BUILDING MATERIALS AND STRUCTURES
REPORT BMS5
Structural Properties of Six Masonry Wall Constructions

by HERBERT L. WHITTEMPER
AMBROSE H. STANG, and DOUGLAS E. PARSONS

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by HERBERT L. WHITTEMORE, AMBROSE H. STANG, and DOUGLAS E. PARSONS

ISSUED NOVEMBER 21, 1938

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

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Foreword

Masonry Constructions utilizing brick, structural clay tile, and concrete units have been used for houses for many years and the behavior of such constructions in service is well known. Data on the structural properties of these constructions obtained in a series of standardized laboratory tests enable comparisons to be made with the structural properties of newer types of constructions.

This report gives the load-deformation relations and strength of these well-known constructions when subjected to compressive, transverse, concentrated, impact, and racking loads by standardized methods described in detail in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions. The results of these laboratory tests show the ability of such constructions to resist compressive loads far greater than those likely to be encountered in actual house construction.

They also show how the compressive strength and other properties may be influenced by changes in materials and workmanship, and provide data which may be compared with service behavior for estimating the limiting strengths for acceptable performance.

Lyman J. Briggs, Director.
Structural Properties of Six Masonry Wall Constructions

by HERBERT L. WHITTEMORE, AMBROSE H. STANG, and DOUGLAS E. PARSONS

CONTENTS

VII. Wall AB—Continued. ........................................... 10
   6. Racking load ........................................... 10

VIII. Wall AC .................................................... 10
   1. Description ........................................... 10
   2. Compressive load ..................................... 11
   3. Transverse load ....................................... 11
   4. Concentrated load ..................................... 12
   5. Impact load ........................................... 12
   6. Racking load ........................................... 12

IX. Wall AD ...................................................... 12
   1. Description ........................................... 12
   2. Compressive load ..................................... 13
   3. Transverse load ....................................... 13
   4. Concentrated load ..................................... 16
   5. Impact load ........................................... 16
   6. Racking load ........................................... 16

X. Wall AF ....................................................... 16
   1. Description ........................................... 16
   2. Compressive load ..................................... 21
   3. Transverse load ....................................... 21
   4. Concentrated load ..................................... 21
   5. Impact load ........................................... 21
   6. Racking load ........................................... 25

XI. Wall AF ....................................................... 25
   1. Description ........................................... 25
   2. Compressive load ..................................... 25
   3. Transverse load ....................................... 27
   4. Concentrated load ..................................... 27
   5. Impact load ........................................... 27
   6. Racking load ........................................... 29

XII. Comments ................................................... 29

XIII. Selected references ......................................... 29

ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the Masonry Construction Section of the National Bureau of Standards built specimens representing six masonry wall constructions as follows: High-strength brick, cement mortar, excellent workmanship; medium-strength brick, cement-lime mortar, commercial workmanship; medium-strength brick, cement-lime mortar, excellent workmanship; structural clay tile on end, cement-lime mortar, excellent workmanship; and stone-concrete block, cement-lime mortar, excellent workmanship.

The specimens were subjected to compressive, transverse, concentrated, impact, and racking loads. For most of these loads three like specimens were tested. The deformation under load and the set after the load was removed were measured for uniform increments of load up to the maximum load, except for concentrated loads, for which the set only was determined. The results are presented graphically and in a table.
1. INTRODUCTION

In the Program in which the National Bureau of Standards is now engaged to determine the structural properties of low-cost house constructions, an important step is the determination of the properties of some constructions for which the behavior in service is generally known. Those selected for this purpose are masonry constructions, utilizing brick, structural clay tile, and stone-concrete block which form the subject of this report, and wood-frame construction, which has been studied by the Forest Products Laboratory of the United States Department of Agriculture, and which will be the subject of a subsequent report in this series.

The strength of masonry construction is dependent on a great many variables. In brick construction, for example, the principal variables are the type of brick, type of mortar, and workmanship, but some of the strength properties depend on other factors. Furthermore, it is practically impossible to determine which construction may be regarded as conventional or typical, because typical constructions vary in different parts of the country as well as with the individual contractors in their respective localities.

It was decided not to devote a large amount of effort to testing familiar types of construction. Therefore, six constructions only were selected, three of brick, two of structural clay tile, and one of stone-concrete block. In the brick constructions, two types of brick, two types of mortar, and two types of workmanship were used in an effort to determine the probable range of properties which might be expected in good practice. It is probable that the highest practical strength has been approached in one of the constructions. However, if brick, mortar, and workmanship are poor, values much lower than those found in these tests will be obtained. The construction consisting of medium-strength brick, cement-lime mortar, and commercial workmanship is believed to be as nearly "typical" as can be obtained without extensive field investigations of current practices.

In the laboratory, the specimens were subjected to compressive, transverse, concentrated, impact, and racking loads to simulate loads to which the walls of a house are subjected. In actual service, compressive loads are produced by the weight of the roof, second floor and second-story walls if any, furniture, and snow and wind loads on the roof. Transverse loads are produced by the wind; concentrated and impact loads by furniture, or accidental contact with heavy objects; and racking loads by the action of the wind on adjoining walls.

