U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS22

Structural Properties of "Dun-Ti-Stone" Wall Construction Sponsored by the W. E. Dunn Manufacturing Company

by

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

NATIONAL
BUREAU OF STANDARDS

The program of research on building materials and structures, carried on by the National Bureau of Standards, was undertaken with the assistance of the Central Housing Committee, an informal organization of governmental agencies concerned with housing construction and finance, which is cooperating in the investigations through a subcommittee of principal technical assistants.

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]

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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. Practically all of these constructions were sponsored by groups within the building industry which advocate and promote the use of such constructions and which have built and submitted representative specimens, as outlined in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions. The sponsor is responsible for the representative character of the specimens and for the description given in each report. The Bureau is responsible for the test data.

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

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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ABSTRACT

For the program on the determination of the structural properties of low-cost house constructions, the W. E. Dunn Manufacturing Co. submitted 18 specimens representing their "Dun-Ti-Stone" construction for walls.

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 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 the structural properties in report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions.

As a part of the research on structural properties, six masonry wall constructions have been subjected to a series of standardized laboratory tests to provide data on the properties of some constructions for which the behavior in service is generally known. These data are given in report BMS5, Structural Properties of Six Masonry Wall Constructions. Similar tests have been made on wood-frame constructions by the Forest Products Laboratory of the United States Department of Agriculture, the results of which will be given in a subsequent report in this series.

This report describes the structural properties of a wall construction sponsored by one of the manufacturers 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, wind load on adjoining second-story walls, 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 the suitability of a wall construction depends in part on its resistance to deformation under load and whether it returns to its original size and shape when the load is removed.

II. SPONSOR AND PRODUCT

The specimens were submitted by the W. E. Dunn Manufacturing Co., Holland, Mich., and represented a wall construction sponsored by this company and marketed under the trade name "Dun-Ti-Stone." The "Dun-Ti-Stone" concrete units were made under franchise by the Silver Hill Brick Corporation, Washington, D. C. Each unit consisted of a facing slab and a backing slab connected by a steel tie bar. When laid the units formed a hollow wall. The specimens were built with cement-lime mortar.

III. SPECIMENS AND TESTS

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

TABLE 1.—*Specimen designations, wall BE*

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	Near upper end.

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

The tests were begun August 17, 1938 and completed September 29, 1938. The specimens were tested 28 days after they were built. The sponsor's representative witnessed the tests.

IV. WALL *BE*

(1) SPONSOR'S STATEMENT

(*a*) *Materials*

Concrete units.—The materials for the units were portland cement, washed bank sand (passed ¼-in. sieve), and steel tie bars made by the Rosslyn Steel and Cement Co.

The units were made by the Silver Hill Brick Corporation. The slabs were 1 part of portland cement and 8 parts of sand, by volume. The slabs were made on a standard "Dunbrik" machine made by the W. E. Dunn Manufactur-

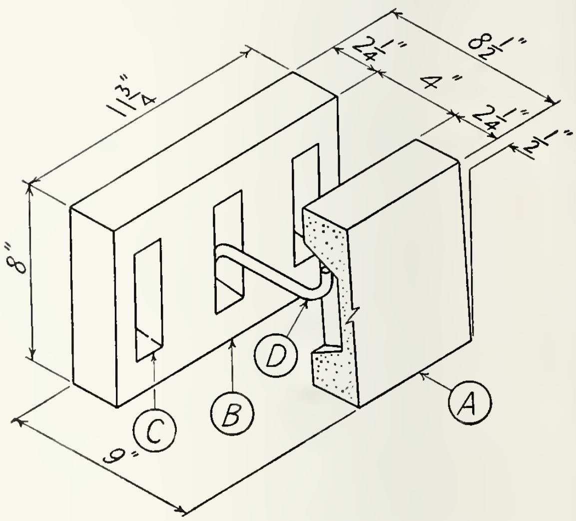


FIGURE 1.—"*Dun-Ti-Stone*" *concrete unit.*

A, facing slab; *B*, backing slab; *C*, recess; *D*, tie bar.

ing Co., Holland, Mich. After curing, the slabs were placed in a spacing mold and the tie bar fastened in place by mortar, 1 part of cement and 3 parts of sand, by volume.

