DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 366
[Part of Vol. 22]

# STRENGTH OF INTERLOCKING-RIB TILE WALLS

BY

A. H. STANG, Engineer
D. E. PARSONS, Associate Civil Engineer
A. B. McDANIEL, Research Associate
*Bureau of Standards*

February 7, 1928

PRICE, 10 CENTS
$1.25 PER VOLUME ON SUBSCRIPTION

Sold only by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

# STRENGTH OF INTERLOCKING-RIB TILE WALLS

By A. H. Stang, D. E. Parsons, and A. B. McDaniel

ABSTRACT

Eight walls, 12 inches thick, 6 feet long by 9 feet high, built of tile of a new design having interlocking ribs, were tested; four walls in compression, three walls under transverse loading, and one wall was subjected to a transverse load before being tested in compression. Lime, cement-lime, cement, and no mortars were used in the horizontal joints. Spaces between the terminal ribs of the tiles in the walls were grouted. The strength of the walls, both under vertical and transverse loads, was affected by the workmanship and the mortar beds. The wall with cement-lime mortar beds sustained a maximum transverse load about two and one-half times that taken by the wall with lime mortar beds and higher than any other tile wall so far tested at the Bureau of Standards. Similarly, the compressive strength of the other cement-lime mortar-bedded wall was about two and one-half times that of the other wall with lime mortar beds.

CONTENTS



## I. INTRODUCTION

During the past decade the Bureau of Standards has made a study of the physical properties of hollow clay building tile and the strength of walls built of these building units. The results of this study are embodied in three [1] [2] [3] reports which have been published by the bureau.

---

[1] B. S. Tech. Paper No. 120, Tests of Hollow Building Tiles, Hathcock and Skillman.

[2] B. S. Tech. Paper No. 238, Some Compressive Tests of Hollow-Tile Walls, Whittemore and Hathcock.

[3] B. S. Tech. Paper No. 311, Compressive and Transverse Strength of Hollow Tile Walls, Stang, Parsons, and Foster.

In more recent years, especially as a result of the destruction of masonry walls in the earthquake of September, 1925, in Japan, and at Santa Barbara, on June 29, 1925, and in the hurricane of September 18, 1926, in southern Florida, engineers and builders are giving increasing attention to the design and use of types of masonry that will successfully withstand these severe conditions. The present paper describes the investigation of the strength of walls built with an interlocking-rib clay building tile which has recently been devised by Luther S. Munson for the purpose of giving walls of greater transverse strength than is obtained with the tiles now available. Mortars of different composition were used and the transverse and compressive strength of the walls determined. It is believed that the results of this investigation are of interest, as they show the possibilities in tile, having interlocking ribs, for masonry walls which may be subjected to extreme conditions of loading or pressures.

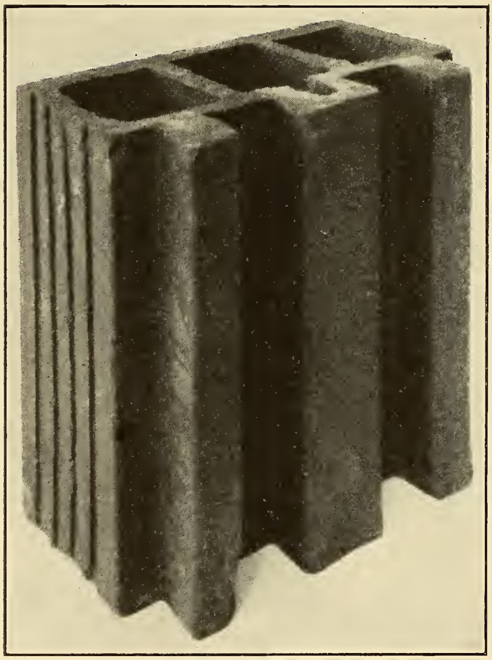

Fig. 1.—*Regular tile*

This investigation was made by the bureau in cooperation with The Research Service (Inc.), Washington, D. C., under the research associate plan.

The labor and materials for the walls and other specimens were furnished by the Munson Auto-Lock Tile Co.

The walls were built in the laboratory at the bureau under the supervision of the staff which made the tests and with the aid of Mr. McDaniel's assistant, A. M. Pisarra.

Acknowledgments are due J. W. McBurney, research associate, Common Brick Manufacturers' Association of America, and to C. T. Ervin, laboratory assistant, for their cooperation in making the tests.

## II. DESCRIPTION OF THE TILE

The tile were made of shale and were fired in the round, down-draft kilns of a plant at Cumberland, Md. The tiles used in these tests were especially selected for the purpose but were "run-of-kiln."

The chief distinctive feature in the design of the tiles is the ribs which project from one face, as shown in Figures 1, 2, and 3 and the cross sections in Figures 4 and 5. These ribs are designed to be set vertically near the mid plane of walls, with the ribs of adjacent tiles

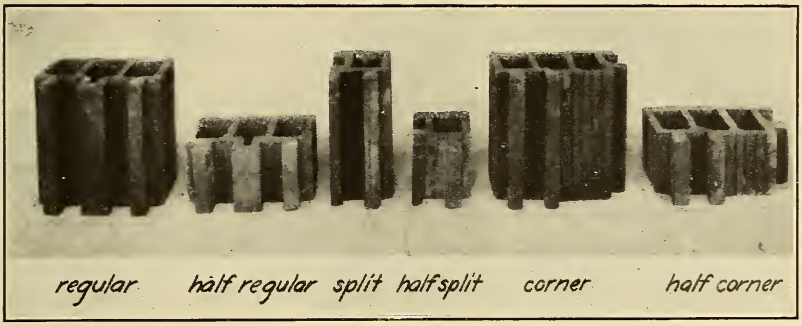


FIG. 2.—*Interlocking rib tiles*

interlocking so as to effect a mechanical bond between the units. The spaces between the outside ribs of adjacent tiles are grouted after the tiles are set in place. It is intended that the grout will flow into and fill the spaces between the outside interlocking ribs.

