

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 subcommittee of principal technical assistants.

CENTRAL HOUSING COMMITTEE

SUBCOMMITTEE ON TECHNICAL RESEARCH

WALTER JUNGE, Chairman. Federal Housing Administration.

ARTHUR C. SHIRE, Vice Chairman. United States Housing Authority.

STERLING R. MARCH, Secretary

ALBERT G. BEAR, Veterans' Administration.

PIERRE BLOUKE, Federal Home Loan Bank Board (Federal Loan Agency).

CARROLL W. CHAMBERLAIN, Procurement Division (Treasury).

JOSEPH M. DALLAVALLE, Public Health Service (Federal Security Agency).

JOHN DONOVAN, Farm Security Administration (Agriculture). GEORGE E. KNOX, Yards and Docks (Navy).

VINCENT B. PHELAN, National Bureau of Standards (Commerce).

Edward A. Poynton, Office of Indian Affairs (Interior).

GEORGE W. TRAYER, Forest Service (Agriculture).

ELSMERE J. WALTERS, Construction Division (War).

CHAIRMEN OF SECTIONS

Specifications Materials CARROLL W. CHAMBERLAIN ELSMERE J. WALTERS

Maintenance John H. Schaefer

Mechanical Equipment ROBERT K. THULMAN Methods and Practices

NATIONAL BUREAU OF STANDARDS

STAFF COMMITTEE ON ADMINISTRATION AND COORDINATION

HUGH L. DRYDEN, Chairman. Mechanics and Sound.

Рнаом H. Bates, Clay and Silicate Products.

HOBART C. DICKINSON, Heat and Power. GUSTAV E. F. LUNDELL, Chemistry.

ADDAMS S. MCALLISTER, Codes and Specifications.

WARREN E. EMLEY, Organic and Fibrous Materials. HENRY S. RAWDON, Metallurgy.

The Forest Products Laboratory of the United States Department of Agriculture is cooperating with both committees on investigations of wood constructions.

[For list of BMS publications and how to purchase, see cover page III.]

UNITED STATES DEPARTMENT OF COMMERCE · Harry L. Hopkins, Secretary NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

BUILDING MATERIALS and STRUCTURES

REPORT BMS25

Structural Properties of Conventional Wood-Frame Constructions for Walls, Partitions, Floors, and Roofs

by GEORGE E. HECK



ISSUED SEPTEMBER 13, 1939

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.

UNITED STATES GOVERNMENT PRINTING OFFICE · WASHINGTON · 1939 FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, WASHINGTON, D. C. · PRICE 15 CENTS

Foreword

This report is one of a series issued by the National Bureau of Standards on the structural properties of constructions intended for low-cost houses and apartments. It deals with the determination of the properties of wood-frame construction. It differs from most of the other reports in the series in that no industrial or commercial concern sponsored the tests; instead the constructions were built and tested at the Forest Products Laboratory. The results afford a basis for comparing other and newer materials and types of construction.

This report embraces load-deformation relations and strength properties of woodframe wall, partition, floor, and roof constructions. The constructions were subjected to compressive, transverse, concentrated, impact, and racking loads by standardized methods substantially as described in Report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions.

LYMAN J. BRIGGS, Director.

Structural Properties of Conventional Wood-Frame Constructions, for Walls, Partitions, Floors, and Roofs

by george E. Heck *

CONTENTS

				Page
Forew	ord_			ĨI
Ι.	Intre	duction		1
II.	Spor	sor		2
III.	Spec	mens and tests		2
	1.	Specimens		2
	2.	Plastering		3
	3.	Test procedure		3
IV.	Mat	rials		3
	1.	Wood		3
		(a) Framing		3
		(b) Sheathin	g	3
		(c) Laths		3
		(d) Siding		3
		(e) Shingles.		3
	2.	Paper		3
	3.	Plaster		3
		(a) Mix		3
		(b) Tensile s	$trength of briquets_{-}$	4
	4.	Nails		4
V.	Wall	frames $QAf_{}$		4
	1.	Comments		4
	2.	Description		4
	3.	Compressive lo	ad	4
	4.	Transverse load	1	6
V1.	Wall	QA		6
	1.	Description		6
	2.	Compressive lo	ad	8
	3.	Transverse load	1	8
	4.	Concentrated l	oad	9
	5.	Impact load		11
	6.	Racking load		11

		Page
VII.	Partition QD—load-bearing	15
	1. Comments	15
	2. Description	15
	3. Compressive load	15
	4. Transverse load	16
	5. Concentrated load	16
	6. Impact load	16
	7. Racking load	17
VIII.	Floor QB	17
	1. Description	17
	2. Transverse load	18
	3. Concentrated load	18
	4. Impact load	18
IX.	Roof QC	18
	1. Description	18
	2. Transverse load	19
	3. Concentrated load	19
Χ.	Loads and deflections in transverse tests_	20
XI.	Significance of set readings	20
XII.	Weights	21
XIII.	Two methods of testing walls under com-	
	pressive load	21
	1. Comments	21
	2. Description	22
	3. Test results	22
	4. Discussion	22
XIV.	Selected references	23

ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the Forest Products Laboratory built 39 specimens representing conventional wood-frame constructions for walls, partitions, floors, and roofs. In addition, six wall frames without covering were built.

The wall-frame specimens were subjected to compressive and transverse loads; the wall and partition specimens to compressive, transverse, concentrated, impact, and racking loads; the floor specimens to transverse, concentrated, and impact loads; and the roof specimens to transverse and concentrated loads. The transverse, concentrated, and impact loads were applied to both faces of wall specimens. For each of these loads three like specimens were tested. The

*Engineer, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture.

deformation under load and the set after the load was removed were measured, except for concentrated loads, for which the set only was determined. The results are presented in graphs and in tables.

I. INTRODUCTION

Information on wood-frame construction and on masonry construction, both of which have been widely used and whose behavior in service is generally known, is desirable as a basis for judging the merits of the newer constructions included in the series of tests on the structural properties of low-cost house construction. Such information on masonry appears in report BMS5, Structural Properties of Six Masonry Wall Constructions. The present report deals with one type of wood-frame construction for each of the elements; walls, partitions, floors, and roofs, specimens of which were built and tested at the Forest Products Laboratory of the U. S. Department of Agriculture. The Laboratory and the University of Wisconsin, both in Madison, Wis., cooperate on problems related to wood and wood products.

In frame-house construction various species and grades of lumber are used for framing, wall and roof sheathing, and subflooring, with considerable diversity in the sizes, spacing, and arrangement of elements. Materials other than wood are used for wall sheathing and subflooring as well as for inside and outside finish faces, and a variety of materials serves as plaster base when plaster is used. Thus it is obviously impossible to select any one combination as the typical conventional wood-frame construction.

The principal features of the constructions, tests of which are reported herein, are:

Walls.—Studs (2 by 4 in. nominal) spaced 16 in. on centers and covered outside with bevel siding on diagonally placed sheathing boards and inside with gypsum plaster on wood laths.

Partitions.—Studs (2 by 4 in. nominal) spaced 16 in. on centers and covered on both sides with gypsum plaster on wood laths.

Floors.—Joists (2 by 8 in. nominal) spaced 16 in. on centers, cross-bridged at midspan, covered above with hardwood strip flooring over diagonally placed boards as subflooring, and below with gypsum plaster on wood laths.

