U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS2

Methods of Determining the Structural Properties of Low-Cost House Constructions

by HERBERT L. WHITTEMORE
and AMBROSE H. STANG

NATIONAL
BUREAU OF STANDARDS

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ISSUED AUGUST 10, 1938

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

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Foreword

THE PRESENT REPORT describes the methods now in use in the laboratories of the National Bureau of Standards for measuring the strength, stiffness, and resistance to abuse of constructions intended for walls, partitions, floors, and roofs of low-cost houses and apartment buildings. These tests represent an attempt to develop a standard procedure for evaluating the structural properties of house constructions.

Tests of new constructions according to this uniform procedure as to size of specimen and test methods, along with similar tests on conventional constructions, are expected to form a more reasonable basis for judging the value of new constructions than any method now available. Ultimately, such performance tests may find their way into building codes to replace present requirements, which specify details of sizes of members for use in conventional types of construction.

Adequate performance requirements of Nation-wide acceptance would facilitate the rapid development of new, better, and, it is hoped, cheaper methods of construction.

LYMAN J. BRIGGS, *Director.*

Methods of Determining the Structural Properties of Low-Cost House Constructions

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CONTENTS

ABSTRACT

This paper describes methods used by the National Bureau of Standards to determine the structural properties of elements of a low-cost house: that is, structural properties of wall specimens under compressive, transverse, concentrated, impact, and racking loads; of partition specimens under impact and concentrated loads; of floor specimens under transverse, concentrated, and impact loads; and of roof specimens under transverse and concentrated loads. A graphic method of presenting the results of the tests is also described. It is believed that the tests of house constructions by the methods described in this paper will give information on the structural properties which will greatly assist in the selection of a low-cost construction for given conditions.

I. INTRODUCTION

In the past, few tests have been made and therefore few data are available on the strength, stiffness, and other structural properties of houses, even for the conventional brick or frame houses which have been so widely used in this country. Progress since the time of the early settlers has been made largely by "cut and try." Constructions not proving satisfactory under service conditions were discarded, but constructions which were unnecessarily strong or expensive were replaced only very gradually by more economical constructions.

To insure more rapid progress in determining the structural properties of houses it is desirable to use research methods which have proved to be efficient and economical in the solution of other industrial problems. Houses might be observed under service conditions to obtain data for determining the minimum requirements for a house which has proved to be satisfactory. However, more definite information could be obtained by applying known loads to the house and measuring their effect. If loads were applied to houses of different constructions and if the effect of service on houses of the same constructions was also recorded over a period of years, minimum requirements could be established for the structural properties which would insure satisfactory houses for a particular climate (temperatures, rain, snow, wind) and which would comply with reasonable requirements for health, safety, etc.

Subjecting complete houses to known loads is very expensive and requires much time; therefore, this method of carrying out investigations of houses is not likely to be used to any great extent. Such tests have the further disadvantage that only the strength of the weakest elements of a particular house could be measured. As an illustration, to determine the strength of the second-story floor in a house, loads could be applied to the floor. If the walls crushed before the maximum load for the floor was applied it would be necessary to test another house having stronger walls.

For these reasons it seems more practicable to apply loads to specimens which accurately reproduce a structural portion of a finished house.[1] These portions of a house have been designated as "elements"; for example, floor, wall, roof, etc. For the program described in this paper, the elements have been restricted to the most important structural portions of a house. For each element the methods of loading were prescribed which simulated the loads to which the element would be subjected under service conditions. It is believed that the results of these measurements on the structural elements of a house will be more useful to architects and engineers than the results of tests on specimens of the materials from which the house was fabricated, or the results of tests of the individual structural members of a house. In all probability, the results will approximate closely those which would be obtained by testing a complete, full-sized house. Provided a sufficient number of constructions are included, some of which have been widely used for many years, and others which may never have been used for a house subjected to service conditions, it should be possible, by comparing the results, to determine approximately whether or not a new construction will be satisfactory as regards structural properties. Carrying out this program will be much less expensive than building houses of these new constructions and awaiting the test of actual service over a period of years.

Although it may be impracticable to determine all of the structural properties of each element of a house, it is believed that the more important properties may be determined by tests described in this report.

Under this program, walls and load-bearing partitions are being subjected to compressive,

[1] Any residential structure.

transverse, concentrated, impact, and racking loads, in the laboratory. In actual service, house walls are subjected to vertical compressive loads by the dead weight of the walls, floor, and roof above, and by the live loads above (wind, and the weight of snow on the roof, furniture, or persons on the floor, etc.). Horizontal transverse (bending) loads, caused by wind, act upon the outside faces of such walls, and sometimes upon their inside faces on the leeward side.

Walls may also be subjected to concentrated loads (large forces over a small area, such as a ladder placed against either face). Impact loads may be applied accidentally to a wall, for example, by a coal truck backing against the outside, or by a person or bookcase falling against the inside face of the wall. Concentrated and impact loads come under the head of abuse, and, to a considerable extent, are unavoidable under service conditions. Racking (shearing) loads are applied to a wall by intersecting walls against which a wind is blowing.

Load-bearing partitions are subjected to the same loads except transverse loads caused by wind. However, transverse loads are applied to load-bearing partitions in the laboratory because if the outside face is weatherproofed but no other change in the construction is made, they may be used for the outside wall of a house.

Nonload-bearing partitions are not designed to withstand compression, transverse or racking loads, and under service conditions, such loads on a nonload-bearing partition are negligible, and therefore may be ignored. On the other hand, impact and concentrated loads, through accidents, are sometimes applied to nonload-bearing partitions. Therefore, partitions are subjected to impact and concentrated loads.

Floors are subjected to transverse, concentrated, and impact loads. Transverse (bending) loads are applied to a floor by the weight of furniture and persons. Concentrated loads are applied by pianos, bookcases, etc. Impact loads are applied by objects and persons falling on the floor, as a person jumping or falling from a stepladder.

Roofs are subjected to transverse and concentrated loads. Transverse (bending) loads are applied by wind, and the weight of snow, or by workmen. Concentrated loads are applied by the weight of material and tools during the construction or repair of the roof.

II. COOPERATION WITH INDUSTRY

In order to cooperate with industry to the fullest extent, specimens for one or more structural elements of a house are solicited for inclusion in this program. Any number of constructions may be submitted. It is believed that in this way the invaluable experience of individuals, organizations, architects, engineers, and others may be coordinated so as to be of the greatest value to those concerned with the design and construction of houses, particularly low-cost houses. Many organizations have had considerable experience with different constructions under service conditions in various parts of the country, and over comparatively long periods of time. They are, therefore, in an excellent position to recommend constructions which they believe are satisfactory for low-cost houses.

Specimens accepted for inclusion in this program will be tested without expense to the sponsor. The sponsor or his representative and any others he may designate are invited to witness the tests and make suggestions. A report giving results of the tests on his construction will first be submitted to the sponsor for his criticism and comments. These will be given careful consideration in the preparation of the final report, which will then be published by the National Bureau of Standards and made available to the public.

The sponsors are earnestly requested to submit constructions which in their opinion are the least expensive, and in this way, assist in providing houses for those lower-income families which heretofore have not been adequately housed.

1. Approval

The reports on this program will be available to all organizations concerned with housing. The responsibility for selecting suitable constructions, issuing building permits, approving a construction, granting mortgage loans, fixing insurance rates, etc., rests with these organizations.

The National Bureau of Standards neither approves nor disapproves any construction. It makes available to the public the results of the tests and inspections made by members of its staff. This Bureau has no requirements for any house or portion of a house. At the present time, it is impracticable to comply with requests for the determination of structural properties of any portion of a house except the elements described hereafter. This Bureau does not test building units or members, such as brick, concrete block, open bar joists, etc., for the public if such tests can be made in the materials testing laboratories of commercial organizations and technical schools. A Directory of Commercial Testing and College Research Laboratories has been published by the Bureau as Miscellaneous Publication M125. Copies of this directory may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 15 cents.