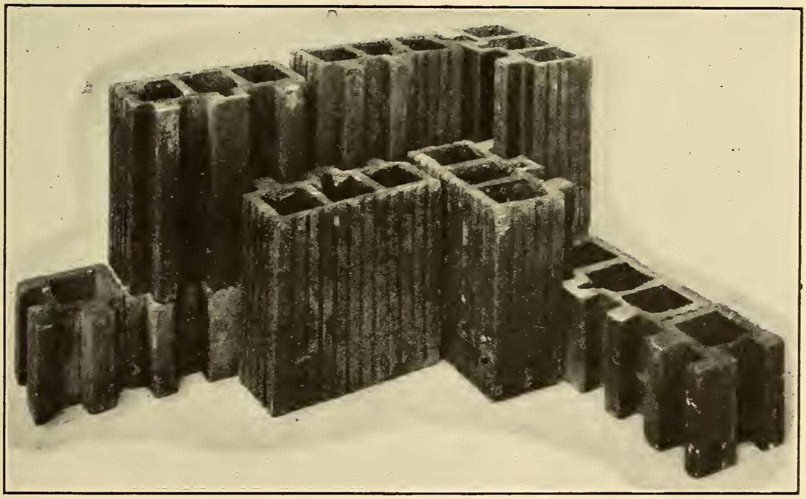

FIG. 3.—*Arrangement of tile for the corner of building*

The six forms of these interlocking tiles used in the walls of a building are listed in Table 1 and shown in Figure 2. In order to obtain a continuous bond throughout the height of walls and to secure the greatest transverse strength from the interlocking ribs, the tile are set, as shown in Figure 3, with the horizontal joints in the outer tile at mid height of the inner tile. This breaking of horizontal joints is accomplished by the use of "half" tile, the length of which is one-half that of the otherwise similar "regular" tile. "Corner" tile, having ribs on an edge as well as on the face, are used in connecting the two walls at the corner of a building.

As the vertical joints in the outer tile come at the middle of the inner tile (see fig. 3), "split tile" having half the width of the regular

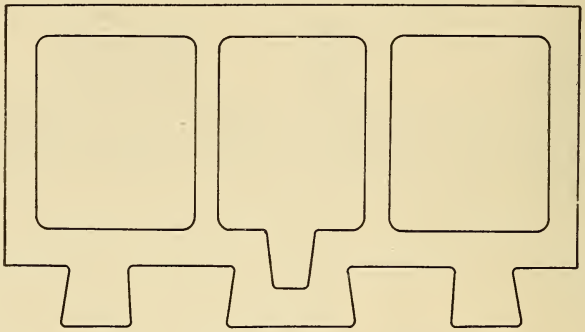

Fig. 4.—*Cross section of regular tile*

tile were provided to bring the wall flush at ends or at door and window jambs. The split tile may also be readily made by striking along the middle of the center rib of a regular tile with the blade of a mason's trowel.

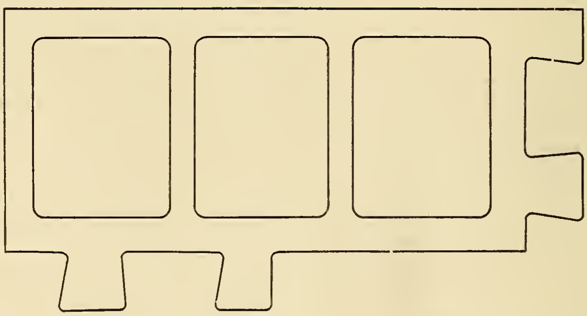

Fig. 5.—*Cross section of corner tile*

## III. TESTS OF THE TILE

Table 1.—*Forms of interlocking-rib hollow tile*

| Form | Nominal size (inches) | Cells |
|---|---|---|
| Regular | 6 by 12 by 12 | 3 |
| Half regular | 6 by 12 by 6 | 3 |
| Split | 6 by 6 by 12 | 1 |
| Half split | 6 by 6 by 6 | 1 |
| Corner | 6 by 12 by 12 | 3 |
| Half corner | 6 by 12 by 6 | 3 |

The specimens used in the determination of absorption, density, and strength were selected at random from the tile to be used in building the walls.

## 1. DIMENSIONS

In determining the properties of the tile both the gross and the net cross-sectional area calculated from measured dimensions were used. These areas and the corresponding gross and net volumes are given in Table 2.

## 2. WEIGHT AND DENSITY

Each tile was dried in a gas oven at 220° F. until the weight became constant. The gross and net densities were determined by dividing the dry weights by the gross and net volumes, respectively. The gross and net densities of the various forms of tile are given in Table 2.

## 3. COMPRESSIVE STRENGTH

Each tile was capped on both of the surfaces, on which the load was to be applied, with mortar composed of 3 parts of Portland cement, 1 part gypsum, by volume, and sufficient water to give the desired plasticity. The caps were allowed to harden for 7 days before the tiles were tested.

Ten regular tiles, five corner tiles, and five split tiles were tested on end (similar to the position in which they were laid in the wall) for compressive strength. The values of stress at first crack and of ultimate compressive strength for the tiles tested are given in Table 2. These values, as was expected from previous tests on tiles made from similar clay, lie well above the average of those found in all the previous series [4] of tests and about the same as the highest (B. S. Tech. Paper No. 311, p. 320, Table 1) used in the previous series of transverse tests, being slightly less when calculated on gross area and slightly greater when calculated on net area. As no relation between the strength of the tile and the transverse strength of the walls was found in these previous tests, this high strength is not thought to be significant in the transverse tests of the walls. It is known that high-strength tiles increase somewhat (although not proportionately) the compressive strength of walls.

---

[4] See footnotes 1, 2, and 3, p. 389.

