U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS30

Structural Properties of a Wood-Frame Wall Construction Sponsored by the Douglas Fir Plywood Association

by

HERBERT L. WHITTEMORE

and AMBROSE H. STANG

with the collaboration of

THOMAS R. C. WILSON

Forest Products Laboratory

NATIONAL BUREAU OF STANDARDS

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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. These constructions were sponsored by industrial organizations within the building industry advocating and promoting their use. The sponsor built and submitted the specimens described in this report for the program outlined in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions. The sponsor, therefore, is responsible for the description of the specimens and the method of fabrication. The Bureau is responsible for the method of testing and the test results.

This report covers only the load-deformation relations and strength of the walls of a house when subjected to compressive, transverse, concentrated, impact, and racking loads by standardized methods simulating the loads to which the walls would be subjected in actual service. Later it may be feasible to determine the heat transmission at ordinary temperatures and the fire resistance of this same construction and perhaps other properties.

The Forest Products Laboratory, Forest Service, United States Department of Agriculture, collaborated in the tests of this construction.

The National Bureau of Standards does not "approve" a construction, nor does it express an opinion as to the merits of a construction, for the reasons given in reports BMS1 and BMS2. The technical facts on this and other constructions provide the basic data from which architects and engineers can determine whether a construction meets desired performance requirements.

Lyman J. Briggs, *Director*.

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Thomas R. C. Wilson, Forest Products Laboratory, Forest Service, United States Department of Agriculture

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ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the Douglas Fir Plywood Association submitted 18 specimens representing a wood-frame wall construction. The sheathing on the outside face and the wallboard on the inside face were both Douglas fir plywood.

The specimens were subjected to compressive, transverse, concentrated, impact, and racking loads. The transverse, concentrated, and impact loads were applied to both faces of the specimens. For each of these loads three like specimens were tested, the concentrated-load tests being made on undamaged portions of the impact specimens. The deformation under load and the set after the load was removed were measured for uniform increments of load, except for concentrated loads, for which the set only was determined. The results are presented in graphs and in a table.

I. INTRODUCTION

In order to provide technical facts on the performance of constructions which might be used in low-cost houses, to discover promising constructions, and ultimately to determine the properties necessary for acceptable performance, the National Bureau of Standards has invited the building industry to cooperate in a program of research on building materials and structures for use in low-cost houses and apartments. The objectives of this program are described in report BMS1, Research on Building Materials and Structures for Use in Low-Cost Housing, and that part of the program relating to structural properties in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions.

Masonry constructions and wood constructions which have been extensively used in this country for houses were included in the program for the determination of the structural properties by the standardized laboratory methods described in BMS2 because their behavior under widely different service conditions is known to both builders and the public. The reports on these constructions are BMS5, Structural Properties of Six Masonry Wall Constructions, and BMS25, Structural Properties of Conventional Wood-Frame Constructions for Walls, Partitions, Floors, and Roofs. These wood-frame constructions were built and tested by the Forest Products Laboratory at Madison, Wis.

This report describes the structural properties of a wall construction sponsored by one of the groups in the building industry. The specimens were subjected to compressive, transverse, concentrated, impact, and racking loads, simulating loads to which the walls of a house are subjected. In actual service, compressive loads on a wall are produced by the weight of the roof, second floor and second-story walls, if any, furniture and occupants, and snow and wind loads on the roof. Transverse loads on a wall 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 deformation and set under each increment of load were measured because, considered as a structure, the suitability of a wall construction depends not only on its resistance to deformation when loads are applied, but also on whether it returns to its original size and shape when the loads are removed.

II. SPONSOR AND PRODUCT

The specimens were submitted by the Douglas Fir Plywood Association, Tacoma, Wash., and represented a wood-frame wall construction. The sheathing on the outside face was Douglas fir plywood covered by wood shingles. The wallboard on the inside face was Douglas fir plywood.

The wood framing was Douglas fir, No. 2 common. The wall constructions had nominal 2- by 4-in. studs, spaced 1 ft 4 in. on centers, fastened to a floor plate and a double top plate.

III. SPECIMENS AND TESTS

The wall construction was assigned the symbol *BU* and the specimens were assigned the designations given in table 1.

TABLE 1.—*Specimen designations*

Specimen designation	Load	Load applied
C1, C2, C3	Compressive	Upper end.
T1, T2, T3	Transverse	Inside face.
T4, T5, T6	do	Outside face.
P1, P2, P3 [a]	Concentrated	Inside face.
P4, P5, P6 [a]	do	Outside face.
I1, I2, I3	Impact	Inside face.
I4, I5, I6	do	Outside face.
R1, R2, R3	Racking	Upper end.

[a] These specimens were undamaged portions of the impact specimens.

The specimens were tested in accordance with BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions, which also gives the requirements for the specimens and describes the presentation of the results of the tests, particularly the load-deformation graphs. Thomas R. C. Wilson of the Forest Products Laboratory, Madison, Wis., cooperated with the Bureau staff in this work by giving advice and suggestions on the technique of testing wood structures.

For the compressive test the thickness of the wall was taken as the thickness of the structural portion, that is, the distance from the inside surface of the studs to the outside surface of the studs. The compressive load was applied one-third this thickness from the inside surface of the studs. The shortenings and sets were measured by means of compressometers attached to the steel loading plates through which the load was applied to the specimen, not to the specimen as described in BMS2. For wood-frame constructions under compressive load there is considerable local shortening caused by crushing of the floor plate and the top plate at the ends of the studs. Therefore, the shortening of the entire specimen is not proportional to the value obtained from compressometers attached near each end of the specimen.

Before applying the loads, the speed of the movable head of the testing machine was measured under no load. For compressive loading the speed was 0.3 in./min. For transverse loading the speed was 0.44 in./min.

The tests were begun October 24, 1938, and completed October 28, 1938.

The sponsor was notified when the tests would be started, but found it impossible to have a representative present.

IV. WALL *BU*

1. Sources of Information

Sponsor's Statement.—Unless otherwise stated, the information on materials was obtained from the sponsor and from inspection of the specimens.

Forest Products Laboratory.—The species of all the wood and also the grade of the wood framing were determined by the Forest Products Laboratory. The Laboratory also supervised the determination of the moisture content of the wood.

2. Materials

(*a*) *Wood*

Framing.—Douglas fir (*Pseudotsuga taxifolia*) No. 2 common, S4S (surfaced four sides). Studs, floor plates, top plates, and girts 1⅝ by 3⅝ in. (nominal 2 by 4 in). Half studs $^{25}/_{32}$ by 3⅝ in. (nominal 1 by 4 in).

To record the appearance of the framing and of the failures, two photographs were taken of each tested specimen after the surfacing material had been stripped from one face. Two typical frames are shown in figs. 1 and 2. Although the knots in the framing were neither large nor numerous, there was severe cross-grain, as shown by the ruptures of the studs and half studs in figs. 1 and 2.

Figure 1.—*Frame of wall specimen BU–T4.*

Severe cross-grain in studs.

The moisture content of the wood is given in table 2.