Roof.—Rafters (2 by 6 in. nominal) spaced 24 in. on centers and covered above with wood shingles on sheathing boards laid perpendicular to the rafters.

All specimens tested were completed parts of walls, partitions, floors, and roofs except for the omission of paint, wallpaper, or other surfacing.

The estimated prices of these constructions in Washington, D. C., as of July 1937 are:

Wall	\$0. 43/ft ²
Partition	$. 31/ft^{2}$
Floor	$. 49/ft^{2}$
Roof	. $27/ft^2$

In some other wood constructions tested by the National Bureau of Standards the framing was very similar, but the covering materials differed.

In addition to tests on specimens of the constructions outlined, tests were made on wall frames without any inner or outer covering.

The constructions were subjected to compressive, transverse, concentrated, impact, and racking loads, thus simulating loads to which the elements of a house are subjected in actual service.

The deflection under each increment of load and the set after its removal were determined, except for concentrated loads for which set only was measured. Maximum loads were also determined except in the impact-load test.

II. SPONSOR

No industrial or commercial concern participated in these tests as sponsor. The specimens were built by experienced workmen at the Forest Products Laboratory.

III. SPECIMENS AND TESTS

1. Specimens

Table 1 shows the construction symbols and specimen designations, the sizes of specimens, and manner of application of the loads.

TABLE 1.— Test specimens

Con- struc- tion- sym- bol	Specimen designation	Kind of test	Size	Load applied
QA QA QA QA QA QA QA QA	$\begin{array}{c} C1, C2, C3 \\ T1, T2, T3 \\ T4, T5, T6 \\ P1, P2, P3 \\ P4, P5, P6 \\ 11, 12, 13 \\ 14, 15, 16 \\ R1, R2, R3 \end{array}$	Compressive_ Transverse_ Concentrated do Impact Racking	ft 4×8 8×8	Upper end. Inside face. Outside face. Inside face. Outside face. Inside face. Outside face. End of top plate.
QAf	C_{1}, C_{2}, C_{3}	Compressive.	4×8	Upper end.
QD	C_{1}, C_{2}, C_{3}	Compressive	4× 8 4× 8	Upper end.
$\begin{array}{c} QD\\ QD\\ QD\\ QD\\ QD\end{array}$	T1, T2, T3 P1, P2, P3 I1, I2, I3 R1, R2, R3	Transverse Concentrated Impact Racking	$\begin{array}{c} 4\times 8\\ 4\times 8\\ 8\times 8\\ 8\times 8\end{array}$	Either face. Do. Do. End of top plate.
$\begin{array}{c} QB \\ QB \\ QB \\ QB \\ OC \\ OC \end{array}$	$\begin{array}{c} T1, \ T2, \ T3 \\ P1, \ P2, \ P3 \\ i \\ I1, \ I2, \ I3 \\ T1, \ T2, \ T3 \\ P1, \ P3 \\ P3 \\ P1, \ P3 \\ P1, \ P3 \\ p3 \\ p1 \\ p3 \\ p1 \\ p3 \\ p1 \\ p3 \\ p3$	Transverse Concentrated Impact Transverse Concentrated_	$\begin{array}{c} 4 \times 12 \frac{1}{2} \\ \hline 4 \times 12 \frac{1}{2} \\ 4 \times 14 \frac{1}{2} \\ 4 \times 14 \frac{1}{2} \end{array}$	Upper face. Do. Do. Do. Do. Do.
	Con- struc- tion- sym- bol QA QA QA QA QA QA QA QA QA QA QA QA QA	$ \begin{array}{c} {\rm Con-}\\ {\rm struc-}\\ {\rm ion-}\\ {\rm sym-}\\ {\rm bol} \end{array} \begin{array}{c} {\rm Specimen}\\ {\rm designation}\\ {\rm designati$	$ \begin{array}{c} {\rm Con} \\ {\rm struc} \\ {\rm signation} \\ {\rm bol} \\ \end{array} \\ \begin{array}{c} {\rm Specimen} \\ {\rm designation} \\ {\rm wind} \\ {\rm of} \\ {\rm test} \\ \end{array} \\ \begin{array}{c} {\rm QA} \\ {\rm C1}, {\rm C2}, {\rm C3} \\ {\rm C2}, {\rm C3} \\ {\rm C4} \\ {\rm T1}, {\rm T2}, {\rm T3} \\ {\rm C0}, {\rm C0} \\ {\rm C4} \\ {\rm P1}, {\rm P2}, {\rm P3} \\ {\rm P4}, {\rm P5}, {\rm P6} \\ {\rm C0} \\ {\rm C4} \\ {\rm P1}, {\rm P2}, {\rm P3} \\ {\rm P4}, {\rm P5}, {\rm P6} \\ {\rm C0} \\ {\rm C4} \\ {\rm P1}, {\rm P2}, {\rm P3} \\ {\rm C0} \\ {\rm C4} \\ {\rm P1}, {\rm P2}, {\rm P3} \\ {\rm C0} \\ {\rm C4} \\ {\rm P1}, {\rm P2}, {\rm P3} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C1}, {\rm C2}, {\rm C3} \\ {\rm C0} \\ {\rm C1}, {\rm C2}, {\rm C3} \\ {\rm C0} \\ {\rm C1}, {\rm C2}, {\rm C3} \\ {\rm C0} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R4} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C7}, {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm R4} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C7}, {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C7}, {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C0} \\ {\rm C7}, {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C0} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C0} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C0} \\ {\rm C1}, {\rm R2}, {\rm R3} \\ {\rm R3} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R1} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C0} \\ {\rm C1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm C0} \\ {\rm C1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm R1} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm C0} \\ {\rm R1} \\ {\rm R1}, {\rm R3} \\ {\rm R1} \\ {\rm R1}, {\rm R2}, {\rm R3} \\ {\rm R1} \\ {\rm R1}, {\rm R3} \\ {\rm R1} \\ {\rm R1}, {\rm R1}, {\rm R3} \\ {\rm R1} \\ $	$ \begin{array}{c ccccc} {\rm Con-} \\ {\rm struc} \\ {\rm size} \\ {\rm designation} \\ {\rm bol} \\ \end{array} & {\rm Kind of test} \\ {\rm Size} \\ \end{array} \\ \begin{array}{c ccccccccccccccccccccccccccccccccccc$

^a These specimens wercundamaged portions of the specimens used for the transverse tests.

the transverse tests. ^b The wall frames were tested to get a comparison between the bare frames and the specimens representing complete walls and partitions. ^c Tests were not made on nonload-bearing partitions, because they are identical with load-bearing partitions. Specific-gravity determinations (see tables 2 to 6) and photographic records of defects in the framing and sheathing indicate the quality of material in the different specimens. The character of the material in the various specimens is illustrated by several photographic figures in this report.

2. Plastering

The specimens were set up for plastering in the positions they would occupy in service. The plaster was applied by an experienced plasterer and struck to grounds projecting ¾ in. from the face of the frame. The laths were thoroughly sprinkled with water before the plaster was applied and the first coat was also sprinkled before application of the second coat. At least 1 day was allowed between the first and second plaster coats.