Each unit consisted of two concrete slabs, 2¼ by 11¾ by 8 in., connected by a tie bar, as shown in figure 1. The top of the facing slab, *A*, was inclined ½ in. toward the backing slab, *B*. The inner face of each slab had three recesses, *C*, 5 by 1⅜ in., 1½ in. deep, spaced 4³⁄₁₆ in. on centers. The slabs were fastened by a Z-shaped tie bar, *D*, made from a ½-in. diam round deformed reinforcement bar.

The physical properties of the concrete units, determined by the Masonry Construction Section of the National Bureau of Standards in accordance with the American Society for Testing Materials Standard C 90–36,[1] are given in table 2.

TABLE 2.—*Physical properties of the concrete units, wall BE*

Thickness of face shell	Compressive strength		Water absorption, 24-hr. cold immersion		Weight, dry	
	Net area	Gross area	By weight	Per cubic foot of concrete	Per unit	Per cubic foot of concrete
in.	*lb/in.²*	*lb/in.²*	*Percent*	*lb*	*lb*	*lb*
2.25	2,240	930	7.0	8.3	29.1	126.4

Mortar.—The materials for the mortar in the wall joints were North American Portland Cement Corporation's portland cement, lime putty made by slaking Standard Lime and Stone Co.'s "Washington" powdered quicklime, and Potomac River building sand.

The mortar was 1 part of cement, 0.42 part of hydrated lime, and 5.1 parts of dry sand, by weight. The proportions by volume were 1 part of cement, 1 part of hydrated lime, and 6 parts of loose damp sand, assuming that portland cement weighs 94 lb/ft^3, dry hydrated lime 40 lb/ft^3, and that 80 lb of dry sand are equivalent to 1 ft^3 of loose damp sand. The materials for each batch were measured by weight and mixed in a batch mixer having a capacity of 2/3 ft^3. The amount of water added to the mortar was adjusted to the satisfaction of the mason.

The following properties of the mortar materials and of the mortar were determined by the Masonry Construction Section. The cement complied with the requirements of Federal Specification SS–C–191a for fineness, soundness, time of setting, and tensile strength. The lime putty contained 40 to 45 percent of dry hydrate, by weight, and had a plasticity of over 600, measured in accordance with Federal Specification SS–L–351. The sieve analysis of the sand is given in table 3.

TABLE 3.—*Sieve analysis of the sand in mortar, wall BE*

U. S. Standard sieve number	Passing, by weight
	Percent
8	100
16	92
30	70
50	16
100	1

[1] Am. Soc. Testing Materials Standards pt. II, 168–171 (1936).

The average water content of the mortar was 22.5 percent, by weight of dry materials. Samples were taken from at least one batch of mortar for each wall specimen, the flow determined in accordance with Federal Specification SS–C–181b, and six 2-in. cubes made. Three cubes were stored in water at 70° F and three stored in air near the wall specimen. The compressive strength of each cube was determined on the day the corresponding wall specimen was tested. The physical properties of the mortar are given in table 4.

TABLE 4.—*Physical properties of mortar, wall BE*

Specimen	Flow	Compressive strength	
		Air storage	Water storage
	Percent	*lb/in.²*	*lb/in.²*
C1	108	788	684
C2	103	888	723
C3	102	673	626
T1	107	613	841
T2	103	581	817
T3	91	692	904
T4	85	669	899
T5	85	658	868
T6		660	799
I1	107	766	715
I2	106	777	733
I3	102	946	700
I4	102	775	688
I5	100	771	697
I6	106	594	867
R1	98	510	731
R2	117	470	717
R3	94	602	702
Average	101	691	762

Concrete.—The materials for the concrete fill in the top course of the wall were North American Portland Cement Corporation's portland cement, Potomac River concrete sand, and Potomac River gravel (maximum size ⅜ in).

The concrete was 1 part of cement, 2.75 parts of dry sand, and 3.65 parts of dry gravel, by weight. The proportions by volume were 1 part of cement, 2 parts of loose damp sand, and 4 parts of gravel.

A 6- by 12-in. cylinder was made by the Masonry Construction Section from the concrete for each wall specimen and stored in air near the specimen. The compressive strength of each cylinder was determined on the day the corresponding wall specimen was tested. The average compressive strength of the concrete was 2,400 lb/in^2.

Metal lath.—Expanded metal lath, galvanized.

Reinforcement bars.—Steel, deformed, ½-in. round.

