U. S. DEPARTMENT OF COMMERCE

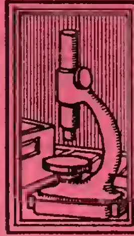
BUILDING MATERIALS AND STRUCTURES

REPORT BMS82

Water Permeability of Walls Built of Masonry Units

by

CYRUS C. FISHBURN



NATIONAL
BUREAU OF STANDARDS

The program of Research on Building Materials and Structures carried on by the National Bureau of Standards was undertaken with the assistance of the Central Housing Committee, an informal organization of governmental agencies concerned with housing construction and finance, which is cooperating in the investigations through a committee of principal technicians.

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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Water Permeability of Walls Built of Masonry Units

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ISSUED APRIL 15, 1942

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 construed accordingly.

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Foreword

Exterior masonry walls of houses or other buildings may occasionally be penetrated by wind-driven rains, with subsequent damage to the interior finish of such structures. An extensive investigation in the water-permeability of small masonry wall specimens has resulted in the publication of reports on the permeability of masonry walls when first constructed, after being exposed outdoors, and after being subjected in the laboratory to alternate wetting and drying and in the dry condition to extremes of temperature. This is a report on the water permeability of walls built of masonry units.

Lyman J. Briggs, *Director.*

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by CYRUS C. FISHBURN

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ABSTRACT

The water permeabilities of small masonry wall specimens were measured. Fourteen kinds of workmanship, 39 kinds of units, and 10 kinds of mortars were represented in a group of 140 walls.

The permeability of the specimens was low when the vertical joints were filled or partly filled with mortar or grout, when the suction of the bricks was low, and when a mortar having a high water retentivity was used. The effect of water retentivity of the mortars on the permeability of the walls was greatest when the brick-suction was high. Mortar having a low water retentivity stiffened rapidly when placed in contact with dry, highly absorptive bricks, and units having a low suction floated out of alinement when placed in contact with such a mortar.

I. INTRODUCTION

The results obtained from a study of the water-permeability of masonry walls have been described in a publication [1] of the National Bureau of Standards. In that investigation the permeabilities of stucco-faced walls and of walls built of masonry units were measured, and the effectiveness of waterproofing treatments applied to leaky brick walls was determined.

This report describes the results obtained from tests on a second group of walls built of masonry units. It reports the effects of different methods of construction, the effects of the absorptive capacity of the bricks at time of laying, and the effects of the water-retaining capacity of the mortars on the water permeability and on the ease of construction of those walls. For convenience, complementary data and information published in BMS7 are included in this report, which therefore contains all of the information on the permeability of walls built of masonry units that was obtained in both investigations (except for that on waterproofings).

II. WALL SPECIMENS

The walls were about 40 in. long, 50 in. high, and 6, 8, 9, 10, or 12 in. thick, depending upon

[1] Building Materials and Structures Report BMS7, Water Permeability of Masonry Walls.

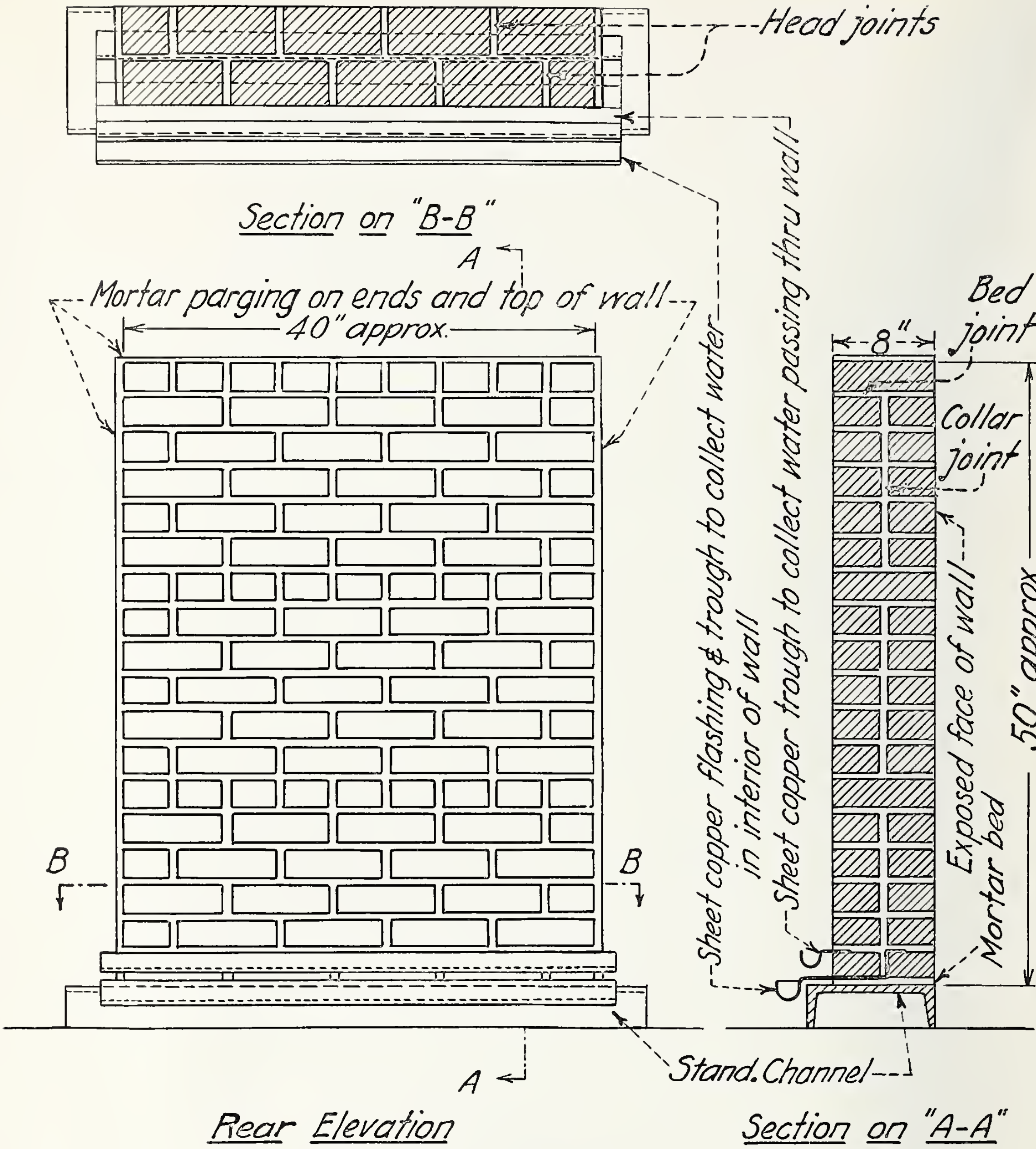

FIGURE 1.—*Brick masonry wall specimen.*

8-inch wall laid in common American bond.

the size of the units, the number of wythes, and the type of construction. The rear elevation and two cross sections of a typical brick masonry test wall are shown in figure 1. The walls, which were built at the Bureau by experienced masons, were supported on steel channels to facilitate handling, and contained one or more copper flashings so placed as to collect any leakage passing through them or dropping between the wythes. They were faced at the ends and top with a mortar parging ⅜ to ½ in. thick, sealing these areas, so that a pressure gradient from the face to the back of the walls was maintained within the masonry when an air pressure was applied to one face.

Fourteen different workmanships or methods of construction, 22 kinds of bricks, 17 kinds of structural clay tiles or concrete units, and 10 mortars were represented in the group of 140 wall specimens.

1. Sponsors

The testing of the walls and the construction of 98 specimens were sponsored by the Governmental agencies that collaborated with the Bureau in the investigation.

Other sponsors furnished the labor and materials for, and supervised the construction of, 42 other walls. These sponsors were:

The Brick Manufacturers Association of New York, Inc., one brick cavity wall.

The W. E. Dunn Manufacturing Co., Holland, Mich., one wall of "Dun-ti-stone" concrete units, and four walls of "Dunstone" concrete units.

The General Shale Products Corporation, Johnson City, Tenn. (with the Structural Clay Products Institute and the Speedbrik Corporation, both of Washington, D. C., and the Pursell Co., of Cincinnati, Ohio, as collaborators), nine walls of "Speedbrik."

The Munlock Engineering Co., Washington, D. C., eight walls of "Munlock" brick.

The National Concrete Masonry Association, Chicago, Ill., one cavity wall of "Mahlstedt" concrete block.

The National Fireproofing Co., Pittsburgh, Pa., three walls of "Dri-Speedwall" tile.

The Puddington Sales Corporation, New York, N. Y., three walls containing "Tight-Wall" brick.

W. H. Spaulding, architect of Long Island, N. Y., four walls containing bricks of his design.

The Structural Clay Products Institute of Washington, D. C., three brick-tile cavity walls and one grouted brick wall containing steel reinforcement. The Institute also furnished bricks for the construction of eight walls built and tested to determine the effects of coring brick on permeability.

The Whitacre-Greer Fireproofing Co., Waynesburg, Ohio, four walls of H-brick.

2. Materials

All of the materials were representative of those used in building construction. They were either furnished by the sponsors or purchased from the makers or from building-supply dealers.

(a) *Bricks*

The 22 kinds of bricks included many units that were hollow or cored; some of the special shapes were designated as bricks by the sponsors even though their net areas were less than 70 percent of their gross cored section. Three kinds of solid bricks, designated as brick *A*, *B*, and *C*, were selected for their absorptive properties and were used in more than half of the wall specimens. The physical properties of all of the bricks are given in table 1. The dimensions of bricks of special shapes are shown in figure 2 and the photographs are shown in figure 3.

The characteristics of the several bricks and their use are listed below:

Brick A.—Red, side-cut, shale, low-absorptive. Made in Martinsburg, W. Va., and typical of shale bricks from the North Central States. Purchased from the United Clay Products Co., Washington, D. C. Used in 15 walls and in walls built for structural tests.[2]

Brick B.—Red, side-cut, surface-clay, medium-absorptive. Made in Baltimore, Md. "Lombardy Colonial" brand of the Hydraulic Press Brick Co., Washington, D. C., used in 44 walls.

Brick C.—Red, dry-press, clay, high-absorptive. Made in Alexandria, Va., and sold by the Hydraulic Press Brick Co. Used in 29 walls.

Brick D.—Dark-red, soft-mud, sanded. About 25 percent contained frogs with the raised letters "Homewood." Made in Baltimore, Md., by the Baltimore Brick Co. Purchased from the Hydraulic Press Brick Co. Used in two walls and also in walls for structural tests; see BMS5.

Brick E.—Red, side-cut, surface clay. Very similar to Brick *B*. Made in Baltimore, Md., by the Baltimore Brick Co. Used in two walls sponsored by the Structural Clay Products Institute, Washington, D. C., and also in similar walls built for structural tests.[3]

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[2] Building Materials and Structures Report BMS5, Structural Properties of Six Masonry Wall Constructions.

[3] Building Materials and Structures Report BMS21, Structural Properties of a Reinforced Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute.

Brick F.—Red, soft-mud, sanded. Contains frogs having the raised letters "SSBCO." Made in Coeymans, N. Y., by the Sutton and Sudderly Brick Co. Used in one wall sponsored by the Brick Manufacturers Association of New York, Inc., and also in similar walls built for structural tests.[4]

Bricks G, H, J, and K.—Furnished by the Structural Clay Products Institute. Used in eight walls for the determination of the effects of cores in brick on permeability. Bricks *G* and *H* were cream, side-cut, fire-clay units made in Canton, Ohio, by the Belden Brick Co. Brick *G* were solid; brick *H* had 21 cored holes 0.56 in. in diameter. Bricks *J* and *K* were gray, side-cut, clay units with textured face and ends, made at Perla, Ark., by the Acme Brick Co. Brick *J* were solid; brick *K* contained three cored holes 1⅛ in. in diameter.

Brick L.—Red, side-cut, shale, with textured ends and face and with three 1¼-in. diameter cored holes; made at Redfield, Iowa, by the Redfield Brick and Tile Co. Used in two cavity walls sponsored by the Structural Clay Products Institute.

Brick M.—Red, end-cut, shale unit of special shape containing five horizontal cored holes about 1 in. in diameter. Trade name, "Munlock Dry Wall Brick." Made at Winchester, Va., by the Colonial Brick Co. Used in eight walls sponsored by the Munlock Engineering Co., Washington, D. C., and also in walls for structural tests.[5]

Brick N.—Yellowish-pink, side-cut, fire-clay brick of H-shape. Heavy vertical scores on one edge and light vertical scores at the four ends. Contained six ⅝-in. diameter vertical cored holes. Used in four walls sponsored by the Whitacre-Greer Fireproofing Co., Waynesburg, Ohio.

Bricks O and P.—Red, side-cut, shale, hollow, of special shapes and of various sizes. Trade name, "Speedbrik." Used in nine walls sponsored by the General Shale Products Co., Johnson City, Tenn. Brick *O* was made at Kingsport, Tenn.; brick *P* was made by the

[4] Building Materials and Structures Report BMS23, Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick Manufacturers Association of New York, Inc.

[5] Building Materials and Structures Report BMS53, Structural Properties of a Masonry Wall Construction of "Munlock Dry Wall Brick" Sponsored by the Munlock Engineering Co.

Table 1.—*Physical properties of the bricks*

Designation	Average dimensions [a]			Average dry weight	Absorption by total immersion			Saturation coefficient, C/B	Absorption [b] by partial immersion, flat, 1 minute	Time required for total penetration by capillary action			Modulus of rupture gross area	Compressive strength gross area
	T	*W*	*L*		5-hr cold	24-hr cold, *C*	5-hr boil, *B*			Flat	Edge	End		
	in.	*in.*	*in.*	*lb*	%	%	%		*g*		*hr*	*hr*	*lb/in.*²	*lb/in.*²
A	3.8	8.1	2.3	5.8	1.6	1.9	3.5	0.53	10	5.2	30.0	------	2,270	17,640
B [c]	3.8	8.1	2.3	5.0	8.7	9.4	13.4	.70	33	0.8	7.9	23.0	820	5,360
C [c]	3.9	8.1	2.3	5.0	14.2	14.6	16.9	.86	112	.1	0.3	1.7	250	3,080
D	3.7	8.0	2.2	4.5	10.2	11.3	15.1	.74	25	1.0	2.0	11.0	550	2,670
E	3.8	8.0	2.3	4.8	9.5	10.2	14.7	.69	38	0.7	6.0	23.0	830	5,160
F	3.7	8.1	2.3	4.1	13.4	13.8	18.7	.74	42	.6	1.4	6.5	540	3,240
G	3.7	8.1	2.2	5.4	5.1	5.4	7.8	.69	12	1.5	8.6	25.2	1,550	9,330
H	3.7	8.1	2.2	4.1	2.9	3.3	6.0	.54	6	4.8	50.0	------	900	11,575
J	3.9	8.2	2.3	4.9	8.5	9.3	13.5	.68	31	0.1	2.6	18.6	1,040	5,340
K	3.7	8.0	2.2	4.2	6.0	6.8	13.4	.54	27	.1	2.8	47.0	980	6,550
L	3.8	8.0	2.2	4.6	2.6	3.5	7.6	.44	9	.1	118.0	------	1,240	10,660
M	8.0	2.2	7.9	9.5	1.5	1.6	1.9	.73	3	1.4	------	------	1,720	4,460
N	7.9	8.1	2.3	7.3	7.2	7.4	8.5	.87	16	0.8	70.0	75.0	550	7,750
O	7.9	12.0	2.8	12.3	------	3.6	6.6	.55	20	------	------	------	------	(d)
P	7.9	11.9	2.7	12.9	------	1.5	2.8	.51	6	------	------	------	------	(d)
R_1	3.7	(e)	2.2	4.0	3.5	4.2	6.5	.64	7	.3	161.0	------	1,360	10,340
R_2 [c]	3.7	7.9	2.2	4.4	1.3	2.1	4.7	.45	3	.8	------	------	1,690	14,180
R_3 [c]	3.8	(f)	2.2	4.4	4.3	4.9	6.6	.73	5	.8	41.0	------	910	12,080
U	3.7	8.1	2.2	5.1	4.8	5.3	9.3	.56	30	.3	24.0	------	830	7,690
V	3.7	8.1	2.2	4.31	8.18	8.98	15.07	.59	32	.2	1.2	------	746	4,237
W	3.3	7.9	2.2	3.93	3.00	4.02	9.82	.38	4	.15	10.6	------	1,319	6,028
X	3.7	8.0	2.2	4.39	8.22	9.11	15.83	.57	35	.3	1.2	5.9	646	3,510

[a] *T*=wall thickness, as laid.
L=length parallel to cores, or height in course for solid units.
[b] Based on an equivalent area of 30 sq in.
[c] Average values for 2 shipments in same kind of unit.
[d] Over 6,500 lb/in.²
[e] Face, 7.60 in.; back, 7.92 in.
[f] Face, 7.92 in.; back, 8.09 in.