3. Test Procedure

The specimens were tested in accordance with BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions, except for the compressive-load test in which a pin-end condition at the bottom rather than a flat-end condition was used. The walls and partitions are close to the dividing line between Euler columns and columns of intermediate length, and it was believed that in such instances a flat bearing at one end might result in an indeterminate increase in load above that corresponding to pin- or hinged-end conditions. In actual structures, vertical loads ordinarily cause compression at right angles to grain in horizontal parts at the top and bottom of the walls. Because the modulus of elasticity in compression at right angles to grain is low, there is no certainty of a significant fixity effect. A further consideration is that, because of the plasticity of wood under stress in compression perpendicular to grain and because of shrinkage and swelling with changes in moisture content, such fixity as may exist at time of erection may gradually decrease. It was therefore thought best to load the specimens through knife-edges at both ends in order to make certain that in test there would be no fixity.

Compressive-load tests were made later at the National Bureau of Standards to determine the difference in the results obtained on pin-end and flat-end bearings at the bottom. The results of these tests are given in section XIII.

The tests were begun February 15, 1938, and completed March 16, 1938. All plastered specimens were tested 28 days after the final coat of plaster was applied.

IV. MATERIALS

1. Wood

(a) Framing

All framing, i. e., studs, joists, plates, headers, and rafters, was No. 1 Douglas fir dimension. The average moisture content of this material was about 15 percent.

(b) Sheathing

Nominal 8-in. shiplap was used for the wall sections and 8-in. boards for the subfloor and roof. This sheathing lumber was No. 2 common southern yellow pine. When received it averaged about 25-percent moisture content. It was piled and stickered in a warm room and was at about 10-percent moisture content when the specimens were built.

(c) Laths

The laths were ³/₂- by 1¹/₂-in. white pine wood laths 4 ft long.

(d) Siding

The siding was 6-in. bevel (actual width $5\frac{1}{2}$ in.) western red cedar.

(e) Shingles

The shingles were 16-in. (five butts to 2 in.) edge-grain western red cedar.

2. PAPER

The building paper applied over the wall sheathing, between the subfloor and the finish floor, and between the roof boards and the shingles was asphalt-impregnated and surface-treated sheathing paper weighing 50 pounds per roll of 500 ft 2 .

3. Plaster

(a) Mix

The plaster on wall, partition, and floor specimens consisted of two coats mixed accord-

ing to the manufacturer's recommendations in the proportions of 1 part of prepared gypsum plaster (U. S. Gypsum Co.) to 2 parts of plaster sand, by weight, for the first coat and 1 part of plaster to 3 parts of sand, by weight, for the second coat, with the necessary water to form a workable mixture.

(b) Tensile Strength of Briquets

Standard briquets were taken from each day's mixing of first and second coats to give an indication of plaster strength. These, as well as the specimens which they represented, were tested on the 28th day after completion of the plastering. The average tensile strength of the briquets was 175 and 115 lb/in.² for the first and second coats, respectively.

4. NAILS

The nails used in building the various specimens were the normal quality of wire nails usually obtained on the market. The size and number used in the different specimens are given under the description of each specimen.

V. WALL FRAMES QAf

1. Comments

The tests on wall frames without covering were included to obtain data that by comparison with data on wall and partition specimens would indicate the effect of sheathing, siding, and plaster on the structural properties of these constructions.

2. Description

The wall frames for compressive- and transverse-load tests were 4 ft wide by 8 ft high overall. They consisted of three studs spaced 16 in. on centers, with a stud at midwidth, a single floor plate, and a double top plate all of nominal 2- by 4-in. material, actual dimensions $1\%_6$ by $3\%_6$ in. The floor plate and the lower unit of the top plate were nailed with two 16d common wire nails driven through these parts into the ends of each stud. The upper unit of the top plate was fastened to the lower with three 10d common wire nails per stud space.

Three frames were tested under compressive and three under transverse load. Each frame for compressive load was braced to prevent bending of the studs in the plane of the frame. The braces consisted of five nominal 1- by 4-in. pieces, two at right angles to the studs at the onethird points of the frame height and three (one in each space) placed diagonally at about 45° to the studs (fig. 1).

3. Compressive Load

In compressive-load tests a small initial load was applied to hold the apparatus in place. Readings of shortening and deflection were taken under this initial load. Additional load was then applied until it reached a predetermined value and shortenings and lateral deflection were read after which the load was reduced to the initial value and readings of set This was repeated several times, inmade. creasing the load each time to a greater value than in the preceding application, and finally the load was increased continuously until failure occurred. The several values to which the load was increased before testing to failure are indicated by the graphs of test results. During the periods of load application, the movable head of the testing machine was operated at a speed of 0.064 in./min.

Wall frame QAf-C3 after test is shown in figure 1.

The results for specimens QAf-C1, C2, and C3 are given in table 2 and in figures 2 and 3.

[A verage moisture content of the frames at time of test was 9.5 percent and the specific gravity (based on weight and volume oven dry) was 0.46]

Load	Load applied	Speei- men desig- nation	Maxi- mum load	Remarks
Compressive	{Eccentric to top plate,	$ \begin{bmatrix} C1 \\ C2 \\ C3 \end{bmatrix} $	Kips/ft ^a 3. 30 4. 28 3. 46	Failure by erushing at top plate by studs fol- lowed by rocking over of top plate. Do. Do.
	Ave r age _		3. 68	
			<i>lb/ft²</i> 213	Failure by tension through small knots in
Transverse	One faee	(T2	159	Failure by tension in
		<i>T</i> 3	175	Failure by tension in one outside stud.
	Average.		182	





FIGURE 1.—Failure of wall frame QAf-C3 under compressive load.

Note rotation of top-plate assembly.

Failure occurred by crushing of the top plate at the studs accompanied by rocking over of this plate toward the eccentric-load side and pulling of the nails fastening the plate to the studs near the opposite edge.

Before testing these specimens in compression, the modulus of elasticity was determined for each one by making a load-deflection test within the proportional limit. The load was applied and the deflection measured as in the transverse-load test, except that no intermediate set readings were taken.

The average modulus of elasticity was 1,587,-000 lb/in.² (individual values were 1,670,000, 1,420,000, and 1,670,000 lb/in²). Computations from this value show that had the wall frames acted as Euler columns, the average maximum load in the compressive-load test would have been approximately 34,200 lb, whereas the actual average was 14,710 lb.

4. TRANSVERSE LOAD

In the transverse test load was applied until it reached a predetermined value; the deflection was read; the load was removed; and the



FIGURE 2.—Compressive load on wall frames QAf.

Lead-shortening (open circles) and load-set (solid circles) results for specimens Q.Af-CI, C2, and C3. Load applied to top end at onethird thickness of the frame from its face; to bottom end at center line of thickness. The loads are in kips per foot of width of specimen (length of floor and top plates 4 ft 0 in.).

set was then read. This was repeated several times, increasing the load each time to a greater value than in the preceding application, and finally the load was increased continuously until failure occurred. The several values to which the load was increased before testing to failure are indicated by the graphs of test results.

During the periods of load application the movable head of the testing machine was operated at a rate of 0.135 in./min.

The results for specimens QAf-T1, T2, and T3 are given in table 2 and in figure 4.

Failures were by tension in the studs.