III. COOPERATION WITH THE UNITED STATES FOREST SERVICE

Because of the long experience of the Forest Products Laboratory of the United States Department of Agriculture in the study and development of wood constructions, and the requirement in the appropriation act that this program shall not duplicate any work now performed by that Laboratory, the National Bureau of Standards requested the assistance of the Forest Service in this program for the determination of the structural properties of low-cost house constructions. The Forest Service very kindly offered its cooperation in tests of wood constructions, that is, constructions having wood structural members.

The Forest Products Laboratory at Madison, Wis., has unequaled facilities for determining the species and commercial grade of wood, moisture content, etc., essential to insure adequate results in wood constructions, and has a personnel experienced in the study of the structural properties of wood. This Laboratory has constructed and tested specimens of conventional wood construction by essentially the same procedure as described in this report. The Laboratory has agreed to the inclusion of the results of its tests in the present series of reports. It has been jointly decided that it will be most convenient to test other wood constructions at the National Bureau of Standards with the active cooperation of personnel representing the Forest Products Laboratory.

IV. DEFINITIONS

1. House

Any residential structure.

2. Element

A portion of the completed house ready for occupancy, having one primary function, for example, a floor or wall.

3. Construction

The materials, dimensions, and method of fabricating an element of a house. Elements are of different constructions if there is a significant difference in the materials, dimensions, and methods of fabrication. Example: A floor having rolled steel I-beams covered by a reinforced concrete slab is one construction, and a floor having the same I-beams and spacing covered by a wood floor is a different construction.

(a) *Wood Construction*

A construction having wood structural members.

4. Sponsor

A sponsor of a house construction is an individual or an organization which submits specimens for inclusion in this program for the determination of their structural properties.

V. SPECIMENS

1. General

(a) *Size*

The specimens should be as large as practicable to minimize the effect of variations in the material and workmanship, and thereby obtain results representative of the construction in an actual house. Obviously, the size of the specimens is limited to the size which can be tested in the larger testing machines available in a well-equipped laboratory, and which can be subjected to loads in accordance with good testing procedure, and for which the deformation can be measured with sufficient accuracy.

(*b*) *Length or height*

A length or height of specimen for each element was chosen which is about the length or height of that element in a small house.

(*c*) *Width*

The width was chosen which, for most constructions, would include several of the principal load-carrying members to insure, insofar as possible, that the specimen under load would behave like a portion of a house under service conditions. With the exception of that for the racking load, a nominal width of 4 feet was chosen for wall specimens.

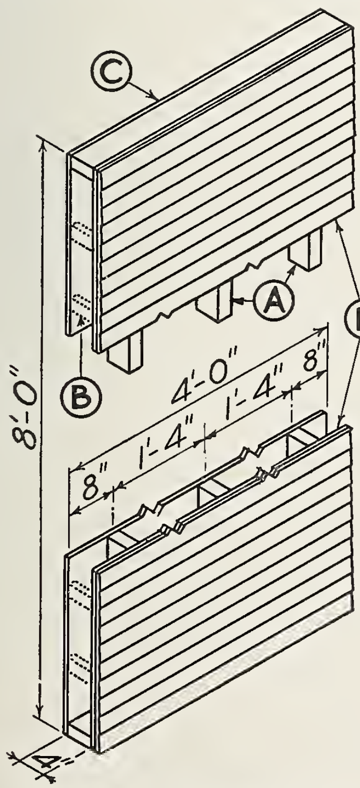

FIGURE 1.—*Typical wall specimen.*

A, three wood studs (2 by 4 inches); *B*, wood blocks to support the edges of the faces, optional with sponsor; *C*, inside face (lath and plaster); and *D*, outside face (wood sheathing, paper, and lap siding).

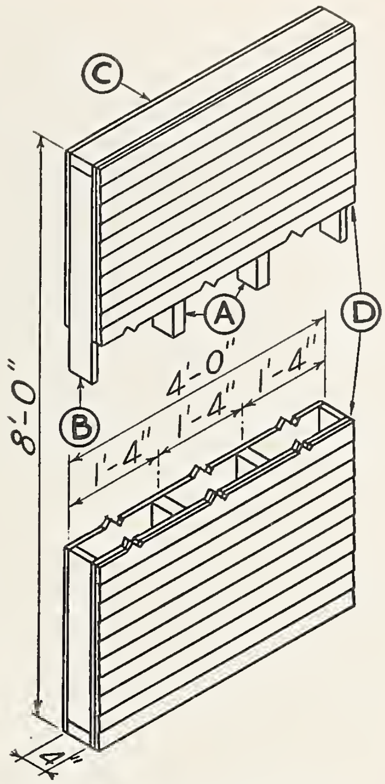

FIGURE 2.—*Typical wall specimen.*

A, two wood studs (2 by 4 inches); *B*, two wood "half" studs (1 by 4 inches); *C*, inside face (lath and plaster); and *D*, outside face (wood sheathing, paper, and lap siding).

The actual width of specimens shall be a whole number multiplied by the spacing of the principal load-carrying members. In no case shall the actual width exceed 6 feet, as this is the greatest width which can be tested under transverse loads in equipment available in the Engineering Mechanics Section of the National Bureau of Standards.

If the structural properties of a particular construction are to be compared with another construction, there should not be a great difference in the actual widths of the specimens. For example, under the impact loading a satisfactory comparison cannot be made if for one construction the specimens had an actual width of 2 feet and for another 12 feet. For walls similar to conventional wood construction having studs spaced 16 inches, the actual width of the specimen shall be 4 feet and have three studs. At the option of the sponsor this specimen may either have three "full-sized" studs as shown in figure 1, or two "full-sized" studs and two "half-thickness" studs, as shown in figure 2. If the sponsor prefers three "full-sized" studs (fig. 1) he may tie the edges of the faces together at intervals of about 1 foot by blocks, as shown by dotted lines in figure 1. These blocks should prevent damage to the specimen when being shipped or handled and may remain in place when the specimen is tested, because their effect on the structural properties of the specimen will not be appreciable. The nominal width of 4 feet was also chosen for specimens of partitions, floors, and roofs.

2. Age

Constructions, such as concrete and masonry (brick, structural clay tile, cement block) for which the structural properties depend upon the age of the specimen, will be tested 28 days after fabrication to obtain comparable results on different constructions. Constructions having plastered or stuccoed faces will be tested 28 days after fabrication.

3. Sponsor's Obligation

(a) *Description*

If a construction is to be considered for the determination of structural properties, the sponsor shall:

First: Select one or more of the four elements of a house for which he wishes to submit specimens, that is, wall, partition, floor, and roof.

Second: For these elements choose one or more low-cost constructions.

Third: Submit dimensioned drawings of specimens and a complete description of the construction for each element. The description should give all available information which will identify the materials or units in the construction, such as name of manufacturer, trade name, commercial grade, manufacturing process, purchase specification, approximate chemical composition, tensile strength, etc. The information and drawings furnished by the sponsor will be used to determine whether the construction will be included in this program.

TABLE 1.—*Price of low-cost house constructions*

Element	*Maximum price per square foot*
Wall and load-bearing partitions; including weatherproofing on outside face of the wall and the finish on inside face of the wall and on both faces of the partition	$0. 60
Partition, nonload-bearing; including finish on both faces	. 35
Floor; including finish floor on upper face and ceiling (if any) on lower face	. 75
Roof; including weatherproofing on upper face and ceiling (if any) on lower face	. 60

Fourth: State the price as of July 1937 of each element per square foot complete, as used in a house, delivered in Washington, D. C. To be included in this program, the price of the specimens shall not exceed the values given in table 1, and preferably should be much lower.

These prices apply to low-cost houses, including apartments in congested areas of large cities and free-standing small houses in suburban or rural districts. Sponsors are earnestly requested to submit the lowest-priced constructions which they believe would be satisfactory for a low-cost house.