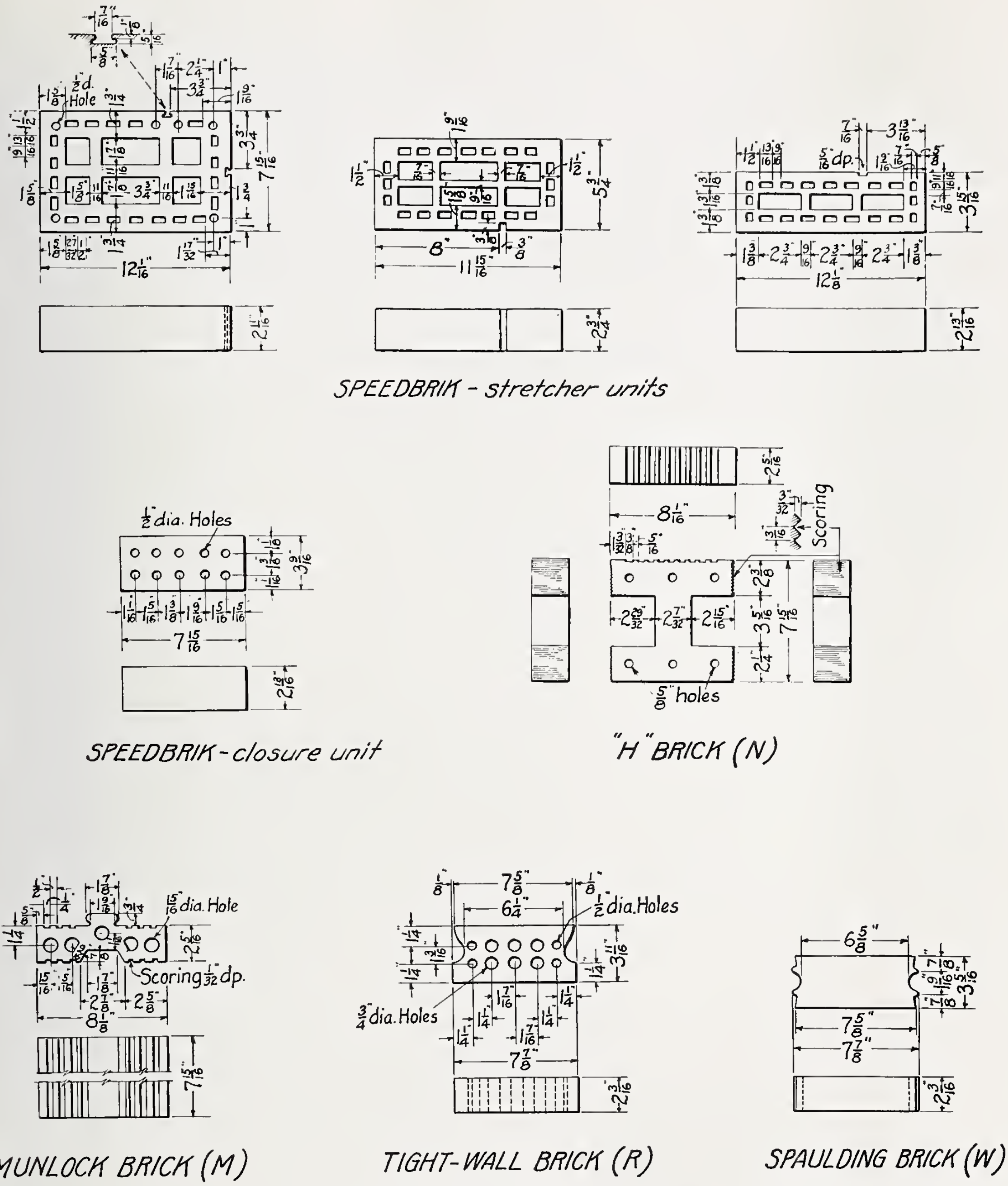

FIGURE 2.—*Details of bricks of special shapes.*

Claycraft Co., Columbus, Ohio. The physical properties of a 6- by 12- by 2.7-in. unit also made in Kingsport, Tenn., and used in three walls, were similar to those of the 8-inch brick *O* listed in table 1.

Bricks R_1, R_2, R_3, and U.—Used in three walls sponsored by the Puddington Sales Corporation, New York, N. Y. Bricks R_1, R_2, and R_3 were side-cut, fire-clay units. The stretcher brick had recessed ends and the header brick were recessed on the sides. Trade name, "Tight-Wall Brick." Brick R_1 was cream-colored, contained six ¾-in. diameter and four ½-in. diameter cored holes, and was made at East Sparta, Ohio, by the U. S. Quarry Tile Co. Bricks R_2 and R_3 were respectively gray and

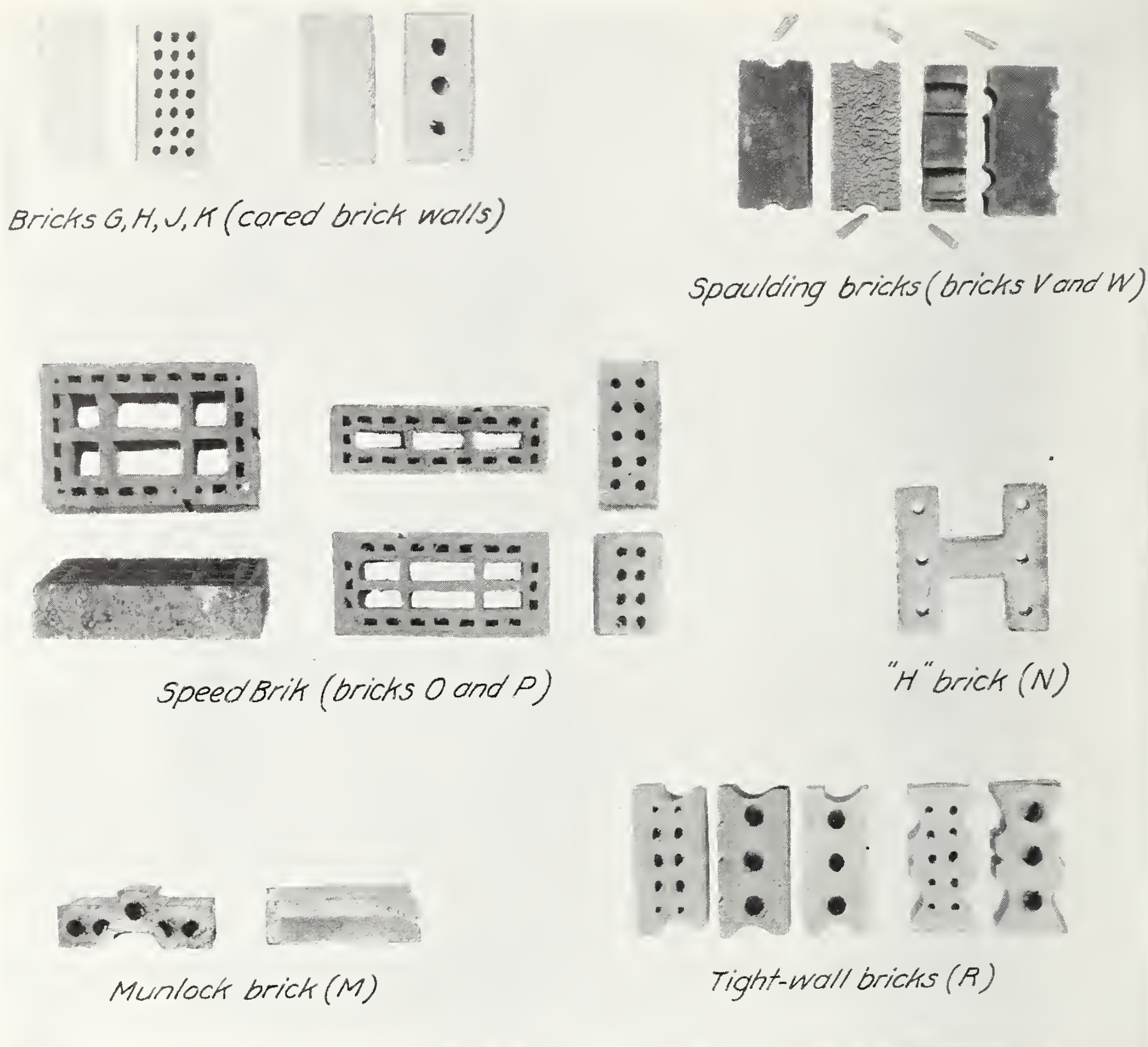

FIGURE 3.—*Bricks of special shapes.*

salmon-pink in color and each contained two cored holes 1$\frac{3}{16}$ in. in diameter and one cored hole 1 in. in diameter. They were made at Midvale, Ohio, by the Evans Brick Co. Brick *U* were red side-cut, clay, common brick, used as backup for the walls. They were made at Bladensburg, Md., by the United Clay Products Co.

Bricks V, W, and X.—Used in four walls sponsored by W. H. Spaulding, Long Island, N. Y. Bricks *V* and *W* were red, soft-mud, sand-struck, with recessed ends. Headers were also of special shape. Brick *V* was made at New Oxford, Pa., by the Allwine Brick Co. Brick *W* was made at the Glenhead, Long Island, N. Y., plant of the Post Brick Co. Brick *X* were red, soft-mud, sand-struck, regularly shaped units. They were made by the Allwine Co. at New Oxford, and were used for backup. The absorptive properties of bricks *X* and *V* were similar.

(*b*) *Structural clay tiles*

The structural clay tiles were used principally as backing units. Their physical properties are given in table 2; detailed measurements and photographs are shown in figures 4, 5, and 6.

The tiles were designated by lower-case letters, and their characteristics and use are listed below:

Tile d.—Double-shell, hard. Stretchers were 6-cell, end-bearing. Bonding units were 4-cell, side-bearing. Used as backing units in two walls.

Tile e.—Side-construction, stretchers were 3-cell and bonding units were 4-cell. Used as backing units in three walls.

Tile f.—Speed-a-backer, hard, side-bearing. Used as backing unit in two walls.

Tile g.—Raritile, end-bearing. Both the stretcher and the bonding units were 4-cell. Used as backing units in two walls.

Tile j.—Standard tile, end- or side-bearing. Used in two walls without facings, as a backing unit in one wall, and in walls (without facings) for structural tests; see BMS5.

Tile k.—Double-shell, soft. Stretchers were 6-cell, end-bearing. Bonding units were 3-cell, side-bearing. Used as backing units in five walls.

Tile l.—Speed-a-backer, soft, side-bearing. Used as backing units in six walls.

TABLE 2.—*Physical properties of structural clay tile*

[Properties of the stretcher units are given in the first line, those of bonding units, if any, are given in the second line]

Designation	Exterior dimensions			Thickness of face shell	Dry weight	Absorption by 24-hr cold immersion, *C*	Absorption by 1-hr boil, *B*	Saturation coefficient *C/B*	Weight per square foot of wall area	Compressive strength		Face shell immersed in ⅛ in. of water			
	T	*W*	*L*							Net area	Gross area	Absorption, 3 minutes	Capillary rise in first hour	Time required for capillary rise through unit	
	in.	*in.*	*in.*	*in.*	*lb*	%	%		*lb*	*lb/in.*²	*lb/in.*²	*g/cm* ²	*in.*	*in.*	*hr*
d	8.2	12.2	10.6	0.71	34.7	10.0	12.5	0.80	38.4	6,280	2,650	0.10	1.8	8.2	84
	8.0	5.0	11.9	.62	14.6	5.1	7.6	.67	35.7	3,290	1,520	.01	1.2	7.5	154
e	7.9	5.0	12.0	.61	17.3	4.2	6.1	.67	41.7	7,290	2,070	.02	2.3	4.7	168
	3.8	5.0	12.0	.52	10.1	4.3	5.8	.72	23.3	6,910	2,490	.02	1.7	3.1	116
f	7.6	7.6	11.8	.66	22.1	1.2	3.2	.37	35.8	2,830	730	.01	2.0	2.6	168
g	8.0	12.1	7.8	1.16	27.8	10.4	14.0	.74	42.7	4,780	2,520	.16	3.0	8.0	11
	7.9	12.0	7.8	1.12	20.7	7.2	11.1	.64	25.8	5,390	2,820	.08	1.9	7.9	29
j	8.0	12.1	12.1	0.70	35.4	3.9	5.6	.67	34.8	(a)	(b)	.025	1.4	4.8	167
k	7.9	12.3	9.8	1.04	32.7	12.1	15.7	.77	39.3	4,950	2,590	.04	1.6	7.9	59
	8.2	5.3	12.3	1.00	16.9	17.7	21.2	.84	37.7	-----	-----	.17	2.0	8.2	29
l	7.9	7.8	12.0	0.81	22.3	18.4	19.5	.95	34.5	3,370	1,150	.35	2.7	7.9	18
p	8.0	12.1	7.6	1.49	26.6	11.4	14.7	.77	42.0	4,690	2,500	.14	2.2	8.0	12
	7.8	11.8	7.5	1.44	20.9	4.8	7.9	.60	34.0	4,360	2,330	.03	1.7	6.3	128
q	3.5	5.0	11.8	0.99	10.4	1.5	2.4	.64	25.7	11,680	3,380	.01	1.8	1.9	168
s_1	8.0	7.7	16.1	.57	37.5	2.0	2.3	.86	43.3	9,390	2,450	.01	1.2	1.5	168
s_2	8.0	5.0	11.9	.56	18.9	3.6	4.1	.87	45.3	9,670	2,470	.03	1.4	2.1	168
s_3	8.0	5.0	12.0	.52	18.7	2.9	3.2	.91	45.4	12,900	3,130	.02	1.2	3.2	168

[a] End bearing, 9,510; side bearing, 8,230.
[b] End bearing, 3,540; side bearing, 1,590.

TABLE 3.—*Physical properties of concrete units*

Designation	Exterior dimensions			Thickness of face shell	Weight			Absorption by 24-hr cold immersion		Compressive strength		Face shell immersed in ⅛ in. of water			
	T	*W*	*L*		Dry	Per cubic foot of concrete	Per square foot of wall area			Net area	Gross area	Absorption, 3 minutes	Capillary rise in first hour	Time required for capillary rise through unit	
	in.	*in.*	*in.*	*in.*	*lb*	*lb*	*lb*	%	*lb/ft* ³	*lb*/in.²	*lb/in.*²	*g/cm* ²	*in.*	*in.*	*hr*
m	7.8	11.5	7.7	1.25	29.4	129	48.1	7.9	10.1	2,050	1,190	0.63	4.6	7.7	50
n	8.1	11.9	7.7	1.30	24.2	88	37.7	16.1	14.0	1,560	1,000	.17	-----	4.8	120
v	(a)	11.8	8.0	(b)	29.1	126	44.2	7.0	8.3	2,240	930	.09	-----	0.7	0.5
w	2.3	[c] 12.4	8.1	(b)	13.9	125	-----	7.4	9.7	[d] 2,100	[d] 1,730	-----	-----	-----	-----
x	4.0	23.8	7.7	0.50	22.7	88	[e] 17.8	14.4	12.7	970	530	.47	2.3	3.7	78

[a] Top, 8.5; bottom, 9.0.
[b] Face shell indented on inside—maximum thickness 2.25 in., minimum thickness 0.67 in.
[c] Indented concrete slabs, similar to those used in the fabricated unit v; also made in 4- and 8-in. widths.
[d] Slab loaded on edge, 8-in. dimension vertical.
[e] Weight of wall 1 unit or wythe in thickness.

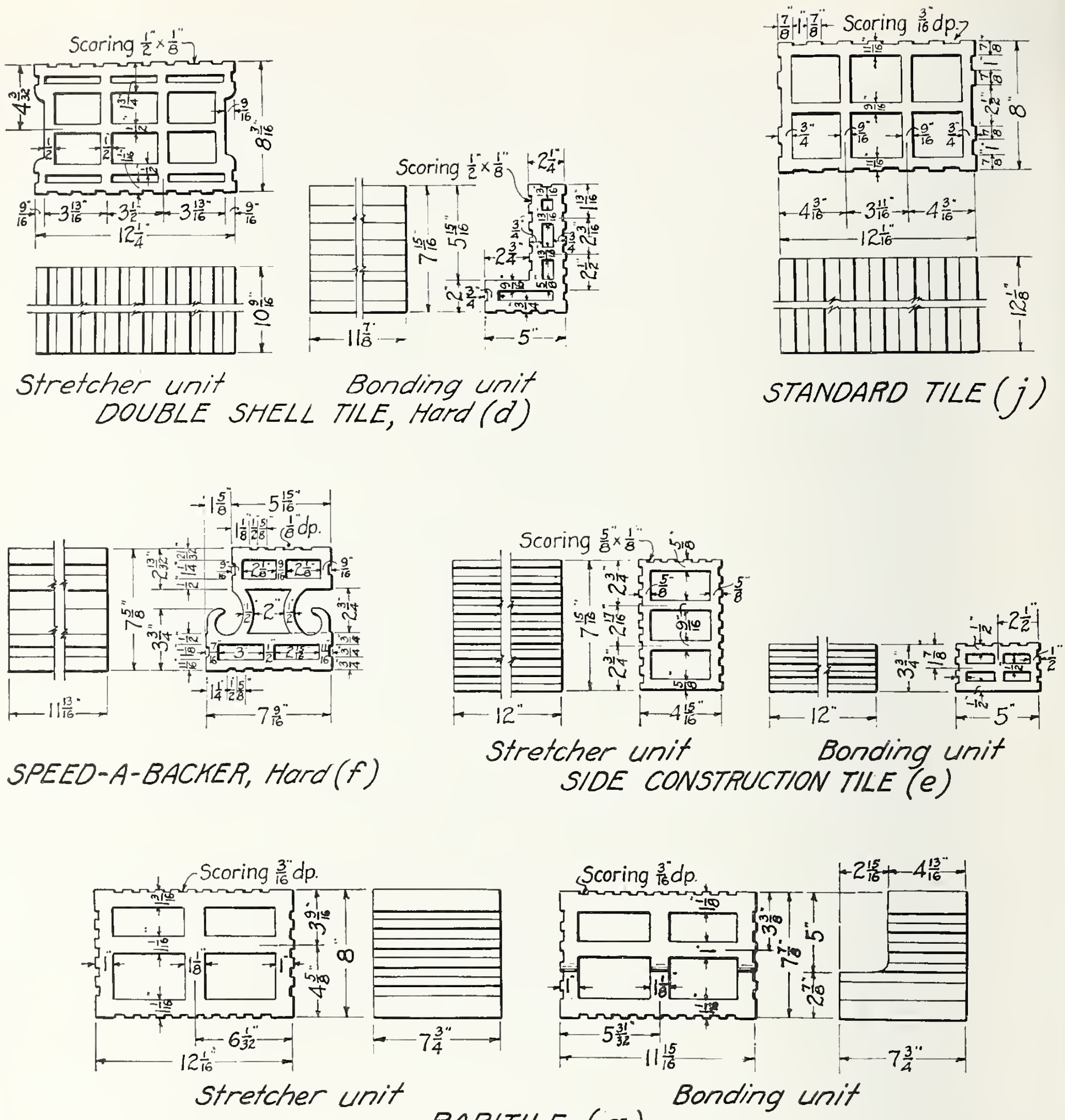

FIGURE 4.—*Details of structural clay tiles.*

Tile p.—End-bearing tile, similar to those used in the Harlem Housing project. Both stretcher and bonding units were 2-cell. Used as backing units in two walls.