The deflection and set under various loads were determined, as well as the strength, since these properties are equally important, and, with some types of construction, are the significant factors in determining whether or not the performance is satisfactory.

II. SPONSOR

The Specimens were built by the Masonry Construction Section of the National Bureau of Standards.

The compressive and transverse strengths of some of these constructions have been determined in previous investigations, but few data are available on the other structural properties. These constructions were included in this program not only to obtain this information, but also to provide data for comparing the structural properties of other constructions which have not been widely used for houses.

III. SPECIMENS AND TESTS

The Specimens were built by an experienced mason employed by the Bureau and working under immediate supervision.

The constructions were assigned symbols in accordance with Table 1, and the specimens were assigned designations in accordance with Table 2.

Table 1.—Construction symbols

<table>
<thead>
<tr>
<th>Construction symbol</th>
<th>Masonry unit</th>
<th>Mortar</th>
<th>Workmanship</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. L.</td>
<td>High-strength brick</td>
<td>Cement</td>
<td>Excellent, Commercial</td>
</tr>
<tr>
<td>A. B.</td>
<td>Medium-strength brick</td>
<td>Cement-lime</td>
<td>Excellent</td>
</tr>
<tr>
<td>A. C.</td>
<td>Structural clay tile</td>
<td>do</td>
<td>Do</td>
</tr>
<tr>
<td>A. D.</td>
<td>Structural clay tile</td>
<td>do</td>
<td>Do</td>
</tr>
<tr>
<td>A. E.</td>
<td>Structural clay tile</td>
<td>do</td>
<td>Do</td>
</tr>
<tr>
<td>A. F.</td>
<td>Stone-concrete block</td>
<td>do</td>
<td>Do</td>
</tr>
</tbody>
</table>
TABLE 2.—Specimen designations

<table>
<thead>
<tr>
<th>Specimen designation</th>
<th>Load</th>
<th>Load applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI, C2, C3</td>
<td>Compressive</td>
<td>Upper end.</td>
</tr>
<tr>
<td>Ti, T2, T3</td>
<td>Transverse</td>
<td>Either face.</td>
</tr>
<tr>
<td>Pi, P2, P3</td>
<td>Concentrated</td>
<td>Do.</td>
</tr>
<tr>
<td>R1, R2, R3</td>
<td>Impact</td>
<td>Do.</td>
</tr>
<tr>
<td>BI, B2, B3</td>
<td>Racking</td>
<td>Near upper end.</td>
</tr>
</tbody>
</table>

*These specimens were undamaged portions of the specimens used for the transverse or impact tests.

The specimens were tested in accordance with BMS2, Methods of Determining the Structural Properties of Low-cost House Constructions. The tests were begun November 9, 1937, and completed March 10, 1938. The specimens were tested 28 days after they were built.

For the transverse and impact loads, only three specimens were built because the specimens were symmetrical about a vertical plane midway between the faces, and the results for transverse and impact loads applied to one face of the specimens should be identical with those obtained by applying the loads to the other face. The concentrated loads were applied to only three specimens, because the inside and outside faces of the specimens were similar.

IV. MATERIALS

1. Brick

(a) High-Strength Brick

The high-strength bricks were obtained from the United Clay Products Co. and were made in Martinsburg, W. Va. The bricks were of shale formed by the stiff-mud side-cut process. The average dimensions were 8.15 by 3.75 by 2.30 in. (about 8½ by 3 by 2½ in). The physical properties, given in table 3, were determined in accordance with the American Society for Testing Materials Standard C67—37, so far as this standard was applicable. When laid, the bricks were air-dried. The absorption for 1-min partial immersion was determined for two bricks taken about every 30 min from the mason’s scaffold.

(b) Medium-Strength Brick

The medium-strength bricks were obtained from the Hydraulic Press Brick Co. and were made in Baltimore, Md., by the Baltimore Brick Co. The bricks were of clay, formed in sanded molds by the soft-mud process. The average dimensions were 8.05 by 3.70 by 2.25 in. (about 8⅛ by 3⅞ by 2⅛ in). Between 25 and 30 percent of these bricks had frogs (depressed panels) on one side. The frogs were 6⅛ by 1⅛ by ½ in. and had the name Home- wood in raised letters. When laid the bricks were damp. The absorption for 1-min partial immersion was determined for two bricks taken about every 30 min from the mason’s scaffold.

2. Tile

The structural clay tiles were obtained from the National Fireproofing Corporation and were made in Magnolia, Ohio. The tiles had six cells, as shown in figure 1, and were intended to be laid either on end or side. The average dimensions were 8.01 by 12.08 by 12.14 in. (about 8 by 12½ by 12 in). The physical properties given in table 4 were determined in accordance with the American Society for Testing Materials Standard C67—37.

*Price 10 cents. See cover p. II.
Figure 1.—Structural clay tile.