TABLE 2.—*Physical properties of interlocking-rib tile*

| Tile No. | Form of tile | Nominal size of tile | Number of cells | Area | | Volume | | Density | | Position in which tested | Stress—first crack | | Compressive strength | | Modulus of elasticity, net area | Dry weight | Absorption | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gross | Net | Gross | Net | Gross volume | Net volume | | Gross area | Net area | Gross area | Net area | | | Immersion 24 hours | Boil 1 hour |
| | | *Inches* | | *Square inches* | *Square inches* | *Cubic feet* | *Cubic feet* | *Lbs./ft.*$^3$ | *Lbs./ft.*$^3$ | | *Lbs./in.*$^2$ | *Lbs./in.*$^2$ | *Lbs./in.*$^2$ | *Lbs./in.*$^2$ | *Lbs./in.*$^2$ | *Pounds* | *Per cent* | *Per cent* |
| 1S | Regular | 6 by 12 by 12 | 3 | 74.60 | 32.54 | 0.51 | 0.22 | 60.5 | 138 | End | 3,480 | 7,990 | 3,670 | 8,410 | 4,540,000 | 31.00 | 3.6 | 6.4 |
| 2S | do | do | 3 | 76.60 | 33.03 | .54 | .23 | 60.5 | 140 | do | 2,580 | 5,990 | 2,700 | 6,270 | 3,470,000 | 32.25 | 3.6 | 6.9 |
| 3S | do | do | 3 | 73.78 | 31.55 | .50 | .21 | 62.2 | 143 | do | 2,810 | 6,570 | 3,270 | 7,650 | 4,720,000 | 31.00 | 3.0 | 6.0 |
| 4S | do | do | 3 | 76.76 | 33.34 | .54 | .23 | 60.5 | 138 | do | 2,190 | 5,040 | 2,350 | 5,420 | 4,020,000 | 32.25 | 3.9 | 7.0 |
| 5S | do | do | 3 | 74.80 | 32.58 | .51 | .22 | 60.5 | 140 | do | 3,930 | 9,030 | 3,930 | 9,030 | 4,760,000 | 31.50 | 2.9 | 5.7 |
| 6S | do | do | 3 | 78.60 | 35.52 | .55 | .25 | 60.5 | 133 | do | 3,470 | 7,680 | 3,470 | 7,680 | 4,170,000 | 32.75 | 4.4 | 7.0 |
| 7S | do | do | 3 | 77.00 | 35.27 | .53 | .24 | 58.8 | 129 | do | 2,730 | 5,960 | 3,090 | 6,740 | 4,210,000 | 31.50 | 4.3 | 7.7 |
| 8S | do | do | 3 | 77.60 | 35.69 | .53 | .24 | 60.5 | 130 | do | 3,020 | 6,560 | 3,310 | 7,200 | 3,960,000 | 31.75 | 4.1 | 7.2 |
| 9S | do | do | 3 | 77.40 | 35.20 | .53 | .24 | 60.5 | 133 | do | 2,830 | 6,220 | 2,830 | 6,220 | 4,170,000 | 31.75 | 4.5 | 7.9 |
| 10S | do | do | 3 | 77.10 | 34.43 | .53 | .24 | 60.5 | 135 | do | 3,310 | 7,400 | 3,890 | 8,710 | 4,170,000 | 32.25 | 3.2 | 6.1 |
| | | Average | | 76.42 | 33.92 | .53 | .23 | 60.5 | 136 | | 3,035 | 6,840 | 3,250 | 7,330 | 4,220,000 | 31.80 | 3.8 | 6.8 |
| 1SS | Split | 6 by 6 by 12 | 1 | 38.50 | 19.94 | .27 | .14 | 65.6 | 127 | End | 2,700 | 5,220 | 3,780 | 7,300 | Not determined. | 17.50 | Not determined. | |
| 2SS | do | do | 1 | 36.84 | 19.60 | .26 | .14 | 68.2 | 129 | do | 3,670 | 6,840 | 4,320 | 8,120 | do | 17.50 | Do. | |
| 3SS | do | do | 1 | 38.28 | 19.85 | .27 | .14 | 65.8 | 127 | do | 3,500 | 6,760 | 4,330 | 8,350 | do | 17.50 | Do. | |
| 4SS | do | do | 1 | 37.20 | 19.22 | .26 | .13 | 66.9 | 129 | do | 3,340 | 6,460 | 3,340 | 6,460 | do | 17.25 | Do. | |
| 5SS | do | do | 1 | 37.94 | 19.84 | .26 | .14 | 64.4 | 123 | do | 3,120 | 5,850 | 3,240 | 6,200 | do | 17.00 | Do. | |
| | | Average | | 37.75 | 19.69 | .26 | .14 | 66.0 | 127 | | 3,270 | 6,230 | 3,800 | 7,290 | | 17.35 | | |
| 1C | Corner | 6 by 12 by 12 | 3 | 84.40 | 34.58 | .59 | .24 | 55.5 | 135 | End | 2,320 | 5,680 | 2,320 | 5,680 | Not determined. | 32.50 | Do. | |
| 2C | do | do | 3 | 85.74 | 35.13 | .59 | .24 | 55.1 | 134 | do | 2,100 | 5,140 | 2,370 | 5,780 | do | 32.75 | Do. | |
| 3C | do | do | 3 | 85.00 | 34.39 | .59 | .24 | 55.9 | 138 | do | 2,820 | 6,980 | 2,820 | 6,980 | do | 33.00 | Do. | |
| 4C | do | do | 3 | 85.72 | 34.53 | .59 | .24 | 54.2 | 135 | do | 2,730 | 6,780 | 2,730 | 6,780 | do | 32.25 | Do. | |
| 5C | do | do | 3 | 85.80 | 35.02 | .60 | .24 | 54.5 | 134 | do | 2,720 | 6,680 | 2,720 | 6,680 | do | 32.50 | Do. | |
| | | Average | | 85.33 | 34.73 | .59 | .24 | 55.0 | 135 | | 2,540 | 6,250 | 2,590 | 6,380 | | 32.60 | | |

The modulus of elasticity of the tiles was determined, for the 10 regular tile, from deformations under load measured in a 10-inch gauge length with a clamp type of compressometer having a single micrometer dial graduated to 0.0001 inch. The values of the modulus of elasticity are given in Table 2. The stress-strain curves, which were plotted from the observed readings of the applications of loads to the 10 regular tile, are given in Figure 6. These results have the same characteristics as those obtained from tests of tile of other shapes as the deformations were approximately proportional to the loads.

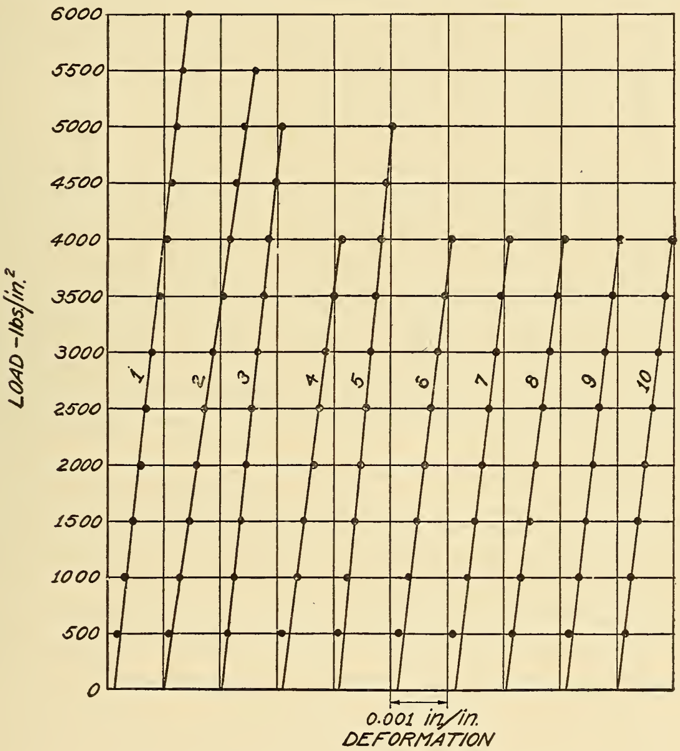


Fig. 6.—*Stress-strain curves for regular tiles*

## 4. ABSORPTION

(*a*) Immersion, 24 Hours.—Three pieces, free from fissures and cracks, and weighing at least one-half pound each, were taken from each tile tested. The edges were ground, and the specimens were placed in a gas oven at 220° F. to dry. A constant weight was obtained, the specimens then being immersed in water at room temperature for 24 hours. Each specimen was taken out of the water and allowed to drain for about 30 seconds and then wiped off with a damp cloth and weighed. The difference in weight, divided by the dry weight, gave the value of absorption. These values for the 10 regular tile are given in Table 2.