Tile q.—Double-wall tile, side-construction, single-cell. Made at Redfield, Iowa, by the Redfield Brick and Tile Co. Used in two cavity walls sponsored by the Structural Clay Products Institute, in which the cavities were filled with Palco wool.

Tiles s_1, s_2, *and* s_3.—These tiles were side-bearing units of special shape, known as "Dri-speedwall" tile. Used without brick facings in three walls sponsored by the National Fire-proofing Co. Tiles s_1 and s_3 were salt-glazed. The finish on tile s_2 is known as manganese-spot.

(c) *Concrete units*

The concrete units included two kinds of concrete blocks purchased under Federal specification, two kinds of sponsored blocks of special shapes, and one sponsored unit consisting of flat slabs of different sizes. Their physical properties are given in table 3; photographs and detailed measurements are shown in figures 6 and 7.

The concrete units were designated by lowercase letters and their characteristics and use are listed below.

Block m.—Stone concrete, 2-cell, end-bearing. Purchased under Federal Specification SS–C–621, type I, load-bearing. Used in three walls with brick facings, in one wall without a facing, and in walls (without facings) for structural tests; see BMS5.

Block n.—Cinder concrete, 2-cell, end-bearing. Purchased under Federal Specification SS–C–621, type I, load-bearing. Used in five walls with brick facings.

Block v.—Two stone-concrete slabs connected

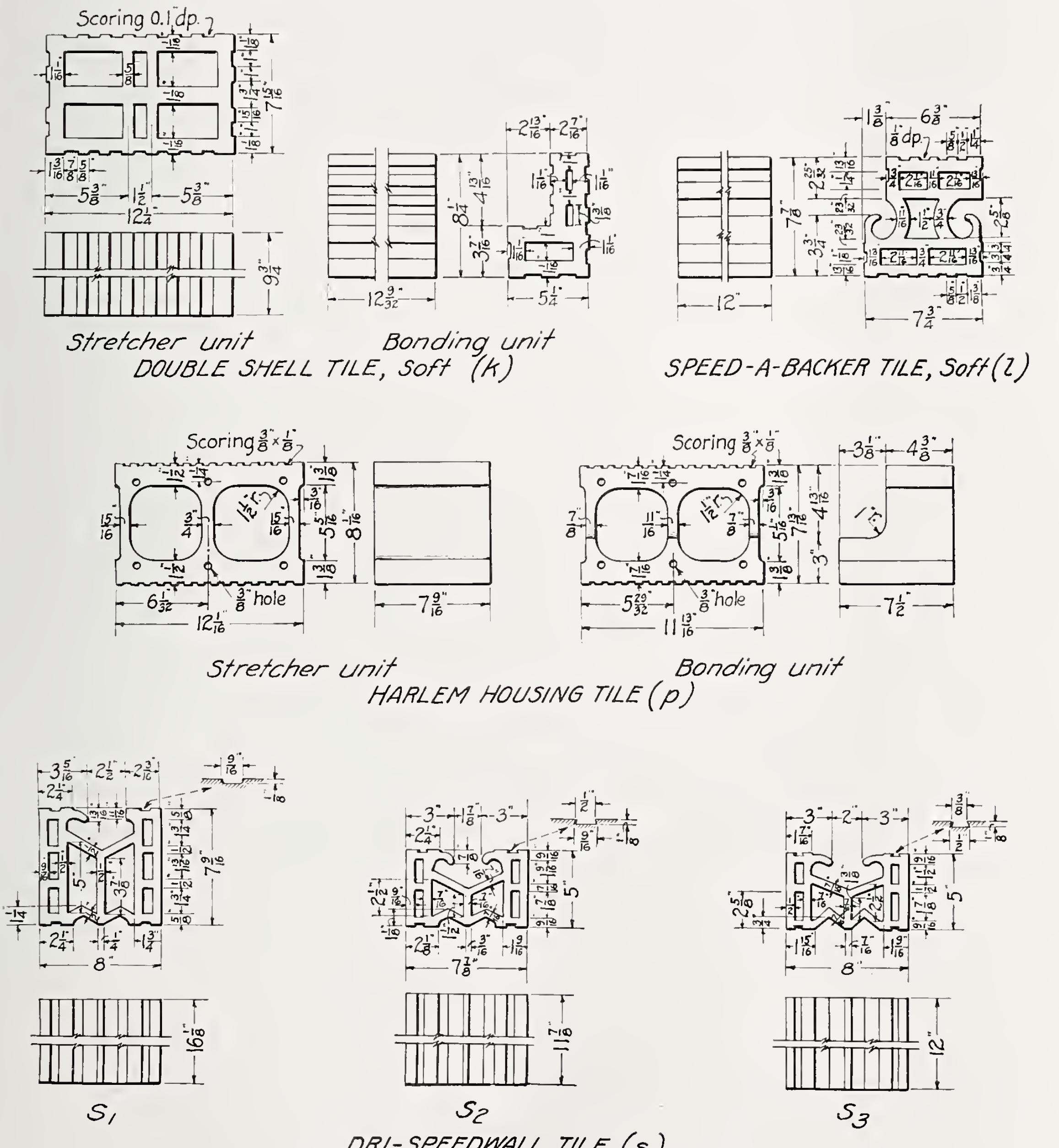

FIGURE 5.—*Details of structural clay tiles*

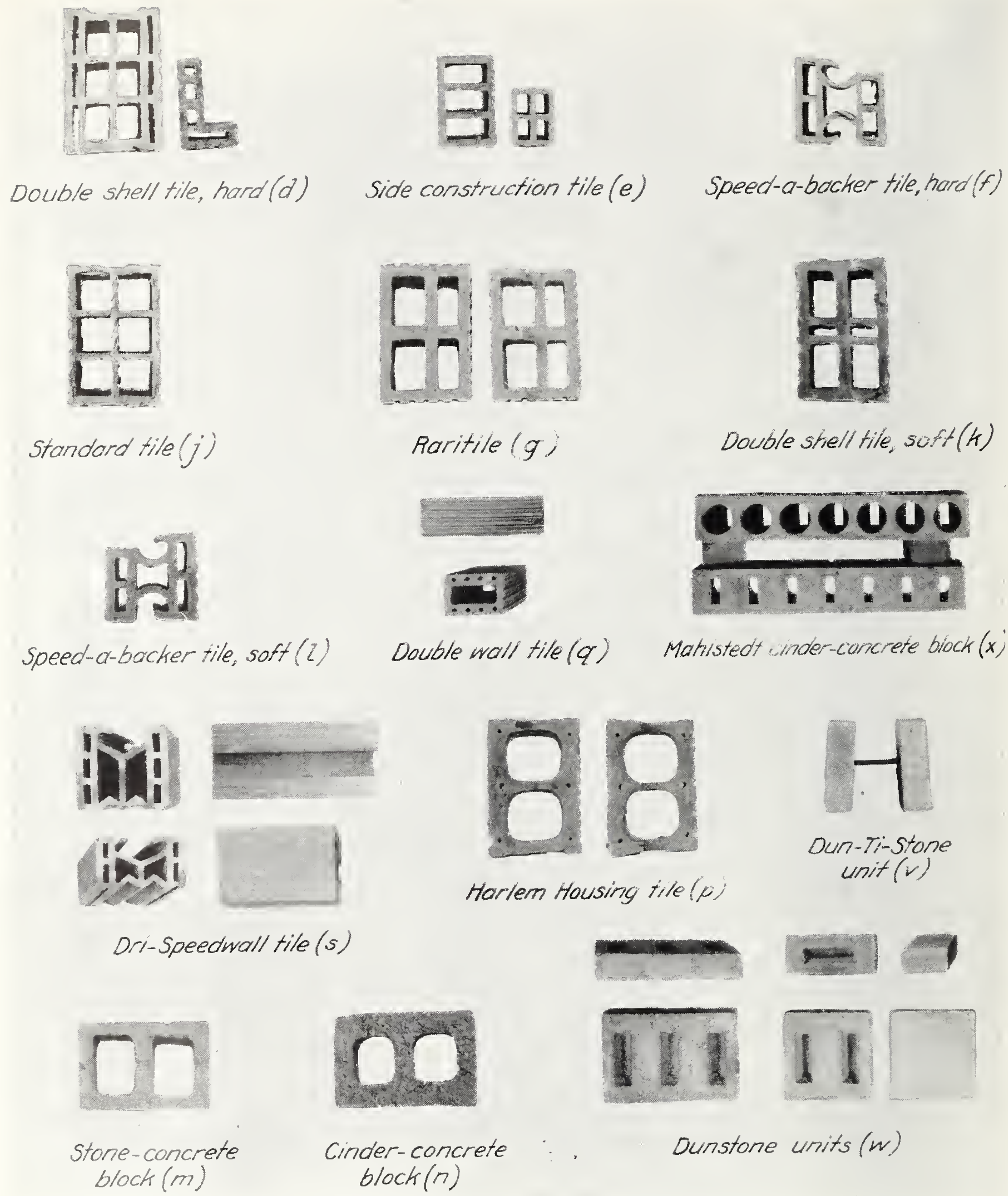

FIGURE 6.—*Structural clay tile and concrete units.*

by a ½-in. diameter, Z-shaped, deformed steel reinforcement bar. Slabs were made on a Dunbrik machine of concrete containing 1 part of portland cement to 8 parts of bank sand (passing No. 4 sieve) by volume. Bars fastened to slabs by a mortar containing 1 part of cement to 3 parts of sand by volume. One of the two shells of each unit was inclined from the vertical. Trade name of fabricated block, "Dun-ti-stone." Used in one wall, sponsored

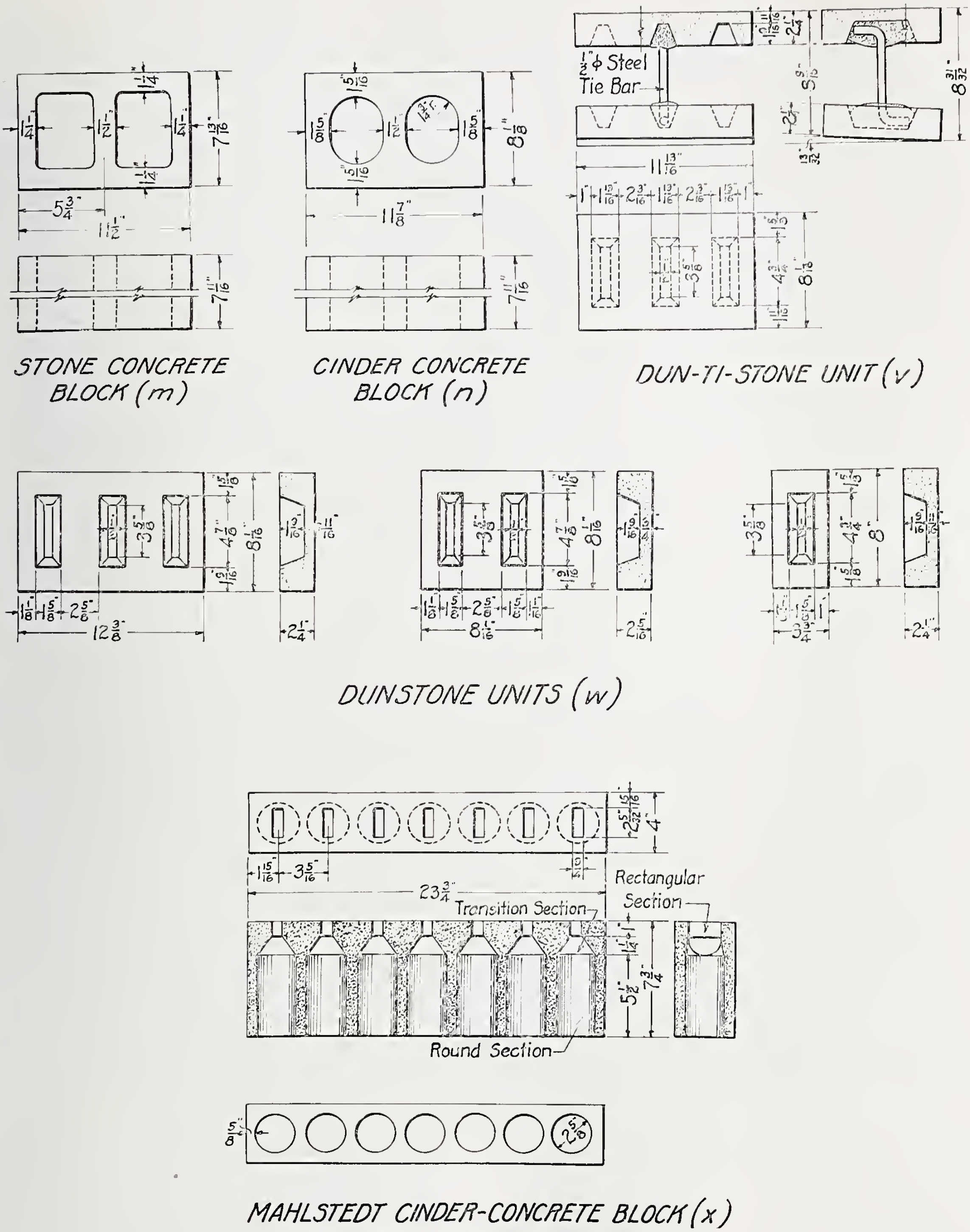

FIGURE 7.—*Details of concrete units.*

by the W. E. Dunn Manufacturing Co., Holland, Mich., and in similar walls for structural tests.[6] The block were made by the Silver Hill Brick Corporation, Silver Hill, Md.

Unit w.—Flat, stone-concrete slabs, similar to and made of the same kind of concrete as

[6] Building Materials and Structures Report BMS22, Structural Properties of "Dun-ti-stone" Wall Construction Sponsored by the W. E Dunn Manufacturing Company.

that used in slabs for block *v*. Made in three nominal widths, 4, 8, and 12 in. Trade name, "Dunstone." Used in four walls sponsored by the W. E. Dunn Manufacturing Co. and in similar walls for structural tests. [7]

Block x.—Cinder-concrete, with cored holes, end-bearing. Manufactured by the Mahlstedt Materials, Inc., New Rochelle, N. Y. Used in one wall similar in construction to those built for structural tests, sponsored by the National Concrete Masonry Association.[8]

(*d*) *Mortars*

The sand used in all of the 10 mortars was washed Potomac River building sand, obtained from the Smoot Sand and Gravel Company, Washington, D. C. A sieve analysis, made from each consignment of sand, is given in table 4. The difference in gradation of the sands was probably not a significant factor in the permeability of the walls.

The cementing material in nine mortars was a mixture of portland cement and lime; that used in one mortar was a masonry cement. Two mortars contained waterproofed portland cement, five contained lime hydrates, and four contained a lime putty made by slaking a pulverized quick lime. The kinds of cementing materials used and the proportions, consistencies, and water retentivities [9] of the mortars are given in table 5. Mortar 2, similar to mortar 2 described in BMS7, was used in a total of 100 wall specimens. Mortars 1, 2, or 5 were used in walls built for the Bureau, and the other mortars were specified by sponsors of walls built of special units. Mortar 6 was used with H-brick, mortars 7, 8, and 12 with "Speedbrik," mortars 9 and 10, as well as mortar 2, with "Munlock" brick, and mortar 11 was used with "Spaulding" brick. All of the portland cements and the masonry cement used in the mortars were tested and found to pass the physical requirements of Federal specifications.

The materials for the mortars were proportioned by weight and mixed in a batch mixer having a capacity of about 0.6 cu ft. When only one mason was employed, mortar batches were prepared every 20 to 40 minutes. The amount of water added to the mix was kept in adjustment to the satisfaction of the mason, and the desired amount used in any one kind of mortar was found to vary with the absorptive properties of the bricks or with sand gradation. It is evident from table 5 that the mason was satisfied to use a lower initial flow for the richer mortars, mortars 6 and 11, than for the leaner mixes. A determination of the flow and of the water retentivity of the mortars was made at least once each day, and it was found that changes in the water content of a mortar did not greatly affect the water retentivity.

TABLE 4.—*Sand sieve-analyses*

Sand purchased by—	Weight passing U. S. Standard-Sieve No. —				
	8	16	30	50	100
	%	%	%	%	%
United States Government [a]	100	96	81	19	2
Structural Clay Products Institute	100	96	82	24	2
National Concrete Masonry Association	100	96	81	25	2
Brick Manufacturers Association of New York, Inc	100	88	53	9	1
W. E. Dunn Mfg. Co	100	98	81	23	3
General Shale Products Corp	100	96	73	18	2
Munlock Engineering Co	100	88	61	21	3
United States Government	99	88	58	11	1
Structural Clay Products Institute	100	92	65	14	2
United States Government	100	91	64	23	4
Average	100	93	70	19	2

[a] About three-quarters of the walls were built with mortar made from this sand.