The moisture content of the plywood sheathing was not determined. The moisture content of the framing of each specimen was determined by means of an electrical moisture

Table 2.—*Moisture content of the wood*

[Determined on the day the wall specimen was tested]

Wood	Moisture content [a]		
	Minimum	Maximum	Average
	Percent	*Percent*	*Percent*
Framing	8	17	12
Shingles	9	12	10
Plywood wallboard	7	11	9

[a] Based on the weight when dry.

therefore, the moisture content of the Douglas fir framing, as given in table 2, was obtained by subtracting 1.3 from the meter readings and rounding the result to the nearest whole number.

Plywood sheathing.—Douglas fir, 3-ply, 5/16 in. thick, unsanded, bonded with water-resistant protein glue having a soya-bean and casein base, complying with Commercial Standard

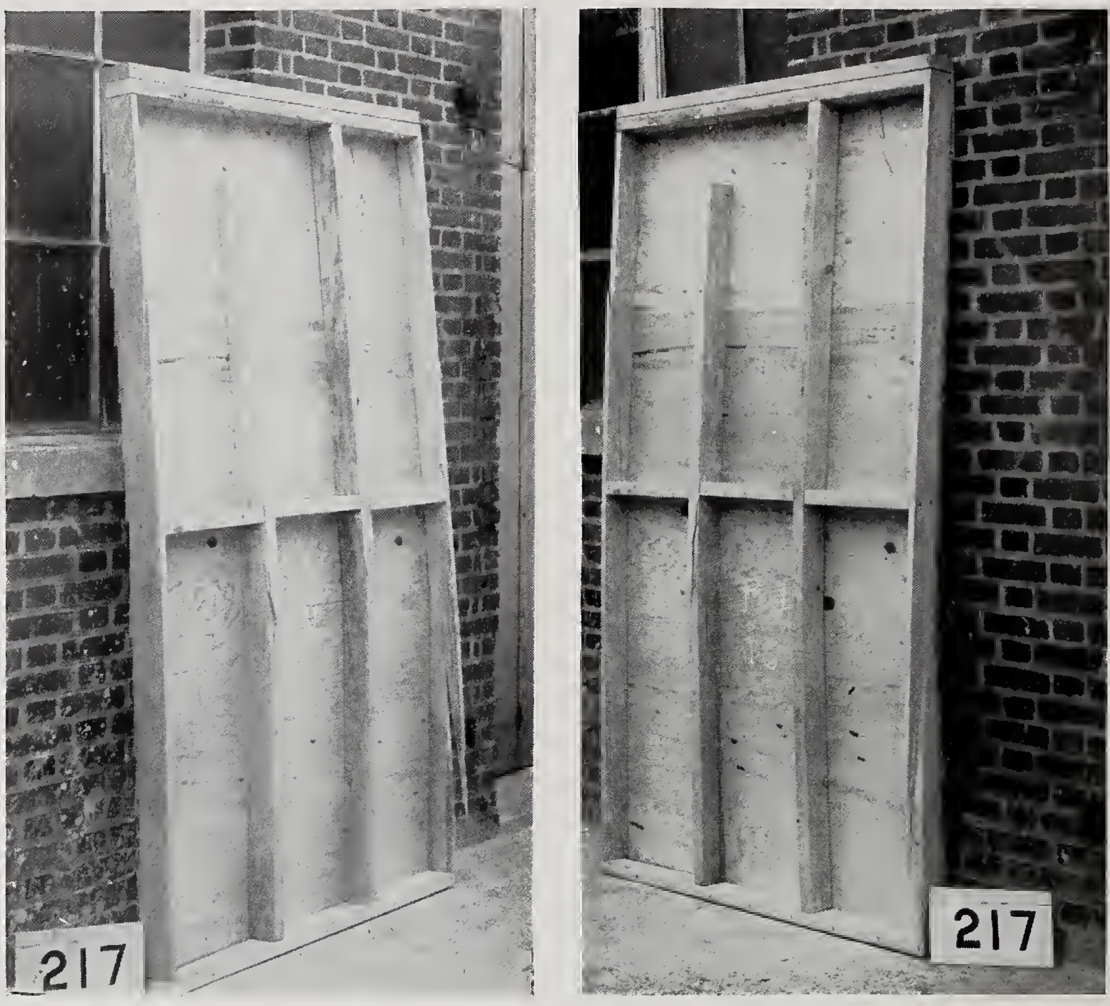

Figure 2.—*Frame of wall specimen BU-T6.*

Severe cross-grain in studs.

meter. The moisture meter was graduated for Douglas fir. To determine the error of the meter, 17 samples taken from the frames were dried in an oven at 212° F until the weight was constant. The moisture content was the difference between the initial weight and the weight when dry, divided by the weight when dry. The average for these samples was 1.3 less than the average of the meter readings;

CS45–38, Douglas Fir Plywood, sheathing grade.

Shingles.—Western red cedar, No. 2, 16 in. long, five butts to 2 in. The moisture content given in table 2 was determined by the moisture meter on about 10 shingles of each wall specimen. The readings of the meter were not checked by oven-dried samples.

Plywood wallboard.—Douglas fir, 3-ply, 1/4 in.

thick, wallboard grade, sanded two sides, bonded with water-resistant protein glue having a soya-bean and casein base, complying with Commercial Standard CS45–38, Douglas Fir Plywood. The moisture contents given in table 2 were determined by oven-drying to constant weight, one sample taken from each wall specimen.

(*b*) *Nails*

The nails were made from steel wire and the description is given in table 3.

TABLE 3.—*Description of nails*

Type	Size	Length	Steel-wire gage		Finish
			Number	Diameter	
	Penny	*In.*		*In*	
Box	16	3½	10	0.135	
Casing	4	1½	14	.080	
Common	6	2	11½	.113	
Shingle	2	1	15	.072	Zinc coated.

3. DESCRIPTION, SPONSOR'S STATEMENT

The price of this construction in Washington, D. C., as of July 1937, was \$0.28/ft.²

(*a*) *Four-Foot Wall Specimens*

The 4-ft wall specimens were 8 ft 0 in. high, 4 ft 0 in. face width, and 4¹⁵⁄₁₆ in. thick. Each specimen consisted of a wood frame to which the faces were fastened. The frame consisted of two studs, *A*, shown in fig. 3, and two half studs, *B*, fastened to a floor plate, *C*, a top plate, *D*, and girts, *E*, by nails. The outside face consisted of Douglas fir plywood sheathing, *F*, and wood shingles, *G*. The inside face was Douglas fir plywood wallboard, *H*. No paint or other decorative finish was applied to the specimens.

Studs.—The studs, *A*, were Douglas fir, 1⅝ by 3⅝ in. (nominal 2 by 4 in), 7 ft 7⅛ in. long, spaced 1 ft 4 in. on centers. The lower end of each stud was fastened to the floor plate by two 16d box nails driven from the bottom of the plate (not toenailed), and the upper end of each stud was fastened to the top plate by two 16d box nails driven from the top of the lower member of the plate.