(*b*) BOILING, ONE HOUR.—After the specimens from the last operation had dried, they were immersed in boiling water for one hour and remained therein until the water had cooled to room temperature. As previously described in (*a*) above, the specimens were then weighed and the percentage of absorption computed. These values for the 10 regular tile are also given in Table 2.

## IV. DESCRIPTION OF THE WALLS

### 1. SIZE

The walls were 6 feet long, about 9 feet high, and about 12 inches thick. Each wall involved the use of 94 regular tile, 10 half regular tile, 16 split tile, and 4 half split tile.

### 2. TYPE OF CONSTRUCTION

The arrangement of the tile in the walls is shown in Figure 3. In the previous tests on walls constructed with the usual type of tiles the transverse strength was found to depend on "the adhesive strengths between tiles and mortar" (B. S. Tech. Paper No. 311, p. 338), failure always occurring as a break between the tile and its mortar bed. With the interlocking-rib tile it was contemplated that a large part of the transverse strength would come from the compressive and shearing strength of the grout between the interlocking ribs and might be expected to be relatively little affected by the kind of mortar bed.

For this reason there was included in the test program two walls (Nos. 4 and 8) in which the tiles were laid up with only sufficient pointing with mortar to hold them in place while the grout was setting. These are noted in the table as "No mortar bed." There were also included two walls (Nos. 1 and 5) with a lime-mortar bed, although in the previous tests lime mortar had given low results in both compressive and transverse tests. The other two sets of walls with a cement-lime bed (Nos. 2 and 6) and a cement-mortar bed (Nos. 3 and 7) were intended to represent types of construction such as might be expected to be used in practice.

### 3. MORTAR

Table 4 gives the amount of mortar materials used for each square foot of wall surface. The amount of water used is reported since it affected the plasticity of the mortar and probably also its strength.

The four mortar mixtures were as follows:

*Lime mortar* (1¼L:3S), by volume 1¼ parts of lime to 3 parts of damp sand, loose measure; weight equivalents, 50 pounds of hydrated lime to 220 pounds of dry sand. (Mortar No. 1 in B. S. Tech. Paper No. 311.)

*Cement-lime mortar* (1C:1¼L:4S), by volume 1 part of cement to 1¼ parts of lime to 4 parts of damp sand, loose measure; weight equivalents, 94 pounds of Portland cement to 50 pounds of hydrated lime to 293 pounds of dry sand. (Mortar No. 3 in B. S. Tech. Paper No. 311.)

*Cement mortar* (1C:3S), by volume 1 part of cement to 3 parts of damp sand, loose measure; weight equivalents, 94 pounds of Portland cement to 220 pounds of dry sand. (Mortar No. 4 in B. S. Tech. Paper No. 311.)

*Grout.*—The grout was cement mortar, with the addition of sufficient water to make it pour from a sprinkling can having a spout 1 inch in diameter.

These mortar mixtures represent certain commonly used volume proportions. Measurement by volume, however, would have resulted in wider variations in the mortar compositions than seemed desirable, so that equivalent proportions by weight were used, assuming that 1 cubic foot of lime weighs 40 pounds and 1 cubic foot of cement weighs 94 pounds. The weight of the dry materials in a cubic foot of damp sand was determined by preliminary tests to be about 73 pounds. Since the weight of a cubic foot of damp sand, loose measure, varied with the moisture content, the moisture content of a sample of sand was determined each day during the construction of the walls, and the weight necessary to make the desired amount of dry sand was computed. This value was used in proportioning the mortar for the day. Water was added to give the consistency desired by the mason and the amount of water recorded. All the mortar used was proportioned by these equivalent weights.

Table 3 gives the compressive strengths of the mortar specimens, which comprised six cylinders (2 inches in diameter, 4 inches long) made from the mortar of each wall with the exception of the lime mortar, for which three cylinders were made for each of walls Nos. 1 and 5. After they had been taken from the molds three cylinders were placed on the walls they represented and allowed to age under the same conditions, and the other cylinders were placed in water. All the cylinders were tested at the same age as the corresponding wall. Two cylinders of grout were made of the material used in each wall, one cylinder being stored in air on the wall with the other mortar specimens and the other cylinder stored in water.

TABLE 3.—*Average strength of mortar specimens*

| Wall No. | Proportions (by volume) | Total specimens tested | Average compressive strength | |
|---|---|---|---|---|
| | | | In air | In water |
| | | | *Lbs./in.²* | *Lbs./in.²* |
| 1 and 5 | 1¼L : 3S | 6 | 90 | ---------- |
| 2 and 6 | 1C : 1¼L : 4S | 12 | 1,330 | 2,190 |
| 3 and 7 | 1C : 3S | 12 | 1,250 | 3,400 |
| 4 and 8 | No mortar | ---------- | ---------- | ---------- |
| | Grout used in all walls | 16 | 720 | 2,000 |

### 4. WORKMANSHIP

The time required to build each wall was recorded, beginning when the base plate was level and ending when the last tile was laid. These time values for the eight walls are given in Table 4, as "Rate of building walls, square feet per hour." The low values for the walls Nos. 4 and 8, with no mortar beds, were caused by the care taken by the mason to select and place the tile, so as to secure as uniform bearing of superimposed tile as was possible.

The condition of the webs and shells of the tile appears to be the criterion by which the quality of workmanship of end construction tile walls can be judged. With tiles having a design like that of the tiles of this investigation (see fig. 5) it is possible to bed the transverse webs as well as the outside shells. A complete bedding would give the greatest strength of the wall. Wall No. 6, which was built first, had practically full mortar bedding of the entire area. The other walls which had mortar beds did not have the transverse webs bedded.