(b) *Description*

(1) *Four-foot wall specimens.*—The 4-ft wall specimens were 8 ft 6½ in. high, 4 ft 1 in. wide, and 9 in. thick, and had 12 courses of units, except for specimens *C1*, *C2*, and *C3*, which were 7 ft 10½ in. high and had 11 courses of units. The units formed a hollow wall with facing, *A*, and backing, *B*, as shown in figure 2, connected by the tie bars, *C*, cast in the slabs. The head joints were staggered by using half slabs at the ends of alternate courses. The half slabs had no tie bars. The lower edges of the slabs in the facing extended ½ in. beyond the upper edges of the slabs in the course below. The slabs in the backing were flush. The bed joints were furrowed and the head joints were filled solidly by applying mortar freely to the edges of each unit before it was laid. The joints were pointed. Metal lath, *D*, was placed in the joint below the top course and the top course was filled with concrete, *E*, reinforced by three reinforcement bars, *F*, one bar placed 1 in. from the top of the concrete and two bars placed 1½ in. from the bottom.

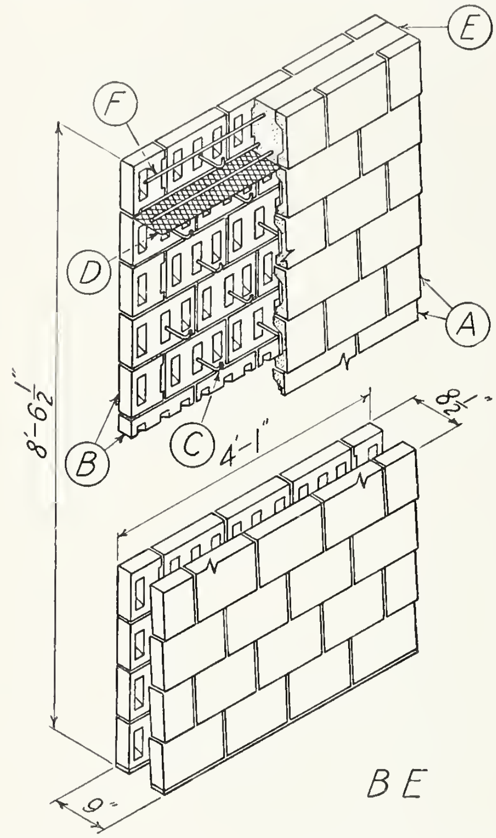


FIGURE 2.—*Faur-foot wall specimen BE, having 12 courses.*

A, facing; *B*, backing; *C*, tie bar; *D*, metal lath; *E*, concrete; *F*, reinforcement bars.

The price of this construction in Washington, D. C., as of July 1937 was $0.40/ft².

(2) *Eight-foot wall specimens.*—The 8-ft wall specimens were 7 ft 10 in. high, 8 ft 3 in. wide, and 9 in. thick, and had 11 courses of units. The specimens were similar to the 4-ft wall specimens.

(c) *Fabrication Data*

The fabrication data, determined by the Masonry Construction Section, are given in table 5.

TABLE 5.—*Fabricatian data, wall BE*

[The values per square foot were computed using the face area of the specimens]

Thickness of joints [a]		Masonry units	Mortar materials			Mason's time
Bed	Head		Cement	Lime, dry hydrate	Sand, dry	
in. 0.53	*in.* 0.65	*Number/ft²* 1.37	*lb/ft²* 1.01	*lb/ft²* 0.42	*lb/ft²* 5.18	*hr/ft²* 0.067

[a] The thickness of the joints in the facing varied considerably because of differences in alignment between the facing and backing slabs of the units. For adjacent units, the variation in joint thickness was as much as 0.4 in.

(d) *Comments*

Reinforced-concrete pilasters or columns are formed in the space between the facing and the backing by inserting stops at the desired location and placing reinforcement steel and concrete in the enclosed space. Beams and lintels are also reinforced concrete, formed in the same manner.

The outside of the wall is usually finished with cement paint and the inside with plaster, consisting of a ½-in. base coat applied directly to the units and covered by the usual white finish coat.

Different outside effects, resembling clapboards or shingles, may be obtained by changing the angle of the facing slab when the slabs are connected.

2. Compressive Load

Wall specimen *BE–C1* under compressive load is shown in figure 3. The results for wall specimens *BE–C1*, *C2*, and *C3* are shown in table 6 and in figures 4 and 5.