Half studs.—The half studs, *B*, were Douglas fir, ²⁵⁄₃₂ by 3⅝ in. (nominal 1 by 4 in), 7 ft 7⅛ in. long. The lower end of each stud was fastened to the floor plate by two 16d box nails driven from the bottom of the plate (not toenailed), and the upper end of each stud was fastened to the top plate by two 16d box nails driven from the top of the lower member of the plate.

Floor plate.—The floor plate, *C*, was Douglas

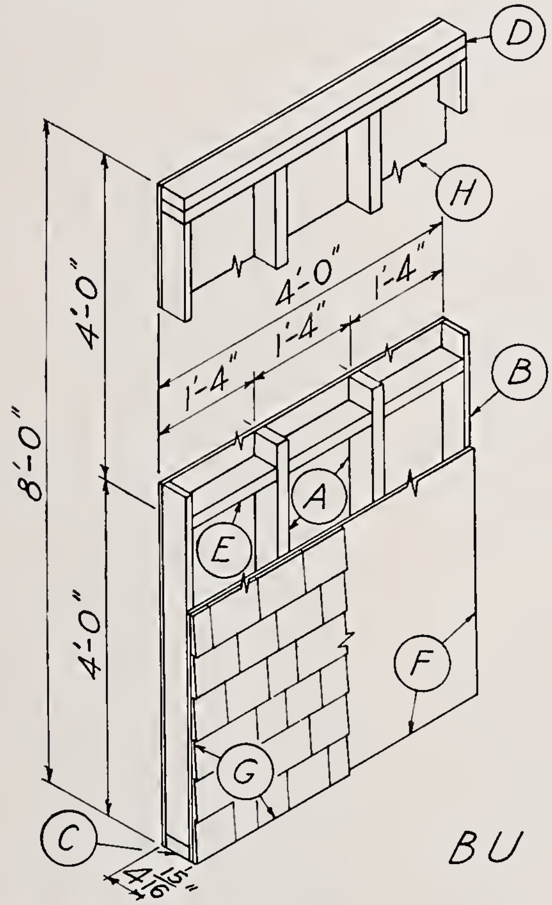

FIGURE 3.—*Four-foot wall specimen BU.*
A, studs; *B*, half studs; *C*, floor plate; *D*, top plate; *E*, girts; *F*, sheatbing; *G*, wood shingles; *H*, plywood wallboard.

fir, 1⅝ by 3⅝ in. (nominal 2 by 4 in), 4 ft 0 in. long.

Top plate.—The top plate, *D*, consisted of two pieces of Douglas fir, 1⅝ by 3⅝ in. (nominal 2 by 4 in), 4 ft 0 in. long, fastened by six 16d box nails, two nails midway between the studs, and two midway between each stud and half stud, driven from the top of the upper member of the plate.

Girts.—The three girts, *E*, were Douglas fir, 1⅝ by 3⅝ in. (nominal 2 by 4 in), 1 ft 2⅜ in. long, fastened at midheight to the studs by

16d box nails, two at each end. The nails in the two outer girts were driven through the studs and half studs. The center girt was toenailed.

Sheathing.—The sheathing, *F*, was two pieces of 3-ply Douglas fir plywood, 5/16 in. thick and 4 ft 0 in. square, having a transverse joint on the girts. The sheathing was applied so that the grain of the outer plies was transverse. The sheathing was fastened to the half studs, floor plate, top plate, and girts by 6d common nails spaced 6 in., and to the studs by 6d common nails spaced 1 ft 0 in.

Shingles.—The shingles, *G*, were western red cedar, 1 ft 4 in. long, exposed 6 in. to the weather and fastened to the sheathing by 2d galvanized shingle nails, two in each shingle.

Wallboard.—The wallboard, *H*, was 3-ply Douglas fir plywood, 8 ft 0 in. by 4 ft 0 in. by 1/4 in. The wallboard was applied so that the grain of the outer plies was longitudinal (vertical). The wallboard was fastened to the half studs, floor plate, and top plate by 4d casing nails spaced 6 in., and to the studs and girts by 4d casing nails spaced 1 ft 0 in.

(*b*) *Eight-Foot Wall Specimens*

The 8-ft wall specimens were 8 ft 0 in. high, 8 ft 0 in. face width, and 4 15/16 in. thick. The specimens were similar to the 4-ft specimens, except that there were seven studs spaced 1 ft 4 in. on centers. There was a full-sized stud at each edge extending one-half its thickness beyond the faces; over-all width 8 ft 1 5/8 in.

Sheathing.—The sheathing was two pieces of plywood, 8 ft 0 in. by 4 ft 0 in., with a transverse joint on the girts. The sheathing was fastened to the edge studs, floor plate, girts, and top plate by 6d common nails spaced 6 in., and to the other five studs by 6d common nails spaced 1 ft 0 in.

Wallboard.—The wallboard was two pieces of plywood, 8 ft 0 in. by 4 ft 0 in., with a longitudinal (vertical) joint on the center stud. The wallboard was fastened to the edge studs, center stud, floor plate, and top plate by 4d casing nails spaced 6 in., and to the other four studs and the girts by 4d casing nails spaced 1 ft. 0 in.

(*c*) *Comments*

If the plywood sheathing and wallboard are to contribute to the strength of a construction similar to wall *BU*, it is essential that all the plywood be fastened at least as securely as for this construction.

The sheathing, whether on the inside or the outside face, should always be fastened by 6d common nails. The spacing of the nails should not exceed 6 in. along each edge of the plywood, and should not exceed 1 ft along supports inside the edge.

The plywood also may be fastened to the frame by securely gluing all the surfaces in contact. This may be done either in a shop or on the building site.

The outside face may be shingles, as for wall *BU*, or other materials such as stucco, brick veneer, or any kind of wood siding.

4. Compressive Load

Wall specimen *BU–C1* under compressive load is shown in fig. 4. The results for wall specimens *BU–C1*, *C2*, and *C3* are shown in table 4 and in figs. 5 and 6.

The lateral deflections shown in fig. 6 are plotted to the right of the vertical axis for deflections of the specimens toward the outside face (positive deflections) and to the left for deflections toward the inside face (negative deflections). Each of the specimens deflected toward the inside face for loads almost to the maximum load. At the maximum load each specimen deflected in the opposite direction, that is, toward the outside face.

Probably the specimens deflected toward the inside face because the wallboard was stiffer under compressive loads than the sheathing. The loading plates at the top and bottom of the specimen extended beyond the wallboard and the sheathing.

Although the wallboard was thinner than the sheathing, it was stiffer because it was one piece and the grain of two of the three plies was longitudinal (vertical). The sheathing was in two pieces with a transverse joint at midheight of the specimen. Under compressive loads this joint closed appreciably before the edges of the sheathing came into bearing. In addition, the grain of only one ply was longitudinal.

board carried little of the compressive load, and the lateral deflection of the specimen changed from toward the inside face to the outside face.