(*e*) *Grout*

The grout used in all but one of the grouted walls was made by adding water to mortar 2, the total amount of water in the grout being equal to about one-third the weight of the dry materials. The grout used with brick *E* in a wall sponsored by the Structural Clay Products Institute was mixed in the proportions, by weight, of 1:0.06:1.45:0.63 parts, respectively, of portland cement, hydrated lime, building sand, and water.

(*f*) *Metal ties*

The wythes of walls built without header brick or bonding units were connected with metal ties. The ties used in all but one wall were ¼-in. diameter steel rods bent to a Z-shape with an angle of 90 degrees between the out-

[7] Building Materials and Structures Report BMS 38, Structural Properties of Two "Dunstone" Wall Constructions Sponsored by the W. E. Dunn Manufacturing Company.

[8] Building Materials and Structures Report BMS21, Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association.

[9] Determined according to Federal Specification SS-C-181b.

TABLE 5.—*Proportions, consistencies, and water retentivities of mortars*

Mortar	Proportions of cement, lime hydrate, and sand[a]		Kind of cement[b]	Kind of lime[c]	Water content by weight of dry materials			Average initial flow[d]	Average water retentivity[d]	Number of walls built of each mortar
	By volume	By weight			Min	Max	Avg			
					%	%	%	%	%	
1	1:0.25:3	1:0.11:2.6	Atlas p. c.	Putty	19.7	20.2	20.0	115	72	3
2	1:1:6	1:0.42:5.1	do	do	20.5	24.4	23.0	105	81	100
5	1:1:6	1:0.42:5.1	do	Berkeley	20.2	22.3	21.3	131	43	14
6	1:1:5	1:0.42:4.2	Medusa p. c.	Putty	22.5	22.5	22.5	90	86	4
7	1:0.3:0.15[e]:3.4	1:0.13:0.13[e]:2.9	Medusa w. p. p. c.	Standard	19.5	19.5	19.5	116	60	4
8	1:1:0.6[e]:5.9	1:0.42:0.51[e]:5.1	do	Putty	21.2	21.8	21.5	97	89	2
9	1:1:6	1:0.42:5.1	Atlas p. c.	Standard	20.8	20.8	20.8	111	55	4
10	1:0:3	1:0:3.4	Hy-test m. c.		14.9	14.9	14.9	100	65	2
11	1:1.5:5	1:0.64:4.3	Atlas p. c.	Miracle			18.7	78	89	4
12	1:1:6	1:0.42:5.1	Greenbag p. c.	Grove	21.1	21.1	21.1	119	64	3

[a] Proportioning was by weight, assuming that portland cement weighed 94 lb/cu ft, hydrated lime 40 lb/cu ft, and that 1 cu ft of loose damp sand contained 80 lb of dry sand. (Hy-Test masonry cement was assumed to weigh 70 lb/cu ft.)
[b] p. c. denotes portland cement.
w. p.-p. c. denotes integrally waterproofed portland cement.
m. c. denotes masonry cement.
All the cements met the physical requirements of Federal Specifications.
[c] All the putty was made from Standard Lime and Stone Company's "Washington" brand, powdered quicklime. Other limes were dry hydrates.
[d] Determined according to Federal Specifications SS–C–181b.
[e] Limestone dust, "Cameline" brand, H. T. Campbell Sons Co.

standing legs and the stem. The length of stem was 6 in. and of the outstanding legs 3 in. The ties used to bond a cavity wall built of "Mahlstedt" cinder block were made of 3/16-in. diameter steel wire bent to the shape of a rectangle with outside dimensions of 4 by 6 in.

In addition to metal ties, 3/8-in. round steel reinforcement bars were placed in the collar joint of one grouted wall.

3. Construction of the Walls

(*a*) *Procedure*

All of the walls were built by skilled masons under the direction of a representative of the National Bureau of Standards or of the sponsor for the walls. During their construction the brick-suction [10] was determined and recorded at intervals of 30 to 40 minutes. When necessary to meet predetermined limits for the amount of suction, the brick were wetted by immersion in water before laying, but no brick were laid while so wet that water was visible on their surfaces. Usually no water was visible on the surfaces of the brick 30 minutes or less after their removal from the bath, especially if the brick were stacked so as to permit the circulation of air. The joints in the face of some of the walls were tooled with a rounded steel bar, and whenever possible the tooling of the joints was done after the mortar had stiffened. The walls were completed on the same day their construction was started, and they were aged for at least 28 days indoors at a temperature of 70° F or higher before being tested.

(*b*) *Designation of specimens*

As the walls were built, they were given consecutive numbers with the prefix B, to identify them as having been constructed subsequent to those described in BMS7. The walls were further identified by the following designation: The first two letters designated, respectively, the kind of units used in the facing and the backing. This was followed by the numeral indicating the nominal thickness of the wall in inches, and by a capital letter designating the type of workmanship. The last numeral gave the kind of mortar used. For example, wall B43, 12 in. thick, built of class F workmanship, using brick *B* for facing units and tile *f* as backing units, with mortar 2, was designated: Wall B43–*Bf*12F2.

(*c*) *Kinds of workmanship*

The workmanships differed in the manner in which the joints were filled with mortar, or in the extent to which the vertical joints were filled. When header brick were used, they were laid in common American bond. Metal ties, when used, were usually placed 24 in. apart in every sixth course and at least 1/2 in. from the

[10] The "brick-suction" is defined as the amount of water, in grams, absorbed by a brick (30 sq in.) placed on the flat side in water to a depth of 1/8 in. for 1 minute.

FIGURE 8.—*Brick wall of workmanship A′.*

The bed joints are furrowed and vertical joints are completely filled. Note the mortar on the stretcher brick, which is ready to be placed in one of the backing wythes after the bed joint is placed.

nearest head joint. The method of bonding the units in sponsored walls was specified by the sponsor. The workmanships were arbitrarily designated by capital letters and the different types are described below.

Type A.—Workmanship A was used in many walls described in BMS7. For the brick walls, mortar in the bed joints was spread and leveled to a uniform thickness, not furrowed. The head joints were filled and were formed by applying the mortar to the ends of stretcher brick or to the sides of header brick before placing them in the wall. The collar joints were filled with mortar and, when necessary, filling of the vertical joints was completed course by course by slushing in mortar from above. The technique employed in filling the vertical joints varied slightly with different masons or even in different walls built by the same mason. Joints in the wall facing were tooled with a rounded iron bar, which formed a concave surface.

The contiguous surfaces of adjacent hollow masonry units were mortared. Mortar was spread evenly over the flat surfaces of the bed joints and was applied to both the inner and outer shells of the end-bearing units. Head joints between hollow units were made by covering all the surfaces at one end of each unit before placing it in the wall. Collar joints were made in the same manner, but it was not practicable to complete the filling of vertical joints between large units by slushing mortar from above.

Workmanship A was used in 25 all-brick walls, in 3 brick-faced walls, and in 3 walls built of hollow masonry units, without facings.

Type A′.—Illustrated in figure 8 is workmanship A′. This was used in 10 walls and was the same as type A, except that the bed joints, under the brick, were furrowed, not leveled. The joints in the wall face were tooled.

Type B.—Workmanship B was used in many of the brick masonry walls described in BMS7 and is typical of that usually employed in speculative building construction. Labor and mortar were used sparingly in walls constructed of this workmanship.

Mortar in the bed joints of brick walls was furrowed. Head joints were made by buttering the outer end portions of the brick, leaving the interior of the joints open. In 12-in. brick walls, the brick in the center wythes were laid on the furrowed bed without buttering the head joints. The collar joints between wythes were left open. The joints in the faces of the wall were cut flush with the surfaces of the brick, forming a rough texture.

Only the face shells of hollow units were provided with mortar beds, and the head joints were made by buttering the edges of the unit that were exposed in the face of the wall.

Type B was also used to designate the work-

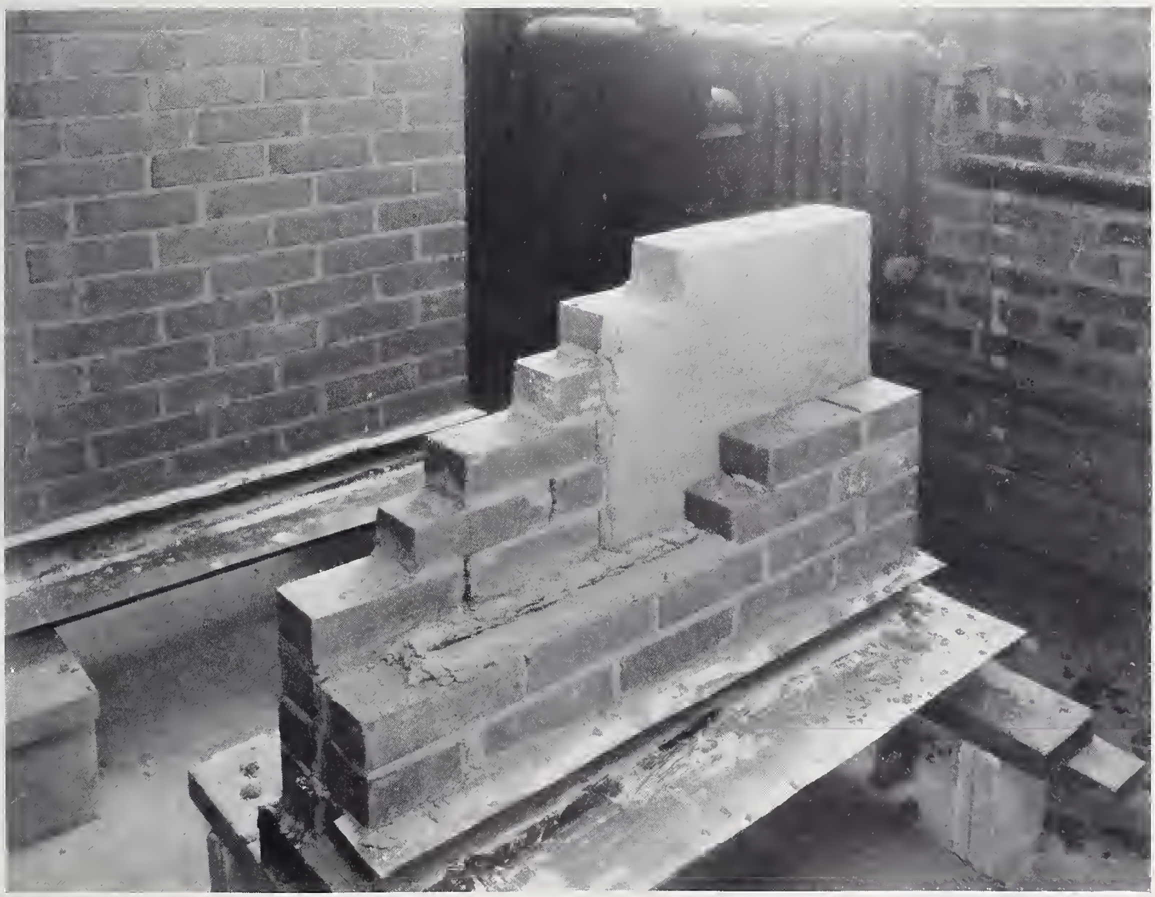

FIGURE 9.—*Brick wall of workmanship F.*

Except for the parging, this wall is typical of type B workmanship. Bed joints are furrowed and head joints are buttered at the wall faces. The parging is applied to the rear of the facing wythe before laying the backing wythe. This wall contains no header brick but is bonded by metal brick ties (not shown).

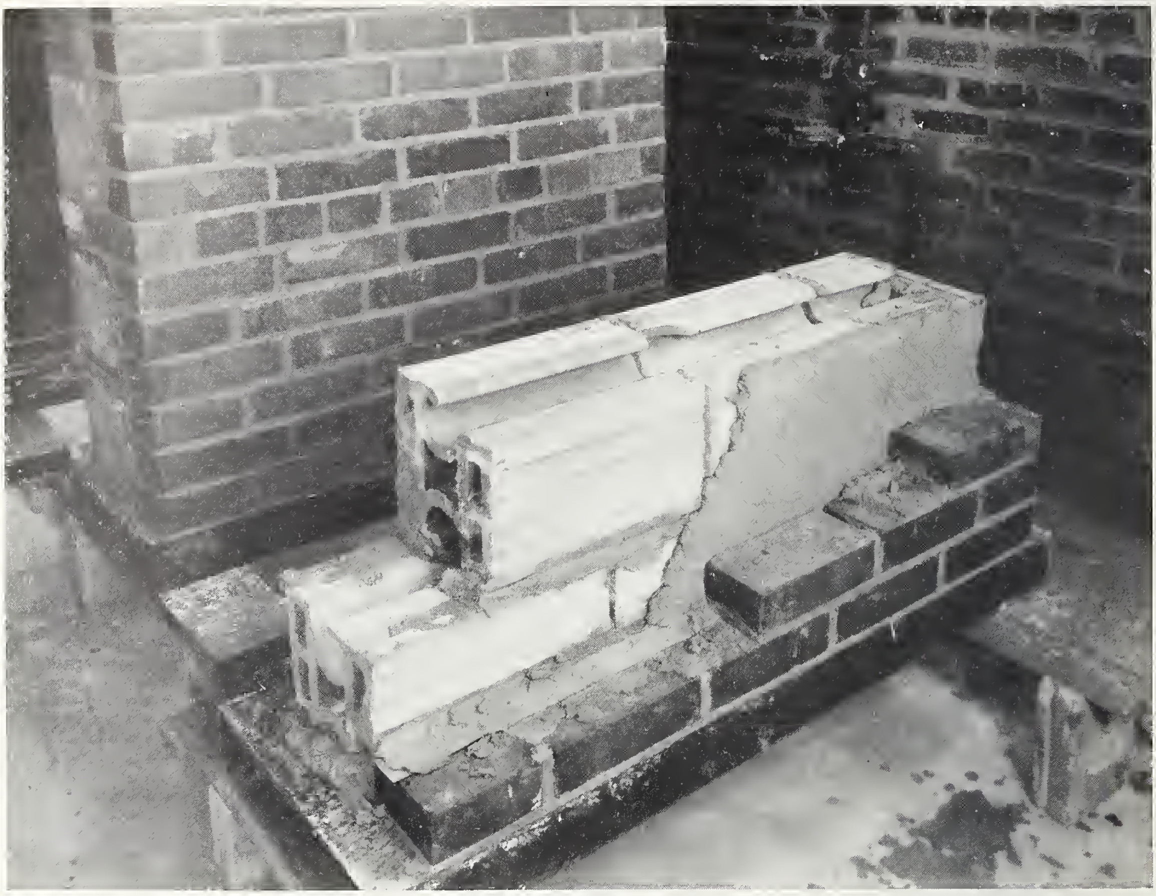

FIGURE 10.—*Brick-faced wall of workmanship G and G′.*

Parging applied to face of the backing. Head joints in both the hollow units and the brick are buttered only at the wall faces.

manship employed in some walls which were built of special units, and in which the interior of the joints or the interior of the wall was left open. Workmanship B was used in the construction of 30 walls.

Type F.—Workmanship F, illustrated in figure 9, was similar to that used in brick walls of workmanship B, except that the collar joints contained mortar pargings. The bed joints were furrowed, and the head joints were buttered at the wall faces. The stretcher courses in the facing were laid to the elevation of the header course or to that of the course containing brick ties. A mortar parging ⅜ to ½ in. thick was carefully applied to the back of the wythe and keyed into the open head joints. The units in the backing wythe were then brought to the elevation of the bonding course. If the wall contained three wythes, as in 12-in. all-brick walls, a mortar parging was similarly applied to the back of the second wythe. The width of the collar joint was such as to leave a narrow space between the parging and the faces of the units in the backing. Since the head joints in header brick were buttered at the edges placed in the wall face, and not completely filled, the continuity of the parging was broken in the vertical joints at each header course. Walls with brick facings, and backings of hollow units, were constructed by first laying the brick to the height of a header course. The backs of the brick were then parged and the backing wythe was laid as in workmanship B to the elevation of the header or bonding units. The joints in the wall face were tooled. Twenty-four walls were built of workmanship F.

Type F′.—Workmanship of type F′ was used in 11 brick walls with hollow-unit backings and was similar to that of workmanship F, except that the head joints between header brick were completely filled, not buttered. The vertical plane of the parging contained no open joints at the header courses.

Type G.—Workmanship G was used in three brick-faced walls backed with hollow units and is illustrated in figure 10. It was similar to that of type F, except that the parging in the collar joint was applied to the backing. The hollow units were laid to the elevation of the brick header courses, using workmanship B. Bed joints were placed under the outer shells of the hollow units, and the head joints were buttered only at the back of the wall. A mortar parging ⅜ to ½ in. thick was then applied to the backing, and the brick facing was laid as in workmanship B to the top of the header course. A narrow open space was left between the back of the bricks and the face of the parging. The head joints in header courses were buttered, not completely filled. The joints in the wall face were tooled.

Type G′.—The head joints between header brick in walls of workmanship G′ were completely filled, not buttered; otherwise this workmanship was similar to that of type G. Six brick-faced walls with backings of hollow units were built with workmanship G′.