(b) *Caution*

1. Do not fabricate specimens before the National Bureau of Standards has agreed to include your construction in this program.

2. Because storage space at the laboratory is limited, do not deliver specimens until advised by the Bureau.

3. For specimens which are to be tested 28 days after fabrication, obtain an assignment of dates for testing to prevent a conflict with other specimens.

(c) *Specimens*

The specimens of each construction shall comply with the following requirements:

Wall.—Fifteen specimens, height 8 feet, nominal width 4 feet (480 ft^2); three specimens, height 8 feet, nominal width 8 feet (192 ft^2). Total area 672 feet^2.

Partition.—Three specimens, height 8 feet, nominal width 4 feet (96 ft^2).

Floor.—Six specimens, length 12 feet 6 inches, nominal width 4 feet (300 ft^2).

Roof.—Three specimens, length 14 feet 6 inches, nominal width 4 feet (174 ft^2).

VI. METHOD OF TESTING WALLS

1. Compressive Load

(a) *Specimen*

Tests are made on three duplicate specimens, each having a height of 8 feet and a nominal width of 4 feet.

(1) *Height.*—A height of 8 feet from floor to ceiling has been widely recognized as satisfactory for a low-cost house. Therefore, a height of 8 feet was selected for the wall specimens for compressive load. This is about the least height that can be used in a low-cost house. The actual height of a wall in a complete house may be somewhat greater than 8 feet, depending upon the connections between wall and floor, roof, etc. For a wall, as for any column, the higher the wall, the less the compressive strength. Most walls for low-cost houses are short, sturdy columns; therefore, the strength is about the same for any height used in a house. For some constructions, particularly thin walls, the strength may be much less if the height is greater than 8 feet; it may be necessary to determine the relation between the height and strength of these constructions by making additional tests. It appears probable, however, that the strength of a wall, having a height greater than 8 feet, can be estimated by the usual engineering methods with sufficient accuracy for practical purposes.

(2) *Width.*—The nominal width of these specimens is 4 feet.

(b) *Loading*

The specimen is tested, as shown in figure 3, as a column having a flat end at the bottom. Compressive loads are applied to a steel plate covering the upper end of the specimen. The load is applied uniformly along a line parallel to the inside face, and one-third the thickness of the specimen from the inside face.

(c) *Apparatus*

To measure the shortening of the specimen four compressometers, *A*, are attached to the faces of the specimen, *B*, one near each corner of the specimen, as shown in figure 4. For each

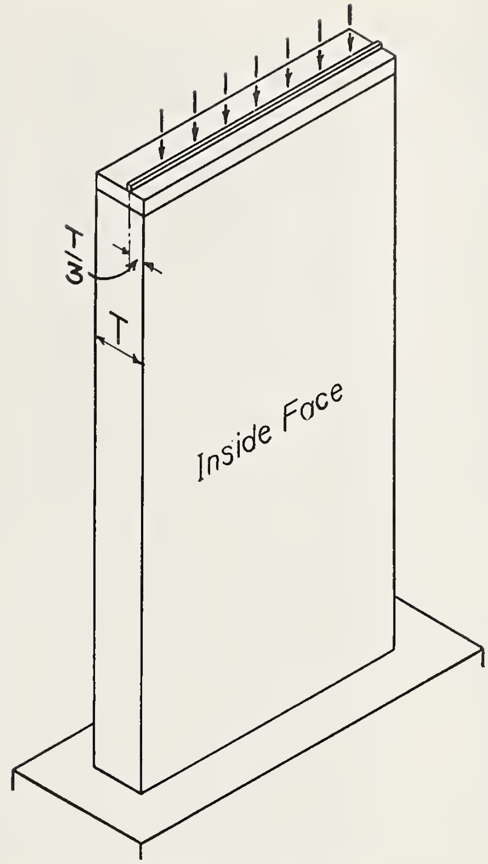

Figure 3.—*Compressive load on specimen.*

compressometer a bracket, *C*, is attached to the specimen near the upper end. The bracket supports a metal rod, *D*. A bracket, *E*, attached to the specimen near its lower end supports a dial micrometer, *F*, with the spindle up. The conical end of the rod, *D*, seats in a hole in the end of the spindle and the rod and spindle are held in contact by stretched rubber bands, *G*. The dial is graduated to 0.001 inch and the readings are recorded to 0.1 of a division.

To measure the lateral deflection, two deflectometers, *H*, are attached, one to each edge of the specimen. Each deflectometer consists of a small wire, *I*, attached at its upper end to a clamp, *J*, near the upper end of the specimen. The lower end, *K*, connected to stretched rubber bands, *L*, is attached to a clamp, *M*, near the lower end of the specimen. A mirror, *N*, having a paper scale, *O*, one-half the width of the mirror is attached horizontally to the edge of the specimen at midheight. The scale is graduated to 0.1 inch and the readings when

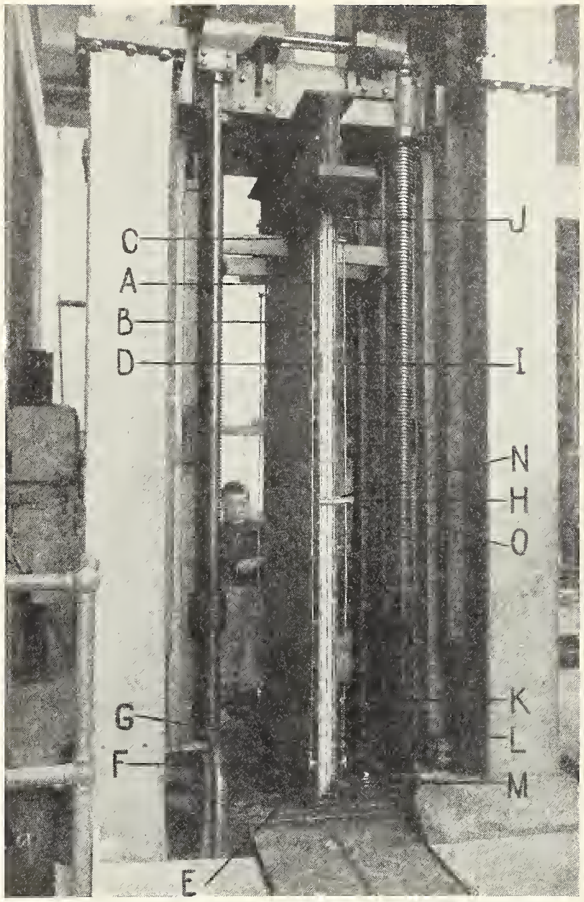

FIGURE 4.—*Apparatus for compressive load on specimen.*

A, compressometer; *B*, specimen; *C*, upper bracket; *D*, rod; *E*, lower bracket; *F*, dial micrometer; *G*, rubber bands; *H*, deflectometer; *I*, wire; *J*, upper clamp; *K*, lower end of wire; *L*, rubber bands; *M*, lower clamp; *N*, mirror; and *O*, scale.

the image of the wire coincides with the wire are recorded to 0.1 division.

(*d*) *Results*

For each compressometer, the shortening under each load is the difference between the reading of the compressometer and the initial reading. The shortening of the specimen in 8 feet is the average of the shortenings for each of the four compressometers multiplied by the ratio: 8 feet divided by the compressometer gage length. Using a similar method, the shortening sets are obtained. The lateral deflection and the lateral set for each deflectometer is the difference between the reading of the deflectometer and the initial reading. The lateral deflection and lateral set for the specimen is the average of the lateral deflection and lateral set of the two deflectometers. The maximum load for each specimen is recorded.

2. TRANSVERSE LOAD

(*a*) *Specimen*

Tests are made on six duplicate specimens each having a height of 8 feet and a nominal width of 4 feet.

