 1 of BMS7, bricks *a* and *b* can be classified as frost resistant.

Although there is no definite explanation for the damage to the pargings and mortar joints in walls containing the high-lime mortar 3, the comparatively low tensile and compressive strength of mortar 3, as compared to mortars 1, 2, 4, and 5 (see table 1), may have been the reason for the relatively low resistance of this mortar to damage from the weathering exposure. The absorptive properties of the mortars may also have had some effect on relative durabilities.

With the exception of one or two of the walls built with brick *c*, there was no important structural damage sustained by the walls listed in table 5.

(*b*) *Other Masonry Walls, Not Waterproofed*

All nine of the brick-faced walls with hollow-unit backings were built with brick *b* and mortar 2. The pargings in only one or two of these

[7] J. W. McBurney, Proc. Am. Soc. Testing Materials **35**, pt. 1, p. 247 (1935).

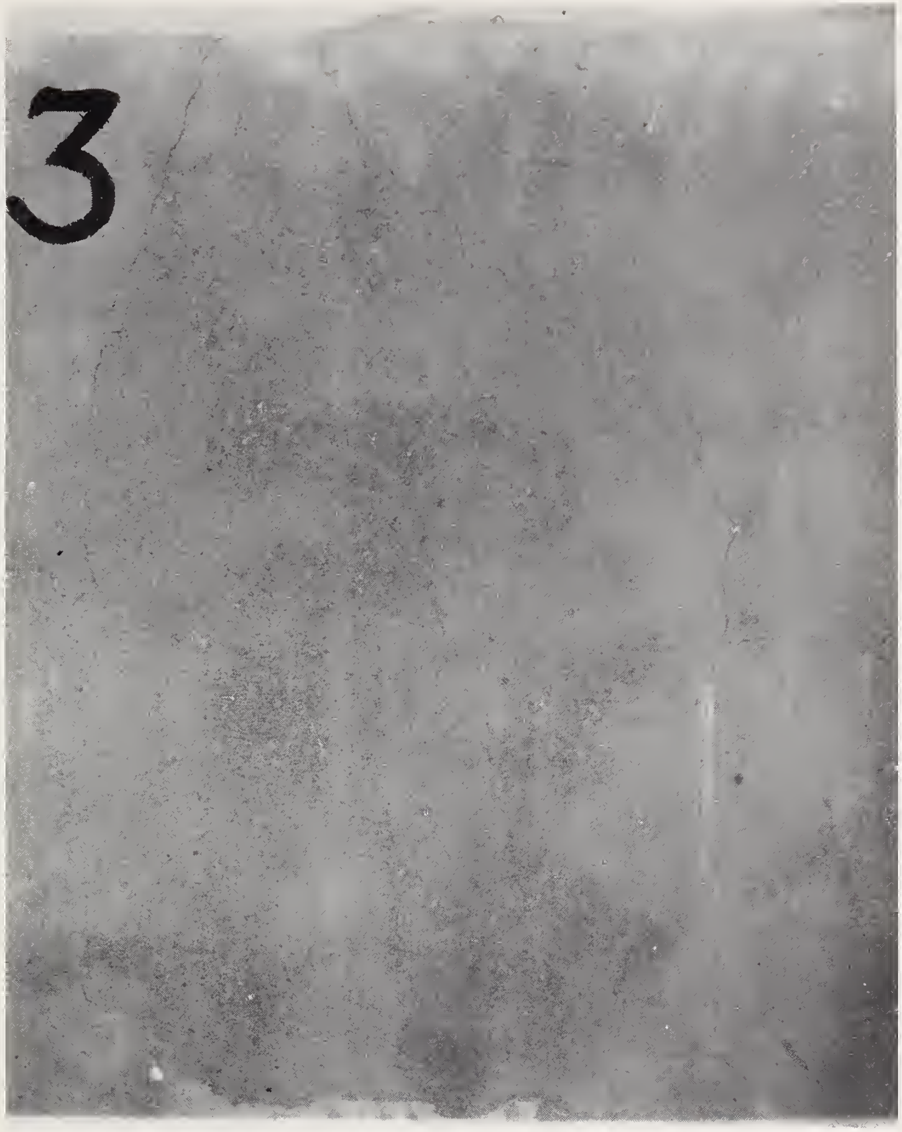

FIGURE 4.—*Upper portion of wall 3 after 2 years' outdoor exposure.*

Cracks about one-fourth actual size.

walls were loose or spalled, and the mortar joints in all of them were intact. The cinder-concrete block used in the backing of some of these walls were somewhat damaged by popping over small isolated areas.

The 4-in. brick walls with parged backings built of brick *c* were damaged by horizontal cracks in the top bed joints. These cracks were extensive and usually extended completely through the pargings and the bed joints. It is probable that the thin section of these walls was vulnerable to sudden changes in temperature which produced a quick freezing of the absorbed or trapped water with consequent cracking of the bed joints and pargings.