Type H.—The letter H designates a workmanship used in building eight grouted brick walls. The method usually followed, and illustrated in figure 11, was to lay the brick as in type B workmanship, plugging the ends of the collar joints with mortar, after which a grout was poured as the brick were laid, one course at a time. The brick in the facing were sometimes laid several courses above the backing or to the height of the bonding course. When furrows in the bed joints were made close to

Figure 11.—*Brick wall of workmanship H, grouted.*

Wall B52-*BB*9H2 under construction. Note the mortar plugs at the ends of the collar joints and the buttered head joints. All the vertical joints were filled with grout as the backing was laid, one course at a time.

the collar joints to facilitate possible filling of the furrows with grout, it was noticed that the stretcher brick tipped slightly toward the collar joints.

The grouts, previously described, consisted either of mortar mixed with water to a pouring consistency, or else a special mixture higher in cement content was prepared. Both grouts stiffened readily, and they had to be stirred and sometimes tempered with additional water as they were used in the walls. One of the grouted walls (B129–*EE*9H1) contained deformed steel reinforcement bars placed in the collar joint. The face joints of grouted walls were tooled.

Type J.—Workmanship J was used in three brick walls built with common American bond. The brick in all the wythes were laid with furrowed bed joints, buttered head joints, and open collar joints, as in workmanship B. The vertical head and collar joints were then filled by slushing in mortar from above with the trowel. This procedure was repeated course by course. Joints in the face of the wall were tooled.

Type M.—Five walls of type M workmanship contained a 2-in. cavity between the wythes, which were connected by means of metal ties. Mortar for the bed joints was furrowed, and the head joints in the brick courses were filled or nearly filled by heavily buttering the ends of the brick. The head joints for the tile backings were buttered only on the outer edges. The cavity contained no projections except the metal ties, and the mortar joints inside the cavity were cut flush. During construction a timber was supported on the metal ties to catch the mortar droppings, thus preventing fouling of the bottom of the cavity. The flashings in these walls were

FIGURE 12.—*Brick-faced cavity wall, workmanship M.*

Note the brick ties and the cut joints inside the cavity. The head joints in the tile are buttered on back face only. This wall was constructed for structural tests but is typical, except for lower flashing, of cavity walls built for water-permeability tests.

placed to divert possible leakage to the backs of the walls, as is shown in figure 1, and not to divert leakage to the exposed faces, as is usually recommended in specifications for cavity walls. Joints of the brick facings were tooled. A typical cavity-wall construction (similar to that described in BMS24) is shown in figure 12.

Type S.—Workmanship S was used in two 12-in., all-brick walls laid in common American bond. C. W. Hammett, a masonry contractor of Washington, D. C., directed the construction of the walls.

The stretcher brick in the facing were laid in furrowed bed joints to the height of the header course. An excess of mortar was placed in the bed joints, so that after placing each brick, considerable mortar was extruded from the sides. This extruded mortar was cut off with a trowel and applied to the end of the next stretcher brick, which was then placed in the wall with a slight shoving motion, filling the head joint. Thus it was not necessary to obtain additional mortar from the board to completely fill the head joints. The back of the facing wythe in one wall (B118) was covered with a mortar parging about ⅜ in. thick.

The brick in the center wythe were laid by the pick-and-dip method. A full trowel of mortar was dropped in a heap in proper position on the bed. Simultaneously, with the other hand, a brick was picked from the pile and shoved into the mortar so as to form the bed joint and to fill the head joint and the collar joint. The mortar was usually extruded slightly above the top surface of the brick in both joints, and it was unnecessary to use the trowel except to place additional mortar for each brick in turn. No mortar was slushed into the head or collar joints if they were not completely filled. A 2- by 4-in. timber was braced vertically at one end of the center wythe to take the thrust of the shoving operation.

Stretcher brick in the backing wythe were laid in a furrowed bed and the head joints were filled, as in workmanship A′. Since extruded mortar from the bed joints was cut only from the back of the wall, it was necessary to obtain additional mortar from the board to completely fill these head joints. No attempt was made to fill the collar joint between the center and the backing wythes.

The header brick were laid in a furrowed bed. Head joints were completely filled by buttering the sides of the headers or, when necessary, additional mortar was slushed in from above. The collar joint between the facing and the center wythes at the elevation of the rear header course (over the center and the backing wythes) contained no mortar, except the thin parging applied to the back of the facing wythe in wall B118.

(*d*) *Construction of Sponsored Walls Built of Special Units*

"Tight-wall" bricks (Puddington Sales Corporation)

Workmanship N, illustrated in figure 13, was used in constructing three walls of "Tight-Wall" brick (bricks R_1, R_2, and R_3) laid in common American bond, with mortar 2. The bricks were recessed at the ends of stretcher units and at the sides of headers. The bed joints were furrowed, and the stretchers in the facing wythe were laid end to end on the bed joint without applying mortar to the ends of the units. Stretcher bricks R_1 and R_3 were about ⅜ in. longer at one face than at the other; and the long faces were laid in contact with each other at the back of the facing wythe, so that a ⅜-in. open joint was left at the head joints in the wall face. Stretcher brick R_2 were of equal lengths front and back and these brick were laid end to end, about ⅜ in. apart. The maximum width of aperture between stretcher units, measured parallel to the face of the walls, was about 1⅝ in. for brick R_1 (wall B300) and about 1⅞ in. for bricks R_2 and R_3 (walls B301 and B302, respectively). Mortar was slushed into the openings between the ends of the bricks, filling the space between the units. Header bricks were laid similarly, and both the front and rear cavities between the header bricks were filled with mortar.

Common brick of regular dimensions were used for backing. The collar joint was left open, and the backing stretchers were laid in furrowed beds and with buttered head joints

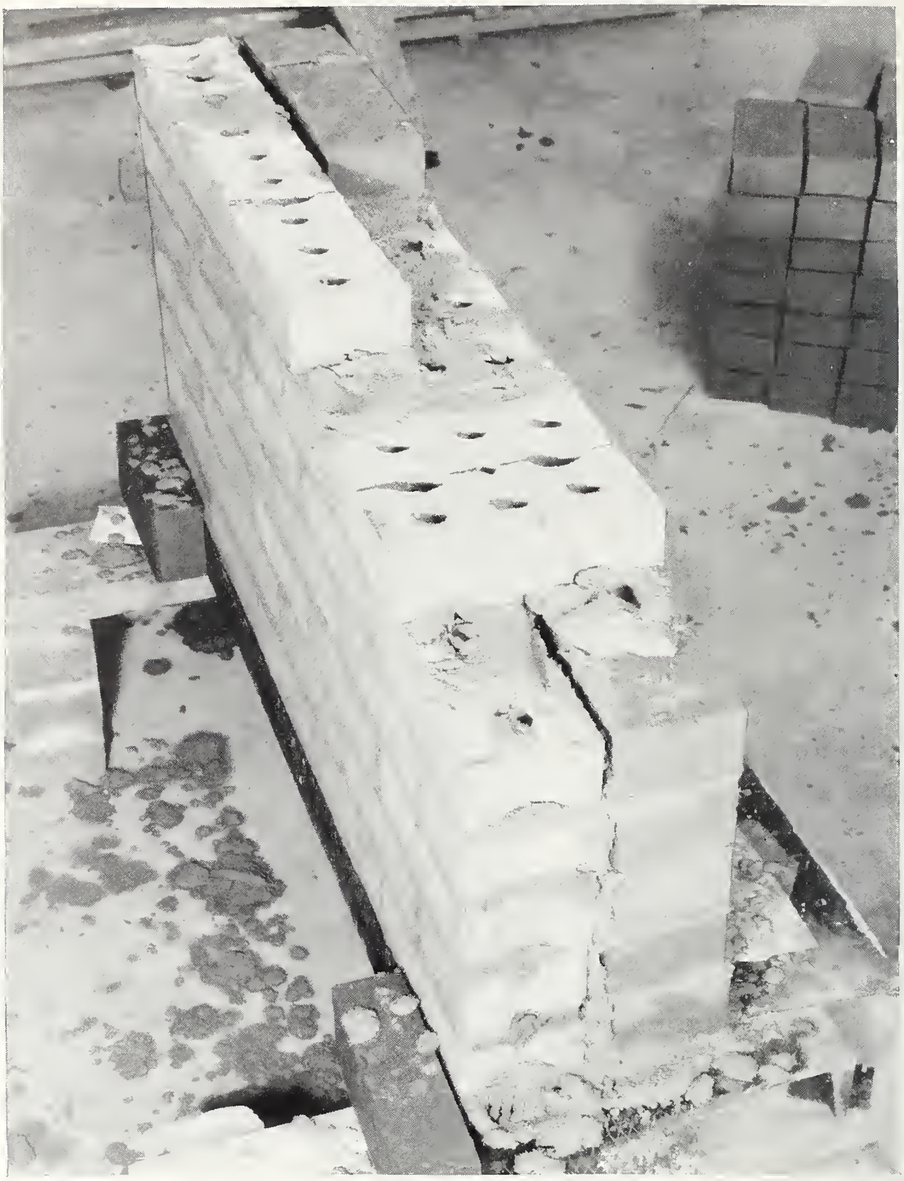

FIGURE 13.—*Brick wall of workmanship N.*

Sponsored construction wall B302 under construction. Note the recessed ends of the stretcher bricks and the sides of the header bricks, which are filled with mortar after the bricks are laid in the wall, without buttering the head joints; the collar joint was left open. The joints in the facing were subsequently tooled.

as in type B workmanship. Joints in the face of the wall were tooled.

"Spaulding" bricks (W. H. Spaulding)

"Spaulding" bricks, bricks *V* and *W*, were used as facing units in four walls with mortar 11. Two kinds of workmanship, types P and Q, were represented, and one wall was built of each kind of facing unit and workmanship. The "Spaulding" bricks were recessed at the ends of stretcher units and at the sides of header units. Bricks with recesses for outside corner work were furnished but not used in these walls. The brick used for backing the walls, brick *X*, were of the ordinary size and shape. All of the bricks were laid dry, as received. Mortar of two degrees of temper was used, designated as mortar (mortar 11, table 5) and retempered mortar, which contained additional water.

In type P workmanship, the beds were furrowed. Head joints between stretchers in the facing were made by first buttering the outer and inner edges of the units, no mortar being placed at the center third or recessed portion of the ends. A portion of retempered mortar was then placed, with the trowel, into the center of the head joint. Usually two applications were made before each joint was filled. A rounded and tapered burned-clay dam was then inserted, pointed end down, into the center of each head joint. Insertion of the dam resulted in the extrusion of some mortar from both faces of the head joint. The clay dams shown in figure 3 were made of the same kind of clay as that used in the manufacture of brick *W*. They were not hard-burned, and their average absorption during a 24-hr. immersion in cold water was about 11 percent. Mortar for the head joints between header brick was applied to the outer edges and to the center portion of the headers before placing them in the wall. Retempered mortar was then placed in the open portions of the head joints over each wythe, but clay dams were placed in the facing wythe only. The collar joints between the wythes and the head joints in the backing wythe were filled with mortar as in work-manship A′.

In type Q workmanship the bed joints were furrowed and the outer edges of the stretcher bricks were buttered before laying. Retempered mortar and clay dams were placed in the center portion of head joints in the facing wythe. The insertion of the dams usually extruded sufficient mortar to fill the inner third of these joints.

The collar joint was open and the stretcher brick in the backing wythe were laid as in workmanship B. The header bricks were buttered at the ends before laying, and the head joints between them were similar to those placed between the stretchers in each wythe.

H-brick (Whitacre-Greer Fireproofing Co.)

Four single-wythe walls (*N*8B6) were built of H-brick. The bed joints were furrowed over those portions of the brick lying in, and parallel to, the wall faces. The head joints were buttered over the ends of the units. No mortar was placed in the center portion of the walls. The smooth edges of the brick were placed in the faces and the joints were tooled.

"Munlock" brick (Munlock Engineering Company)

Eight single-wythe, 8-in. walls were built of "Munlock" brick *M*. Mortar for the bed joints was beveled double from the outer edges downward to the base of the longitudinal ridge at the center of the units. The head joints were buttered to a depth of 2 or 3 in. from each face, and no mortar was placed at the center portion of the wall. The joints were tooled in the exposed face of the wall and cut flush with the units at the back. The brick were air-dry when laid. The method of constructing the walls was similar to that described in building walls for structural tests (see BMS53).

Four walls were built with mortar 9, two with mortar 10, and two with mortar 2. The brick tended to float when laid with mortar 9, and this mortar extruded slightly from the joints. There was no difficulty noted in laying the "Munlock" brick with either mortar 2 or 10.

"Speedbrik" (General Shale Corporation)

One 12-in. and three 8-in. walls were built of "Speedbrik" *O* with mortar 7, and three 6-in. walls were built of brick *O* with mortar 12. The "Speedbrik" *P* was used in two walls with mortar 8.

The mortar beds were furrowed under the double outer shells of the units. The head joints were buttered in each wall face to a depth equal to the width of the bed joints, about 1½ in. No mortar was placed in the interior portions of either the 6- or the 8-in. walls. The face joints were tooled. The method of constructing these walls was similar to that used in building 6-in. walls of brick *O* for structural tests.[11]

"Dri-Speedwall" tiles (National Fireproofing Company)

Walls B277, 278, and 279 (*s*8B2) were built of "Dri-Speedwall" tiles. These side-bearing units contained baffles designed to prevent the penetrations of water through a wall by diverting any leakage downward at the center of the tile to the bottom of the wall, where, presumably, it could be drained to suitable outlets. No mortar was placed in the interior portion of

[11] The results obtained from the structural tests will be described in a Building Materials and Structures Report.

these walls, and the bed joints were placed under the double outer shells. The head joints were carefully applied to a depth approximately equal to the width of the bed joints (1½ to 2 in.). The facing joints were struck and weep holes were placed above the flashings, at the rear of the walls, so that the rate of leakage could be measured.

"Dun-ti-stone" and "Dunstone" units (W. E. Dunn Manufacturing Company)

One wall (B159–*v*8B2) was built of "Dun-ti-stone" units. The inclined shell of each unit was placed in the face of the wall so that the bottom of the shell extended over the bed joint. The bed joints were furrowed on both the face and back shells. The head joints were buttered over the entire ends of both shells. This wall was similar in construction to those built for the structural tests which are described in BMS22. Joints in the face of the wall were struck, those in the back were cut.

Four 8-in. walls (B231-, 232-, 233-, and 234-*w*8B2) were built with "Dunstone" units. They were similar in construction to those used for the structural tests described in BMS38. Two of these walls (B231 and 233) were built by placing 8- by 8-in. header units in a vertical position at each end of 8- by 12-in. stretcher units, also laid vertically. Each course was about 8 in. high. Bond of the vertical joints was broken by using 4- or 8-in. stretchers at alternate ends of successive courses.

The other two walls were built by placing 8- by 12-in. header units horizontally at the tops and bottoms of 8- by 12-in. vertical stretcher units. Bond of the vertical joints was broken by using 4- or 8-in. units at the ends of header courses.

Mortar in the bed joints was furrowed, and the head joints were made by heavily buttering the ends or edges of the units. No mortar was placed in any of the walls between the inner faces of the stretcher units. The sponsor of "Dun-ti-stone" and of "Dunstone" units recommends that a protective coating, known as "Mat Glazing", be used on exterior walls built of these units.

"Mahlstedt" block (National Concrete Masonry Association)

One wall (B123–*xx*10M1) was built of "Mahlstedt" cinder-concrete block. This cavity wall was similar in construction to those built for structural tests described in BMS21 and sponsored by the National Concrete Masonry Association. The width of the cavity between the inner faces of the wythes was 2 in. The mortar beds were furrowed over the 4-in. width of the top of the block, and the head joints were buttered only at the outer edges in each face. The sponsor of this construction recommends that a waterproof protective coating be applied to the outer faces of exterior walls built of these units.

III. TESTING OF THE WALLS

Inasmuch as the permeability of masonry wall specimens decreases slightly with repeated test exposures (see BMS7, p. 14, section VI–1), all of the walls were given a preliminary, or "breaking in", test lasting 2 days. The walls were then dried to nearly constant weight before they were tested for record. The test exposure simulated the effects of a heavy wind-driven rain and was the same as that of the "heavy rain" test described in BMS7.

1. Apparatus and Test Method

The apparatus is shown in figures 14 and 15. The walls were supported on metal skids during the permeability tests, and they were clamped into position against the sponge-rubber gaskets of the testing apparatus so that the exposed face formed one side of a pressure chamber. An air pressure was maintained within the chamber, and water from a perforated tube was applied to the upper portion of the exposed face (inside the chamber) at the rate of 40 gal (152 liters) per hour. Since the exposed length of the wall was 35 in., the amount of water applied per linear foot of wall per hour was 13.7 gal (52 liters), an amount sufficient to cover the wall face with a thin sheet of running water. The applied air pressure was equal to that produced by a head of 2 in. of water, about the maximum difference in pressure on two faces of a wall which may be caused by a wind having a velocity of 50 mph.

The relative humidity of the air in the testing room and of that in contact with the backs of the walls was usually between 80 and 90 percent.