(1) *Height.*—As it appeared desirable to avoid unnecessary differences in the heights of the wall specimens, 8 feet was selected for the height of the wall specimen for transverse load. Necessarily, the span is slightly less than 8 feet.

(*b*) *Loading*

Because there is no satisfactory method of applying loads uniformly over the face of a transverse specimen, particularly if the loads are applied in increments, the deflection recorded, then the load released, and the set recorded, "two-point" loading was chosen for the transverse load tests on walls, floors, and roofs. The two equal loads are applied, each at one-quarter of the span from the supports, toward the middle of the span. The bending moment then is constant for the portions of the specimen between the two loads, a longitudinal distance of one-half the span. This bending moment is equal to the bending moment which would exist at midspan if the total load were uniformly distributed over the face of the specimen between the supports.

The vertical shear is constant for the two portions of the specimen between each load and the adjacent support. This shear is equal to the shear which would exist at the supports if the total load were uniformly distributed over the face of the specimen between the supports.

Under "two-point" loading, much larger portions of the specimen are subjected to the maximum bending moment and to the maximum shear, than if the same total load were uniformly distributed over the face of the specimen between the supports. The deflection at midspan, however, is not equal to the deflection if the load were uniformly distributed. The deflection under uniformly distributed load can be estimated with sufficient accuracy for practical purposes by the usual engineering methods, or the deflection can be measured under a uniformly distributed load.

The strength is of much greater importance than the deflection for house construction, and "two-point" loading is more satisfactory for determining the strength from the results on these specimens than uniformly distributed loading.

The specimen is tested as shown in figure 5, as a simple beam on a span, *S*, of 7 feet 6 inches. The two supports for specimen, *A*, figure 6, are steel rollers, *B*, to prevent longitudinal constraint. There is a steel plate, *C*, between each supporting roller and the specimen. Two equal loads are applied uniformly across the specimen, one at each quarter point of the span, through two rollers, *D*, to prevent longitudinal constraint. There is a steel plate, *E*, between each loading roller and the specimen.

For wall specimens tested horizontally, as shown in figure 6, the load on the specimen includes weight of specimen between the supports.

For three of the specimens the transverse loads are applied to the outside face and for three of the specimens to the inside face.

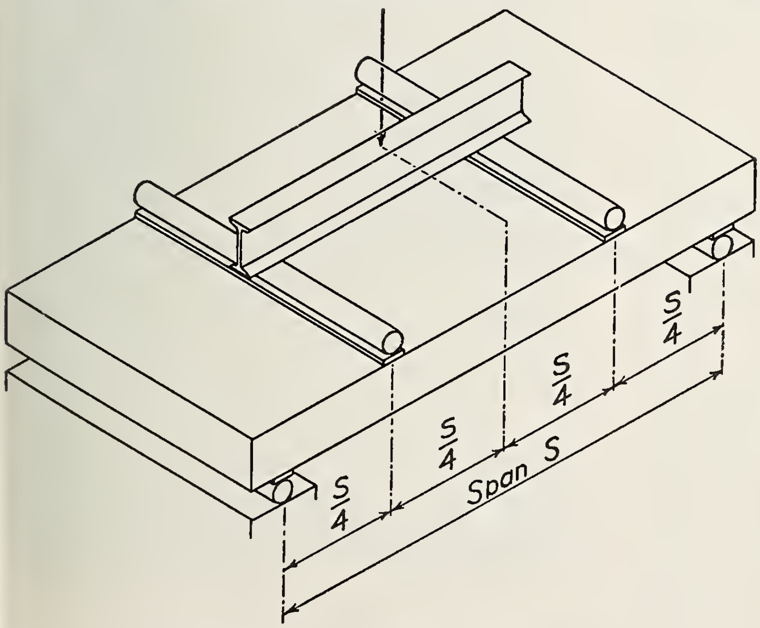

FIGURE 5.—*Transverse load on specimen.*

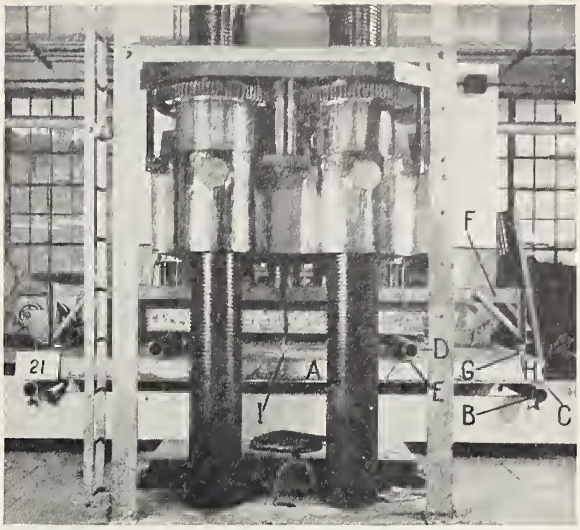

FIGURE 6.—*Apparatus for transverse load on specimen, tested horizontally.*

A, specimen; *B*, supporting roller; *C*, plate; *D*, loading roller; *E*, plate; *F*, frame; *G*, ball; *H*, blocks; and *I*, dial micrometer.

(*c*) *Apparatus*

To measure the deflection of the specimen, a frame, *F*, is placed on the upper face of the specimen, as shown in figure 6. To prevent stresses deforming the frame as the specimen deforms under load, this frame rests on three hardened steel balls, *G*, each supported by a steel block, *H*, on the face of the specimen. Two of the balls are in a line vertically above one support and the third ball vertically above the other support.

One foot of the frame is free to rotate about a point, one to move along a line, and one to move in a plane; the frame therefore is kinematically nonredundant or stress-free.

Two dial micrometers, *I*, one near each longitudinal edge of the specimen, are attached to the frame, *F*, at midspan. The spindles rest on the upper face of the specimen. The micrometers are graduated to 0.001 inch and the readings are recorded to the nearest division.

(*d*) *Results*

For each micrometer, the deflection under a given load is the

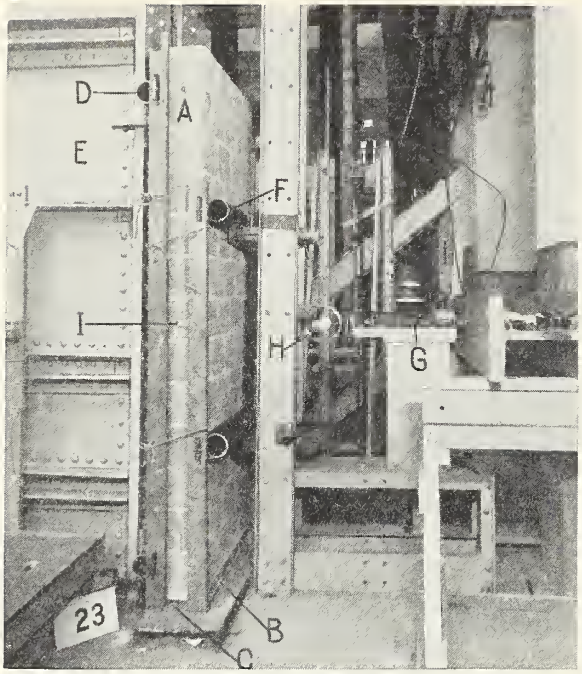

FIGURE 7.—*Apparatus for transverse load on specimen tested vertically.*

A, specimen; *B*, channel; *C*, roller; *D*, supporting roller; *E*, frame; *F*, loading roller; *G*, screw jack; *H*, ring dynamometer; and *I*, deflectometer.

difference between the reading of the micrometer and the initial reading. The deflection of the specimen, for the span of 7 feet 6 inches, is the average of the deflections for each of the two micrometers. By using a similar method, the sets under the initial load are obtained. The maximum load for each specimen is recorded.

(*e*) *Masonry Constructions*

For wall constructions, such as masonry, to which transverse loads cannot be applied satisfactorily with the specimen in a horizontal position, the loads are applied with the specimen in a vertical position, as shown in figure 7, thus simulating service conditions.