The compressive loads were applied to both the facing and the backing, 2.81 in. (one-third the thickness at the top of the units) from the inside face. The shortenings and sets shown in figure 4 for a height of 8 ft were computed from the values obtained from the compressometer readings. The gage length of the compressometers was 6 ft 5½ in. The lateral deflections shown in figure 5 are the averages of the deflection of the facing and the backing, measured independently. The facing deflected the same amount as the backing within 0.01 in., the estimated error of measurement.

Figure 3.—*Wall specimen BE–C1 under compressive load.*

TABLE 6.—*Structural properties, wall BE*

[Weight, 49.5 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*	[a]*Kips/ft*
Compressive	Upper end, 2.81 in. from the inside face.	*C1*				42.3
		C2				47.0
		C3				44.6
	Average					44.6
						lb/ft²
Transverse	Inside face; span, 7 ft 6 in	*T1*				22.4
		T2				21.5
		T3				19.7
	Average					21.2
Do	Outside face; span, 7 ft 6 in.	*T4*				22.0
		T5				18.0
		T6				21.0
	Average					20.3
						lb
Concentrated	Inside face	*P1*				[b]1,000
		P2				[b]1,000
		P3				[b]1,000
	Average					[b]1,000
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*	2.5	1.5	3.0	
		I2	2.5	1.0	3.0	
		I3	1.5	1.0	2.0	
	Average		2.2	1.2	2.7	
Do	Outside face; span, 7 ft 6 in.	*I4*	2.5	2.0	3.0	
		I5	3.0	1.0	3.0	
		I6	2.5	0.5	2.5	
	Average		2.7	1.2	2.8	
						[a]*Kips/ft*
Racking	Near upper end	*R1*				2.08
		R2				2.00
		R3				1.98
	Average					2.02

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

Each of the specimens failed by crushing of units in the backing in two courses either at midheight or near the upper end, cracking of the backing vertically through about four courses, and rupture of the bond between the units and the mortar at one or two bed joints in the facing at the height at which the units in the backing crushed.

3. Transverse Load

Wall specimen *BE–T1* under transverse load is shown in figure 6. The results are shown in table 6 and in figure 7 for wall specimens

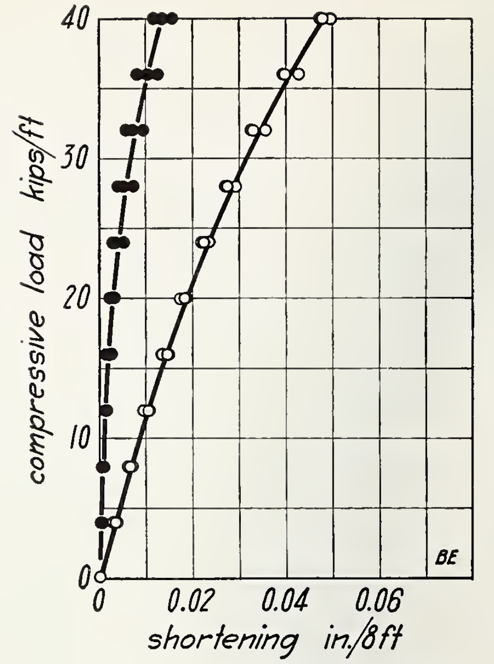


FIGURE 4.—*Compressive load on wall BE.*

Load-shortening (open circles) and load-set (solid circles) results for specimens *BE-C1*, *C2*, and *C3*. The load was applied 2.81 in. from the inside face. The loads are in kips per foot of actual width of specimen.

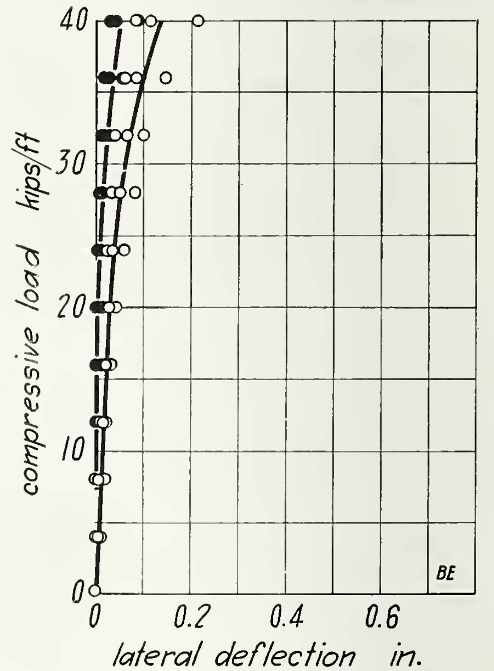


FIGURE 5.—*Compressive load on wall BE.*

Load-lateral deflection (open circles) and load-lateral set (solid circles) results for specimens *BE-C1*, *C2*, and *C3*. The load was applied 2.81 in. from the inside face. The loads are in kips per foot of actual width of specimen. The deflections and sets are for a gage length of 6 ft 5 in., the gage length of the deflectometers.