At loads of 5, 4, and 3.5 kips/ft for specimens *C1*, *C2*, and *C3*, respectively, the wallboard

FIGURE 4.—*Wall specimen BU–C1 under compressive load.*

At loads approaching the maximum load, the wallboard buckled, resulting in separation from the studs and half studs for half the height of the specimen; as a consequence, the wallboard started to separate from the studs and half studs, pulling the nails from the studs. At the maximum loads (5.27, 6.75, and 4.8 kips/ft) each of the specimens failed by the wallboard separating from all the studs and half studs for at least half the height of the specimen, and by crushing of the lower member of the wall plate locally at the ends of the studs and half studs, causing the wall plate to rotate and allowing the specimens to push out under load without breaking the studs. Some of the shingles near the upper end of the specimen separated from the sheathing.

TABLE 4.—*Structural properties, wall BU*

[Weight, 4.23 lb/ft²]

Load	Load applied	Specimen designation	Failure of loaded face, height of drop	Failure of opposite face, height of drop	Maximum height of drop	Maximum load
			ft	*ft*	*ft*	*Kips/ft*[a]
Compressive	Upper end, applied one-third the thickness (1.21 in.) from the inside surface of the studs (see section III).	C1				5.27
		C2				6.75
		C3				4.83
	Average					5.62
						lb/ft²
Transverse	Inside face; span 7 ft 6 in	T1				200
		T2				233
		T3				203
	Average					212
Do	Outside face; span 7 ft 6 in	T4				162
		T5				222
		T6				271
	Average					218
						lb
Concentrated	Inside face	P1				750
		P2				650
		P3				650
	Average					683
Do	Outside face	P4				[b] 1,000
		P5				[b] 1,000
		P6				[b] 1,000
	Average					[b] 1,000
Impact	Inside face; span 7 ft 6 in	I1	(c)	(c)	[d]10.0	
		I2	(c)	10.0	[d]10.0	
		I3	(c)	(c)	[d]10.0	
	Average		(c)		[d]10.0	
Do	Outside face; span 7 ft 6 in	I4	(c)	(c)	[d]10.0	
		I5	(c)	(c)	[b]10.0	
		I6	(c)	(c)	[b]10.0	
	Average		(c)	(c)		
						Kips/ft[a]
Racking	Upper end	R1				1.34
		R2				1.44
		R3				1.42
	Average					1.40

[a] A kip is 1,000 lb.
[b] Test discontinued. Specimen did not fail.
[c] Face did not fail.
[d] Test discontinued. Specimen damaged

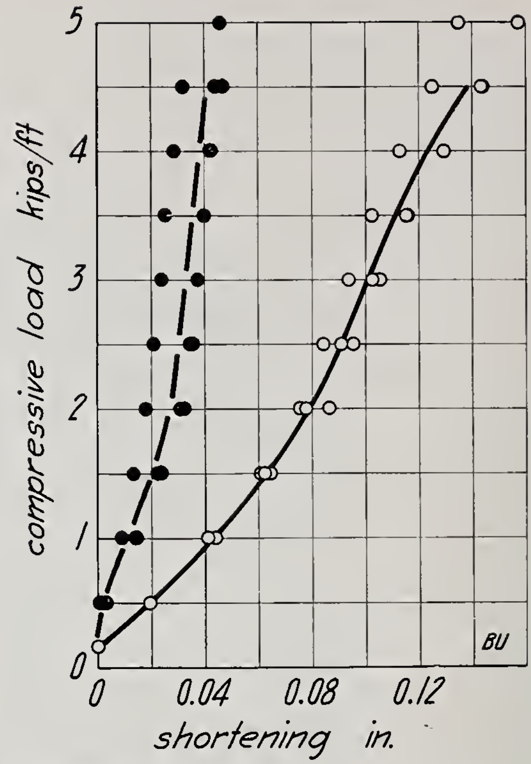

FIGURE 5.—*Compressive load on wall BU.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *BU-C1*, *C2*, and *C3*. The load was applied one-third the thickness (1.21 in.) from the inside surface of the studs. The loads are in kips per foot of actual width of specimen.

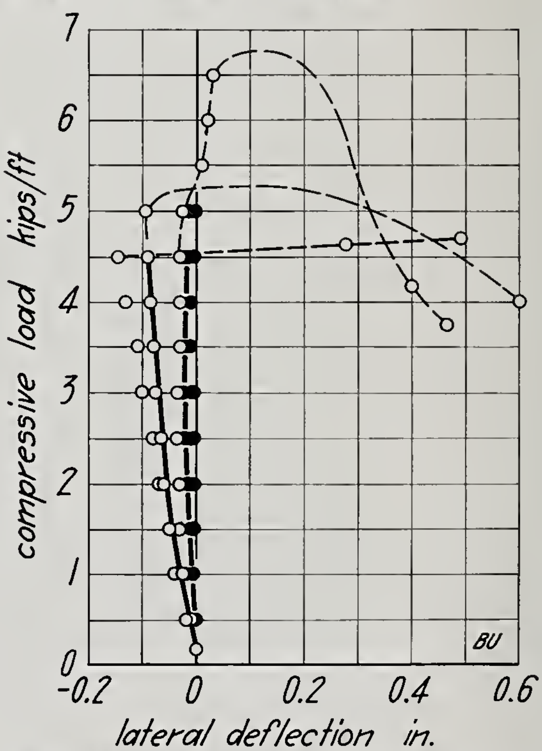

FIGURE 6.—*Compressive load on wall BU.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens *BU-C1*, *C2*, and *C3*. The load was applied one-third the thickness (1.21 in.) from the inside surface of the studs. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a height of 7 ft 10½ in., the gage length of the deflectometers.