The specimen, *A*, on a steel channel, *B*, rests on cylindrical rollers, *C*, to prevent constraint. The axes of the rollers are parallel to the faces of the specimen. The two supporting rollers, *D*, are in contact with the vertical surface of the frame, *E*, and each roller rests on sponge rubber about ½ inch thick to prevent longitudinal constraint. Each of the two loading rollers, *F*, also rests on sponge rubber. The loads are applied horizontally by a screw jack, *G*, and measured by a ring dynamometer, *H*, between the jack and the specimen. The error in the load indicated by the dynamometer does not exceed 1 percent. Two taut-wire mirror-scale deflectometers, *I*, are attached to the specimen, one to each vertical edge. These deflectometers are similar to those used to measure the lateral deflection of walls under compressive loads and described in section VI–1–(c).

3. CONCENTRATED LOAD

(*a*) *Specimen*

Tests are made on each transverse specimen after the transverse load tests, the load being applied to the same face of the specimen.

(*b*) *Loading*

Either the entire specimen or a portion of the specimen, *A*, figure 8, is placed on a horizontal support. A steel disk, *B*, having a diameter of 1 inch and the lower edge rounded to a radius of 0.05 inch is placed on the upper face of the specimen at what is judged to be the weakest

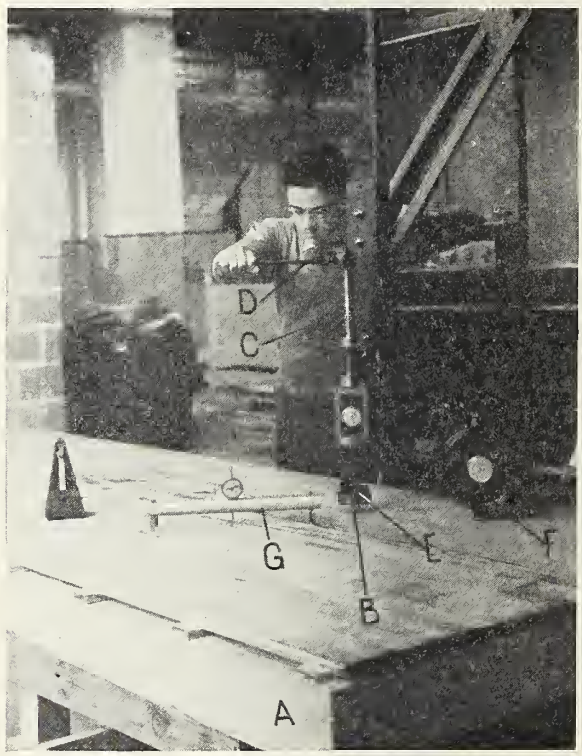

FIGURE 8.—*Concentrated load on specimen.*

A, specimen; *B*, disk; *C*, screw; *D*, wrench; *E*, spring dynamometer; *F*, ring dynamometer; and *G*, depth gage.

place. A load is applied vertically downward to the upper surface of the disk by the screw, *C*, which can be rotated by the ratchet wrench, *D*. To measure the load, either the spring dynamometer, *E*, or the ring dynamometer, *F*, is placed between the disk, *B*, and the lower end of the screw, *C*. The error in the load, indicated by either of these dynamometers, does not exceed 1 percent. The capacity of the spring dynamometer, *E*, is 500 pounds and the principal elements are a helical steel spring and a dial micrometer. The shortening of the spring under compressive loads is indicated on the dial of the micrometer. The capacity of the ring dynamometer, *F*, is 20,000 pounds and the principal elements are a heat-treated steel ring and a dial micrometer. The shortening of the vertical diameter of the ring under compressive loads is indicated on the dial of the micrometer.

(*c*) *Apparatus*

To measure the depth of the indentation the depth gage, *G*, figure 8, is used. This gage consists of a light tubular frame, having two legs at one end and one leg at the other. A dial micrometer is attached to the frame at midlength. The micrometer is graduated to 0.001 inch and the readings are recorded to the nearest division. Readings are taken by placing the depth gage on the specimen with the spindle of the micrometer at the center of the indentation and recording the reading of the micrometer.

(*d*) *Results*

The depth of the indentation (set) after a given load has been applied and the disk removed is the difference between the depth for that load and the initial reading of the micrometer before a load has been applied to the specimen. The maximum load is recorded, provided this load does not exceed 1,000 pounds.

4. Impact Load

(*a*) *Specimen*

Tests are made on six duplicate specimens each having a height of 8 feet and a nominal width of 4 feet.

(*b*) *Loading*

The specimen is tested as shown in figure 9 as a simple beam on a span of 7 feet 6 inches. The two supports for the specimen, *A*, figure 10, are steel rollers, *B*, to prevent longitudinal constraint. An impact load is applied to the middle of the upper face of the specimen by dropping a sandbag, *C*.

(1) *Sandbag.*—The wall of the bag is Indian-tanned lace leather, type *B*, Federal Specification KK–L–201, purchased from I. B. Williams & Sons, Dover, N. H. It is 28 inches high by 29 inches wide. The vertical edges were sewed together flesh side out. The wall then was turned hair side out and one end sewed to a disk, *D*, having a diameter of 9 inches. The disk was either harness or belting leather having a thickness of 3/16 inch. All seams were stitched with linen shoe thread and there were two rows of stitching.

To hoist the bag a strap 1/8 inch thick, 5/8 inch wide, and 24 inches long having a buckle at one end and holes near the other end is passed through two diametrically opposite holes in the wall 1½ inches from the upper end and buckled. There are two reinforcements sewed to the wall on the inside, one at each hole. The reinforcements are made of the same leather as the wall and are 3 by 3 inches.

Building sand was placed in a cloth bag, tied with a cord, and placed inside the leather bag.

The sandbag weighs 60 pounds and the weight is adjusted to this value before each series of impact tests. After a few tests the diameter of the bottom of the bag was 10 inches. Before testing a specimen, the bag is rolled on the floor to loosen the sand and obtain insofar as possible constant conditions. When making a test (fig. 10), the bag is hoisted by the overhead crane and released by pulling the trip cord, *E*, when the bag is at the desired height.

(2) *Height of drop.*—For the first drop, the height of the bag is measured from the upper face of the specimen and for subsequent drops from a taut cord in contact with the face vertically above the supports. The height of the bag is indicated by a series of light (duralumin) tubes, *F*, the lengths of which are multiples of 6 inches.

For three of the specimens, the impact loads

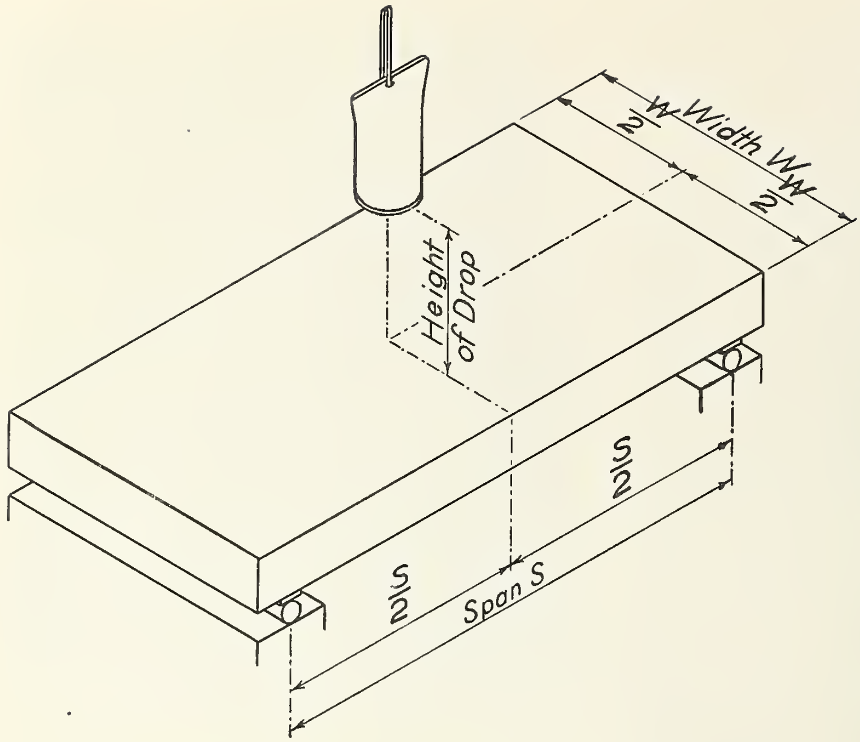

FIGURE 9.—*Impact load on specimen.*

are applied to the outside face and for three of the specimens to the inside face.