The walls were built by a brick mason and one helper. The mason was instructed to build the walls with the same care as would be used on a commercial job.

### 5. AGING CONDITIONS

All the walls remained in the heated laboratory until tested during the last week of December, 1926, at ages of from 54 to 58 days. Neither the tile nor walls were wetted at any time during the aging period.

## V. TESTS OF THE WALLS

### 1. TRANSVERSE TESTS

Figure 7 shows wall No. 2 in position for the transverse test. It was restrained laterally at the bottom by means of two pins embedded in the concrete flooring, against which the channel holding the wall abutted. The top of the wall was restrained horizontally as shown by means of two cross rods holding the wooden beam in position. The vertical load on the wall was a steel beam whose weight amounted to 5 lbs./in.$^2$, gross wall area, which corresponded to a light roof load. The transverse load was applied to two crossbeams extending horizontally across the full length of the wall, each beam being 18 inches from the mid height of the wall. The load was applied by means of a hydraulic jack on a crosspiece joining the beams, so that equal loads were applied on each crossbeam. A pressure gauge was calibrated with the pump and jack used for these tests.

The deflection of the wall on both sides at mid height was obtained by having a wire extended between two points about 8 inches from the top and bottom of the wall. As each load increment was applied

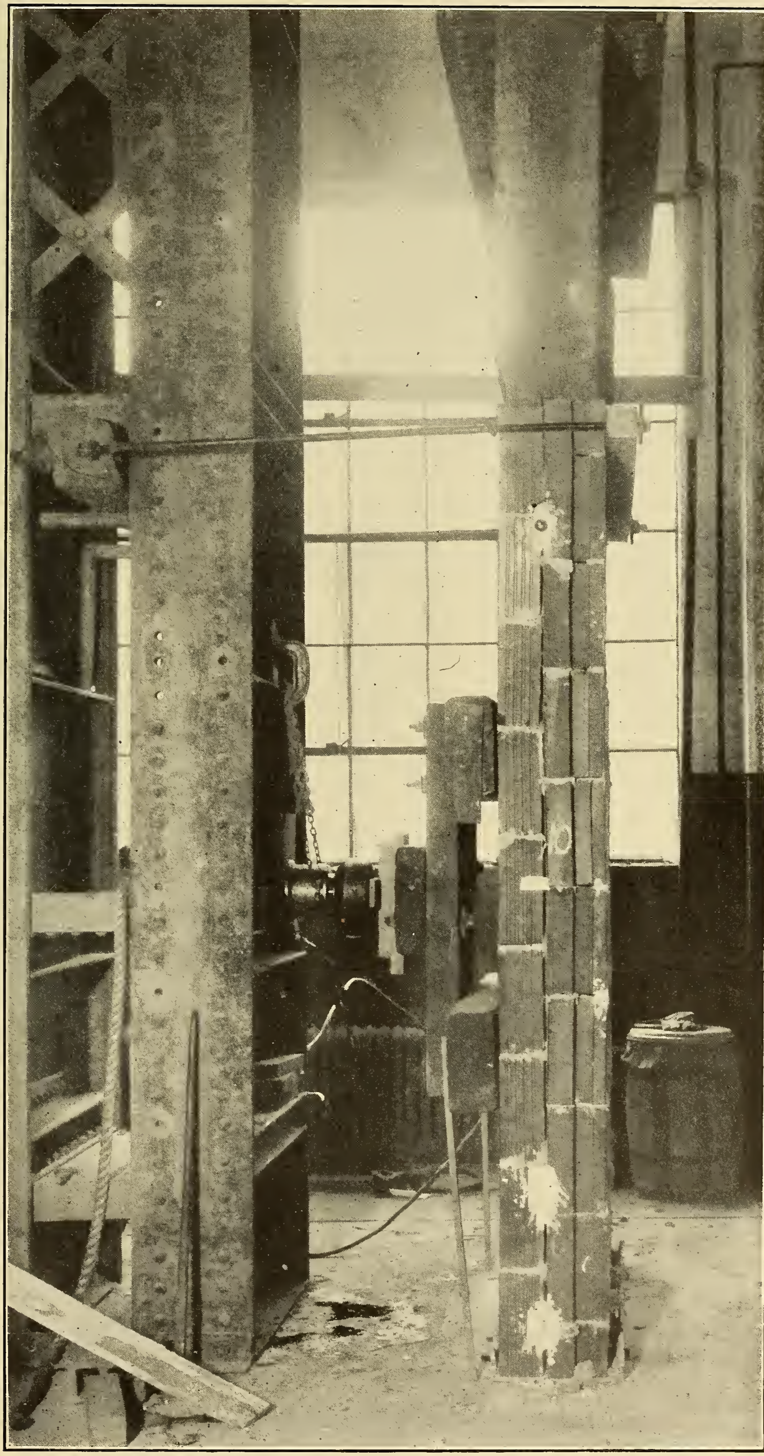

Fig. 7.—*Wall No. 2 in position for transverse test*

the deflection at mid height was measured by means of mirror scales. The load increments were applied until the maximum load was obtained.

The result of the transverse tests of the tile walls are given in Table 4. The equivalent uniform loads in Table 4 were calculated to give the same bending moment on the assumption that the wall was a simple beam with two equal loads. On the same assumption, the modulus of rupture was computed, with the vertical load of 5 lbs./in.$^2$ plus the weight of the wall above the line of fracture, as the axial load. The beam section was considered to be a solid rectangle of breadth equal to the nominal length of the wall (72 inches) and of depth equal to the nominal thickness (12 inches). This is, of course, an arbitrary assumption, but the true modulus of rupture varies with the location of the section considered.