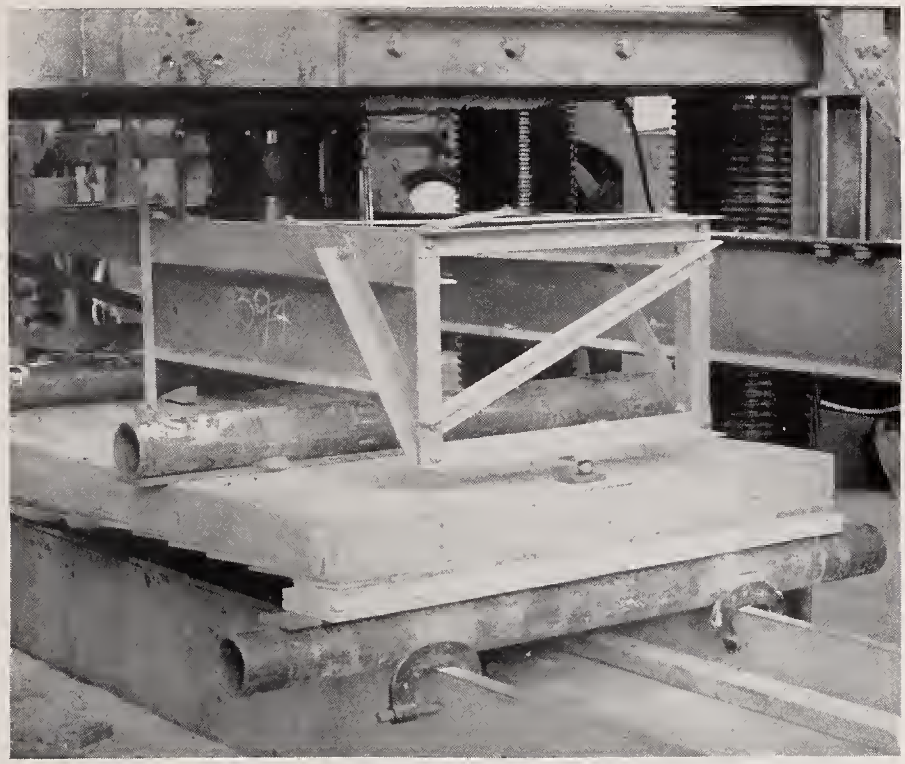

FIGURE 7.—*Wall specimen BU–T3 under transverse load.*

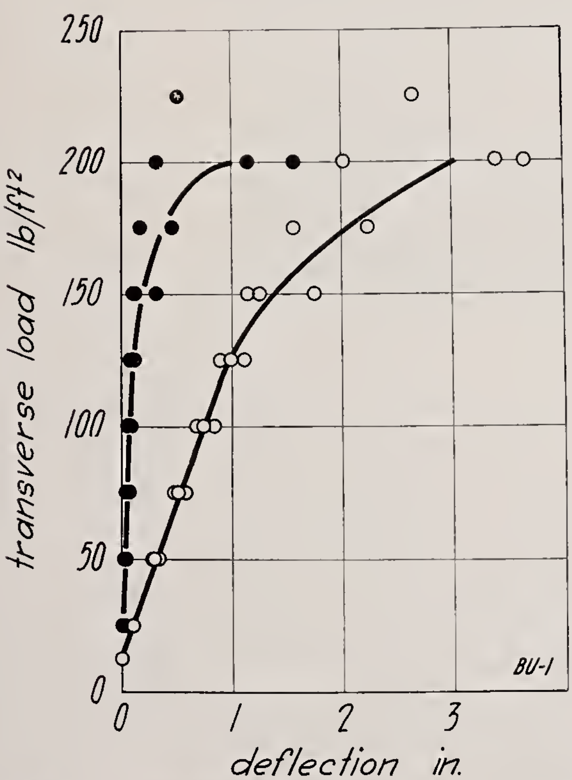

FIGURE 8.—*Transverse load on wall BU, load applied to inside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *BU–T1*, *T2*, and *T3* on the span 7 ft 6 in.

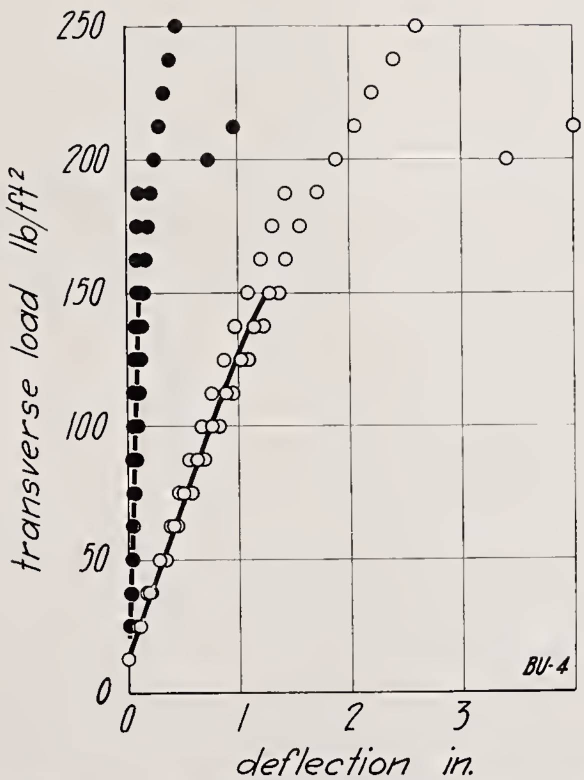

FIGURE 9.—*Transverse load on wall BU, load applied to outside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *BU–T4*, T5, and *T6* on the span 7 ft 6 in.

5. Transverse Load

Wall specimen *BU–T3* under transverse load is shown in fig. 7. The results are shown in table 4 and in fig. 8 for wall specimens *BU–T1*, *T2*, and *T3*, loaded on the inside face, and in fig. 9 for wall specimens *BU–T4*, *T5*, and *T6*, loaded on the outside face.

Specimen *T1* (loaded on the wallboard) failed by rupture of both studs and one half stud near midspan. Specimen *T2* failed by rupture of both studs and both half studs near midspan. In specimen *T3* one stud broke at a load of 153 lb/ft^2 and a half stud at 175 lb/ft^2. At the maximum load (203 lb/ft^2) the other stud and the other half stud broke. The faces were undamaged.

Specimen *T4* (loaded on the shingles) failed by rupture of all the studs and half studs at or between the loading rollers. The wallboard pulled away from the floor plate and one broken stud punched through, pushing the wallboard from all the studs at midspan. In specimen *T5* one stud and one half stud broke at a load of 200 lb/ft^2. At the maximum load the other stud broke and the wallboard pulled away from the floor plate, but was undamaged. In specimen *T6*, one half stud broke at a load of 87.5 lb/ft^2 and the other at a load of 255 lb/ft^2 at or between the loading rollers. The specimen failed when both studs ruptured near midspan. The wallboard pulled away from the floor plate but was undamaged.

6. Concentrated Load

Wall specimen *BU–P2* under concentrated load is shown in fig. 10. The results are shown in table 4 and in fig. 11 for wall specimens *BU–P1*, *P2*, and *P3*, loaded on the inside face, and in fig. 12 for wall specimens *BU–P4*, *P5*, and *P6*, loaded on the outside face.

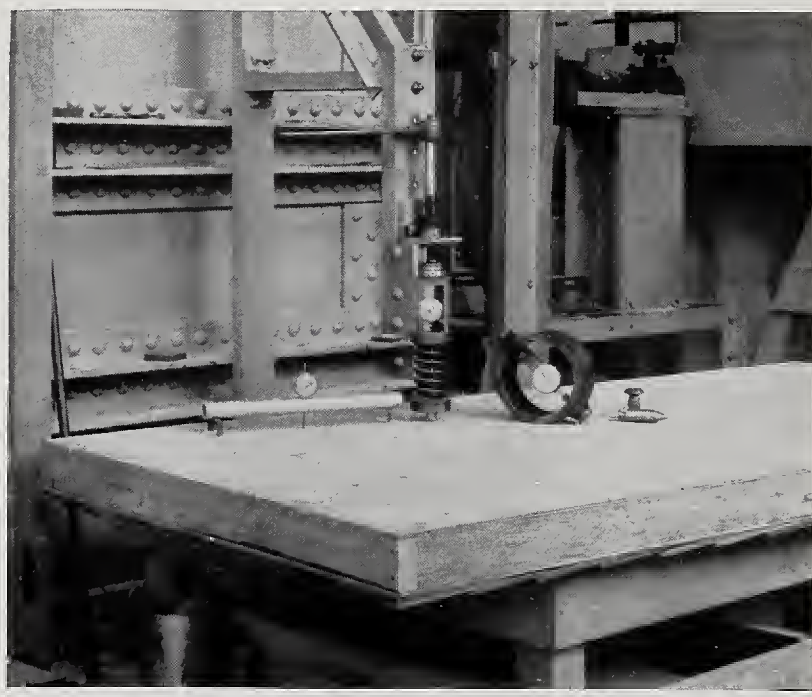

Figure 10.—*Wall specimen BU–P2 under concentrated load.*

The concentrated loads were applied to the inside face of specimens *P1*, *P2*, and *P3* on the wallboard between a stud and a half stud and from 2 to 2½ ft from one end of the specimen. Each of the specimens failed by punching of the disk through the wallboard.