VI. WALL QA

1. Description

Wall specimens for the compressive, transverse, and impact tests were 8 ft high by 4 ft wide, and those for the racking test were 8 ft high by 8 ft face width. The studs and plates were nominal 2 by 4's (actually $1\%_6$ by $3\%_6$ in.) spaced 16 in. on centers with a stud at midwidth of both the 4-ft and the 8-ft specimens. The floor plate and the lower unit of the double top plate were nailed with two 16d common wire nails driven through the plates into the ends of each stud. The upper unit of the double top plate was fastened to the lower with three 10d common wire nails per stud space.

Before lathing and plastering the specimens, the floor plate of each 8-ft specimen was



FIGURE 3.—Compressive load on wall frames QAf.

Load-lateral deflection (open circles) and load-lateral set (solid circles) for specimens CI, C2, and C3. Load applied to top end at one-third thickness of the frame from its face; to bottom end at center of thickness. The loads are in kips per foot of width of specimen (length of floor and top plates 4 ft 0 in.).

securely nailed to a 6- by 6-in. timber about 10 ft long to facilitate handling and to prevent lateral deflection of the floor plate during test.

TABLE 3.—Structural properties of wall QA

Load	Load applied	Specimen designa- tion	Maximum height of drop ^a	Indenta- tion at 100 lb	Maximuni load	Remarks
	1	(C1	ft	in.	Kips/ft ^b 8, 55	Slight crushing of plaster at 2.75 kips/ft. First tension plaster crack at 8.15 kips/ft. Final failure due to crushing of place at stud ends fallowed by bending failure in two
Compressive _	{Eccentric to top plate.	C2			7.79	studs. Bending of panel was toward the inside face. Plaster erushed at 2.85 kips/ft. First tension crack in plaster at 7.63 kips/ft. Final failure by crushing at upper plate followed by cross-breaking of studs at 5.67 kips/ft
		C3			8.80	after maximum load. Panel deflected toward inside face. First failure in plaster was crushing near top at 4.75 kips/ft. Final failure due to crushing of upper pla'e followed by cross-breaking of two studs. Reverse bend—bending toward outside face at top but toward inside face at center and bottom.
	Average				8.38	
		(T1			<i>lb/ft</i> ² 262	Tension in studs. First plaster crack at load points near
Transverse	{Inside (plastered) face.	T2			267	maximum load. Tension in studs. Plaster cracks under load points near
		T3		••••	289	Tension in one stud. Plaster cracks at load points visible only on removal of load after maximum load.
	Average				273	
		[<i>T</i> 4			219	First plaster crack at 63 lh/ft ² at seventh loading. Princi- pal failure by tension in studs.
Do	{Outside (sheatbed and sided) face.	T5			215	First plaster crack under load point at 42 lb/it ² at lifth loading. Tension at knot in outside stud followed by
		<i>T6</i>			243	First plaster erack across center at 26 lb/ft ² at fifth loading. Tension at knots in studs.
	Avcrage				226	
Concentrated	{Inside (plastered) face.	$\begin{cases} P1 & & \\ P2 & & \\ P3 & & \\ \end{cases}$		0.000 .000 .000	<i>lb</i> 318 245 355	i la
	Average			0.000	306	
Do	{Outside (sheatbed and sided) face.	$\begin{cases} P_4 \\ P_5 \\ P_6 \\ \dots \\ \end{pmatrix}$		0.001 .001 .000	$ \begin{array}{r} 1, 520 \\ 1, 300 \\ 2, 050 \end{array} $	Loaded at about 1 in. from sheathing joint. Loaded at about 1¾ in. from sbeatbing joint.
	A verage			0.001	1, 623	
		(11	9.0			First plaster crack at 2½-ft drop. Lath and plaster broke through near center at 9-ft drop. Outside face undam-
Impact	{Inside (plastered) face.	I2	a 10.0			aged. First plaster crack at 5-ft drop. Plaster badly shattered at 10-ft drop, but no failure in latb and studs. Outside face
		<i>I</i> 3	a 10. 0			Do.
	Average					
		14	a 10.0			First plaster crack at 1½-ft drop. Most of plaster loose at 10-ft drop. Upper face and study undamaged.
Do	and sided) face.	15	a 10. 0			First plaster crack at 2½-it drop. Plaster and some latin loose and failure of one outside stud at small knot at 10-ft drop.
		16	a 10. 0			First plaster crack at 2½-ft drop. Plaster and some latb loose and slight tension in one stud at small knot at 10-ft drop.
	Average		a 10. 0			
	4	(R1			Kips/ft b 2.03	First plaster crack at 1.50 kips/ft. Final failure due to
Racking	End of top plate_					plaster shearing keys and sheatbing shearing from floor plate with cross-breaking and splitting of studs.
		R2			2.15	First plaster crack at 0.88 kip/it at last loading. Final failure similar to R1.
					2.10	failure similar to $R1$.
	Average				2.09	

[Weights of constructions and of plaster are shown in table 7. The average moisture content of the framing at time of test was 11.1 percent and the specific gravity (based on weight and volume when oven dry) was 0.50]

Test discontinued at 10-ft drop.
A kip is 1,000 lb.
Specimens loaded on top plate through knife-edge at one-third width of frame from inside face of frame and supported at bottom on similar knife-edge at center of frame.

The sheathing on all walls was applied diagonally at an angle of about 45° with the studs and nailed with two 8d common wire nails at crossing of studs, floor plate, and upper unit of the double top plate and with one 8d nail at each crossing of the lower unit of the top plate, then covered with sheathing paper and finally bevel siding. The 4-ft specimens had no joints in the sheathing boards. The 8-ft specimens



FIGURE 4.—Transverse load on wall frames QAf.

had joints in sheathing boards located at stud crossings, as indicated in figure 5.

Twenty-one widths of bevel siding were applied to each specimen with a resulting average exposure of $4\%_6$ in., the top piece being ripped to this dimension. The actual widths of the siding being 5% in., the average "overlap" was $1\%_6$ in., and one 7d siding nail was driven through the overlapping edges at each stud crossing.

The inner faces of outside walls were lathed and given two coats of gypsum plaster to a combined thickness of lath and plaster of $\frac{3}{4}$ in. The laths were nailed with one 3d sterilized, blued lath nail at each stud crossing. The laths were applied in courses of eight laths each, the joints being broken in a uniform manner for each size of specimen, 51 widths of lath being required in each instance. Support for the 8-in. overhang of the lath at each edge of the 4-ft specimens was provided in conjunction with the plastering grounds, the supporting pieces being removed before test (fig. 6).

2. Compressive Load

The operation of the testing machine was as described for wall frames under section V-3.

The results for wall specimens QA-C1, C2, and C3 are shown in table 3 and in figures 7 and 8.

The average maximum load of 8.38 kips/ft is approximately 60 percent of the value computed by inserting in the Euler column formula the average value of stiffness (*EI*) derived from the transverse-load tests on specimens QA-T1, T2, and T3.

The failures were characterized by crushing of the plaster near the plates, crushing of the plates at the ends of the studs, tension plaster cracks after maximum load, and finally crossbreaking of the studs. In specimens C1 and C2 bending was toward the inside face (negative deflection) despite the fact that the load was eccentric toward that face. The resultant greater crushing of the upper plates at the edge toward the sheathed outer face is illustrated by figure 9. Specimen C3 took a reverse bend, the deflection being toward the outside face in the upper half, but toward the inside face at and below the center of the height.

3. TRANSVERSE LOAD

The operation of the testing machine was as described for wall frames under section V-4.