Testing Materials Standard C112-36 so far as this standard was applicable. When laid the tiles were air-dried.

Table 4.—Physical properties of tile
[Each value is the average for 10 specimens]

<table>
<thead>
<tr>
<th>Thickness of face shell, minimum</th>
<th>Compressive strength</th>
<th>Water absorption, 24-hr cold</th>
<th>Weight, dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>in.</td>
<td>lb/in.² net area</td>
<td>lb/in.² gross area</td>
<td>lb/ft³ of concrete</td>
</tr>
<tr>
<td>0.50</td>
<td>4.03</td>
<td>9.50</td>
<td>3.50</td>
</tr>
</tbody>
</table>

3. Block

The stone-concrete blocks were made by the Cherrydale Cement Block Co., Arlington, Va. The blocks had two cells, as shown in figure 2. The average dimensions were 7.81 by 11.50 by 7.66 in. (about 7 13/16 by 11 1/2 by 7 13/16 in). The physical properties given in table 5 were determined in accordance with the American Society

Table 5.—Physical properties of block
[Each value is the average for 10 specimens]

<table>
<thead>
<tr>
<th>Thickness of face shell, minimum</th>
<th>Compressive strength</th>
<th>Water absorption, 24-hr cold</th>
<th>Weight, dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>in.</td>
<td>lb/in.² net area</td>
<td>lb/in.² gross area</td>
<td>lb/ft³ of concrete</td>
</tr>
<tr>
<td>1.25</td>
<td>2,000</td>
<td>1,190</td>
<td>3.9</td>
</tr>
</tbody>
</table>

4. Mortar

(a) Cement

The cement was Medusa Cement Company’s “Medusa” portland cement. The cement conformed to the requirements of Federal Specification SS-C-191a for fineness, soundness, time of set, and tensile strength.

(b) Lime

The lime putty was made by slaking powdered high-calcium quicklime. The quicklime was Standard Lime and Stone Company’s “Washington.” The putty contained about 40 percent of dry hydrate and had a plasticity of over 600, measured in accordance with Federal Specification SS-L-351.


Figure 2.—Stone-concrete block.
(c) Sand

The sand was dry Potomac River building sand. The sieve analysis of the sand is given in table 6.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>100</td>
<td>16</td>
<td>95</td>
</tr>
<tr>
<td>16</td>
<td>50</td>
<td>30</td>
<td>200</td>
</tr>
</tbody>
</table>

(d) Mix

(1) Cement mortar.—The cement mortar was 1 part cement, 0.11 part hydrated lime, and 2.6 parts dry sand, by weight. The proportions by volume were 1 part cement, 0.25 part hydrated lime, and 3 parts loose damp sand, assuming that portland cement weighs 94 lb/ft³, dry hydrated lime 40 lb/ft³, and 80 lb of dry sand is equivalent to 1 ft³ of loose damp sand.

(2) Cement-lime mortar.—The cement-lime mortar was 1 part cement, 0.42 part hydrated lime, and 5.1 parts dry sand, by weight. The proportions by volume were 1 part cement, 1 part hydrated lime, and 6 parts loose damp sand.

Table 7.—Physical properties of the mortars

<table>
<thead>
<tr>
<th>Construction symbol</th>
<th>Kind of mortar</th>
<th>Water cement, by weight of dry materials</th>
<th>Flow</th>
<th>Compressive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Air storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water storage</td>
</tr>
<tr>
<td>AA</td>
<td>Cement</td>
<td>%</td>
<td>10.4</td>
<td>113</td>
</tr>
<tr>
<td>AB</td>
<td>Cement-lime</td>
<td>23.8</td>
<td>107</td>
<td>40</td>
</tr>
<tr>
<td>AC</td>
<td>do</td>
<td>23.2</td>
<td>106</td>
<td>465</td>
</tr>
<tr>
<td>AD</td>
<td>do</td>
<td>23.1</td>
<td>110</td>
<td>465</td>
</tr>
<tr>
<td>AE</td>
<td>do</td>
<td>23.2</td>
<td>113</td>
<td>500</td>
</tr>
<tr>
<td>AF</td>
<td>do</td>
<td>23.2</td>
<td>107</td>
<td>445</td>
</tr>
</tbody>
</table>

The mortars were proportioned by weight and mixed in a batch mixer having a capacity of about 2/3 ft³. The amount of water added to the mortars was adjusted to the satisfaction of the mason. Samples were taken from every fifth or sixth batch of mortar, the flow determined in accordance with Federal Specification SS-C-181a, and six 2-in. cubes made. Three cubes were stored in water at 70°F and three stored in air on the specimen. The compressive strength of the cubes was determined on the day the corresponding wall specimen was tested. The physical properties of the mortars are given in table 7.

V. FABRICATION DATA

The Fabrication Data are given in table 8. The time required for the construction of the first three specimens was not used in com-

Figure 3.—Four-foot brick-wall specimen.