(c) *Apparatus*

To measure the instantaneous deflection of the specimen, the deflectometer shown in figure 11 is used. The deflectometer consists of a metal tube, *A*, having a base, *B*, at the lower end and a friction clamp, *C*, at the upper end. A light metal rod, *D*, movable in the tube is held in contact with the middle of the lower face of the specimen by the clamp. The rod, *D*, is graduated to 0.1 inch and readings relative to the fiduciary mark, *E*, on tube, *A*, are estimated to 0.1 division. When the specimen deflects under the impact load this rod is held in its lowest position. The deflectometer is placed on the concrete floor under the specimen as shown at *A* in figure 12.

To measure the set, the set gage, *B*, figure 12, is placed on the upper face of the specimen. This gage consists of a light (duralumin) tubular frame having two legs at one end and one leg at the other. The distance between the legs is equal to the span. A dial micrometer is attached to the frame at midlength. The micrometer is graduated to 0.001 inch and the readings are recorded to the nearest division.

Readings are taken as shown in figure 12 by placing the set gage on the specimen with the legs vertically above the supports and the spindle of the micrometer in contact with the middle of the specimen and the reading of the micrometer. If the set exceeds the range of the micrometer, gage blocks, *C*, are placed between the specimen and the spindle of the micrometer.

For some specimens, the upper face is broken by the impact of the sandbag while the lower face remains unbroken; therefore, the set measured to the upper face is greater than the deflection measured to the lower face.

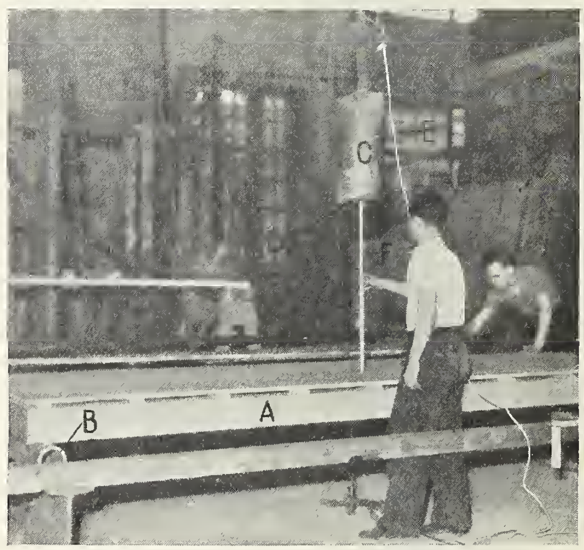

FIGURE 10.—*Impact load on specimen, tested horizontally.*

A, specimen; *B*, supporting roller; *C*, sandbag; *D*, bottom disk; *E*, trip cord; and *F*, heigbt-measuring tube.

(d) Results

For each height of drop the deflection is the difference between the reading of the deflectometer and the initial reading. Similarly, the set is the difference between the reading of the set gage and the initial reading. The maximum height of drop is recorded, provided this height of drop does not exceed 10 feet.

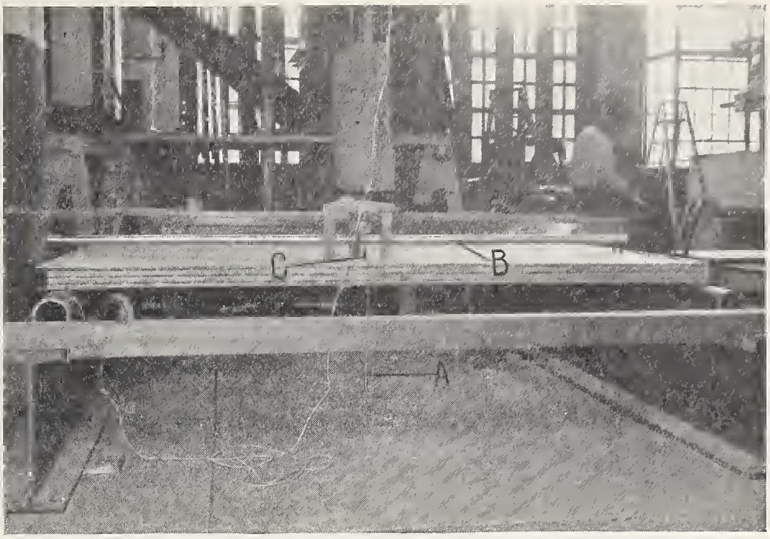

FIGURE 12.—*Apparatus for impact load on specimen, tested horizontally.*
A, deflectometer; *B*, set gage; and *C*, gage block.

(e) Masonry Constructions

For wall constructions, such as masonry, to which impact loads cannot be applied satisfactorily with the specimen in a horizontal position, the loads are applied with the specimen in a vertical position, as shown in figure 13, thus simulating service conditions. The specimen, *A*, on a steel channel, *B*, rests on cylindrical rollers, *C*, to prevent

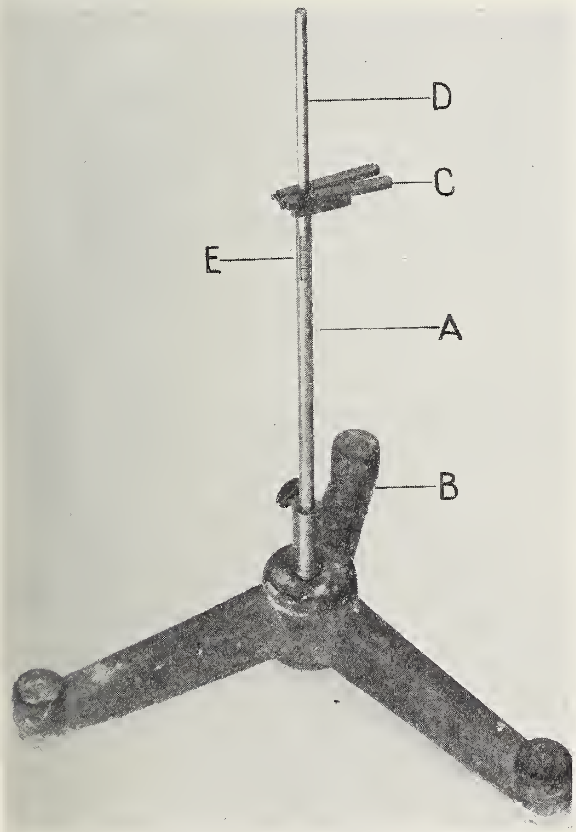

FIGURE 11.—*Deflectometer for measuring instantaneous deflection of specimen under impact loads.*
A, tube; *B*, base; *C*, friction clamp; *D*, rod; and *E*, fiduciary. mark.