The stucco facings in all of the tile-backed stucco-faced walls were crazed and the facings in some of them were badly cracked, as can be seen from figures 3, 4, and 5. It was not determined if large cracks in the stucco facings coincided, in location, with mortar joints in the tile backing or if they were caused by possible differential movements in the backing. The tile appeared to be in good condition after exposure,

FIGURE 5.—*Upper portion of wall 8–sj9A2 after 3 years' outdoor exposure.*

Stucco-faced wall with tile on side. Cracks about one-fourth actual size.

and there was no loose or spalled stucco in the facings.

(c) *Waterproofed Masonry Walls*

Since the waterproofing gave some protection to the faces of the treated walls and since most of these walls were also protected with metal coverings, the weathering exposure produced very little structural damage to either the pargings or the masonry. The discussion of the structural effects of weathering on the treated walls will therefore be confined to a few statements on the general condition or appearance of the waterproofed surfaces.

The color of walls treated with waxes or solutions containing paraffin and tung oil was darkened, but it is significant that none of the high-absorptive brick *c* in these walls were spalled or damaged.

Mortar joints treated with grouting materials or joints that had been repointed appeared to be in good structural condition, except that one proprietary material, Rocktite, applied as a relatively thick grout coating to the face joints

FIGURE 6.—*Oil paint film on wall A10–bb8B2, after 3 years' outdoor exposure.*

Wall was reported before painting.

of wall 88, was badly eroded, exposing the original mortar surface.

The oil paint applied to wall A10–bb8B2 was in fair condition after 3 years' outdoor exposure. This wall had been repointed before painting, and the paint film over the joints was crazed and slightly peeled, as is shown in figure 6. This wall was tested once for permeability between the repointing and the painting treatments, and it is possible that the alkalinity of the repointed joints was not sufficiently neutralized before painting. There was considerable dusting in the paint film over the brick.

Walls 44–cc12B4, A12–m8A2, and A11–n8A2 were painted with a cement-water paint. After an exposure outdoors for 1 year, the paint film on wall 44 was badly crazed and was cracked away at 30 or 40 points along the upper and lower edges of the stretcher brick. Two brick were badly spalled to a depth of one-half inch. After 3 years' outdoor exposure, the paint films on the concrete-block walls were crazed and dusting. There was no scaling of the paint film except in wall A11 where the cinder block had popped or spalled (see fig. 7).

After 3 years' outdoor exposure, the Rocktite grout coating over the brick facing of wall 34–cc8B2 was badly crazed and two brick were spalled, one to a depth of five-eighths inch. These brick were covered with mortar and a cement-water paint before the final test was made on the wall. Neither the cement-water paint or the Rocktite grout coating prevented severe spalling of some of the brick in walls containing the high-absorptive brick *c*.

FIGURE 7.—*Cement-water paint film on cinder block wall A11–n8B2 after 3 years' outdoor exposure.*
Note crazing of paint film. Dark vertical stains are from dirt washed off metal covering at top of wall.

2. PERMEABILITY OF THE PLAIN, NOT WATER-PROOFED WALLS

(*a*) *All-Brick and Brick-Faced Walls 8 or More Inches in Thickness*

The data (see table 3) showing the effects of outdoor exposure on the water permeability of all-brick walls 8 or 12 in. thick, and of brick-faced walls with hollow-unit backings, indicate no great change in the permeability of about two-thirds of them, a considerable decrease in the permeability of nearly one-quarter, and an increase in less than one-tenth. Only one wall that was visibly damaged (wall 33) showed a large increase in permeability. There was no significant change in the relative permeability, before and after outdoor exposure, resulting from differences in wall thickness, kind of mortar, or in the kind of backing. The average permeability of walls containing frost-resistant bricks was slightly reduced. The rate of leakage through all of the highly permeable specimens was greatly reduced, and as a result the performance ratings of 3 in 13 of the Very Poor walls were bettered. The general effects of weathering on permeability are given in table 6, which contains the total number of walls faced with each kind of brick and the number of walls showing changes in permeability sufficient to raise or lower their performance ratings. The changes in permeability so indicated were considerable and are highly significant except where permeabilities of the walls were near the borderline between two performance classifications. Even so, the ratings of 13 walls were increased and those of only 5 were decreased.