A specimen (QA-T1) under transverse-load test is shown in figure 10. The results of the tests are shown in table 3 and in figures 11 and 12, respectively, for specimens QA-T1, T2, and T3 loaded on the inside face, and for specimens QA-T4, T5, and T6 loaded on the outside face.

With the load applied to the outside face, the first failure was by cracking of the plaster. When the load was applied to the inside (plas-

Load-deflection (open circles) and load-set (solid circles) results for specimens Tl, Tl, and Tl on the span of 7 ft 6 in. The loads are in pounds per square foot on the area of 30 sq ft (span times the length of wall represented by the 4-ft specimen).



FIGURE 5.—Wall specimen QA before application of laths, plaster, or siding, showing construction of 8- by 8- ft. specimens and position of joints in sheathing (indicated by x's).

In racking tests the horizontal forces were applied in the direction to eause tension in the sheathing, i. e., pushing toward the right at the top of the specimen and toward the left at the bottom.

tered) face, cracks were not observed until near the maximum load and were usually not visible until the load was removed.

4. Concentrated Load

A specimen (QA-P3) set up for the concentrated-load test is shown in figure 13. The micrometer dial and supporting bar shown in this figure are removed when making the indentation. The circular supporting ring remains in place.

The results are given in table 3 for wall specimens QA-P1, P2, and P3 loaded on the

inside face, and in table 3 and figure 14 for wall specimens QA-P4, P5, and P6 loaded on the outside face. Indentation on the plastered face was negligible up to the point where the plaster crushed or cracked, consequently only the indentation at 100 lb was recorded for specimens QA-P1, P2, and P3.

When loaded on the inside (plastered) face, failure occurred by crushing and cracking of the plaster and breaking of the laths. When loaded on the outside face, failure occurred by crushing of the siding under the tool, and splitting and cross-breaking of the sheathing.



FIGURE 6.—Partition specimen QD-T1 with laths on one face only.

The pieces shown at vertical edges formed supports for lath ends and grounds for plastering and were removed before the specimen was tested.



FIGURE 7.—Compressive load on wall QA.

Load-shortening (open circles) and load-set (solid circles) results for specimens $Q_{A}-C_{I}$, C_{2} , and C_{3} . The loads are in kips per foot of width of specimen (4 ft 0 in).



FIGURE S.-Compressive load on wall QA.

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens QA-CI, C2, and C3. The loads are in kips per foot of width of specimen (4 ft 0 in).



FIGURE 9.—Crushing of lower face of upper plate against ends of studs in compressive-load test of specimen QA-C2.

5. Impact Load

The results of the impact-load tests are given in table 3 and in figures 15 and 16, respectively, for specimens QA-I1, I2, and I3loaded on the inside face, and for specimens QA-I4, I5, and I6 loaded on the outside face.

No failure occurred in the frame members of the wall panels up to the final drop from a height of 10 ft. In tests with the outside face up, most of the plaster and some of the laths had broken loose at this drop. Specimens tested with the inside (plastered) face up sustained only a general loosening of the plaster, and in one specimen (II) the laths broke through near the center at the 9-ft drop.

6. RACKING LOAD

In the racking-load test, load was applied until it reached a predetermined value; the deflection was read; load was removed; and readings of set at zero load taken. This was repeated several times and finally the load was increased continuously until failure of the specimen occurred. The several values to which the load was increased before testing to failure are indicated by the graph of test results (fig. 17). During the periods of load application, the upper end of the specimen was moved longitudinally at a rate of 0.2 in./min.

The walls were tested with the diagonal sheathing stressed in tension (fig. 5), which previous tests have indicated is the weaker direction.



FIGURE 10.-Wall specimen QA-T1 in position for transverse-load test.





FIGURE 11.—Transverse load on wall QA, load applied to inside face.

Load-deflection (open circles) and load-set (solid circles) results for specimens QA-TI, T2, and T3 and on the span of 7 ft 6 in. Loads are in pounds per square foot of the area (span times the width of specimen 30 sq ft).

FIGURE 12.—Transverse load on wall QA, load applied to outside face.

Load-deflection (open circles) and load-set (solid circles) results for specimens $QA-T_4$, T_5 , and T_6 on the span of 7 ft 6 in. Loads are in pounds per square foot of the area (span times the width of specimen 30 sq ft).



FIGURE 13.- Wall specimen QA-P3 in position for the concentrated-load test.

[12]



FIGURE 14.—Concentrated load on wall QA, load applied to outside face.

Load-indentation results for specimens QA-P4, P5, and P6.



FIGURE 15.—Impact load on wall QA, load applied to inside face.

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens QA-H, I2, and I3 on the span of 7 ft 6 in.



FIGURE 16.—Impact load on wall QA, load applied to outside face.

Height of drop-deflection (open circles) and height of drop set (solid circles) results for specimens QA-I4, I5, and I6 on the span of 7 ft 6 in.



FIGURE 17.—Racking load on wall QA

Load-deformation (open circles) and load-set (solid circles) results for specimens QA-R1, R2, and R3. Loads are in kips per foot of the face width of specimen (8 ft 0 in.).



FIGURE 18.—Partition specimen QD-C3 under compressive-load test.

Shortening is read by means of the dial gage mounted on a telescoping rod attached to the bearing plates by pins centered at the middle of the thickness of the frame and in the planes of the ends of the specimen. Lateral deflection is the reading of the steel seale which is attached to the specimen at midheight against a fine wire stretched between end fittings of the telescoping rod and kept taut by ruhher bands.



FIGURE 19.—Compressive load on partition QD.

Load-shortening (open circles) and load-set (solid eireles) results for specimens QD-CI, C2, and C3. Loads are in kips per foot of width of specimen (4 ft 0 in.).



FIGURE 20.—Compressive load on partition QD.

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens QD-C1, C2, and C3. Loads are in kips per foot of width of specimen (4 ft 0 in.).

TABLE 4.—Structural properties of partition QD

Load	Load applied	Specimen designa- tion	Maximum height of drop	Indenta- tion at 100 lb	Maximum load	Remarks
		(C1	ft	in.	Kips/ft a 6, 58	First plaster failure by crushing near bottom plate. Rock- ing over of upper plate due to eccentric loading caused
Compressive	{ Eccentric to top plate. ^b	C2			6, 44	Plaster cracked near bottom at 2.00 kips/ft. Final failure
		C3			7.67	First plaster crack at 0.96 kip/ft, fourth loading. Final fail- ure similar to specimen C1.
	A verage				6, 90	
		[<i>T1</i>			<i>lb/ft</i> ² 240	First plaster crack in lower face at 52 lb/ft ² at fifth loading. Failure due to cross grain tension in one outside stud followed by horizontal shear in center stud
Transverse	One face	T2			292	First plaster crack in lower face at 49 lb/ft ² at fifth loading. Failure by tension in studs.
		\ <i>T3</i>	-		290	First plaster crack in lower face at 48 lb/ft ² at fifth loading. Failure by tension in studs.
	Average				274	
		{ <i>P1</i>		0.004	<i>lb</i> 185	Average of two tests—220 and 150 lb for loads at joint and
Concentrated	One face	P2 P3		. 003 . 007	290 180	Loaded at joint between two laths. Loaded at center of width of lath.
	Average			0.005	218	
		111	8.5			First plaster crack on both faces at 3-ft drop. One outside
Impact	One face	{I2	8.0			First plaster crack in both faces at 2.5-ft drop. Brash ten- sion in center stud and tension in one side stud at 8-ft drop.
		<i>I</i> 3	8.5			First plaster crack in lower face at 2.5-ft drop and top face at 3.5-ft drop. Tension in center stud at 8.5-ft drop.
	Average		8.3			
		{ <i>R1</i>			Kips/ft a 1.06	First plaster crack at 0.88 kip/ft at sixth loading. Final
Racking	End of top plate	R2			1.00	First plaster crack at 0.38 kip/ft at fifth loading. Final
		R3			1.05	First plaster crack at 0.50 kip/ft at fifth loading. Final fail- ure due to plaster shearing keys.
	Average				1.04	