AA, high-strength brick, cement mortar, excellent workmanship; AB, medium-strength brick, cement-lime mortar, commercial workmanship; and AC, medium-strength brick, cement-lime mortar, excellent workmanship.
putting the values of the mason's time given in the table, because the mason was not familiar with the working conditions.

Table 8.—Fabrication data

<table>
<thead>
<tr>
<th>Construction symbol</th>
<th>Thickness of bed joints</th>
<th>Masonry units</th>
<th>Mortar materials</th>
<th>Mason's time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in</td>
<td>No./ft²</td>
<td>lb/ft²</td>
<td>lb/ft²</td>
</tr>
<tr>
<td>AA</td>
<td>0.506</td>
<td>12.6</td>
<td>6.37</td>
<td>0.78</td>
</tr>
<tr>
<td>AB</td>
<td>0.447</td>
<td>12.6</td>
<td>2.72</td>
<td>1.14</td>
</tr>
<tr>
<td>AC</td>
<td>0.446</td>
<td>12.6</td>
<td>3.85</td>
<td>1.44</td>
</tr>
<tr>
<td>AD</td>
<td>0.426</td>
<td>0.915</td>
<td>1.44</td>
<td>0.61</td>
</tr>
<tr>
<td>AE</td>
<td>0.443</td>
<td>1.87</td>
<td>1.11</td>
<td>0.47</td>
</tr>
<tr>
<td>AF</td>
<td>0.441</td>
<td>1.47</td>
<td>1.48</td>
<td>0.62</td>
</tr>
</tbody>
</table>

* Face area of specimen.

VI. WALL AA

1. Description

The specimens were built with high-strength bricks laid in common American bond, as shown in figure 3, and cement mortar. There were alternately five stretcher courses of bricks and then a header course. The 4-ft wall specimens were 8 ft 2 in. high, 4 ft 0 in. wide, and 8½ in. thick. The 8-ft wall specimens were 8 ft 3 in. high, 8 ft 0 in. wide, and 8½ in. thick.

All the joints were completely filled with mortar. The bed joints were level. The head and collar joints were filled by buttering heavily the ends of bricks laid in the facing and both the ends and sides of bricks laid in the backing. The mortar was applied to the bricks by scraping the trowel against the lower edges, and unfilled portions of the joints were filled by slushing mortar from above. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.58/ft².

2. Compressive Load

The results for wall specimens AA–C1, C2, and C3 are shown in table 9 and in figures 4 and 5.

Table 9.—Structural properties of masonry wall constructions AA, AB, AC, AD, AE, and AF

<table>
<thead>
<tr>
<th>Construction symbol</th>
<th>Weight (lb/ft²)</th>
<th>Load Designation</th>
<th>Maximum Load (kips/ft²)</th>
<th>Maximum Load (lb)</th>
<th>Maximum Height of Drop (ft)</th>
<th>Racking (kips/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>96.0</td>
<td>C1</td>
<td>T1</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T2</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T3</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>AB</td>
<td>73.9</td>
<td>C1</td>
<td>T1</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T2</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T3</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>AC</td>
<td>78.9</td>
<td>C1</td>
<td>T1</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T2</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T3</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>AD</td>
<td>42.6</td>
<td>C1</td>
<td>T1</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T2</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T3</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>

See footnotes at end of table.
Table 9.—Structural properties of masonry wall constructions AA, AB, AC, AD, AE, and AF—Continued

<table>
<thead>
<tr>
<th>Construction symbol</th>
<th>Weight</th>
<th>Compressive</th>
<th>Transverse</th>
<th>Concentrated</th>
<th>Impact</th>
<th>Racking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/ft²</td>
<td>ft² kips/ft²</td>
<td>ft² lb/ft²</td>
<td>ft² lb/ft²</td>
<td>ft² lb/ft²</td>
<td>ft² lb/ft²</td>
</tr>
<tr>
<td>AB</td>
<td>38.9</td>
<td>23.7</td>
<td>38.0</td>
<td>1,000</td>
<td>1.5</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27.5</td>
<td>76.8</td>
<td>1,000</td>
<td>1.5</td>
<td>3.56</td>
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<tr>
<td></td>
<td></td>
<td>27.9</td>
<td>56.8</td>
<td>1,000</td>
<td>1.5</td>
<td>3.42</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>39.4</td>
<td>63.9</td>
<td>1,000</td>
<td>1.8</td>
<td>3.74</td>
</tr>
<tr>
<td>AF</td>
<td>54.5</td>
<td>41.2</td>
<td>29.6</td>
<td>1,000</td>
<td>1.5</td>
<td>3.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>38.8</td>
<td>39.7</td>
<td>1,000</td>
<td>1.5</td>
<td>3.05</td>
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<td>37.6</td>
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<td>31.3</td>
<td>1,000</td>
<td>1.3</td>
<td>3.18</td>
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* Load applied at one-third the thickness of the specimen from the inside face.
* Specimen did not fail.
* A third racking specimen was not built.

Figure 4.—Compressive load on wall AA.

Load-shortening and load-set results for specimens AA-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 7 ft 2 in.