TABLE 4.—*Physical properties of interlocking-rib tile walls*

| Wall No. | Number of tile courses | Rate of building (square feet wall surface per hour) | Mortar volume ratio | Mortar materials used | | | | Grout materials used | | | Transverse test | | | | Compressive test | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cement | Lime | Sand (dry) | Water | Cement | Sand (dry) | Water | Maximum load | Distance between restraints | Equivalent uniform load | Modulus of rupture[1] | Maximum load | Compressive strength[2] | Modulus of elasticity[2] |
| | | | | *Lbs./ft.² wall surface* | | | | *Lbs./ft.² wall surface* | | | *Pounds* | *Inches* | *Lbs./ft.²* | *Lbs./in.²* | *Pounds* | *Lbs./in.²* | *Lbs./in.²* |
| 1 | 9 | 10.6 | Lime, 1¼L:3S | ----- | 1.39 | 6.26 | 2.09 | 0.65 | 1.55 | 0.52 | 4,200 | 106 | 105 | 35 | ----- | ----- | ----- |
| 2 | 9 | 12.4 | Cement-lime, 1C:1¼L:4S | 1.38 | .72 | 4.30 | 1.38 | .91 | 2.15 | .75 | 10,800 | 106 | 270 | 102 | ----- | ----- | ----- |
| 3 | 9 | 11.8 | Cement, 1C:3S | 1.96 | ----- | 4.68 | 1.37 | .70 | 1.62 | .62 | 8,800 | 106 | 220 | 82 | 854,500 | 990 | ----- |
| 4 | 9 | 10.9 | No mortar bed | .79 | ----- | 1.88 | .58 | .76 | 1.78 | .61 | 5,350 | 106 | 130 | 47 | ----- | ----- | ----- |
| 5 | 9 | 13.9 | Lime, 1¼L:3S | ----- | 1.13 | 5.08 | 1.71 | .61 | 1.46 | .48 | ----- | ----- | ----- | ----- | 429,500 | 500 | 680,000 |
| 6 | 9 | 9.2 | Cement-lime, 1C:1¼L:4S | 1.52 | .81 | 4.75 | 1.81 | .84 | 1.95 | .68 | ----- | ----- | ----- | ----- | 1,095,500 | 1,270 | 1,780,000 |
| 7 | 9 | 13.5 | Cement, 1C:3S | 2.09 | ----- | 4.98 | 1.35 | .80 | 1.90 | .71 | ----- | ----- | ----- | ----- | 665,200 | 770 | 1,380,000 |
| 8 | 9 | 10.8 | No mortar bed | .73 | ----- | 1.69 | .51 | .85 | 1.98 | .58 | ----- | ----- | ----- | ----- | 265,500 | 310 | 230,000 |

[1] In computing the modulus of rupture the usual formula for solid specimens of rectangular cross-section was used.
[2] In computing the compressive strength and the modulus of elasticity the nominal gross area was used.

The walls failed at the maximum load by opening up a horizontal-bed joint; in the cases of walls Nos. 1, 2, and 4 two and one-half full-tile lengths from the top of the wall, and three and one-half tile lengths from the bottom of the wall for wall No. 3 (cement mortar beds). At the joint where failure occurred it was evident that the adhesion of the mortar (where present) to the tile was overcome, and likewise the cementing effect of the grout in the vertical joints, near the plane of rupture, was broken down.

The deflections of the walls at mid height are shown in Figure 8. In all four cases, upon the release of the pressure, the walls returned to approximately their original positions.

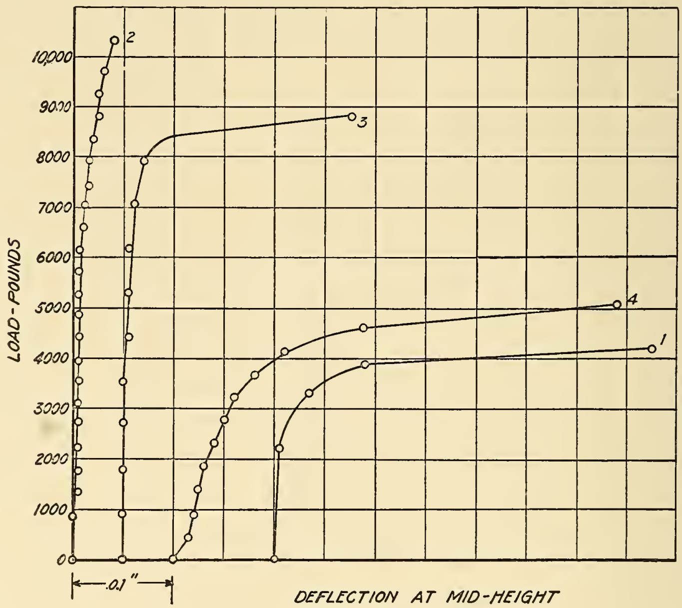


Fig. 8.—*Deflection at mid height*

The demolition of the walls, after the tests, showed that much of the grout ran through the vertical joints to the bottom of the walls, leaving spaces a tile or more in length without any grouting material. In many cases the grout worked around the ends of the lugs and pushed the adjacent tile apart. This condition undoubtedly had some effect upon the results of these transverse-strength tests.

Wall No. 2, with cement-lime mortar (1C:1¼L:4S), took the highest load before failure, and about 25 per cent more load than the wall (No. 3) with cement mortar (1C:3S) beds. This difference in strength was due partly to the better workmanship in the case of the former wall and to the fact that the proportion of cementing materials to sand was greater in the cement-lime mortar. The idea that the transverse strength would be relatively little affected by the kind of mortar bed was not borne out by the tests. The results with no mortar bed (No. 4) and with lime mortar bed (No. 1) were much lower than with cement lime (No. 2) and cement (No. 3) mortar beds, and unexpectedly the lime mortar gave a lower value than no mortar. The difference, however, is no greater than the accidental variations found in tests of masonry.

The test with no mortar bed is, however, significant in showing that the grout bond between the interlocking ribs contributes materially to the transverse strength of this type of wall.

It is of interest to compare the maximum transverse loads which the interlocking-rib tile walls, made with cement and cement-lime mortar, carried with those found in the previous tests. (B. S. Tech. Paper No. 311, p. 337.)

To maintain the notation of the previous article the interlocking-rib tiles are given the serial No. 16 and the mortars the symbols of the previous article, viz, lime, No. 1; cement-lime (1C:1¼L:4S), No. 3; cement, No. 4. "No mortar" is given the symbol zero. Thus:

| Present series | Previous notation |
|---|---|
| Wall No. 1 | =16–E–1 |
| No. 2 | =16–E–3 |
| No. 3 | =16–E–4 |
| No. 4 | =16–E–0 |

In Table 5 the data on transverse tests of the previous series (taken from B. S. Tech. Paper No. 311, Table 4 p. 337) are rearranged for easier comparison and combined with the comparable data from Table 4 of the present series. The one test in the previous series on a wall of mixed construction (1M2 modulus of rupture 29 lbs./in.$^2$) is omitted because it does not fit into the arrangement.