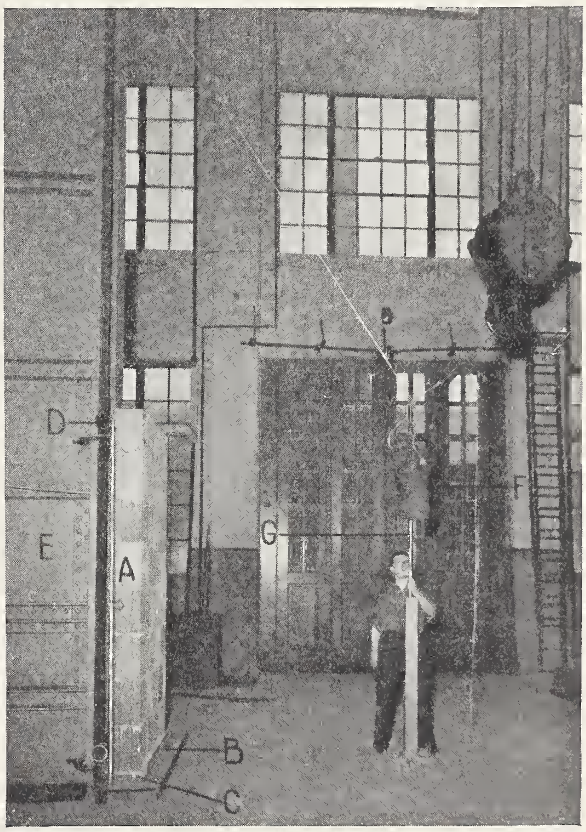

FIGURE 13.—*Impact load on specimen, tested vertically.*
A, specimen; *B*, channel; *C*, roller; *D*, supporting roller; *E*, frame; *F*, sandbag; and *G*, height-measuring tube.

constraint. The axes of the rollers are parallel to the faces of the specimens. The two supporting rollers, *D*, are in contact with the vertical surface of the frame, *E*, and each roller rests on sponge rubber about ½ inch thick to prevent longitudinal constraint. The impact load is applied by the sandbag, *F*, weighing 60 pounds, described in section VI–4–(b). The bag is supported as a pendulum and from its initial position against the middle of the face of the specimen is raised to the desired height, as determined by the measuring tube, *G*, and then released. The deflection under the impact load and the set are measured, using the instruments described in section VI–4–(c), for the impact tests on specimens in the horizontal position.

5. Racking Load

(*a*) *Specimen*

Tests are made on three duplicate specimens, each having a height of 8 feet, and a nominal width of 8 feet.

A nominal width of 8 feet, twice the width of the wall specimens for the other tests, was chosen because the less the width, the greater the vertical forces on the upper and lower ends required to prevent rotation of the specimen under a racking load.

(*b*) *Loading*

The specimen is tested as shown in figure 14, supported on its lower end with a block at the right to prevent horizontal movement when the racking load is applied. There are two tie rods at the left, one on each side of the specimen to prevent an upward movement of the left edge of the specimen. There are two steel plates separated by rollers between the upper end of the specimen and the plate on the tie rods to prevent horizontal constraint. The racking load is applied near the upper end to the left edge of the specimen, causing shearing stresses.

The racking loads are applied horizontally to the specimen *A*, figure 15, by a hydraulic jack, *B*, having a capacity of 50 kips. (A kip is 1,000 pounds.) To measure the load, the ring dynamometer, *C*, having a capacity of 50 kips is placed between the jack and the specimen. The error in the load indicated by the dynamometer does not exceed 1 percent. Horizontal movement of the specimen longitudinally under the racking loads is prevented by the stop, *A*, shown in figure 16. The stop is bolted to the base of the racking frame. There are plates between the end of the specimen and the stop.

(*c*) *Apparatus*

To measure the horizontal deformation of the specimen parallel to the faces and the set, a taut-wire mirror-scale measuring device is used for the racking load similar to the deflectometers used to measure the lateral deflection of the wall specimens under compressive load. The deflectometers are described in section VI–1–(c).

Two mirror scales, *A*, are attached horizontally to one face of the specimen, as shown in figure 17, one near the upper end and the other near the lower. A vertical wire, *B*, is attached to the frame, *C*, and tension in the wire is maintained by rubber bands. The frame, *C*, resting on the floor is moved to position the wire near the mirror-scales. Both mirror scales are read simultaneously before the specimen is loaded, then under a racking load, and again after the load has been released.

The tie rods shown in figure 14, and at *D*, figure 15, are provided to prevent vertical movement of the edge of the specimen to which the racking load is applied. However, there is a rotation of the specimen because the tie rods stretch elastically under load. A taut-wire mirror-scale device having the wire horizontal is used to measure this rotation which is subtracted from horizontal movement indicated by the mirror scales and the vertical wire to obtain the horizontal deformation and the set of the specimen.

(*d*) *Results*

For each mirror scale the movement under each racking load is the difference between the reading of the mirror scale and the initial reading. For the vertical wire the horizontal movement of the specimen is the difference between the movements for the two mirror scales multiplied by the ratio: 8 feet divided by the vertical distance between the mirror scales. Using a similar method and the readings for the horizontal wire, the vertical movement of the specimen is obtained and subtracted from the horizontal movement to obtain the actual horizontal deformation and the set of the specimen in a vertical distance of 8 feet for a given racking load.

The maximum racking load is recorded, provided this load does not exceed 50 kips.

VII. METHOD OF TESTING PARTITIONS, NONLOAD-BEARING

1. Impact Load

(a) *Specimen*

Tests are made on three duplicate specimens, each having a height of 8 feet and a nominal width of 4 feet.

Because most partitions are symmetrical about a plane midway between the faces, the results for impact loads applied to one face of a specimen should be identical with those obtained by applying impact loads to the other face.

(b) *Procedure*

The test procedure is identical with that for impact load on walls described in section VI–4, except that only three specimens are tested.

2. Concentrated Load

(a) *Specimen*

Tests are made on each of the impact specimens after the impact tests, the load being applied to the same face of the specimen.

(b) *Procedure*

The test procedure is identical with that for concentrated load on walls described in section VI–3.

VIII. METHOD OF TESTING FLOORS

1. Transverse Load

(a) *Specimen*

Tests are made on three duplicate specimens, each having a length of 12 feet 6 inches and a nominal width of 4 feet.

In a small house the length of a floor between supports and parallel to the joists is about 12 feet. A span of 12 feet was chosen for floor specimens because for shorter spans in the floor of a house the construction usually is identical with that for spans of 12 feet. For floor constructions included in this program, the strength for spans greater than 12 feet can