Figure 5.—Compressive load on wall AA.

Load-lateral deflection and load-lateral set results for specimens AA-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 7 ft 2 in., the gage length of the deflectometers.
Figure 6.—Transverse load on wall AA.

Load-deflection and load-set results for specimens AA-T1, T2, and T3 on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 4 in., the gage length of the deflectometers.

Specimens C1 and C3 failed by rupture of the collar joints and breaking of the headers midway between the faces. Specimen C2 collapsed suddenly, probably after the collar joints and headers broke.

3. Transverse Load

The results for wall specimens AA-T1, T2, and T3 are shown in table 9 and in figure 6.

Each of the specimens failed by rupture of the bond between the bricks and the mortar at a bed joint near midspan. In each case the failure occurred at a joint between a header course and a stretcher course.

4. Concentrated Load

The results for wall specimens AA-P1, P2, and P3 are shown in table 9 and in figure 7.

There was no measurable indentation for any of the specimens after a load of 1,000 lb had been applied.

5. Impact Load

The results for wall specimens AA-I1, I2, and I3 are shown in table 9 and in figure 8.

Each of the specimens failed by rupture of the bond between the bricks and the mortar at a bed joint near midspan. For specimens I2 and I3 the failure occurred at a joint between a header course and a stretcher course.

6. Racking Load

The results for wall specimens AA-R1 and R2 are shown in table 9 and in figure 9.

There was no measurable set for either of the specimens after a load of 50 kips (50,000 lb) had been applied. A third racking specimen was not built because for specimens R1
and R2 the deformation and set were very small for a load of 50 kips.

VII. WALL AB

1. Description

The specimens were built with medium-strength bricks laid in common American bond, as shown in figure 3, and cement-lime mortar. There were alternately five stretcher courses of bricks and then a header course. The 4-ft wall specimens were 8 ft 2 in. high, 4 ft 0 in. wide, and 8\(\frac{3}{16}\) in. thick. The 8-ft wall specimens were 8 ft 2 in. high, 8 ft 0 in. wide, and 8\(\frac{3}{16}\) in. thick.

The joints were not completely filled with mortar. The bed joints were furrowed, the collar joints were left open, as shown in figure 10, and only the outside of the head joints was filled by lightly buttering the outer edges of the bricks. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.38/ft^2.

2. Compressive Load

The results for wall specimens AB-C1, C2, and C3 are shown in table 9 and in figures 11 and 12.

Each of the specimens failed by breaking of the headers midway between the faces. In addition, for specimen C1 a few stretchers cracked near the upper end of the specimen, and for specimen C2 a few stretchers cracked on the inside face and bricks in two courses near the upper end crushed.
Each of the specimens failed by rupture of a bed joint near midspan. For specimens I2 and I3 the failure occurred at a joint between a header course and a stretcher course.

6. Racking Load

The results for wall specimens AB-R1, R2, and R3 are shown in table 9 and in figure 16.

The set after a load of 50 kips had been applied was less than 0.03 in. for each of the specimens and no other effect was observed.

VIII. WALL AC

1. Description

The specimens were built with medium-strength bricks laid in common American bond.

![](image)

**Figure 10.**—Wall specimen AB-T1 under transverse load.

3. Transverse Load

The results for wall specimens AB-T1, T2, and T3 are shown in table 9 and in figure 13.

Each of the specimens failed by rupture of the bond between the bricks and the mortar at a bed joint between the loading rollers. In each case the failure occurred at a joint between a header course and a stretcher course.

4. Concentrated Load

The results for wall specimens AB-P1, P2, and P3 are shown in table 9 and in figure 14.

The indentations after a load of 1,000 lb had been applied were 0.002, 0.000, and 0.013 in. for specimens P1, P2, and P3, respectively, and no other effect was observed.

5. Impact Load

The results for wall specimens AB-I1, I2, and I3 are shown in table 9 and in figure 15.

![](image)

**Figure 11.**—Compressive load on wall AB.

Load-shortening and load-set results for specimens AB-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 7 ft 3 in.
The estimated price of this construction was $0.51/ft^2.

2. Compressive Load

The results for wall specimens AC-C1, C2, and C3 are shown in table 9 and in figures 17 and 18.

Each of the specimens failed by cracking of the collar joints and breaking of some of the headers midway between the faces. In addition, for specimens C1 and C2 a few stretchers cracked, and for specimens C2 and C3 several courses of bricks fell from the facing at the upper ends of the specimens.

3. Transverse Load

The results for wall specimens AC-T1, T2, and T3 are shown in table 9 and in figure 19.

Each of the specimens failed by rupture of either the mortar or the bond between the

as shown in figure 3, and cement-lime mortar. There were alternately five stretcher courses of bricks and then a header course. The 4-ft wall specimens were 8 ft 3 in. high, 4 ft 0 in. wide, and 8 1/8 in. thick. The 8-ft wall specimens were 8 ft 2 in. high, 8 ft 0 in. wide, and 8 3/8 in. thick.