The concentrated loads were applied to the outside face of specimens *P4*, *P5*, and *P6*, on a shingle from 3 to 4 in. from the lower edge and about 2 ft from one end of the specimen between a stud and a half stud. On specimen *P4* at a load of 750 lb the shingle split along the grain at both edges of the disk. On specimen *P5* at a load of 800 lb the shingle split along the grain at one edge of the disk,

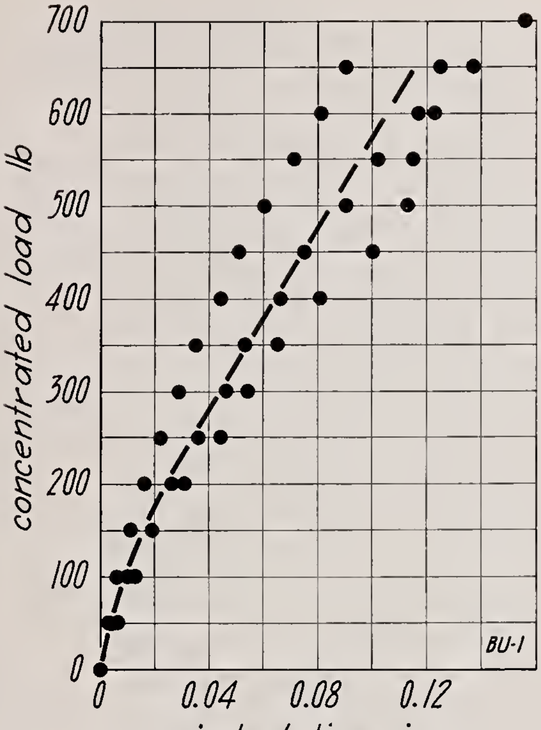

FIGURE 11.—*Concentrated load on wall BU, load applied to inside face.*

Load-indentation results for specimens *BU–P1*, *P2*, and *P3*.

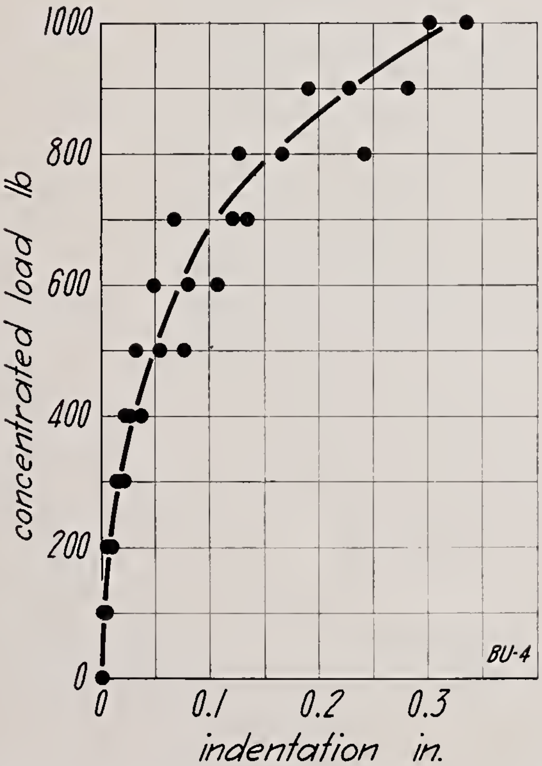

FIGURE 12.—*Concentrated load on wall BU, load applied to outside face.*

Load-indentation results for specimens *BU–P4*, *P5*, and *P6*.

at 900 lb also at the other edge, and at 1,000 lb the shingle below split along the grain. On specimen *P6* at a load of 800 lb the shingle split along the grain at one edge of the disk and at 1,000 lb also on the other edge. The sets after a load of 1,000 lb had been applied were 0.30, 0.34, and 0.33 in. for specimens *P4*, *P5*, and *P6*, respectively, and no other effect was observed.

7. Impact Load

Wall specimen *BU–I1* during the impact test is shown in fig. 13. The results are shown in table 4 and in fig. 14 for wall specimens *BU–I1*, *I2*, and *I3*, loaded on the inside face, and in fig. 15 for wall specimens *BU–I4*, *I5*, and *I6*, loaded on the outside face.

The impact loads were applied to the center of the inside face of specimens *I1*, *I2*, and *I3*, the sandbag striking the wallboard directly over the center girt and midway between the studs. On specimen *I1* at a drop of 3 ft the wallboard started to separate from the center girt, pulling some of the nails from the girt; at 6.5 ft the wallboard started to separate from the studs near midspan; and at 8.5 ft the wallboard separated from the floor plate and top plate at midwidth. The set after a drop of 10 ft was 0.27 in.; one half stud was split for about 1 ft along the grain at midspan, but the faces did not fail. On specimen *I2* at a drop of 6 ft the wallboard separated from the floor plate, pulling some of the nails with it; at 8 ft some of the shingles started to separate from the sheathing near midspan; at 8.5 ft one half stud split slightly; at 9 ft one stud broke at midspan; and at 9.5 ft the half stud previously split broke and the wallboard started to separate from the girts. The set after a drop of 10 ft was 0.46 in.; the outside face failed by separation of some of the shingles near midspan at the break in the studs, but the inside face did not fail. On specimen *I3* at a drop of 5.5 ft the wallboard separated noticeably from the floor plate and one half stud, pulling some of the nails with it; and at 9 ft some of the shingles separated from the sheathing near midspan and one half stud split. The set after a drop of 10 ft was 0.60 in.; the wall board separated from the center of