TABLE 5.—*Summary of transverse tests on hollow-tile walls from Table 4 and Bureau of Standards Technologic Paper No. 311, p. 337*

| Wall thickness (in inches) | Description of tile and size (in inches) | End construction | | | Side construction | | |
|---|---|---|---|---|---|---|---|
| | | Wall designation | Equivalent uniform load | Modulus of rupture | Wall designation | Equivalent uniform load | Modulus of rupture |
| | | | Lbs./ft.² | Lbs./in.² | | Lbs./ft.² | Lbs./in.² |
| 8 | XXX, 8 by 12 by 12 | 7-E-3 | 55 | 41 | | | |
| 8 | H-shaped, 8 by 10¼ by 12 | | | | 8-S-2 | 115 | 73 |
| 8 | Double shell, 8 by 12 by 5 | 9-E-3 | 82 | 70 | | | |
| 8 | 2-cell, 8 by 5 by 12 | | | | 10-S-3 | 76 | 60 |
| 8 | 3-cell, 8 by 5 by 12 | | | | 13-S-3 | 92 | 72 |
| 8 | T-shaped, 8 by 6¼ by 12 | | | | 14-S-3 | 49 | 38 |
| 8 | do | | | | 15-S-3 | 62 | 52 |
| 8 | 6-cell, 8 by 12 by 12 | 4-E-2 | 60 | 47 | | | |
| 8 | do | | | | 4-S-3 | 51 | 44 |
| 8 | do | 1-E-1 | 27 | 18 | 1-S-1 | 49 | 39 |
| 8 | do | 1-E-2 | 52 | 41 | 1-S-2 | 71 | 62 |
| 8 | do | 1-E-3 | 41 | 32 | 1-S-3 | 66 | 57 |
| 8 | do | 1-E-4 | 66 | 53 | 1-S-4 | 110 | 98 |
| 8 | do | 5-E-3 | 50 | 36 | 5-S-3 | 50 | 38 |
| 8 | XXX, 8 by 12 by 12 | 6-E-3 | 49 | 39 | 6-S-3 | 60 | 47 |
| 12 | 6-cell, 12 by 12 by 12 | 2-E-2 | 140 | 49 | 2-S-2 | 151 | 57 |
| 12 | {6-cell, 8 by 12 by 12<br>3-cell, 3¾ by 12 by 12 | (1+3)-E-2 | 142 | 50 | | | |
| 12 | Faced with brick | | | | (10+11+12)-S-3 | 152 | 55 |
| 12 | T-shaped, 8 by 6¼ by 12 | | | | 14-S-3 | 121 | 42 |
| 12 | Interlocking rib, 6 by 12 by 12 | 16-E-0 | 130 | 47 | | | |
| 12 | do | 16-E-1 | 105 | 35 | | | |
| 12 | do | 16-E-3 | 270 | 102 | | | |
| 12 | do | 16-E-4 | 220 | 82 | | | |

In rearranging the table, the walls differing in only one feature were, so far as possible, brought into direct comparison. As was also pointed out in the previous paper, the "modulus of rupture" was computed on the arbitrary assumption of material uniformly distributed over the section. No other assumption was generally available, since the distribution of material in a tile wall is not uniform over the face of the wall. However, for a given thickness of wall, the moduli so computed give a measure of the relative resistance of the walls to lateral load, such as a wind load.

Comparing end construction with side construction, we see that invariably, where all other factors are alike, side construction gives the higher modulus of rupture, and in most cases the difference seems large enough to be significant. This is consistent with the interpretation of the previous paper that "the modulus of rupture values, then, are roughly measures of the adhesive strengths between tiles and mortar," since in the side construction there is a greater area of mortar bedding.

For comparing different mortars, two groups in the old series (1-E-1, 1-E-2, 1-E-3, 1-E-4; 1-S-1, 1-S-2, 1-S-3, and 1-S-4) were available. As was pointed out (B. S. Tech. Paper No. 311, p. 338), these show increasing transverse strength with increasing strength of mortar with the exception of mortar No. 3. A possible explanation was offered that the wetting of the tiles in these walls (1–E–3 and 1–S–3) had weakened the adhesion between mortar and tile. In the present series the tests on 16–E–O (wall No. 4), with no mortar bed, showed that the transverse strength with interlocking tiles was not wholly dependent on the mortar bedding but partly on the grout bond between the interlocking ribs. A stronger bond between the tile and mortar bed should, however, give a higher modulus of rupture. The lower value, 82 lbs./in.$^2$, found for cement mortar, compared with 102 lbs./in.$^2$ for cement-lime mortar indicates that in this case the stronger mortar had the weaker bond. This can not be explained, as were the results in the previous series, by wetting of the tile, since in both cases the walls were laid with dry tile. The most probable explanation is the superior workmanship of wall 16–E–3 (No. 2).

The moduli of rupture of the 12-inch walls in the previous series were, in spite of differences of construction and differences of mortar, fairly uniform, ranging from 42 lbs./in.$^2$ (14–S–3) to 57 lbs./in.$^2$ (2–S–2), the highest value being obtained with the leaner mortar. The maximum transverse loads and moduli of rupture of the interlocking-rib tile walls built with cement-lime (16–E–3, 102 lbs./in.$^2$) and cement (16–E–4, 82 lbs./in.$^2$) mortar were much higher than any of these.

Of less certain meaning is the comparison of "modulus of rupture" of 12 and 8 inch walls. The 12-inch walls should be expected to carry higher transverse loads than the 8-inch walls, and in only one case (16–E–1 lime mortar) did a 12-inch wall carry a transverse load as low as any one of the 8-inch walls. Whether their transverse strength for otherwise identical construction should be proportional to their "section modulus" computed on the arbitrary assumption of material uniformly distributed over the section is far from certain. The greater irregularity of the moduli of rupture for the 8-inch walls suggests also that these thinner walls are much more influenced by small differences in construction.

On the assumption that the "modulus of rupture" is a fair basis of comparison of the relative transverse strength of 8 and 12 inch walls, it can be stated that no wall of the ordinary type of tile tested showed as high transverse strength as the 12-inch interlocking-rib tile wall with cement-lime mortar (16–E–3, No. 2), and only one 8-inch wall (1–S–4) showed transverse strength comparable with it.