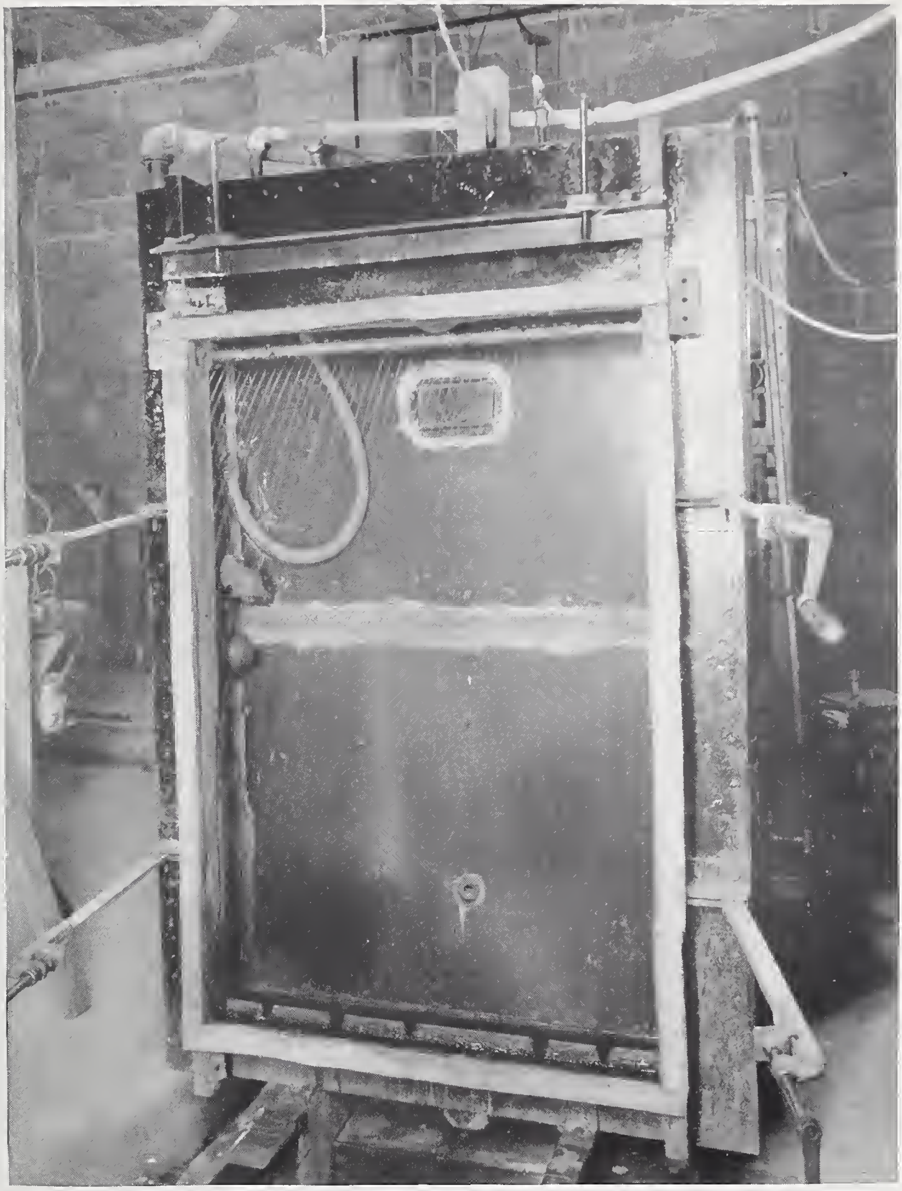

Figure 14.—*Water-permeability test chamber.*

Face of chamber before placing wall in position. Note streams of water from perforated pipe at top of opening.

The temperature of the air in the testing room varied with the seasons and ranged between 50° and 75° F. The temperature of the water applied to the walls was maintained above the dew-point temperature of the air in the testing room, and the water was heated when necessary.

The tests on the walls were continued for not less than 1 day or for more than 5 days. The backs of the walls had been painted with whitewash and the discoloration produced by moisture (dampness) on the back could be easily detected.

2. Observations

Continual observations of the specimens were made for about 2 hours after starting each test, after which the observer inspected the walls at increasingly longer intervals.

The following observations were made during the tests:

(1) Time required for the appearance of moisture (dampness) on the backs of the walls, above the flashings.

(2) Time required for the appearance of

visible water on the backs of the walls, above the flashings.

(3) Time required for leakage to flow from the flashings.

(4) Maximum rate of leakage, if any.

(5) Extent of damp area on the backs of the walls, including that produced by the capillary rise of moisture from water on the flashings.

When not determined during the continual observation period, the time for leakage or penetration of the walls was assumed to be the middle of the time interval between two inspections, and the uncertainty of the observations was assumed to be equal to plus or minus one-third of the interval between the inspections. The highest observed rate of leakage was assumed to be the maximum rate of flow.

3. Method of Rating Performance

The permeability test is severe, and of greater duration than the natural wind and rain storms to which most building walls are subjected.

Figure 15.—*Water-permeability test chamber.*

Wall similar to B127-j8A2 in position for test. Back of wall not whitewashed (preliminary test).

Information of a practical value on the permeability of the specimens may therefore be obtained during an exposure period of 1 day; but in order to determine slight differences between the performances of the least permeable walls, the tests were sometimes continued for the maximum period of 5 days.

In order to reduce the initial cost of masonry building walls, plaster sometimes is applied directly to the back of the walls, without furring. The test walls were not plastered, and the arbitrary ratings of wall performance, given below, are based on the assumption that visible water, extensive dampness on the back, or leakage through the base of a wall would damage plaster applied directly to the wall or would injure the interior trim or furnishings of a building. The exposure given the test walls was controlled to prevent the condensation of moisture on the backs of the specimens, and the probability of condensation damaging plaster applied directly to the back of building walls similar to the test specimens was not determined.

The ratings are not fully applicable for use in judging the performances of cavity-type walls, because, in practice, water penetrating the facing of such walls is usually diverted by flashings to the exposed face instead of to the inside face, as in the wall specimens.

Wall-performance ratings:

Excellent (*E*).—No water visible on back of the wall (above the flashings) at the end of 1 day. Not more than 25 percent of the wall area damp at the end of 5 days. No leaks[12] through the wall in 5 days.

Good (*G*).—No water visible on back of the wall at the end of 1 day. Less than 50 percent of the wall area damp at the end of 1 day. No leaks [12] through the wall at the end of 1 day.

Fair (*F*).—Water visible on back of wall in more than 3 or less than 24 hours. Rate of leakage through the wall less than 1 liter per hour at the end of 1 day.

Poor (*P*).—Water visible on the back in 3 hours or less. Rate of leakage less than 5 liters per hour at the end of 1 day.

Very Poor (*VP*).—Rate of leakage through the wall equal to or greater than 5 liters per hour at the end of 1 day.

In general, there was little practical difference between the performances of walls rated as either "good" or "excellent," and it is possible that building walls similar to those rated as "fair" in the permeability tests would be considered to have a satisfactory resistance to rain penetration except when subjected to rain and to winds of high velocity for long periods.

IV. DATA AND DISCUSSION

1. Data

Data obtained from the permeability tests are given in tables 6, 7, 8, and 9, which also include the wall-performance ratings. Table 6 gives data on brick walls built of solid or cored bricks of the ordinary size and shape. Table 7 gives data on sponsored walls containing bricks of special shapes and sizes. Data on walls with brick facings and backings of hollow units are given in table 8, and table 9 gives data on structural clay tile walls and on walls built of concrete units, without brick facings. The data in table 6 are summarized in table 10 for groups of like wall specimens. Table 11 gives construction notes on some walls which were difficult to build.

[12] Leaks are defined as follows: A leak is a flow of water from one or both flashings, the total rate of flow being equal to or greater than 0.05 liter per hour.

Table 6.—*Permeability of brick walls*

Wall	Destination [a]	Brick suction per 30 sq. in.	Approximate water retentivity of mortar	Kind of ties [c]	Time to failure as indicated by [d]— Damp	Visible water	Leak	Maximum rate of leakage per hour	Area damp in 1 day	Rating
Walls or workmanship A										
		Grams	*Percent*		*Hours*	*Hours*	*Hours*	*Liters*	*Percent*	
B125 [e]	*AA*8A1	6	70	HB	4.8			0	4	*E*
60 [f]	*aa*8A2	2	85	HB	57.0			0	0	*G*
B37	*AA*8A2	9	80	MT	66.0			0	0	*G*
86 [f]	*ac*8A2	[b] 2 to 50	85	HB	84.0			0	0	*G*
B64	*AC*8A2	[b] 6 to 18	80	MT	59.0			0	0	*G*
B122 [e]	*DD*8A2	13	80	HB	0.3			0	51	*F*
B47	*BB*8A2	16	80	MT	2.9	35 ±8		0	18	*G*
B55	*CC*8A2	19	80	MT	0.3	2.3	14 ±6	.2	100	*P*
B160	*CC*8A2	24	80	MT	3.6	14 ±6		0	95	*F*
36 [f]	*cc*8A2	50	85	HB	0.3	1.5	1.5	1.0	100	*P*
B2	*BB*12A2	2	80	HB				0	0	*E*
B4	*CC*12A2	3	80	HB	11 ±4			0	4	*G*
B157	*CC*12A2	3	80	HB	24			0	1	*G*
B25	*AA*12A2	11	80	HB	34			0	0	*G*
B158	*CC*12A5	3	45	HB	19 ±3			0	4	*G*
B3	*BB*12A5	4	45	HB				0	0	*E*
B6	*CC*12A5	6	45	HB	34			0	0	*E*
B8	*BB*12A2	18	80	HB	3.0			0	13	*G*
B120	*CC*12A2	22	80	HB	10.0			0	8	*G*
B12	*CC*12A2	29	80	HB	0.6	21		0	26	*F*
B1	*BB*12A2	35	80	HB	.1			0	37	*G*
B135	*CC*12A5	20	45	HB	3.1	19 ±3		0	32	*F*
B20	*CC*12A5	21	45	HB	26.0			0	0	*E*
B16	*BB*12A5	33	45	HB	0.7	9 ±3	18 ±3	.03	70	*F*
B10	*CC*12A2	53	80	HB	10 ±3	18 ±3		0	30	*F*
B18	*CC*12A5	49	45	HB	0.8	2.2	5.0	.5	90	*P*
B5	*CC*12A2	89	80	HB	1.4	18 ±3		0	75	*F*
B7	*CC*12A5	120	45	HB	0.3	1.8	1.3	4.3	90	*P*
Walls of workmanship A′										
B89	*AA*12A′2	8	80	HB	42			0	0	*E*
B88	*BB*12A′2	14	80	HB	54			0	0	*G*
Walls of cored brick series, workmanship A′										
B290	*GG*8A′2	9	80	HB	11 ±3			0	7	*G*
B293	*GG*8A′2	9	80	HB	11 ±3			0	11	*G*
B291	*HH*8A′2	6	80	HB	35			0	0	*E*
B292	*HH*8A′2	9	80	HB	35			0	0	*G*
B294	*JJ*8A′2	9	80	HB	5			0	22	*G*
B297	*JJ*8A′2	9	80	HB	11 ±3	39 ±6		0	20	*G*
B295	*KK*8A′2	9	80	HB	18 ±4			0	1	*G*
B296	*KK*8A′2	9	80	HB	28			0	0	*G*
Walls of workmanship B										
61 [f]	*aa*8B2	2	85	HB	0.05	0.05	0.03	20	80	*VP*
87 [f]	*ac*8B2	[b] 2 to 40	85	HB	.05	.8	.3	25	100	*VP*
B121 [e]	*DD*8B2	13	80	HB	.03	.05	.2	34	100	*VP*
34 [f]	*cc*8B2	50	85	HB	.03	.05	1.8	51	100	*VP*

See footnotes at end of table.

TABLE 6.—*Permeability of brick walls*

Wall	Destination	Brick suction per 30 sq. in.	Approximate water retentivity of mortar	Kind of ties [e]	Time to failure as indicated by [d]— Damp	Visible water	Leak	Maximum rate of leakage per hour	Area damp in 1 day	Rating
Walls of workmanship F										
		Grams	*Percent*		*Hours*	*Hours*	*Hours*	*Liters*	*Percent*	
B33	*AA*8F2	8	80	MT	0.3	18 ±3		0	19	*F*
B63	*AC*8F2	[b] 7 to 20	80	MT	.7			0	22	*G*
B48	*BB*8F2	16	80	MT	.6	15 ±6	2.9	1	55	*P*
B58	*CC*8F2	20	80	MT	.4	3.4	14 ±6	2.2	100	*P*
B11	*BB*12F2	4	80	HB	—	—	—	0	0	*E*
B13	*CC*12F2	6	80	HB	35		—	0	0	*E*
B15	*BB*12F5	3	45	HB				0	0	*E*
B17	*CC*12F5	6	45	HB	42		—	0	0	*E*
B14	*BB*12F2	17	80	HB	58.0		—	0	0	*E*
B26	*CC*12F2	20	80	HB	56.0	109.0	—	0	0	*E*
B19	*BB*12F5	27	45	HB	0.2	0.3	4.8	.4	80	*P*
B22	*CC*12F5	22	45	HB	8 ±2	65.0		0	3	*G*
B9	*BB*12F2	40	80	HB	11 ±3	—	—	0	10	*G*
B28	*CC*12F2	47	80	HB	1.3	4.0	15 ±5	.4	58	*F*
B24	*CC*12F5	47	45	HB	0.2	0.2	0.5	13.0	65	*VP*
B23	*CC*12F2	93	80	HB	1.2	15 ±6		0	47	*F*
B21	*CC*12F5	116	45	HB	0.4	0.7	0.9	16	80	*VP*
Walls of workmanship H (grouted)										
B42	*AA*9H2 [g]	8	80	MT	19 ±3	—	—	0	20	*G*
B67	*AC*9H2 [g]	[b] 8 to 22	80	MT	35	—	—	0	0	*G*
B129	*EE*9H1 [h]	15	70	MT	0.3	2.6	—	0	25	*P*
B52	*BB*9H2 [g]	16	80	MT	19 ±3	—	—	0	1	*G*
B59	*CC*9H2 [g]	24	80	MT	11 ±3	19 ±3	—	0	100	*F*
B27	*AA*12H2 [g]	9	80	HB	—	—	—	0	0	*G*
B31	*CC*12H2 [g]	20	80	HB	34	—	—	0	0	*G*
B29	*BB*12H2 [g]	18	80	HB	0.4	—	—	0	6	*G*
Walls of workmanship J (slushed)										
B34	*AA*12J2	9	80	HB	0.1	—	—	0	1	*E*
B30	*BB*12J2	17	80	HB	17 ±3	—	—	0	6	*G*
B32	*CC*12J2	23	80	HB	1	11 ±2	—	0	35	*F*
Walls of workmanship M (cavity)										
B169 [j]	*FF*10M2	11	80	MT	13 ±6	—	0.5	3	1	([k])
Walls of workmanship S (combination shove with pick-and-dip)										
B118	*AA*12S2	9	80	HB	—	—	—	0	0	*E*
B119	*AA*12S2	9	80	HB	—	—	—	0	0	*E*

[a] The first 2 letters designate respectively the kind of masonry units used in the facing and the backing wythes. The first numeral indicates the nominal wall thickness in inches, the next capital letter designates the type of workmanship, and the final numeral the kind of mortar used.
[b] The suction of the brick in the facing is given first for walls containing 2 kinds of bricks.
[c] HB indicates that the wythes were tied with header brick, laid in common American bond.
MT indicates that the wythes were tied with metal ties, spaced approximately every 6th course.
[d] The uncertainty of the observation is given only if it exceeds 10 percent of the total elapsed time. A dash indicates no failure of the wall.
[e] The wall was similar to one of the constructions described in BMS5.
[f] Taken from table 8, of BMS7.
[g] The grout consisted of mortar 2 mixed with about 33 percent of water by weight of dry materials.
[h] The grout contained 1:0.06:1.45:0.63 parts by weight of portland cement, lime hydrate, dry sand, and water. The collar joint of this wall contained 2 vertical and 3 horizontal 3/8-in. round reinforcing bars.
[j] The wall was similar to the construction described in BMS23.
[k] The rating of this wall would have been "good" or "excellent" (instead of "fair" or "poor") if the leakage through the facing had been diverted to the exposed face.

TABLE 7.—*Permeability of walls containing bricks of special shapes*

Wall	Designation [a]	Brick suction per 30 sq. in.	Approximate water retentivity of mortar	Time to failure as indicated by [c] — Damp	Visible water	Leak	Maximum rate of leakage per hour	Area damp in 1 day	Rating
Walls containing "Tightwall" bricks, workmanship N									
		Grams	%	*Hours*	*Hours*	*Hours*	*Liters*	%	
B300	*RU*8N2	[b] 6 to 13	85	0.05	0.05	0.4	2	90	*P*
B301	*RU*8N2	[b] 4 to 15	85	10 ±3	—	—	0	2	*G*
B302	*RU*8N2	[b] 6 to 9	85	114	—	—	0	0	*E*
Walls containing "Spaulding" bricks, workmanships P and Q									
B334	*WX*8P11	[b] 4 to 35	90	0.2	0.3	—	0	85	*P*
B332	*VX*8P11	[b] 37 to 35	90	.1	.7	2.8	.3	100	*P*
B335	*WX*8Q11	[b] 4 to 35	90	.3	—	2.8	.6	60	*F*
B333	*VX*8Q11	[b] 37 to 35	90	.2	1.0	1.8	2.7	100	*P*
Walls of H-Brick									
B165	*N*8B6	13	85	0.2	14 ±6	0.1	3.2	55	*P*
B166	*N*8B6	12	85	.5	—	1.5	6.8	30	*VP*
B167	*N*8B6	13	85	.3	—	1.3	0.7	30	*F*
B224	*N*8B6	11	85	3.0	—	0.6	3.4	20	*P*
	Average	12	85	1.0	([d])	.9	3.5	35	*P*
Walls of "Munlock" brick									
B259	*M*8B9	4	55	0.30	0.30	1.2	4.2	85	*P*
B260	*M*8B9	4	55	.08	.08	0.3	3.5	85	*P*
B261	*M*8B9	4	55	.04	—	.9	2.6	75	*P*
B262	*M*8B9	4	55	.04	.60	1.6	3.2	85	*P*
	Average	4	55	0.1	—	1.0	3.4	80	*P*
B267	*M*8B10	4	65	3.6	—	1.8	1.4	25	*P*
B268	*M*8B10	2	65	0.5	3.5	4.0	0.3	75	*F*
	Average	3	65	2.0	([d])	2.9	0.8	50	*F*
B269	*M*8B2	5	80	2.7	—	—	0	30	*G*
B270	*M*8B2	9	80	4.6	—	—	0	3	*G*
	Average	7	80	3.6	—	—	0	15	*G*
Walls of "Speedbrik"									
B229	*P*8B8	6	90	—	—	18 ±3	0.02	0	*E*
B230	*P*8B8	6	90	—	—	0.5	.25	0	*F*
	Average [d]	6	90	—	—	9	0.13	0	*F*
B225	*O*8B7	20	60	39 ±6	—	0.4	0.9	4	*F*
B227	*O*8B7	20	60	6.4	—	.3	2.4	5	*P*
B228	*O*8B7	20	60	5.4	—	.5	0.8	4	F
	Average	20	60	17	—	0.4	1.4	4	*P*
B226	*OO*12B7	20	60	—	—	0.2	3.0	5	*P*
B336	*O*6B12	20	64	2.4	—	2.7	0.7	70	*F*
B337	*O*6B12	20	64	0.2	—	0.8	2.8	75	*P*
B338	*O*6B12	20	64	1.8	—	4.3	0.4	40	*F*
	Average	20	64	1.5	—	2.6	1.3	60	*P*

[a] See note "a", table 6.
[b] The suction of the brick in the facing is given first, for walls containing two kinds of bricks.
[c] The uncertainty of the observation is given only if it exceeds 10 percent of the total elapsed time. A dash indicates no failure of the wall.
[d] The data from tests on individual specimens show a wide dispersion.