All the joints were completely filled with mortar. The bed joints were level. The head and collar joints were filled by buttering heavily the ends of bricks laid in the facing, and both the ends and sides of bricks laid in the backing. The mortar was applied to the bricks by scraping the trowel against the lower edges, and unfilled portions of the joints were filled by slushing mortar from above. The joints were cut flush with the faces of the specimens.

![Figure 12. Compressive load on wall AB.](image)

Load-lateral deflection and load-lateral set results for specimens AB-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 7 ft 2 in., the gage length of the deflectometers.

![Figure 13. Transverse load on wall AB.](image)

Load-deflection and load-set results for specimens AB-T1, T2, and T3 on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 4 in., the gage length of the deflectometers.
bricks and the mortar at one or more bed joints between the loading rollers. For specimens T2 and T3 the failure occurred at a joint between a header course and a stretcher course.

4. Concentrated Load

The results for wall specimens AC-P1, P2, and P3 are shown in table 9 and in figure 20.

The indentations after a load of 1,000 lb had been applied were 0.002, 0.000, and 0.001 in. for specimens P1, P2, and P3, respectively, and no other effect was observed.

5. Impact Load

The results for wall specimens AC-I1, I2, and I3 are shown in table 9 and in figure 21.

Each of the specimens failed by rupture of a bed joint near midspan. For specimens I1 and I2 the failure occurred at a joint between a header course and a stretcher course.

6. Racking Load

Wall specimen AC-R1 under racking load is shown in figure 22. The results for wall specimens AC-R1 and R2 are shown in table 9 and in figure 23.

The sets after a load of 50 kips had been applied were 0.000 and 0.010 in. for specimens R1 and R2, respectively, and no other effect was observed. A third racking specimen was not built because for specimens R1 and R2 the deformation and set were very small for a load of 50 kips.

IX. WALL AD

1. Description

The specimens were built with structural clay tiles laid on end, as shown in figure 24, and cement-lime mortar. The head joints were
Each of the specimens failed by crushing of one or more of the bed joints near the inside face. In addition, for specimen C2 there were two vertical cracks through some of the tiles and joints on the outside face, and for specimen C3 the shell of one tile broke on the inside face near the upper end of the specimen.

3. Transverse Load

The results for wall specimens AD-T1, T2, and T3 are shown in Table 9 and in Figure 27.

Each of the specimens failed by rupture of either the mortar or the bond between the tiles and the mortar at a bed joint between the loading rollers.

2. Compressive Load

The results for wall specimens AD-C1, C2, and C3 are shown in Table 9 and in Figures 25 and 26.
Figure 18.—Compressive load on wall AC.

Load-lateral deflection and load-lateral set results for specimens AC-Cl, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 7 ft 2 in., the gage length of the deflectometers.

Figure 19.—Transverse load on wall AC.

Load-deflection and load-set results for specimens AC-T1, T2, and T3 on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 4 in., the gage length of the deflectometers.
Figure 20.—Concentrated load on wall AC.

Load-indentation results for specimens AC-P1, P2, and P3.

Figure 21.—Impact load on wall AC.

Height of drop-deflection and height of drop-set results for specimens AC-11, P2, and P3 on the span 7 ft 6 in.
4. Concentrated Load

The results for wall specimens AD-P1, P2, and P3 are shown in table 9 and in figure 28.

The indentations after a load of 1,000 lb had been applied were 0.001, 0.000, and 0.000 in. for specimens P1, P2, and P3, respectively, and no other effect was observed.

5. Impact Load

Wall specimen AD-II during the impact test is shown in figure 29. The results for wall specimens AD-II, I2, and I3 are shown in table 9 and in figure 30.

Each of the specimens failed by rupture of the bond between the tiles and the mortar at a bed joint near midspan.

6. Racking Load

The results for wall specimens AD-R1, R2, and R3 are shown in table 9 and in figure 31.

Each of the specimens failed by rupture of the bed and head joints in stepwise cracks approximately along a diagonal between the point of application of the load and the stop. In addition, for specimen R3 the bed joint under the top course broke across the entire width of the specimen.

Specimen R1 after the racking test is shown in figure 32. The failure by stepwise cracks through the joints is typical of the failure for both the AD and the AE racking wall specimens.

X. WALL AE

1. Description

The specimens were built with structural clay tiles laid on side, as shown in figure 33, and cement-lime mortar. The head joints were staggered by using cut stretchers at the ends of alternate courses. The 4-ft wall specimens were 8 ft 4 in. high, 4 ft 2 in. wide, and 8 in. thick. The 8-ft wall specimens were 8 ft 4 in. high, 8 ft 4 in. wide, and 8 in. thick.
Figure 23.— Racking load on wall AC.

Load-deformation and load-set results for specimens AC-R1 and R2. The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 0 in. The gage length of the horizontal measuring device was 5 ft 10 in.

Figure 24.— Four-foot structural clay tile-wall specimen AD.
Figure 25.—Compressive load on wall AD.