BE–T1, *T2*, and *T3*, loaded on the inside face, and in figure 8 for wall specimens *BE–T4*, *T5*, and *T6*, loaded on the outside face.

The deflections shown in figures 7 and 8 are the averages of the deflection of the facing and the backing, measured independently. The facing deflected the same amount as the backing within 0.01 in., the estimated error of measurement.

Each of the specimens failed by rupture of the bond between the mortar and the units at a bed joint at or between the loading rollers. The cracks usually appeared first in the face opposite the load and then in the loaded face.

FIGURE 6.—*Wall specimen BE–T1 under transverse load.*

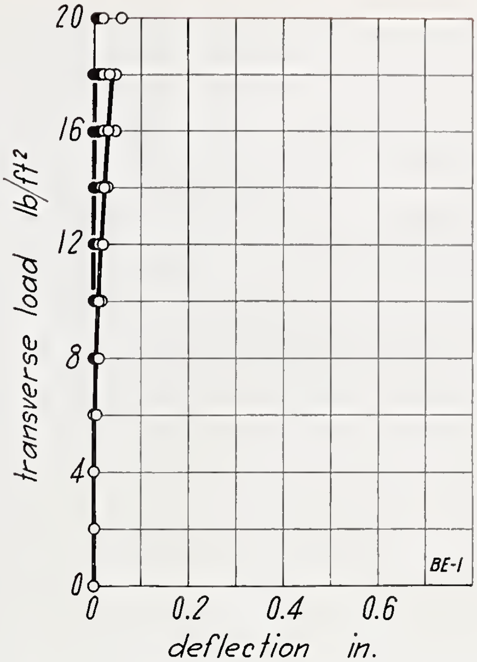


FIGURE 7.—*Transverse load on wall BE, load applied to inside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *BE–T1*, *T2*, and *T3* on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 1½ in., the gage length of the deflectometers.

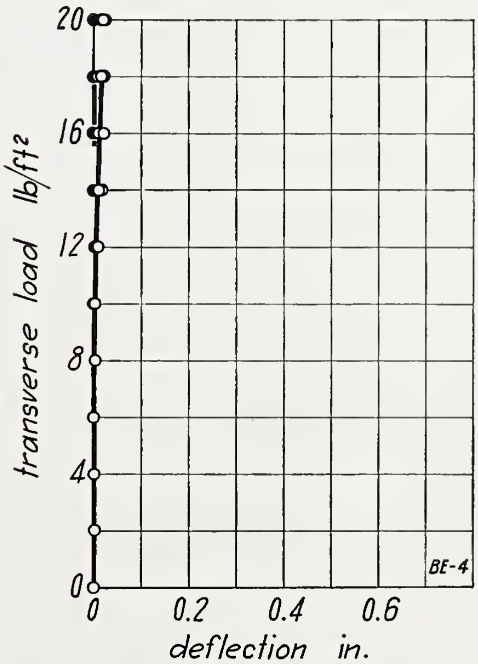


FIGURE 8.—*Transverse load on wall BE, load applied to outside face.*

Load-deflection (open circles) and load-set (solid circles) results for specimens *BE–T4*, *T5*, and *T6* on the span 7 ft 6 in. The deflections and sets are for a gage length of 7 ft 1½ in., the gage length of the deflectometers.