Weights of constructions and of plaster are shown in table 7. The average moisture content of the framing at time of test was 11.3 percent and the specific gravity (based on weight and volume when oven dry) was 0.51]

^a A kip is 1,000 lb. ^b Specimens loaded on top plate through knife edge at one-third width of frame from inside face of frame and supported at bottom on similar knife edge at center of frame.

The results for wall specimens QA-R1, R2, and R3 subjected to the racking test are given in table 3 and in figure 17.

Failure was characterized by the sheathing pulling the nails and shearing from the lower plate ¹ and by the studs breaking in bending or splitting from the nails driven through the lower plate into their ends.

VII. PARTITION QD-LOAD-BEARING

1. Comments

Since nonload-bearing partitions are usually built the same as load-bearing partitions, no nonload-bearing partitions were included.

2. Description

The partitions were of the same construction as the walls with the exception that both faces were lathed and plastered and the impact specimens QD-I1, I2, and I3 had single 2- by 4-in. top plates. As with the wall specimens, the floor plate of each 8-ft partition specimen was nailed to a 6- by 6-in. timber before plaster was applied to the specimen.

3. Compressive Load

A partition specimen (QD-C3) under compressive load is shown in figure 18. The operation of the testing machine was as described for wall frames under section V-3.

The results for specimens QD-C1, C2, and C3 are shown in table 4 and in figures 19 and 20.

¹ Sheathing was less securely nailed to the lower or floor plate than to the upper. (See sec. VI-1.)

The average maximum load of 6.90 kips/ft is approximately 35 percent of the computed value obtained by inserting in the Euler column



FIGURE 21.—Transverse load on partition QD.

Load-deflection (open circles) and load-set (solid circles) results for specimens QD-T1, T2, and T3 on the span of 7 ft 6 in. Loads are in pounds per square foot of the area (span times the width of specimen 30 sq ft).

formula the average value of stiffness derived from the transverse-load tests on specimens QD-T1, T2, and T3. The three specimens failed by crushing of the plaster near the plates, crushing of the plates at the stud ends, tension plaster cracks after maximum load, and finally rocking over of the upper plate allowing the studs to kick out, as shown in figure 18, without breaking.

4. TRANSVERSE LOAD

The operation of the testing machine was as described for wall frames under section V-4.

The results of transverse-load tests (specimens QD-T1, T2, and T3) are given in table 4 and figure 21.

First failure in these panels was by tension in the plaster on the lower face. Final failure was by bending in the studs.

5. Concentrated Load

The results for specimens QD-P1, P2, and P3 are given in table 4. Indentation on the plaster was so influenced by crushing and cracking of the plaster that consistent load-indentation readings were not obtained. Consequently only the indentation at 100 lb was recorded. Failure was by crushing and cracking of the plaster and breaking of the laths.

6. Impact Load

A setup for an impact test on a partition specimen is shown in figure 22.



FIGURE 22.—Partition specimen QD in position for impact-load test.

The results for specimens QD-I1, I2, and I3 are given in table 4 **a**nd figure 23.

The three specimens failed by breaking of the stude accompanied by shattering of the plaster and breaking of the laths.

7. RACKING LOAD

A partition specimen (QD-R1) under the racking-load test is shown in figure 24. The



FIGURE 23.—Impact load on partition QD.

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens QD-11, I2, and I3 on the span of 7 ft 6 in.

racking-load test was conducted as outlined for walls under section VI-6.

The results for specimens QD-R1, R2, and R3 are given in table 4 and figure 25.

Final failure was due to shearing off of the plaster keys, thus lowering the resistance to distortion.

VIII. FLOOR QB

1. Description

Floor specimens (fig. 26) were 4 ft wide by $12\frac{1}{2}$ ft long and consisted of three 2- by 8-in. joists (actual dimensions $1\frac{1}{16}$ by $7\frac{3}{8}$ in.) spaced 16 in. on centers and symmetrically placed with respect to the width. A 2- by 8-in. by 4-ft header was fastened to each end of the speci-



FIGURE 24.—Partition specimen QD-R1 under rackingload test.

men by two 16d common wire nails driven into the end of each joist. The subfloor, which was applied in full-length pieces, was laid diagonally at an angle of about 45° with the joists, and nailed to each joist and header with two 8d common nails. Building paper was laid between the subfloor and the finish floor, then one row of 1- by 4-in. cross bridging, each piece of which was nailed at each end with two 8d nails, was applied at midlength of the specimen. The finish floor was laid 1 week before test and nailed with 8d casing nails. The lower surface was lathed, the joints being broken for each course of eight laths, and plastered.

2. TRANSVERSE LOAD

The operation of the testing machine was as described for wall frames under section V-4,



FIGURE 25.—Racking load on partition QD.

Load-deformation (open circles) and load-set (solid circles) results for specimens QD-R1, R2, and R3. Loads are in kips per foot of the face width of specimen (8 ft 0 in).

except that the rate of movement of the head was about 0.08 in./min, which was increased to 0.13 in./min in the final run to failure.

The results for specimens QB-T1, T2, and T3 are given in table 5 and figure 27.

First failure was by cracking of the plaster at relatively low loads. Final failure was by tension in the joists, influenced in specimens T1 and T3 by knots.

3. Concentrated Load

The results for specimens QB-P1, P2, and P3 are given in table 5 and figure 28.

Failure was by local splitting and breaking of the flooring and subflooring as the tool penetrated the floor panel.

4. Impact Load

The results for specimens QB-I1, I2, and I3 are given in table 5 and figure 29.

The floor panels showed no failure in the joists at the final drop from a height of 10 ft. The plaster broke loose very generally in the central portion of specimens I1 and I2, and only slightly at one edge of I3.

IX. ROOF QC

1. Description

Roof specimens (fig. 30) were 4 ft wide by 14 ft 6 in. long. They consisted of two 2- by 6-in. (actual $1\frac{1}{16}$ by $5\frac{1}{16}$ in.) rafters spaced 24 in. on centers and symmetrically placed with respect to the width. A 2- by 6-in. header 4 ft long was fastened to each end of the specimen by two 16d common wire nails driven into the end of each joist. The roof boards were laid snug, perpendicular to the rafters, and nailed with two 8d nails at each rafter crossing and were covered with building paper and shingles laid with a 5-in. exposure.



FIGURE 26. Under side of floor specimen QB before plastering, showing construction.