Table 6.—*Effects of outdoor exposure on the permeability of 57 all-brick or brick-faced walls, 8 or 12 in. thick*

Kind of brick in facing	Number of walls			Total number of walls
	Performance rating unchanged	Performance rating increased (less permeable)	Performance rating decreased (more permeable)	
a	12	5	0	17
b	10	6	3	19
c	17	2	2	21
Total	39	13	5	57

Most of the walls faced with the low-absorptive brick *a* were less permeable after outdoor exposure than before. The performance ratings of none of these walls was reduced, whereas those of nearly 30 percent were raised. Previous observations on the effects of repeated permeability tests have indicated a slight but definite decrease in permeability, and it appears from the data (table 6) that the effects of weathering exposure did not prevent these walls from also becoming more resistant to penetration.

The relative performances, before and after outdoor exposure, of the walls faced with the medium-absorptive brick *b* were about the same as those of walls faced with brick *a*, except that the permeability ratings of two specimens were reduced from Good to Fair.

Although nearly 30 percent of the walls built with brick *c* had sustained some damage to the joint structure, the permeability of only 10 percent of the total number was greatly increased while that of another 10 percent showed a considerable decrease. The average permeability of this group of walls was practically unchanged.

(*b*) *Four-Inch Brick Walls With Parged Backings*

The permeability of all of the 4-in. brick walls with parged backings was greatly increased by the weathering exposure (table 3). Failure through these walls appeared much higher on the back than was the case for the Heavy Rain tests made before outdoor exposure, thus indicating a penetration through new cracks or openings at the top of the walls.

(*c*) *Stucco-Faced Walls*

The weathering exposure greatly reduced the time required for the penetration of moisture through the stucco-faced walls. The penetration of water in quantity sufficient to become visible on the backs of walls 6 and 8 reduced their performance ratings from Excellent to Fair or Poor. These walls were not flashed at the bottoms, and the bond between the supporting channel and the wall was broken in all except wall 2, so that no measurements could be made of the relative amounts of leakage through the faces occurring before and after exposure. The walls with tile backings laid on the side (walls 5, 6, 7, and 8) appeared to be affected more by the exposure than did the walls in which the tile cells were placed vertically, but this observation may have been influenced by the tendency for water entering hollow units with vertical cells to drop or run down the interior of the wall. There was no apparent advantage in favor of either the plain or waterproofed stucco facings, but walls with the smooth-finished facings (walls 1, 3, 5, and 7) appeared to be slightly less permeable after exposure than did the walls with rough surface textures, wood floated. This difference, however, was very small and may not be significant. In general, although the permeability of the stucco-faced walls was noticeably increased, the performance of these walls after exposure was about the same as that of 8-in. all-brick walls of workmanship *A* built of medium or low-absorptive bricks.

3. Permeability of the Waterproofed Walls

The effectiveness of the waterproofings applied to the walls before they were exposed outdoors is discussed in section IX of BMS7. A measure of the durability, or effectiveness, of the waterproofing treatments, after weathering exposure, is obtained by comparing the permeabilities of the specimens before and after outdoor storage. Only brief references are made to the original effectiveness of the treatments, but in table 4 there is given complete data obtained from all the permeability tests that have been made before and after the treatments were applied. In reviewing the data given in table 4, it should be remembered that the exposure periods preceded in the table with an asterisk indicate that the top, back, and sides of the walls were protected with sheet metal during the outdoor storage, thereby exposing only the treated faces to the weather.

(a) *Walls Treated With Paraffin and Tung-Oil Solutions and Waxes*

Paraffin and tung oil in a solution of mineral spirits was applied to both the brick and the mortar joints in the wall face, whereas a paraffin and tung-oil wax was usually applied only to the joints. Although the permeability of walls of workmanship *B* was greatly reduced by buttering the joints with wax, the effect was only temporary and the specimens were found to be highly permeable after an exposure outdoors of only 1 year (see table 4). Similarly, two or three applications of a paraffin and tung oil, applied to the high-absorptive brick facing of a wall of workmanship *B* with repointed joints, wall 37–cc12B2, was effective for at least 1 year, but some leakage through the wall was observed after an exposure of 3 years. The treatments reduced the rate of absorption and the amount of water absorbed by walls of low permeability, but they were either ineffective or of poor durability when used where they were most needed, on walls that leaked badly.

(b) *Walls With Repointed Face Joints*

Repointing and tooling of the face joints was found to be the most effective and durable method of sealing the joints in walls of workmanship *B*. Although the treatment stopped leaks through the joints, it was not successful on walls built with the high-absorptive bricks *c*, unless the brick were also treated. The permeability of most of the repointed walls, either with or without additional treatments, was found to have become progressively lower after successive periods of outdoor exposure, and the final test performance on half of them was rated Excellent.

(c) *Walls With Grouted Face Joints*

Grouting or filling interstices in the face joints with cementitious materials greatly reduced the permeability of walls of workmanship *B* built of the low- or the medium-absorptive bricks. Although most of the grouted walls were more permeable when tested after 3 years' outdoor exposure than they were before, the treatment was still highly effective and may be expected to have a satisfactory durability and to be economical, especially since the probable cost of grouting is considerably lower than that of repointing.