## 2. COMPRESSIVE TESTS

The channel at the base of the wall, which was set up vertically, was put on the lower head of the 10,000,000-pound compression machine in a bed of plaster of Paris. The lower head was then adjusted so that the wall was "plumb." On the top of the wall was then spread a similar capping of plaster of Paris, and the upper head of the machine was lowered until the space between it and the wall was completely filled with plaster of Paris. Vertical compressometers, having a gauge length of about 90 inches, were attached near each corner of the wall, as shown in Figure 9. The deformations

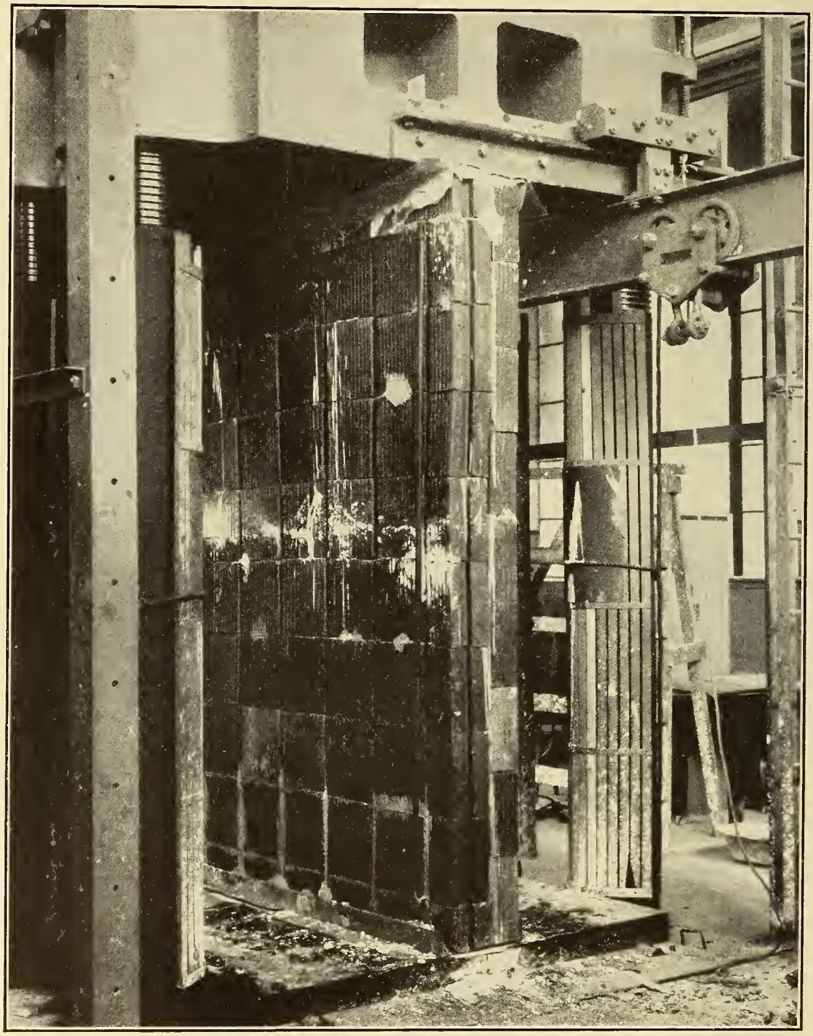

FIG. 9.—*Wall No. 8 in testing machine*

were obtained from the dial micrometers that were graduated to 0.001 inch. These observations were plotted and stress-strain curves drawn, as shown in Figure 10.

The compressive strength of each of the walls is given in Table 4. The compressive strength is based on a nominal thickness of wall of 12 inches and a length of 72 inches.

Wall No. 3 was tested for transverse strength previous to the compressive test.

The wall with no mortar bed (No. 8, fig. 9) gave the lowest result, due to the nonuniform distribution of the load over the ends of the adjacent tiles. Wall No. 5, laid with lime mortar, was also low in strength. The mortar beds started to crumble at a low load and gradually ran out of the joints like sand as the load was increased. The wall that gave the highest strength in compression (No. 6), cement-lime mortar, took a load about 50 per cent greater than the average load carried by the two walls (Nos. 3 and 7) having cement mortar beds. This difference in strength was due to the better workmanship for wall No. 6 and probably also to the greater proportion of cementing materials in the mortar for this wall. As previously explained, the entire sectional areas of the tiles in wall No.

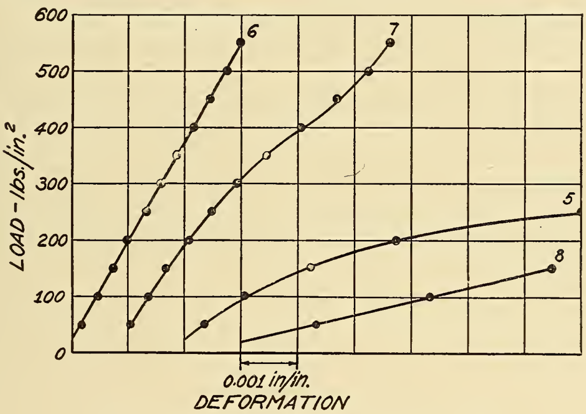


Fig. 10.—*Stress-strain curves for walls*

6 were given a mortar bearing while for all other walls only the shells were bedded. Furthermore, the workmanship of wall No. 7, cement mortar (1C : 3S), seemed from an examination during the loading to be poorer than for any other. This was indicated by the falling out of the front faces of the upper tile under a load of from 500,000 to 600,000 pounds, which showed the omission of mortar in the transverse webs and shells.

The maximum compressive strength observed was 1, 270 lbs./in.² gross area and (Table 4) was somewhat greater than any found in either of the two previous series of tests.[5]

## VI. CONCLUSIONS

The results of these tests of eight tile walls built of the interlocking-rib tiles, with different mortar beds, under average indoor conditions, lead to the following conclusions:

---

[5] See footnotes 2 and 3, p. 389.

1. Walls built of interlocking-rib tiles with staggered horizontal joints gave results in the transverse tests indicating that the resistance of the walls to side pressures was affected by the condition and nature of the cementing material used in the walls. The wall with no mortar in the horizontal joints took a maximum thrust of 5,350 pounds, or about 25 per cent greater load than that sustanied by the wall with lime mortar beds; namely, 4, 200 pounds. The highest maximum thrust (10,800 pounds) was sustained by the wall with cement-lime mortar joints. This latter case gave an equivalent uniform wall load of 270 lbs./ft.$^2$ of wall surface and a "modulus of rupture" of 102 lbs./in.$^2$, which was higher than any other tile wall so far tested at the Bureau of Standards.

2. The compressive strength of these walls seemed to be directly dependent upon the workmanship and the mortar used in the horizontal joints. The wall with no mortar beds had a compressive strength of 310 lbs./in.$^2$ gross area, the wall having cement-lime beds developed a compressive strength of 1, 270 lbs./in.$^2$, while the two walls with cement mortar beds gave an average compressive strength of 880 lbs./in.$^2$

3. The results of this series of tests indicate that walls built of these interlocking-rib hollow tile have considerably higher transverse strength and at least as high compressive strength as similar walls built of tile of the usual design.

WASHINGTON, November 26, 1927.