[18]

TABLE 5.—Structural properties of floor QB

Load	Load applied	Specimen designa- tion	Maximum height of d r op ^a	Indenta- tion at 100 lb	Maximum load	Remarks
Transverse	Upper face	$\begin{cases} T1 \\ T2 \\ T3 \\ \end{cases}$	ft	in.	<i>lb/ft</i> ² 242 259 358	First plaster crack at 29 lb/ft ² at third loading. Failure by tension at knots in 2 joists. First plaster crack at 31 lb/ft ² at fourth loading. Failure by tension in joists. First plaster crack at 39 lb/ft ² at fourth loading. Failure hy tension in joists influenced by knots.
	Average				287	
Concentrated	Upper face	$\begin{cases} P1 \\ P2 \\ P3 \\ \end{cases}$		0.000 .000 .000	<i>lb</i> 3, 500 3, 320 3, 610	Loaded at center of flooring strip over joint in subfloor. Loaded at center of flooring strip over center of subfloor board. Do.
	Average			0.000	3, 477	
lmpact	Upper face	11 12 13	^a 10.0 ^a 10.0 ^a 10.0			First plaster crack at 4.5-ft drop. No failure in flooring or joists. First plaster crack at 4-ft drop. No failure in flooring or joists. First plaster crack at 6.5-ft drop. No failure in flooring or joists.
	Average		a 10. 0			

[Weights of constructions and of plaster are shown in table 7. The average moisture content of the framing at test was 10.5 percent and the specific gravity (based on weight and volume when oven dry) was 0.50]

a Test discontinued at 10-ft drop.

2. TRANSVERSE LOAD

The operation of the testing machine was as described for wall frames under section V-4, except that the rate of movement of the head was 0.13 in./min and was doubled in the final run to failure.

The results for specimens QC-T1, T2, and T3 are given in table 6 and figure 31.

TABLE 6.—Structural properties of roof QC

[Weights of constructions and of plaster are shown in table 7. The average moisture content of the rafters at test was 8.5 percent and the average specific gravity (based on weight and volume when oven dry) was 0.44]

Load	Load applied	Speci- men desig- nation	Inden- tation at 100 lb	Maxi- mum load	Remarks
Transverse	{Upper {face.	$\begin{cases} T1 \\ T2 \\ T3 \end{cases}$	in.	<i>lb/ft²</i> 84.7 113.2 74.0	Tension in both rafters. Tension in one rafter. Tension in both rafters.
	Average.			90.6	
Concentra- ted.	Upper face.	P1 P2 P3	0.000 .001 .001	1, 670 1, 760 1, 350	Load on one roof board only. Load at least 1 in. from joint in roof. Loaded over joint between two roof boards.
	Average.		0.001	1, 593	

Failure was by tension in the rafters.

3. CONCENTRATED LOAD

The results for specimens QC-P1, P2, and P3 are given in table 6 and figure 32.



FIGURE 27.—Transverse load on floor QB.

Load-deflection (open circles) and load-set (solid circles) results for specimens QB-TI, T2, and T3 on the span of 12 ft 0 in. Loads are in pounds per square foot of the area (span times the width of specimen 48 sq ft).

Failure was by the test tool puncturing the shingles and breaking through the roof board.

X. LOADS AND DEFLECTIONS IN TRANSVERSE TESTS

Results of transverse tests on walls, partitions, floors, and roofs are expressed in this



FIGURE 28.—Concentrated load on floor QB.

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

report in terms of load per square foot of area although in test the load was applied at the quarter points of the span and thus was not uniformly distributed. The deflections recorded were measured at midspan.

Maximum loads as found in the transverse tests are practically the same as would be found from tests with the load uniformly distributed. The deflections in the earlier stages of the tests are 10 percent greater than would be caused by uniformly distributed load of the same magnitude.



FIGURE 29.—Impact load on floor QB.

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens QB-II, I2, and I3 on the span of 12 ft 0 in.

XI. SIGNIFICANCE OF SET READINGS

Readings of set in the compressive-, transverse-, impact-, and racking-load tests on all covered specimens were so influenced by friction between the parts, closing of parts, and in some instances crushing of the plaster or plates that



FIGURE 30.-Under side of roof specimen QC, showing construction.

[20]

they are of doubtful significance. For example, in the transverse-load test the set reading would in many instances entirely disappear with a slight pressure momentarily applied underneath the panel. Under the impact test, vibrations were set up, and when the panel came to rest it might be at either a low or a high point in its amplitude, due to friction between the various parts. The panel coming to rest at the high point would account for the negative



FIGURE 31.—Transverse load on roof QC.

Load-deflection (open circles) and load-set (solid circles results for specimens QC-T1, T2, and T3 on the span of 14 ft 0 in. Loads are in pounds per square foot of the area (span times the width of specimen 56 sq ft).

set obtained at a 10-ft height of drop in the walls tested with the outside face up (fig. 16).

XII. WEIGHTS

The weights of the various constructions before plastering and at time of test have been summarized in table 7. The weights of plaster were found by differencing the weights before plastering and at time of test, which was 28 days later. Change of weight of parts other than plaster over this period was no doubt very small and has been disregarded in deriving the figures for weight of plaster.



FIGURE 32.—Concentrated load on roof QC. Load-indentation results for specimens QC-P1, P2, and P3.

XIII. TWO METHODS OF TESTING WALLS UNDER COMPRESSIVE LOAD

1. Comments

In BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions, p. 7, the compressive load is described as being applied to the specimen as a column having a flat end at the bottom. For the reasons given in section III-3, Test Procedure, the walls and partitions tested for this report were supported by a knife-edge at the bottom. To determine the effect of the type of lower bearing on the results for compressive loading, specimens ZZ were tested in the laboratory of the National Bureau of Standards at Washington, D. C., using knife-edge and flatend bearings at the bottom. They were built under the supervision of a member of the staff of the Forest Products Laboratory who assisted in the tests.

2. Description

Three specimens were made for each of the two types of lower bearing. The framing for these specimens consisted of 2- by 4-in. (nominal) studs, a doubled 2- by 4-in. plate at the top, and a single 2- by 4-in. floor plate at the bottom. These parts were arranged in like manner to the 4-ft wall specimens (QA) described under section VI-1.

Douglas fir was used for the framing; and, in order to avoid any effect of defects on the desired comparison, straight-grained material free from knots was selected. To further assure valid comparison between tests with the two kinds of end bearing the specimens were paired in such a manner that studs cut from end-to-end positions in a 2- by 10-in. plank, jointed straight, and surfaced to width, occupied like positions in the specimens of a pair and were oriented alike, i. e., with the same end up and the same edge toward the inside face of the specimen. Floor plates and top-plate parts were similarly matched. The frames were faced on both sides with ²/₃₂-in. fiberboard in two pieces, with the junction on the center stud. Each piece of fiberboard was nailed to the top and floor plates and to the center stud with 8d common nails spaced 3 in. Nail spacing along the other studs was 6 in., 8d common nails being used on the outside face of the specimen and 6d casing or finish nails on the inside face.

3. Test Results

The data from the tests in series ZZ are given in table 8.