(d) *Walls Painted With Oil or Cement-Water Paints*

Both oil and cement-water paints were found to be highly effective waterproofings after 3 years of outdoor exposure, even though there was evidence of dusting and peeling or crazing of the paint films. Large openings in the facing joints of the brick walls 44 and A10 were filled by repointing before these walls were painted. The performance of wall 44, built of high-absorptive brick and painted with a cement-water paint, was rated Excellent. Although the paint film showed considerable deterioration, the waterproofing effect was not changed after an exposure period of 1 year. Since the concrete block walls (A11 and A12) were not flashed, it was not possible to measure the rate of leakage, if any, through the walls and thereby determine their performance ratings, but the available data indicate that the cement-water paints were still effective as waterproofings after 3 years of exposure. The back of wall A12, at the supporting channel, was dry or merely damp during the latter tests.

(e) *Proprietary Waterproofing Materials*

The grouting treatment of CAP 515, applied to the joints of wall 61–aa8B2 by the Building Chemicals Corporation, was still highly effective after 3 years' outdoor exposure, and there was no significant change in the permeability of the wall during that period. A grouting treatment of Rocktite grout was applied thickly to the face joints of wall 88–aa8B2 by representatives of a waterproofing company. This grout was fairly effective but, after 3 years, the permeability of the wall was greatly increased. It would appear, therefore, that cementitious grouts applied as a thick coating to the joints may be neither as effective nor as durable as relatively thin coatings whose primary purpose is to fill interstices between the mortar joints and the building units.

Wall 34-cc8B2 brushed with a grout containing Rocktite color coating was rated Excellent after an exposure of 1 year and was rated Good after an exposure of 3 years. There was no leakage through the wall, but two spalled brick were covered with a cement mortar and paint before the final test.

Walls 39 and 49 were also treated by the Building Chemicals Corporation (see pages 28 and 29 of BMS7). The permeability of wall 49–bb8A4, treated with paraffin and tung-oil solution and wax, was greatly increased after 3 years' exposure. The joints of wall 39–cc8B2 were filled with CAP 515 in addition to the paraffin and tung-oil treatments and the performance of this wall was rated Good after more than 3 years of outdoor exposure.

V. SUMMARY

These conclusions pertain to the effects of a 3-year period of outdoor exposure at Washington, D. C., on the structural appearance and the water permeability of a group of small masonry wall specimens.

The exposure did not have much effect on the permeability of all-brick or brick-faced walls 8 or 12 in. in thickness. The average permeability of walls built with the low- or with the medium-absorptive bricks was slightly but significantly reduced. This was true irrespective of the kind of mortar used. With the exception of one or two specimens (badly damaged by weathering), the average permeability of walls containing salmon brick was not greatly changed.

The joint structure or masonry in all-brick and in brick-faced walls, 8 or 12 in. thick, built of frost-resistant bricks, was not damaged by the exposure. The masonry in 30 percent of the walls containing salmon brick was damaged, and the damage was most severe in those walls which contained the lowest proportion of cement in the mortar.

The upper bed joints in brick walls, 4 in. thick, with mortar pargings on the backs, were badly cracked. The cracks extended through the pargings, and the permeability of the walls was greatly increased.

The weathering exposure damaged the mortar pargings applied to the tops and ends of brick walls. Both end and top pargings were more or less crazed, and about 30 percent of the top pargings were cracked loose or spalled. Pargings that were made of mortar containing the lowest proportion of portland cement to lime (1:2:9 parts by volume of cement, hydrated lime, and loose damp sand) were more severely damaged than were those of the 1:1:6 or the 1:1/4:3 mortars.

Portland cement stucco, used as a facing on a structural clay tile backing, was cracked or badly crazed, but not loose or spalled from the backing. Although the permeability of the stucco-faced walls was significantly increased, the average performance, after exposure, was nearly the same as that of 8 in. brick walls built of low-absorptive brick with the joints filled with mortar.

Repointing of the face joints was both an effective and durable method of waterproofing when applied to brick walls of medium- or of low-absorptive brick. Nearly all of the repointed walls were less permeable after exposure than before.

Grouts containing portland cement and fine sand, thinly applied to the face joints of brick walls built of low- or of medium-absorptive brick, were effective as waterproofings after 3 years of exposure. The average permeability of the grouted walls was increased but their performances were still satisfactory.

A paraffin and tung-oil wax, applied to the face joints of brick walls that leaked badly, was ineffective as a waterproofing after an exposure of 1 year, at which time the specimens were highly permeable.

Although the paint films were visibly damaged, both oil and cement-water paints were still highly effective as waterproofings after exposure.

Washington, March 28, 1941.

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