Load-shortening and load-set results for specimens AD-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 3 in.

Figure 26.—Compressive load on wall AD.

Load-lateral deflection and load-lateral set results for specimens AD-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.
Figure 27.—Transverse load on wall AD.

Load-deflection and load-set results for specimens AD-T1, T2, and T3 on the span 7 ft 6 in. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.

Figure 28.—Concentrated load on wall AD.

Load-indentation results for specimens AD-P1, P2, and P3.
Figure 29.—Wall specimen AD-11 during the impact test.

Figure 30.—Impact load on wall AD.
Height of drop-deflection and height of drop-set results for specimens AD-11, 12, and 13 on the span 7 ft 6 in.

Figure 31.—Racking load on wall AD.
Load-deformation and load-set results for specimens AD-R1, R2, and R3. The loads are in kips per foot of actual width of specimen. The deformations and sets are for a height of 8 ft. They were computed from the values obtained from the measuring-device readings. The gage length of the vertical measuring device was 7 ft 6 in. The gage length of the horizontal measuring device was 6 ft 0 in.
All the joints were completely filled with mortar. The bed joints were level. The head joints were made by buttering the ends of all shells and webs. To prevent mortar from dropping off the shells when placing, the tiles were buttered and then tapped lightly against the mortar board with the cells in a vertical position. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.31/ft^2.

2. Compressive Load

The results for wall specimens AE-C1, C2, and C3 are shown in table 9 and in figures 34 and 35.

Each of the specimens failed by breaking of the tiles in the two courses at the upper end of the specimen. In addition, for specimen C3 the inside face of the tiles in a third course broke.

3. Transverse Load

The results for wall specimens AE-T1, T2, and T3 are shown in table 9 and in figure 36.

Each of the specimens failed by rupture of the bond between the tiles and the mortar at a bed joint between or near one of the loading rollers.

4. Concentrated Load

The results for wall specimens AE-P1, P2, and P3 are shown in table 9 and in figure 37.

For specimen P1, the indentation after a load of 1,000 lb had been applied was 0.004 in. and the tile was slightly spalled where the load was applied. For specimens P2 and P3, the indentations after a load of 1,000 lb had been applied were 0.001 and 0.000 in., respectively, and no other effect was observed.

5. Impact Load

The results for wall specimens AE-I1, I2, and I3 are shown in table 9 and in figure 38.

Each of the specimens failed by rupture of the bond between the tiles and the mortar at a bed joint near midspan.

[21]
Figure 34.—Compressive load on wall AE.

Load-shortening and load-set results for specimens AE-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 3 in.

Figure 33.—Four-foot structural clay tile wall specimen AE.
Figure 35.—Compressive load on wall AE.

Load-lateral deflection and load-lateral set results for specimens AE-C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.

Figure 36.—Transverse load on wall AE.

Load-deflection and load-set results for specimens AE-T1, T2, and T3 on the span 7 ft 6 in. The deflections and sets are for a gage length of 6 ft 3 in., the gage length of the deflectometers.
Figure 37.—Concentrated load on wall AE.
Load-indentation results for specimens AE-P1, P2, and P3.

Figure 38.—Impact load on wall AE.
Height of drop-deflection and height of drop-set results for specimens AE-H, E, and B3 on the span 7 ft 6 in.
6. **Racking Load**

The results for wall specimens **AE-R1, R2, and R3** are shown in table 9 and in figure 39. Each of the specimens failed by rupture of the bed and head joints in stepwise cracks approximately along a diagonal between the point of application of load and the stop. In addition, for specimen **R1**, several tiles broke.

**XI. WALL AF**

1. **Description**

The specimens were built with stone concrete blocks and cement-lime mortar as shown in figure 40. The head joints were staggered by using cut stretchers at the ends of alternate courses. The 4-ft wall specimens were 8 ft 1 in. high, 4 ft 0 in. wide, and 7\(\frac{3}{16}\) in. thick, except for specimens **T1, T2, T3, and T3**, which were 8 ft 9 in. high. The 8-ft wall specimens were 8 ft 1 ft in. high, 8 ft 0 in. wide, and 7\(\frac{3}{16}\) in. thick.

All the joints were completely filled with mortar. The bed joints were made by heaping mortar over all shells and webs and the head joints were formed by spreading mortar over the entire end of the block before placing. The joints were cut flush with the faces of the specimens.

The estimated price of this construction was $0.30/ft².

2. **Compressive Load**

Wall specimen **AF-C1** under compressive load is shown in figure 41. The results for wall specimens **AF-C1, C2, and C3** are shown in table 9 and in figures 42 and 43.
Figure 41.—Wall specimen AF–C1 under compressive load.

Figure 42.—Compressive load on wall AF.

Load-shortening and load-set results for specimens AF–C1, C2, and C3. Load applied at one-third the thickness of the specimen from the inside face. The loads are in kips per foot of actual width of specimen. The shortenings and sets are for a height of 8 ft. They were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 9 in.
3. **Transverse Load**

The results for wall specimens \(AF-T1, T2,\) and \(T3\) are shown in table 9 and in figure 44.