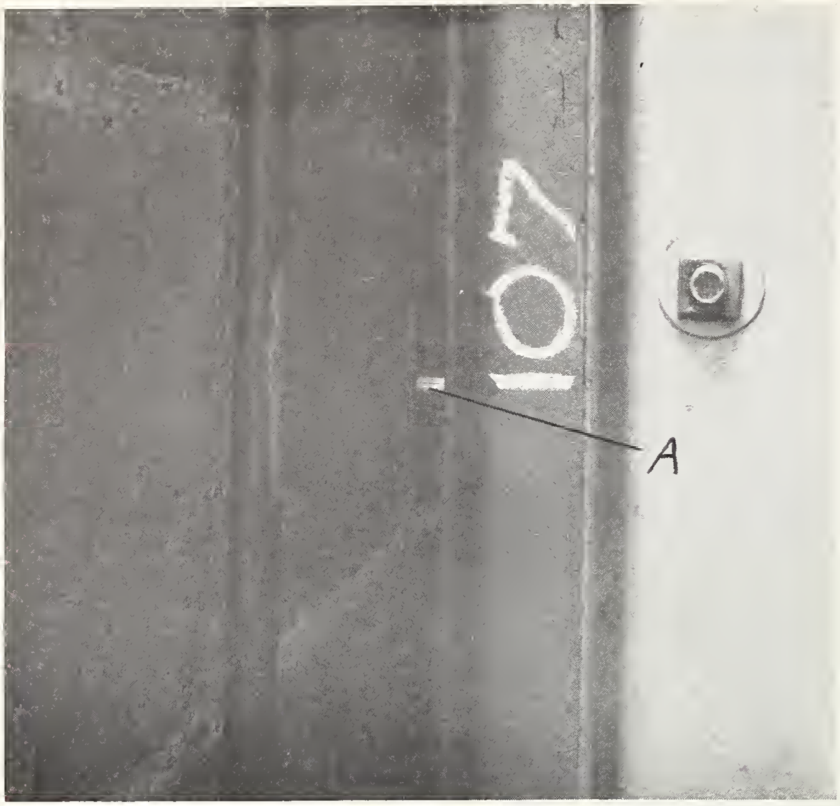


FIGURE 9.—*Wall specimen BE–P1 under concentrated load.*

A, loading disk.

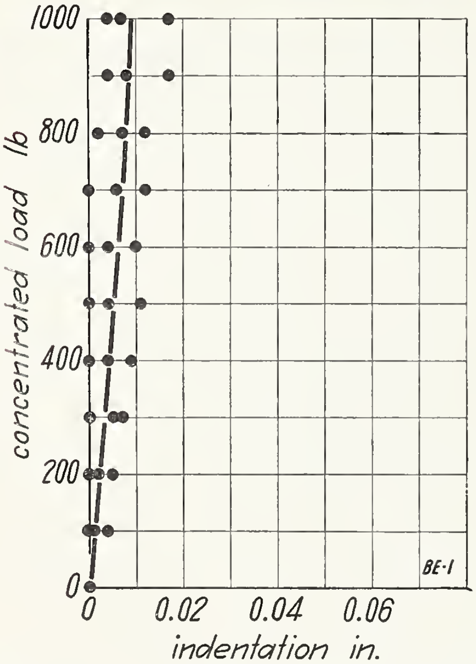


FIGURE 10.—*Concentrated load on wall BE, load applied to inside face.*

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

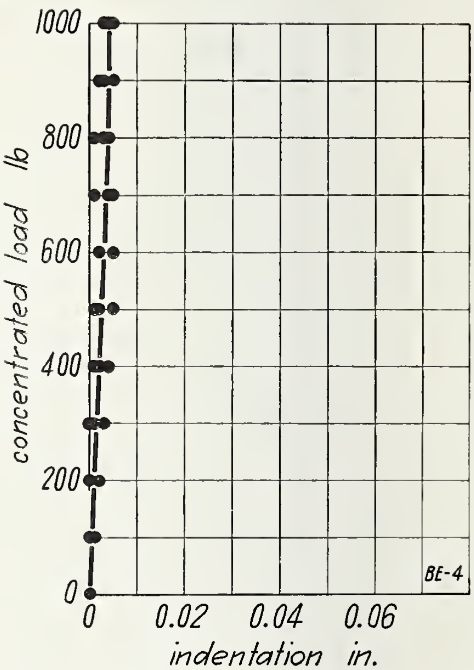


FIGURE 11.—*Concentrated load on wall BE, load applied to outside face.*

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

4. Concentrated Load

Wall specimen *BE–P1* under concentrated load is shown in figure 9. The results are shown in table 6 and in figure 10 for wall specimens *BE–P1*, *P2*, and *P3*, loaded on the inside face, and in figure 11 for wall specimens *BE–P4*, *P5*, and *P6*, loaded on the outside face.