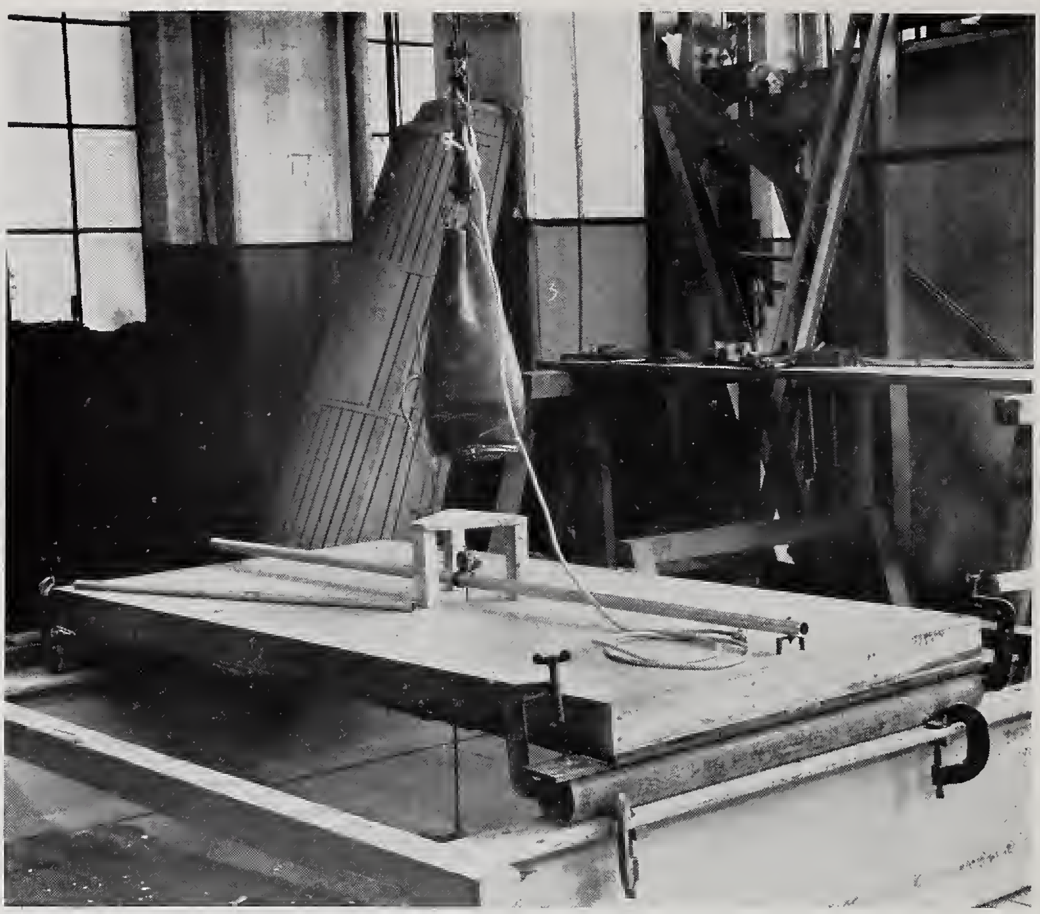

Figure 13.—*Wall specimen BU–I1 during the impact test.*

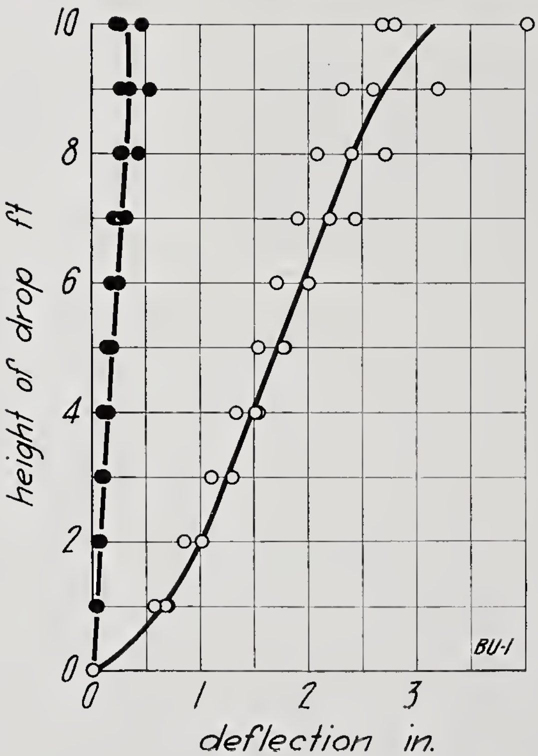

Figure 14.—*Impact load on wall BU, load applied to inside face.*

Height of drop-deflection (open circles) and height of drop-set (solid circles) results for specimens *BU–I1*, *I2*, and *I3* on the span 7 ft 6 in.

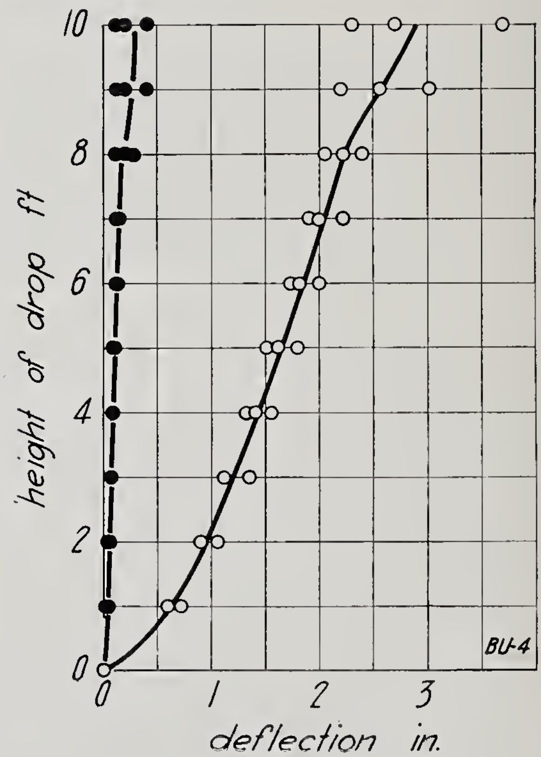

Figure 15.—*Impact load on wall BU, load applied to outside face.*

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

the specimen where the bag struck, but the faces did not fail. The impact load was applied to the center of the outside face of specimens *I4*, *I5*, and *I6*, the sandbag striking the shingles directly over the center girt and midway between the studs.

On specimen *I4* at a drop of 9 ft one of the half studs split along the grain; at 9.5 ft the wallboard separated noticeably from the outer girts and some of the shingles near one end of the specimen separated from the sheathing. The set after a drop of 10 ft was 0.42 in.; both studs were split near midspan, but the faces did not fail. On specimens *I5* and *I6* at drops of 7 and 9 ft respectively, the wallboard separated noticeably from the frame near midspan, pulling some of the nails with it. The sets after a drop of 10 ft were 0.11 and 0.20 in., respectively, but the faces and studs did not fail.

8. Racking Load

Wall specimen *BU-R2* under racking load is shown in fig. 16. The results for wall specimens *BU-R1*, *R2*, and *R3* are shown in table 4 and in fig. 17.

The racking loads were applied to specimen *R1* at one end of both members of the top plate only, and the stop at the diagonally opposite corner of the specimen was in contact with the opposite end of the floor plate and the longitudinal (vertical) edges of both the sheathing and the wallboard.

At a load of 1 kip/ft the wallboard buckled from the longitudinal (vertical) plane and at the loaded corner separated from the upper end of the edge stud for a distance of about 2 ft downward from the top plate; there was about ¼ in. longitudinal displacement between the two wallboards at the joint. At 1.25 kips/ft the separation of the wallboard extended down to midheight. At the maximum load the specimen failed by separation of the wallboard and sheathing from the first three studs near the load and from the lower end of the edge stud at the stop.