Specimen \(T1\) failed by rupture of both the mortar and the bond between the blocks and the mortar at a bed joint near one of the loading rollers. Specimen \(T2\) failed by rupture of the bond between the blocks and the mortar at a bed joint near one of the loading rollers, and specimen \(T3\) failed by rupture of the bond between the blocks and the mortar at a bed joint between the loading rollers.

4. **Concentrated Load**

The results for wall specimens \(AF-P1, P2,\) and \(P3\) are shown in table 9 and in figure 45.

The indentations after a load of 1,000 lb had been applied were 0.000, 0.004, and 0.002 in. for specimens \(P1, P2,\) and \(P3,\) respectively, and no other effect was observed.

5. **Impact Load**

The results for wall specimens \(AF-I1, I2,\) and \(I3\) are shown in table 9 and in figure 46.

Each of the specimens failed by rupture of the mortar at a bed joint in the middle half of the specimen.
Figure 45.—Concentrated load on wall AF.
Load-indentation results for specimens AF-P1, P2, and P3.

Figure 46.—Impact load on wall AF.
Height of drop-deflection and height of drop-set results for specimens AF-H1, H2, and H3 on the span 7 ft 6 in.
6. Racking Load

The results for wall specimens *AF-R1*, *R2*, and *R3* are shown in table 9 and in figure 47.

Specimen *R1* failed by rupture of the bond between the blocks and the mortar in stepwise cracks through the bed and head joints approximately along a diagonal between the point of application of load and the stop. Two blocks were broken at the lower end of the specimen near the edge at the stop. Specimens *R2* and *R3* failed by rupture of the bed and head joints in stepwise cracks approximately along a diagonal between the point of application of load and the stop. In addition, a few blocks near the point of application of load cracked.

**XII. COMMENTS**

It is customary when building houses of these constructions to finish the inside face of the walls either by applying wood furring strips, lath, and plaster, or by applying the plaster directly to the wall. These specimens were not finished in either of these ways; therefore, the structural properties given in this report may not be exactly the same as the structural properties of the corresponding construction as customarily finished in a house. It is believed that the difference, if any, is so small, except for concentrated loads and possibly impact loads, that the structural properties given in this report may be considered as the structural properties for the corresponding construction whatever the finish on the inside face.

The experimental data in this report were obtained from tests made by the Engineering Mechanics Section, under the supervision of H. L. Whittemore and A. H. Stang, and the Masonry Construction Section, under the supervision of D. E. Parsons. The following members of the professional staff participated in the work: C. C. Fishburn, F. Cardile, R. C. Carter, H. Dollar, M. Dubin, A. H. Easton, A. S. Endler, C. D. Johnson, T. M. Kelly, P. H. Petersen, A. J. Sussman, and L. R. Sweetman.

**XIII. SELECTED REFERENCES**

<table>
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<th>Year</th>
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<tr>
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**WASHINGTON, June 15, 1938.**
The National Bureau of Standards was established by act of Congress, approved March 3, 1901, continuing the duties of the old Office of Standard Weights and Measures of the United States Coast and Geodetic Survey. In addition, new scientific functions were assigned to the new Bureau. Originally under the Treasury Department, the Bureau was transferred in 1903 to the Department of Commerce and Labor (now the United States Department of Commerce). It is charged with the development, construction, custody, and maintenance of reference and working standards, and their intercomparison, improvement, and application in science, engineering, industry, and commerce.

SUBJECTS OF BUREAU ACTIVITIES

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

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

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

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

**Chemistry**
- Paints, Varnishes, and Bituminous Materials
- Detergents, Cements, Corrosion, Etc.
- Organic Chemistry—Continued
  - Metal and Ore Analysis, and Standard Samples
  - Reagents and Platinum Metals
  - Electrochemistry (Plating)
  - Gas Chemistry
  - Physical Chemistry
  - Thermochemistry and Constitution of Petroleum
- Mechanics and Sound
  - Engineering Instruments and Mechanical Appliances
  - Sound
  - Aeronautic Instruments
  - Aerodynamics
  - Engineering Mechanics
  - Hydraulics
- Organic and Fibrous Materials
  - Rubber
  - Textiles
  - Paper
  - Leather
  - Testing and Specifications
  - Fiber Structure
  - Organic Plastics
- Metallurgy
  - Optical Metallurgy
  - Thermal Metallurgy
  - Mechanical Metallurgy
  - Chemical Metallurgy
  - Experimental Foundry
- Clay and Silicate Products
  - Whiteware
  - Glass
  - Refractories
  - Enamed Metals
  - Heavy Clay Products
  - Cement and Concreting Materials
  - Masonry Construction
  - Lime and Gypsum
  - Stone
- Simplified Practice
  - Wood, Textiles, and Paper
  - Metal Products and Construction Materials

**Simplified Practice—Continued**
- Containers and Miscellaneous Products
- Materials-Handling Equipment and Ceramics

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

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

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

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

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