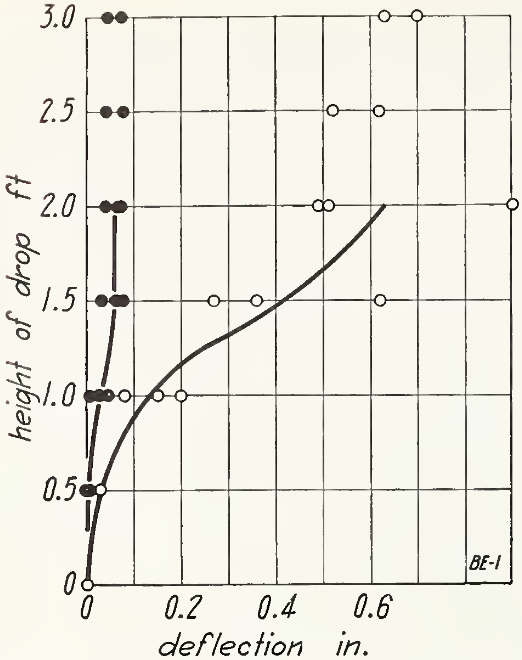
The concentrated loads were applied to the mortar bed and head joints at midwidth for all specimens except *P6*, to which the load was applied on a concrete unit. The indentations after a load of 1,000 lb had been applied were 0.004, 0.007, 0.017, 0.005, 0.004, and 0.003 in. for specimens *P1*, *P2*, *P3*, *P4*, *P5*, and *P6*, respectively, and no other effect was observed.

5. Impact Load

Wall specimen *BE–I1* during the impact test is shown in figure 12. The results are shown in table 6 and in figure 13 for wall specimens *BE–I1*, *I2*, and *I3*, loaded on the inside face, and in figure 14 for wall specimens *BE–I4*, *I5*, and *I6*, loaded on the outside face.

At the drops given in table 6 the faces of each specimen failed by rupture of the bond between the units and the mortar at bed joints near