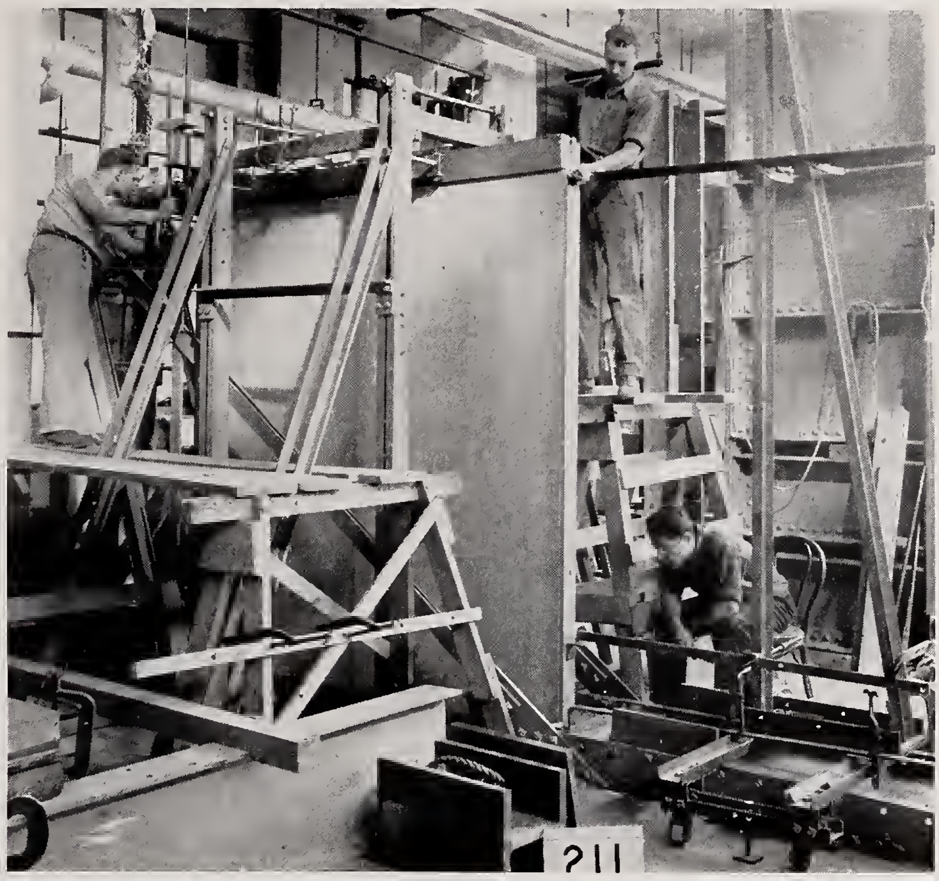

FIGURE 16.—*Wall specimen BU-R2 under racking load.*

In specimens *R2* and *R3* the racking loads were applied to one end of a 6- by 6-in. timber, 8 ft 3 in. long, fastened to the upper surface of the top plate by twenty No. 14 wood screws, 2¾ in. long, spaced uniformly. They were countersunk into the timber and extended about 1¾ in. into the top plate. The stop was in contact with the opposite end of the floor plate and the lower edges of the faces.

At a load of 1.25 kips/ft on specimen *R2* the wallboard and sheathing buckled outward from the longitudinal (vertical) plane and separated from the upper end of the edge stud at the loaded corner, pulling the nails from the stud; the wallboard separated from the lower end of the stud at the stop; and there was about ½-in. displacement at the joint between the two pieces of plywood sheathing. At the maximum load the specimen failed by displacement of the top plate transversely with respect to the studs, pulling the nails from the studs and through the upper edge of the wallboard and sheathing, and also through the edge along the edge stud at the stop. The wallboard separated from the other studs, pulling the nails from the studs, and the center stud ruptured at midheight.

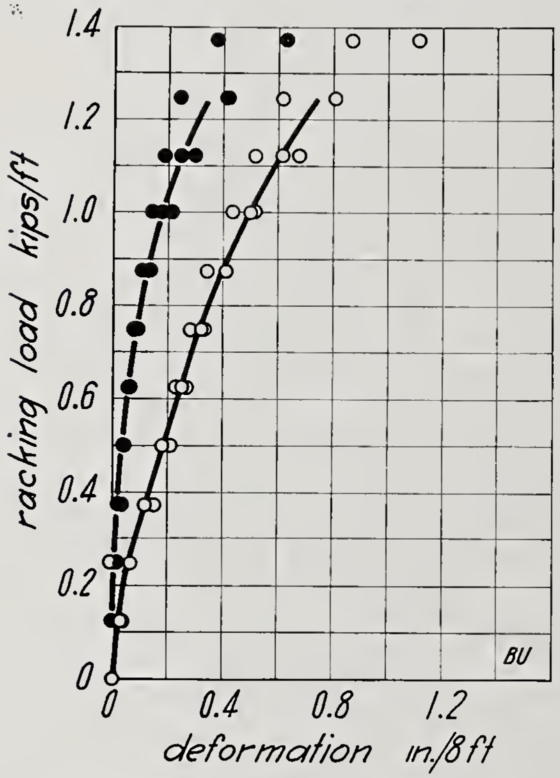

Figure 17.—*Racking load on wall BU.*

Load-deformation (open circles) and load-set (solid circles) results for specimens *BU-R1*, *R2*, and *R3*. The loads are in kips per foot of face width of specimen.

At a load of 0.875 kip/ft on specimen *R3* the wallboard and sheathing at the loaded corner buckled, resulting in pulling of nails and separation from the edge stud along the upper part of its length. The sheathing at the corner in contact with the stop also separated from the edge stud along the lower part of its length. At a load of 1.25 kips/ft there was about ¼-in. displacement at the joint between the two pieces of plywood sheathing. At the maximum load the specimen failed by displacement of the top plate along the upper ends of the studs, pulling the nails from them and through the upper edge of the wallboard and sheathing, and also through the edge along the edge stud at the stop. The wallboard separated from the other studs, pulling the nails from the studs.

The description and drawings of the specimens were prepared by E. J. Schell, G. W. Shaw, and T. J. Hanley of the Building Practice and Specifications Section, under the supervision of V. B. Phelan, from the information supplied by the sponsor and from the specimens. The structural properties were determined by the Engineering Mechanics Section, under the supervision of H. L. Whittemore and A. H. Stang, with the assistance of the following members of the professional staff: F. Cardile, R. C. Carter, H. Dollar, M. Dubin, A. H. Easton, A. S. Endler, C. D. Johnson, A. J. Sussman, and L. R. Sweetman.

V. SELECTED REFERENCES

American Builder and Building Age, **59,** No. 12, 41–84 (1937); **60,** No. 12, 43–86 (1938); **61,** No. 3, 46–49 (1939).

Architect and Engineer (September 1938).

Architectural Record, **83,** No. 5, 92–99 (1938); **83,** No. 6, 74–79 (1938); **85,** No. 3, 38–40 (1939).

Construction Methods and Equipment, p. 36–41 (March 1939).

Engineering News-Record, **120,** 855–858, 881–883 (1938).

The Timberman, **39,** No. 2, Plywood Supplement 10–24 (1937).

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