TABLE	8R	esults	of co	mpres	ssive-l	oad	tests	on	wall
specim	ens ZZ	compa	aring	knife	-edge t	o fla	t-end i	beari	ng

Specimen des- ignation	Bottom bear- ing	Maxi- mum load	Later mid	al defi height	Shortening at—		
			12,000 1b	20,000 1b	28,000 1b	12,000 1b	20,000 lb
C1a C1b C2a C2b C3a	Flat Knife edge Flat Knife edge Flat	<i>lb</i> 29,000 32,000 34,000 25,740	in. 0.12 .08 .02 .05 .03	$in. \\ 0.21 \\ .16 \\ .10 \\ .12 \\ .08$	$in. \\ 0.40 \\ .32 \\ .36 \\ .38$	in. 0.05 .06 .08 .08 .05	$in. \\ 0.10 \\ .11 \\ .13 \\ .12 \\ .11$
A verage A verage	Knife edge Flat Knife edge	24, 500 28, 580 29, 170	0.05 0.05 0.06	. 18 0. 13 0. 15	0. 38 0. 35	.06 0.06 0.07	. 15 0. 11 0. 13

In the tests of series ZZ, as well as in other compressive-load tests of wood constructions with 2- by 4-in. studs and doubled 2- by 4-in. top plates, final failure was preceded by severe eccentric crushing of the plate against the ends of the studs. (The eccentricity was so great in some instances that studs and plate were in contact over only part of the width, as shown in fig. 1.)

In the special tests with flat bearing at the lower end of the specimen, eccentric yielding also occurred at the bearing of studs on the floor plate and contributed to the eccentricity of loading, although it was not great enough to be apparent as visible crushing.

In many of the tests on specimens with doubled 2- by 4-in. top plates the eccentric crushing of the under side of the plate against the ends of the studs caused the plates to roll and carry the upper ends of the studs so far laterally that "jack-knifing" or collapse of the specimen and apparatus occurred, probably without the full load capacity of the studs being developed. This was true in the tests of wall frames QAf (see fig. 1 and table 2) in partition specimens QD (see table 4) and in all but one, C1b, of the wall specimens ZZ. For all the other specimens, lateral movement at the top of the studs greatly increased the effective eccentricity of loading.

4. Discussion

The tests on the ZZ specimens were carried out subsequent to those described in preceding parts of this report but in advance of any other tests of wood constructions under this program. On the basis of the results of tests on QA, QD, and ZZ specimens and in order to obtain uniformity with tests on other types, it was decided that in all future compressive-load tests of wood constructions under this program flat bearing would be used at the lower end in accordance with BMS2.

Considering the numerical results listed in table 8 and the behavior observed in tests of the ZZ series and other wood constructions, it is improbable that the values from the present tests on walls (QA), partitions (QD), and wall frames differ significantly from those that would have resulted had flat bearings been used.

XIV. SELECTED REFERENCES

- G. W. Trayer, *Rigidity and strength of frame walls*, Forest Products Laboratory Mimeograph R896 (1929); Eng. News-Record **103**, 656-7 (1929).
- G. W. Trayer, Practical suggestions on frame house constructions, President's Conference on Home Building and Home Ownership, Final Report of Committees 7, 79–93 (1932); Forest Products Laboratory Mimeograph R991 (1932).
- G. W. Trayer, Plywood as a structural covering for frame walls and wall units, Forest Products Laboratory Mimeograph R1025 (1934); Eng. News-Record 113, 172-4 (1934).
- G. W. Trayer, Floor panels with stressed plywood covering, Forest Products Laboratory Mimeograph R1026 (1934), Eng. News-Record 113, 174-6 (1934).

MADISON, WIS., May 8, 1939.

- Forest Products Laboratory Wood Handbook, Basic information on wood as a material of construction with data for its use in design and specifications, U. S. Department of Agriculture Publication (1935).
- R. F. Luxford, Fabricated wall panels with plywood coverings, Forest Products Laboratory Mimeograph R1099 (1936); Wood Products 41, 2, 8-10 (1936); Timberman 37, 4, 22, 24-26 (1936); Abstract: American Builder 58, 9, 82, 114 (1936); Abstract: Architectural Record 79, 4, 334 (1936).
- G. E. Heek, Rigidity and strength of frame walls sheathed with fiberboard, Forest Products Laboratory Minneograph R1151 (1937); Wood Construction 25, 2, 14-15, 23 (1939).

0





BUILDING MATERIALS AND STRUCTURES REPORTS

The following publications in this series are now available by purchase from the Superintendent of Documents at the prices indicated:

BMS1	Research on Building Materials and Structures for Use in Low-Cost Housing	10¢
BMS2	Methods of Determining the Structural Properties of Low-Cost House Constructions	10¢
BMS3	Suitability of Fiber Insulating Lath as a Plaster Base	10¢
BMS4	Accelerated Aging of Fiber Building Boards	10¢
BMS5	Structural Properties of Six Masonry Wall Constructions	15¢
BMS6	Survey of Roofing Materials in the Southeastern States	15¢
BMS7	Water Permeability of Masonry Walls	10¢
BMS8	Methods of Investigation of Surface Treatment for Corrosion Protection of Steel	10¢
BMS9	Structural Properties of the Insulated Steel Construction Co.'s "Frameless-Steel"	
	Constructions for Walls, Partitions, Floors, and Roofs	10¢
BMS10	Structural Properties of One of the "Keystone Beam Steel Floor" Constructions Spon-	
	sored by the H. H. Robertson Co	10¢
BMS11	tions for Walls and Partitions	10¢
BMS12	Structural Properties of "Steelox" Constructions for Walls, Partitions, Floors, and Roofs	
	Sponsored by Steel Buildings, Inc	15¢
BMS13	Properties of Some Fiber Building Boards of Current Manufacture	10¢
BMS14	Indentation and Recovery of Low-Cost Floor Coverings	10¢
BMS15	Structural Properties of "Wheeling Long-Span Steel Floor" Construction Sponsored by	
	Wheeling Corrugating Co	10¢
BMS16	Structural Properties of a "Tilecrete" Floor Construction Sponsored by Tilecrete	
	Floors, Inc	10¢
BMS17	Sound Insulation of Wall and Floor Constructions	10¢
BMS18	Structural Properties of "Pre-Fab" Constructions for Walls, Partitions, and Floors	
	Sponsored by the Harnischfeger Corporation	10ϕ
BMS19	Preparation and Revision of Building Codes	15ϕ
BMS20	Structural Properties of "Twachtman" Constructions for Walls and Floors Sponsored by	
	Connecticut Pre-Cast Buildings Corporation	10¢
BMS21	Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the	
	National Concrete Masonry Association	10¢
BMS22	Structural Properties of "Dun-Ti-Stone" Wall Construction Sponsored by the W. E.	
	Dunn Manufacturing Co	10¢
BMS23	Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick	
	Manufacturers Association of New York, Inc	10¢
BMS24	Structural Properties of a Reinforced-Brick Wall Construction and a Brick-Tile Cavity-	
	Wall Construction Sponsored by the Structural Clay Products Institute	104

How To Purchase

BUILDING MATERIALS AND STRUCTURES REPORTS

On request, the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., will place your name on a special mailing list to receive notices of new reports in this series as soon as they are issued. There will be no charge for receiving such notices.

An alternative method is to deposit with the Superintendent of Documents the sum of \$5, with the request that the reports be sent to you as soon as issued, and that the cost thereof be charged against your deposit. This will provide for the mailing of the publications without delay. You will be notified when the amount of your deposit has become exhausted.

If 100 copies or more of any report are ordered at one time, a discount of 25 percent is allowed. Send all orders and remittances to the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.