Table 8.—*Permeability of walls with brick facings and backings of hollow units*

Wall	Designation [a]	Average brick suction per 30 sq. in.	Kind of backing [b]	Time to failure as indicated by [c]—			Maximum rate of leakage per hour	Area damp in 1 day	Rating
				Damp	Visible water	Leak			
Walls of workmanship A									
		Grams		*Hours*	*Hours*	*Hours*	*Liters*	%	
B40	*Bk*12A2	19	End	0.4	—	—	0	7	*G*
B44	*Bl*12A2	16	Side	1.3	14 ±6	14 ±6	.2	80	*F*
B49	*Bn*12A2	16	Cinder	0.2	0.3	1.2	2.3	55	*P*
Walls of workmanship F									
B35	*Bd*12F2	19	End	1.5	—	2.2	[d] 0.08	22	*G*
B38	*Bk*12F2	20	do	3.3	18 ±4	2.0	.98	37	*F*
B36	*Be*12F2	17	Side	1.5	1.5	15 ±6	.01	70	*P*
B43	*Bf*12F2	19	do	0.3	0.5	0.5	13.50	65	*VP*
B45	*Bl*12F2	15	do	1.5	1.7	3.5	5.50	67	*VP*
B39	*Bm*12F2	18	Stone	0.1	2 ±0.4	0.3	3.20	70	*P*
B46	*Bn*12F2	18	Cinder	.2	2.0	.5	6.10	70	*VP*
Walls of workmanship F′									
B276	*Aj*12F′2	5	End	—	—	—	0	0	*E*
B275	*Al*12F′2	4	Side	—	—	—	0	0	*E*
B84	*Bk*12F′2	16	End	0.5	—	—	0	15	*G*
B85	*Bd*12F′2	18	do	2.8	—	—	0	20	*G*
B131	*Bg*12F′2	13	do	9 ±2	—	9 ±2	.3	39	*F*
B133	*Bp*12F′2	15	do	19 ±3	—	—	0	11	*G*
B75	*Bl*12F′2	14	Side	0.3	1.6	2.5	2.2	80	*P*
B86	*Bf*12F′2	16	do	4.0	—	—	0	20	*G*
B87	*Be*12F′2	15	do	0.2	0.7	—	0	35	*P*
B91	*Bm*12F′2	15	Stone	—	—	—	0	0	*E*
B90	*Bn*12F′2	14	Cinder	.5	15 ±6	15 ±6	.03	25	*F*
Walls of workmanship G									
B41	*Bk*12G2	19	End	1.1	1.1	1.8	1.7	52	*P*
B50	*Bl*12G2	18	Side	2.5	15 ±6	—	0	50	*F*
B53	*Bn*12G2	16	Cinder	4.2	15 ±6	15 ±6	.3	14	*F*
Walls of workmanship G′									
B114	*Bk*12G′2	11	End	3.4	—	—	0	15	*G*
B132	*Bg*12G′2	17	do	43.0	—	—	0	17	*G*
B134	*Bp*12G′2	18	do	99.0	—	—	0	0	*E*
B128	*Bl*12G′2	15	Side	43.0	—	103	.01	0	*E*
B117	*Bm*12G′2	14	Stone	0.6	—	—	0	22	*G*
B110	*Bn*12G′2	13	Cinder	10 ±3	—	—	0	5	*E*
Walls of workmanship M (cavity walls, bonded with brick ties)									
B124	*Ee*10M2	16	Side	—	—	10 ±3	0.3	5	([e])
B271	*Lq*10M2	9	do	10 ±2	—	0.2	2.3	4	([e])
B271 [f]	*Lq*10M2	—	—	0.2	—	.2	3.9	20	([e])
B272 [f]	*Lq*10M2	9	do	18 ±4	—	.5	0.8	10	([e])

[a] See note "a", table 6.
[b] Legend: Side—denotes side-construction structural clay tile.
End—denotes end-construction structural clay tile.
Cinder—denotes cinder concrete block, end construction.
Stone—denotes stone concrete block, end construction.
[c] The uncertainty of the observation is given only if it exceeds 10 percent of the total elapsed time. A dash indicates no failure of the wall.
[d] The flow at the end of 1 day was 0.02 liters per hour.
[e] See note "k", table 6.
[f] Test made after filling the cavity with Palco wool.

Table 9.—*Permeability of structural clay tile and of concrete unit walls*

Wall	Designation [a]	Method of laying units [b]	Time to failure as indicated by—			Maximum rate of leakage per hour	Area damp in 1 day	Rating
			Damp	Visible water	Leak			
Walls of structural clay tile, *j*								
			Hours	*Hours*	*Hours*	*Liters*	%	
B126 [c]	*j*8A2	End	0.03	0.03	0.07	7.7	50	*VP*
B127 [c]	*j*8A2	Side	.01	.01	.03	27.0	100	*VP*
Walls of "Dri-Speedwall" tiles, *s*								
B277	*s*8B2	Side			1.1	0.5	1	([d])
B278	*s*8B2	do			0.3	.6	2	([d])
B279	*s*8B2	do			2.2	.3	4	([d])
		Average			1.2	0.5	2	*F*
Wall of stone-concrete block, *m*								
B130 [c]	*m*8A2	End	0.04	0.04	0.08	54	90	*VP*
Wall of "Dun-Ti-Stone" stone-concrete block, *v*								
B159	*v*8B2	End	1.7		0.09	13	13	*VP*
Walls of "Dunstone" stone-concrete units, *w*								
B231	*w*8B2	([e])	0.3	0.3	0.1	50	90	*VP*
B233	*w*8B2	([e])	.4	.4	.1	20	80	*VP*
		Average	0.4	0.4	0.1	35	85	*VP*
B232	*w*8B2	([f])	0.1	0.1	0.2	42	100	*VP*
B234	*w*8B2	([f])	.05	.07	.07	43	95	*VP*
		Average	0.1	0.1	0.1	42	95	*VP*
Cavity-type wall of "Mahlstedt" cinder-concrete block, *x*								
B123	*xx*10M1	End	0.2	0.2	0.08	103	[g] 65	*VP*

[a] See note "a", table 6.
[b] End denotes units laid with cells vertical. Side denotes units laid with cells horizontal.
[c] The wall was similar to one of the constructions described in BMS5.
[d] See note "k", table 6.
[e] Header units laid vertically, on edge (see BMS38, wall CF).
[f] Header units laid horizontally, flat (see BMS38, wall CG).
[g] Percent of damp area on back after 6 hours' exposure, when test was stopped.

2. Effect of Workmanship on Permeability

Workmanship was the most important factor affecting the permeability of the walls described in BMS7; and it was found that walls of workmanship A, in which the vertical joints were completely filled, were markedly less permeable than walls of workmanship B. In the walls of most of the workmanships described in this paper, the vertical joints, particularly the collar joints, were filled with mortar, or grout, or were parged. Since the brick suction and the water retentivity of the mortar were found to affect the permeability of the specimens described in BMS7, the comparison of workmanships (tables 6 and 10) is made for walls having approximately equal values for the brick suction and for the water retentivity of the mortar.

TABLE 10.—*Effect of workmanship on permeability of brick walls*

Workmanship	Nominal wall thickness	Number of walls [a]	Range of brick suction of facing brick	Average water retentivity of mortar	Average time for failure as indicated by [d]— Damp	Visible water	Leak	Average maximum rate of leakage per hour	Average area damp in 1 day	Rating
	Inches		*Grams*	%	*Hours*	*Hours*	*Hours*	*Liters*	*Percent*	
A	8	3	0 to 10	75	43			0	1	*G*
A[b]	8	[b] 4	0 to 10	85	48			0	0	*G*
A	8	3	10 to 20	80	1.2	20	28	.07	55	*F*
A	8	1	20 to 40	80	3.6	14±6	---	0	95	*F*
A	12	4	0 to 10	80	47	---	---	0	2	*G*
A[b]	12	[b] 4	0 to 10	85	---	---	---	0	0	*E*
A	12	3	0 to 10	45	27		---	0	1	*E*
A	12	1	10 to 20	80	3	---	---	0	15	*G*
A	12	3	20 to 40	80	4	39	---	0	25	*G*
A[b]	12	[b] 4	20 to 40	85	24	(c)	---	0	10	*G*
A	12	3	20 to 40	45	10	49	---	0	35	*G*
A	12	1	40 to 60	80	10	18	---	0	30	*F*
A[b]	12	[b] 4	40 to 60	85	7	(c)	---	0	25	(c)
A	12	1	40 to 60	45	0.8	2.2	5.0	.5	90	*P*
A	12	1	90 to 120	80	1.4	18	---	0	75	*F*
A	12	1	90 to 120	45	0.3	1.8	1.3	4.3	90	*P*
A′	8	8	0 to 10	80	19	---	---	0	8	*G*
A′	12	1	0 to 10	80	42	---	---	0	0	*E*
A′	12	1	10 to 20	80	54	---	---	0	0	*G*
B[b]	8	[b] 4	0 to 10	85	0.05	0.10	0.05	21	70	*VP*
B	8	1	10 to 20	80	.03	.05	.2	34	100	*VP*
B[b]	8	[b] 4	30 to 40	85	.02	.03	.05	53	100	*VP*
B[b]	8	[b] 4	40 to 60	85	.08	.10	.60	81	100	*VP*
B[b]	12	[b] 4	0 to 10	85	.80	(c)	.08	17	45	*VP*
B[b]	12	[b] 4	30 to 40	85	.07	.08	.03	60	90	*VP*
B[b]	12	[b] 4	40 to 60	85	.3	5.0	10.0	62	85	*VP*
F	8	2	0 to 10	80	.5	33	---	0	20	*G*
F	8	2	10 to 20	80	.5	9	8	1.6	80	*P*
F	12	2	0 to 10	80	80	---	---	0	0	*E*
F	12	2	0 to 10	45	80	---	---	0	0	*E*
F	12	2	10 to 20	80	57	---	---	0	0	*E*
F	12	2	20 to 30	45	4	33	37	.2	40	*G*
F	12	2	40 to 60	80	6	26	31	.2	35	*G*
F	12	1	40 to 60	45	0.2	0.2	0.5	13	65	*VP*
F	12	1	90 to 120	80	1.2	15.0	---	0	45	*F*
F	12	1	90 to 120	45	0.4	0.7	0.9	16	80	*VP*
H	9	2	0 to 10	80	27	---	---	0	10	*G*
H	9	2	10 to 20	75	10	37	---	0	15	*G*
H	9	1	20 to 40	80	11	19	---	0	100	*F*
H	12	1	0 to 10	80	---	---	---	0	0	*G*
H	12	2	20 to 30	80	17	---	---	0	3	*G*
J	12	1	0 to 10	80	0.1	---	---	0	1	*E*
J	12	1	10 to 20	80	17.0	---	---	0	6	*G*
J	12	1	20 to 30	80	1.0	11	---	0	35	*F*
M	10	1	10 to 20	80	13	---	0.5	3	1	(e)
S	12	2	0 to 10	80	---	---	---	0	0	*E*

[a] Data on the performances of the individual specimens are given in table 6, unless otherwise noted.
[b] Taken from table 7 of BMS7.
[c] Not determined.
[d] The uncertainty of the observation is given only if it exceeds 10 percent of the total elapsed time. A dash indicates no failure of the wall.
[e] See note "k," table 6.

(a) *Brick Walls*

Table 10 summarizes the data for the individual wall specimens listed in table 6 with respect to the significant factors, such as workmanship, wall thickness, brick-suction, and the water retentivity of the mortar. For low values of brick-suction the representative walls (table 10) of all workmanships except those of type B were rated as "good" or "excellent." For brick-suctions of 10 g or more, the 8-in. walls representing workmanships A, A′, and H, in which the vertical joints were completely filled with mortar or with grout, were less permeable than the parged walls, workmanship F, of the same thickness. When the brick-suction exceeded 40 g, the 12-in. walls of workmanships A, A′, H, and J were slightly less permeable than walls of workmanship F. All of the walls of workmanship B were highly permeable.[13]

The two wythes of many 8-in. walls were

[13] Similar data on the water permeability of brick masonry walls were given by R. E. Copeland and C. C. Carlson, *Tests of the resistance to rain penetration of walls built of masonry units*, Proc. Am. Concrete Inst. **36**, 169 (1940).

bonded with metal ties instead of with header bricks. Wall B122–*DD*8A2 was bonded with header brick; and at the end of 1 day in the test chamber, the back of the wall showed three damp belts, extending across the wall, at each header course. The extent of the damp area was so large that the performance of the wall was rated as "fair." The time required for moisture to rise to the tops of bricks *D* and *C*, when these units were placed on end in ⅛ in. of water, was 11 and 1.7 hours, respectively. In the test, however, the time required for the penetration of moisture through header courses of bricks *D* and *C* (walls B122 and 36, table 6) was only 0.3 hour. The data for 8-in. walls of workmanship A indicate that the method of bonding (metal ties or header brick) had little effect on the permeability of walls faced with low- or with medium-absorptive bricks, but that the use of high-absorptive header units instead of metal ties did increase the permeability of the walls.

Tooling of the face joints in brick walls had an important effect on permeability. Walls of workmanship A, with tooled joints, were markedly less permeable than similar walls in which the joints were cut flush with the surfaces of the bricks (table 6 of BMS7). The test results for walls of workmanships A and B, listed in table 7 of BMS7, are in close agreement with those obtained from similar walls described in this paper.

(*b*) *Brick-faced walls backed with hollow units*

The data on the individual performances of brick-faced walls backed with hollow units are listed in table 8. With the exception of walls of workmanship G′, containing a mortar parging applied to the backing wythe, the permeabilities of individual specimens of like workmanship show a wide dispersion, and it is probable that differences in the watertightness of the 4-in. brick facings affected the performances of these walls.

The data on walls of workmanships F, F′, G, and G′ show the importance of watertight joints in the header courses of parged walls of common American bond backed with hollow units. The interior portions of the head joints between header bricks in walls of workmanships F and G permitted the passage of leakage water through the plane of the parged collar joint. When these head joints were solidly filled with mortar for the full length of the header brick, as in workmanships F′ and G′, the permeabilities of the walls were greatly decreased. Although walls of workmanships F′ and G′ were usually rated as "good," those of workmanship G′ were the least permeable. However, in building constructions in which type G′ workmanship is used, it may be necessary to install adequate flashings around wall openings and at floor levels to prevent breaking the continuity of the protection given by the pargings at these points.

One of the three walls of workmanship *A*, B49–*Bn*12A2, leaked badly and was rated as "poor;" the others were rated as "fair" or "good." In general, for similar workmanship, mortars, and values of brick suction, the performances of brick-faced walls with backings of hollow units were less consistent than those of 12-in. all-brick walls, and the all-brick walls were also less permeable.

The walls backed with end-bearing units were slightly less permeable than those backed with side-bearing units. The permeability of the walls was affected by the watertightness of brick facings, and leakage through the facings probably penetrated to the backs of side-construction units at higher elevations than was the case for walls backed with end-construction units.

(*c*) *Cavity walls*

Cavity walls are extensively used in England, where they have given excellent protection from wind-driven rains when properly flashed over wall openings and at the bottom so as to divert possible leakage to the outside. When so constructed,[14] the penetration of water through the facings has been of minor importance so long as there was no bridge permitting the leakage to penetrate the inside face of the walls.

The cavity walls tested in this investigation failed through leakage at the base, and there was usually little or no dampness observed on the backs of the walls above the base course.

[14] Information on cavity wall construction is contained in the book "Principles of Modern Building," by R. Fitzmaurice, vol. 1 (Building Research Station, His Majesty's Stationery Office, London).

It is evident, from the data, that wall B169 (table 6) and walls B124, B271, and B272 (table 8) would all have been rated as "good" or "excellent" if the flashings in these specimens had been reversed so as to divert the leakage to the exposed face. Without such flashings, however, the performances of the walls would have been rated as "fair" or "poor."