Figure 12.—*Wall specimen BE–I1 during the impact test.*



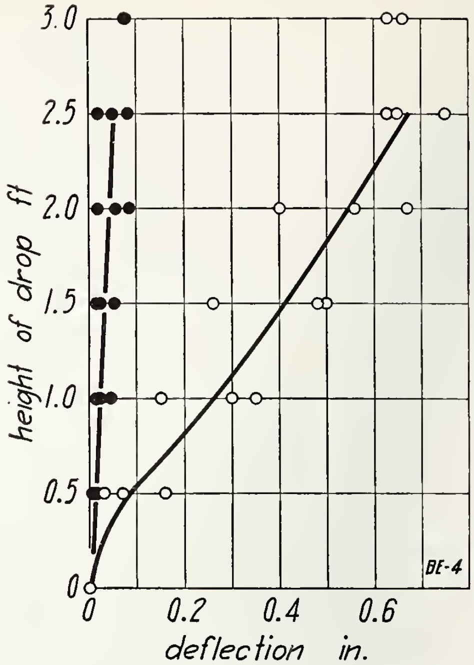


FIGURE 13.—*Impact load on wall BE, load applied to inside face.*

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

FIGURE 14.—*Impact load on wall BE, load applied to outside face.*

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

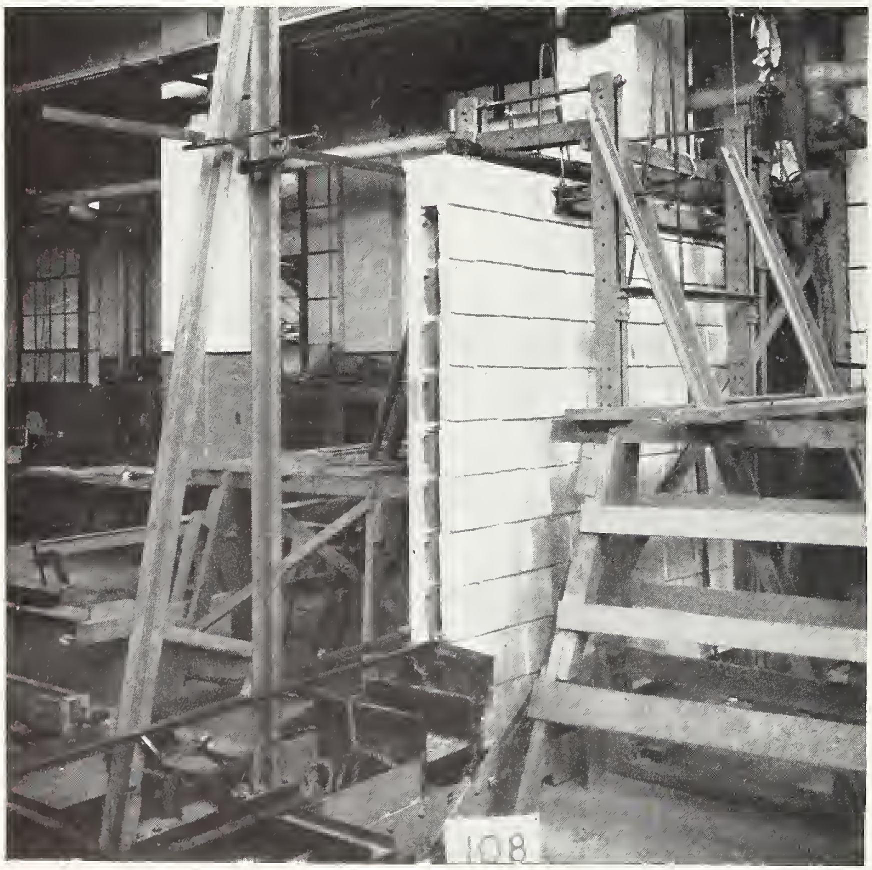


FIGURE 15.—*Wall specimen BE–R1 under racking load.*

midspan. At the maximum drops, each specimen failed by opening of these joints.

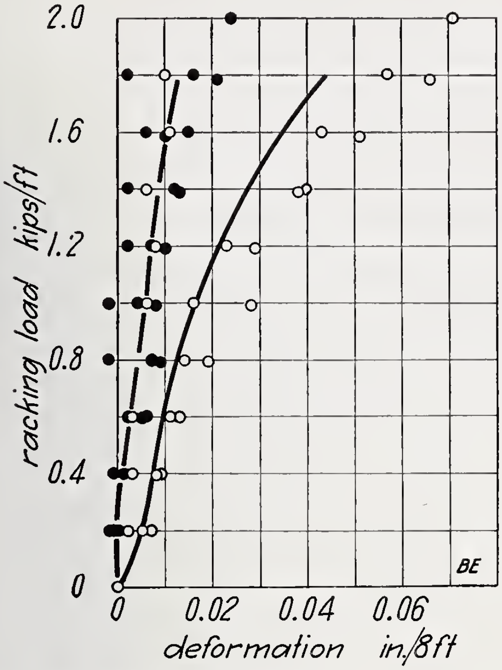


FIGURE 16.—*Racking load on wall BE.*

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

6. Racking Load

Wall specimen *BE–R1* under racking load is shown in figure 15. The results for wall specimens *BE–R1*, *R2*, and *R3* are shown in table 6 and in figure 16.

The racking loads were applied to the top course and the stop was in contact with the first and second courses from the lower end. For specimen *R3* at a load of 1.188 kips/ft, a head joint at the end of a unit near the loaded corner cracked. At the maximum load, each of the specimens failed by rupture of the bed and head joints in stepwise cracks approximately along a diagonal between the point of application of load and the stop. In addition, for specimens *R1* and *R2* the two top courses sheared off by rupture of the bond between the units and the mortar in the bed joint, and for specimen *R3* the bond between the units and the mortar ruptured in a bed joint between the sixth and seventh courses.

The sponsor supplied the information contained in the sponsor's statement. The drawings of the specimens were prepared by E. J. Schell, G. W. Shaw, and T. J. Hanley of the Bureau's Building Practice and Specifications Section, under the supervision of V. B. Phelan.

The structural properties were determined by the Engineering Mechanics Section, under the supervision of H. L. Whittemore and A. H. Stang, and the Masonry Construction Section, under the supervision of D. E. Parsons, with the assistance of the following members of the professional staff: C. C. Fishburn, F. Cardile, R. C. Carter, H. Dollar, M. Dubin, A. H. Easton, A. S. Endler, C. D. Johnson, L. M. Karpeles, P. H. Petersen, A. J. Sussman, and L. R. Sweetman.

WASHINGTON, April 14, 1939.

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