The cavities in walls B271 and B272 were filled with Palco wool (shredded redwood bark furnished by the Pacific Lumber Co.). The amount of wool placed in the 2-in. cavities was about 0.7 lb/ft.^{2} Wall B272 was filled when built, but wall B271 was tested both before and after filling the cavity. The back of wall B271, with the cavity open, was penetrated by moisture in 10 hours, but in the second test (with the cavity filled) a damp area appeared on the back in 0.2 hour (see table 8). The facing of wall B272 was much less permeable than that of wall B271, and it required an exposure period of 18 hours before moisture appeared on the back. After the tests, when the backing wythes were carefully removed, the Palco wool in both walls remained standing. Water was visible at only a few points on the back of the fillings, but the inside of the brick facing wythes were dripping wet.

The Palco wool contained about 14 percent of moisture by weight before it was placed in the walls. After the tests, the amount of moisture in the fillings was nearly 50 percent at the bottom and about 20 percent at the top of the walls.

3. Effect of Brick-Suction on Permeability

Brick-suction, an absorptive property of the brick at time of laying, was one of the most important factors affecting the permeability of brick walls. For like workmanships and similar mortars, the data in table 10 indicate a consistent increase in permeability with increase in the value of the brick-suction up to 60 g per brick. Walls containing low-absorptive bricks or those in which the absorption of the bricks at time of laying was reduced by prewetting were the least permeable. For equal performance ratings, 8-in. brick walls of workmanships A, F, and H required a lower brick-suction than did 12-in. walls. The effects of brick-suction were most pronounced in brick walls of workmanship F, in which the head joints, particularly those between header bricks, were not completely filled. The rate of leakage through the highly permeable walls of workmanship B also increased with increase in the value of brick-suction. It is evident (table 6) that filling of the vertical joints in brick walls did not always result in a "good" or "excellent" performance unless the brick-suction was less than 10 to 25 g depending upon the wall thickness and the kind of materials used.

Data in table 8 indicate that brick-suction greatly affects the permeability of brick walls backed with hollow units. Walls B275 and B276, of workmanship F′, were faced with brick *A* after the suction of these brick was reduced from 10 g, by prewetting, to about 5 g. These walls gave excellent performances and were less permeable than similar walls faced with brick *B*, in which the brick-suction was about 15 g.

4. Effect of Water Retentivity of the Mortars on Ease of Construction and on Permeability

The mason experienced difficulty in building some walls of bricks that had been wetted, especially when the bricks contained large amounts of absorbed water. For example, the high-absorptive brick *C* each contained about 0.7 lb of water when the brick-suction per unit was 10 g or less. Regardless of the kind of mortar used, walls built of brick *C*, having the above value of brick-suction, tended to bleed (become wet on the surface) and to spread out of alinement. However, the bleeding was more pronounced when mortar 5, which had a water retentivity of 45 percent (see table 5), was used than for mortar 2, which had a water-retentivity of 80 percent. Notes on the relative difficulty experienced in building brick walls with mortars 2 and 5, taken from the construction records, are given in table 11. The table does not list all of the walls on which similar observations were made.

TABLE 11.—*Effect of brick-suction and of the water retentivity of mortar on the ease of constructing some brick walls*

Wall	Designation	Average brick suction	Average water retentivity of mortar	Comments from construction records [a]	Performance ratings
		Grams	*Percent*		
B4	*CC*12A2	3	80	Bleeding, not excessive. Joints tooled 5 hours after laying	*G*
B157	*CC*12A2	3	80	Bleeding	*G*
B3	*BB*12A5	4	45	Severe bleeding. Mortar dropping from head joints	*E*
B158	*CC*12A5	3	45	Bleeding, more than that noted for B157	*G*
B135	*CC*12A5	20	45	Severe bleeding	*F*
B20	*CC*12A5	21	45	Excessive bleeding. Head joints extruded from face after cutting	*E*
B18	*CC*12A5	49	45	Although wet, the mortar curled away from edges of brick	*P*
B5	*CC*12A2	89	80	The mason stated that the brick were laid easier and faster than those used for walls 3 and 4.	*F*
B11	*BB*12F2	4	80	Some bleeding, but the parging was applied to backs of the wythes without difficulty.	*E*
B13	*CC*12F2	6	80	Considerable bleeding	*E*
B15	*BB*12F5	3	45	Excessive bleeding. Difficult to apply the parging	*E*
B17	*CC*12F5	5	45	Bleeding. More difficult to apply parigng than for wall B15	*E*
B19	*BB*12F5	27	45	Mortar hardened rapidly in joints	*P*
B22	*CC*12F5	22	45	Bleeding—parging dropped off and was replaced	*G*
B21	*CC*12F5	116	45	Mortar for head joints did not stick well to buttered edges of brick	*VP*

[a] Bleeding is defined as the separation of water from the mortar in the joints, the released water dripping from the faces of the wall to the floor. Severe bleeding was marked by extrusion of mortar from the joints.

Brick *C* were easily laid with mortar 2 in walls of workmanship A when the brick-suction was greater than 10 g, but severe bleeding was noted during the construction of similar walls built with mortar 5 for a suction of 20 g (see data on walls B20- and B135-*CC*12A5, table 11). Similarly, for brick suctions of 10 g, mortar 2 was easily applied as a parging to the backs of the wythes in walls built with workmanship F, whereas pargings of mortar 5 did not adhere well to the bricks and sometimes had to be replaced. It was difficult to use mortar 5 with bricks having suctions of 50 g or more, because it stiffened rapidly after being in contact with the bricks and there was little adhesion of the mortar to the edges of the units when it was applied by buttering.

The bleeding and the extrusion of mortar from the joints did not increase the permeability of the walls (see table 11); and it was noted that when the bricks tended to "float" slightly, the walls usually had a high resistance to moisture penetration. For suctions of over 40 g the brick walls built with workmanships A and F with mortar 5 (low water retentivity) were much more permeable than similar walls built with mortar 2 (see table 10). Corroborative data on the effects of the water retentivity of the mortar on both the permeability and on the ease of constructing brick walls are given in BMS7. The most satisfactory mortars had a high water retentivity and an initial flow greater than 100 percent. The relative proportions of cement and lime had little practical effect on either the permeability of the walls or the ease of constructing them.

In general, the masons who constructed the walls disliked to lay bricks that had been wetted, because of the abrasive action of such bricks on the damp skin of the fingers. They also preferred to use mortar 2 rather than mortar 5, and their complaints about the bricks being either too dry or too wet were usually made when using mortar 5. The walls that were rated as "good" or "excellent" and that were also easily constructed were built with mortars having a high water retentivity, using low-absorptive bricks or medium-absorptive bricks that had been prewetted.

5. Effect of Properties of Unit on Permeability

(*a*) *Absorptive Properties of the Bricks*

The data, table 6, show that the "suction" of the bricks rather than their total absorptive capacity when dry was a principal factor affecting wall permeability, and for low values of brick-suction the performances of walls built of high-absorptive brick was comparable to those of walls built of low- or of medium-absorptive units. Test walls with facings of low-absorptive brick and with backings of high-absorptive brick were usually more resistant to water penetration than similar walls containing only low- or high-absorptive bricks (see table 6 for 8-in. walls of workmanships A and F). The high-absorptive brick *C* were difficult to lay when they had either a very high or a very low suction, and such units may therefore be preferred for backing, with the brick-suction adjusted to the satisfaction of the mason.

(*b*) *Cored Holes in Bricks*

In order to determine the effects of coring bricks on wall permeability, two walls were built of the cored and two of the solid bricks from each of two plants. The cored and the solid bricks from each plant were alike except for the coring and for a slight difference in the hardness to which they were burned (see table 1, bricks *G*, *H*, *J*, *K*). The walls were built of workmanship A′ with mortar 2. The Belden bricks (bricks *G* and *H*) were not wetted, but the "suction" of the Acme bricks was reduced to a value of 9 g, which was approximately that of the Belden bricks.

There was no bleeding or spreading of the wythes noted during the construction of any of the eight walls, but the mason remarked that the solid Belden brick had a slight tendency to float, which the cored (harder burned) Belden brick did not have. Although the mason placed about the same amount of mortar in the bed joints of all the walls, the cored bricks tended to settle in the mortar bed, and the walls containing the cored bricks were of less height than those containing the solid bricks by one-half a course in 18 courses.

The data for the individual walls (walls of the cored brick series, table 6) show that all had a high resistance to water penetration. Walls containing the cored bricks (bricks *H* and *K*) were significantly less permeable than those containing the solid bricks (bricks *G* and *J*), but the differences in permeability were of little practical importance.

(*c*) *Brick of Special Shapes*

Data on the permeability of sponsored walls, built of bricks of special shapes, are given in table 7. Although the performance ratings of the walls listed in table 7 are informative, a fair comparison of the water permeabilities of the different kinds of units is difficult to make because of the wide diversity in construction methods, in the kinds of mortar, and in the absorptive properties of the units, which were not wetted but were laid as received.

One of the 8-in. walls built of "Tightwall" brick, B300, leaked badly and was rated "poor"; the others were rated "good" or "excellent." Since no mortar was placed in the collar joints of the walls, their resistance to rain penetration depended greatly upon the watertightness of the head joints in the wall facings. Even so, their performances were comparable to those of 8-in. all-brick walls of workmanship A′ or F.

The 8-in. walls faced with "Spaulding" bricks were rated either "poor" or "fair." Mortar 11, used in these walls, was much richer than most mortars, and the initial flow averaged less than 80 percent (see table 5). The mortar was "fat," and it is not known if the comparatively high permeability of the walls resulted from the mason being satisfied with an extraordinarily low water content in the mortar, which in turn may have prevented a good bond of the brick to the mortar.[15] The least permeable of the walls, wall B335, was built with workmanship Q, ordinarily not expected to be as good a type of workmanship as type P. The high brick-suction of the facing bricks in walls B332 and B333 was a factor in the low rating given these walls. Had these bricks been wetted before laying and if more water had been used in the mortar, it is probable that the performance would have been greatly improved.

The mortar used in the 8-in. walls built of **H**-brick was rich, and the initial flow was 90 percent (see table 5), which is lower than that usually desired by most masons. The average performance of these walls was poor. It is possible, as in the case of the walls containing "Spaulding" bricks, that if more water had been used in the mortar the performance of these walls would have been better. Even so, the performance of the walls containing either the "Spaulding" or the "H" bricks was better than those of 8-in. all-brick walls of workmanship B (see table 6).

A different mortar was used in each of three groups of 8-in. walls built of "Munlock" brick.

[15] Tests on masonry mortars made by M. O. Withey show a large increase in bond strength between brick and mortar when the initial flow of the mortar was raised. Recent Experiments on Masonry Building Materials Made in the Materials Testing Laboratory of the University of Wisconsin, Univ. Wis., Eng. Exp. Sta., Reprint 53.

The workmanship used in constructing all of the walls was alike, and the average permeability of each group was found to decrease with increase in the water retentivity of the mortars. The water retentivity of mortars 9, 10, and 2 was 55, 65, and 80 percent, and the respective performances of walls containing these mortars were rated as "poor," "fair," and "good" (see table 7).

Nine walls were built of "Speedbrik" received from two different plants, one in Ohio and the other in Tennessee (see description of the "Speedbrik" walls). The brick suction for the walls built with Ohio "Speedbrik" (brick *P*) was 6 g and that of walls built with Tennessee "Speedbrik" (brick *O*) was about 20g. The average performance of 8-in. walls built of the Ohio brick with mortar 8 (water retentivity of 90 percent) was rated as "fair," while that of 8-in. walls built of Tennessee units with mortar 7 (water retentivity of 60 percent) was rated as "poor." Most of the "Speedbrik" walls failed by leakage from the flashings regardless of wall thickness (see table 7), but 6-inch walls of Tennessee brick were also penetrated at the back above the flashings by moisture which spread over about 60 percent of the wall area. The 8- and 12-in. walls of the Tennessee brick were only about 5 per cent damp.

The head joints in the sponsored walls containing large units, such as H-brick, "Munlock" brick, and "Speedbrik,"were not completely filled with mortar, but they were filled to a greater depth than was usual for the 8-in. brick walls of workmanship B, listed in table 6. The performances of the sponsored walls containing these units were better than those of brick walls of workmanship B; they were comparable to those of 8-in. brick walls of workmanship F, but were not so good as those of walls built with workmanships A or A′. The data (table 7) indicate that the effects on permeability of variation in the water retentivity of the mortars, and of the brick-suction of the sponsored units, were similar to those noted in walls containing brick of ordinary size and shape.

(d) Structural Clay Tile or Concrete Units

The performances of walls of structural clay tile and of concrete units laid without facings of brick are given in table 9. Two of these walls contained standard 8- by 12- by 12-in. tile (tile *j*) and one contained 8- by 12- by 8-in. stone concrete block (block *m*). The remaining walls listed in this table were built of sponsored units.

The effect of laying the structural clay tile *j* on end or on the side (cells respectively vertical or horizontal) may be obtained by comparing the performances of walls B126 and B127, table 9. Both walls were highly permeable, but the rate of leakage through wall B127, with tile laid on the side, was nearly four times that of wall B126. The shells in the head joints of the side-bearing tile were difficult to butter, and much less mortar was used in them than for the solid head joints in wall B126. It is probable that the comparatively high rate of leakage through wall B127 was due to the greater permeability of the head joints.

The backs of walls B277, 278, and 279 built of "Dri-Speedwall" tiles were not penetrated by moisture, and the baffles in these units effectively diverted leakage to the bottom of the walls. As in the case of cavity-wall specimens, these walls may be rated as "good" to "excellent" or "fair," depending upon what provision is made for the disposal of leakage water. Even so, with leakage diverted to the inside face, these walls gave the best performances of any listed in table.9

After wall B279 had been tested for several days, three holes were drilled in the upper head joints of the exposed face. When the test was resumed, the leakage rate through the facing increased to 18 liters per hour and several joints in the inside face became damp in about 14 hours, but there was no water visible above the flashing.

The rate of leakage through walls of concrete units was much greater than that observed for walls built of structural clay tile. The walls of concrete units were more permeable to air than were the tile walls, and it was not always possible to maintain an air pressure of 10 lb/ft^2 in the test chamber until after the concrete units in the specimens had become wetted. Except for the walls built of "Dri-Speedwall" tile, it is evident that all of the constructions listed in table 9 require protective coatings or treatments, such as brick or stucco facings, paints, or waterproofings, in order to have a satisfactory resistance to wind-driven rains.[16]

As part of a later investigation the exposed face of wall B123, of "Mahlstedt" cinder-concrete block, was treated with a cement-water paint, and the performance of the wall, after painting, was "excellent." The walls of "Dunstone" and of "Dun-ti-stone" units were not so treated, but it is probable that they would have given excellent resistance to water penetration if they had been.

V. SUMMARY

1. Brick walls, in which labor and mortar were used sparingly, so that the interior of the vertical joints were left open and not filled with mortar, were highly permeable and leaked excessively.

2. Brick walls, in which the vertical joints were filled with mortar or grout and built of bricks having a low "suction" when laid, were highly resistant to water penetration.

3. There was little practical difference in the performance of walls in which the vertical joints were filled (a) by heavily buttering the bricks with mortar before placing them in the wall, (b) by slushing mortar into the joints from above, (c) by pouring in a grout, or (d) by shoving the bricks into a heap of mortar placed on the bed (pick-and-dip method).

4. Twelve-inch brick walls in which the head joints were lightly buttered at the exposed faces only, but which contained a mortar parging applied to the backs of both the first and second wythes, were highly resistant to water penetration. Eight-inch walls of this type were more permeable than similar 8-in. walls in which the vertical joints (head and collar joints) were completely filled.

5. There was no significant difference in the permeability of brick walls in which mortar for the bed joints was leveled or furrowed before placing the bricks, sufficient mortar having been used to cover the bed.

6. Brick walls, 8-in. thick, containing cored bricks and in which the vertical joints were completely filled, were highly resistant to water penetration and were slightly but significantly less permeable than similar walls built of solid bricks.

7. The least permeable brick walls were built of units having a low brick-suction. Eight-inch brick walls in which the vertical joints were completely filled, were rated as "good" or "excellent" when the brick suction did not exceed 10 g. Twelve-inch walls, with filled vertical joints, were rated as "good" when the brick-suction averaged about 20 g. Similar walls were highly permeable if the brick-suction exceeded 50 or 60 g, particularly when built with a mortar having a low water retentivity.

8. Low-absorptive bricks or those in which the "suction" was greatly reduced by pre-wetting, but which did not contain excessive amounts of absorbed water, were laid without difficulty in a mortar of high water retentivity. When such bricks were used with a mortar of low water retentivity, the construction of the walls was marked by excessive bleeding or by extrusion of the mortar from the joints. However, the walls so constructed were highly resistant to water penetration.

9. When the bricks had a high suction and were laid in a mortar having a low water retentivity, the walls were difficult to build and they were also more permeable than if a mortar having a high water retentivity was used.

10. Twelve-inch walls faced with brick and backed with hollow units were more permeable than similar all-brick walls. The kind of hollow unit used in the backing had no consistent or important effect on permeability, but the walls containing the end-bearing units appeared to be slightly less permeable than those containing side-bearing hollow units.

11. Walls of concrete units, without protective facings or coatings, were highly permeable.

WASHINGTON, January 23, 1942.

[16] Tests of the water permeability of masonry walls by R. E. Copeland and C. C. Carlson show that plain (unpainted) concrete masonry walls were highly permeable. Proc. Am. Concrete Inst. **36**, 169 (1940).

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