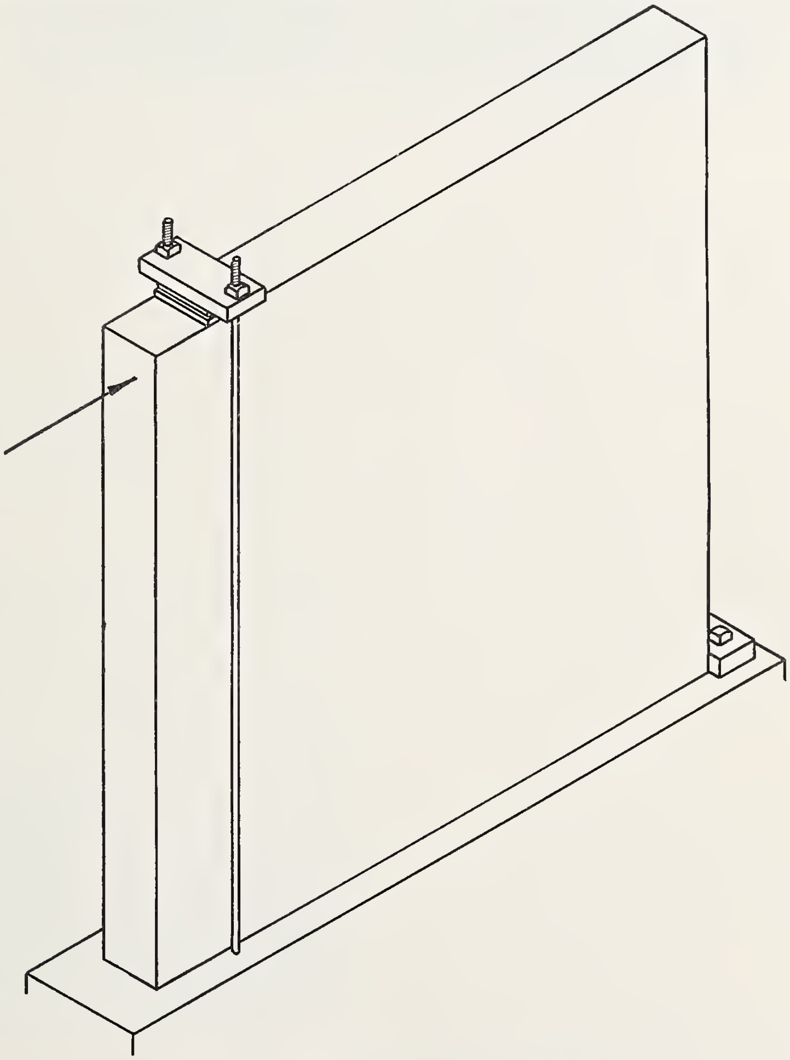

Figure 14.—*Racking load on specimen.*

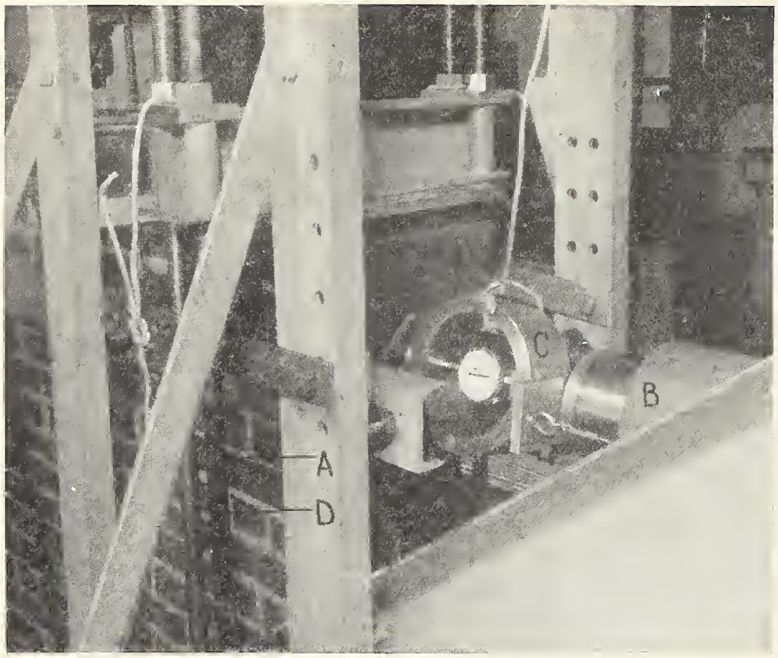

FIGURE 15.—*Racking load equipment.*

A, specimen; *B*, hydraulic jack; *C*, ring dynamometer; and *D*, tie rod.

be estimated with sufficient accuracy for practical purposes by the usual engineering methods.

The specimens are 6 inches longer than the span so that each end extends 3 inches beyond the support.

(*b*) *Procedure*

The test procedure is identical with that for transverse load on walls described in section VI–2, except that the span is 12 feet and the loads are applied only to the upper (finish floor) face of the specimen. No specimens are tested in the vertical position.

2. CONCENTRATED LOAD

(*a*) *Specimen*

Tests are made on each of the transverse specimens after the transverse tests.

(*b*) *Procedure*

The test procedure is identical with that for concentrated load on walls described in section VI–3, except that the loads are applied only to the upper (finish floor) face of the specimen.

3. IMPACT LOAD

(*a*) *Specimen*

Tests are made on three duplicate specimens, each having a length of 12 feet 6 inches and a nominal width of 4 feet.

(*b*) *Procedure*

The test procedure is identical with that for impact load on walls described in section VI–4, except that the span is 12 feet and the impact loads are applied only to the upper (finish floor) face of the specimen.

IX. METHOD OF TESTING ROOFS

1. TRANSVERSE LOAD

(*a*) *Specimen*

Tests are made on three duplicate specimens, each having a length of 14 feet 6 inches and a nominal width of 4 feet.

In a small house if the supports for the roof are vertically above those for the floor and the

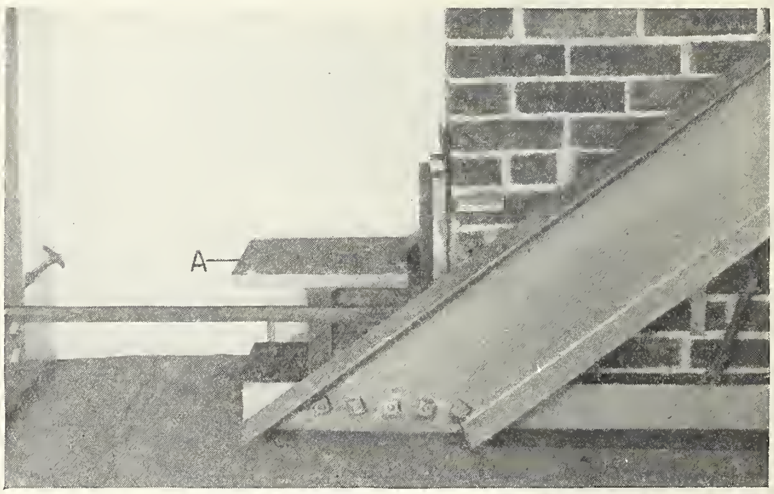

FIGURE 16.—*End of racking frame.*

A, stop.

horizontal distance between the supports is 12 feet (floor span) the roof span is also 12 feet if the roof is flat. If the roof slopes at an angle of 30° with the horizontal, the distance between roof supports measured along the roof is about 14 feet. For a low-cost house it is unlikely that the slope of the roof will exceed 30° (3 in 5) because the cost of the roof increases more rapidly than the increase in the angle of the slope. A roof span of 14 feet was, therefore, chosen for the roof specimen because for shorter spans in the roof of a house the construction usually is identical with that for spans of 14 feet. For roof constructions included in this program, the strength for spans greater than 14 feet can be estimated with sufficient accuracy for practical purposes by the usual engineering methods. The specimens are 6 inches longer than the span so that each end extends 3 inches beyond the support.

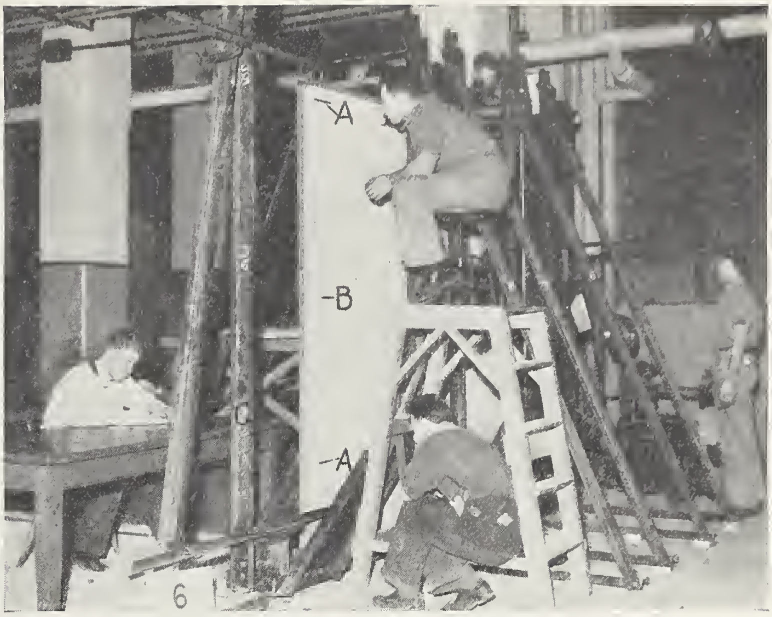

FIGURE 17.—*Apparatus for racking load on specimen.*

A, mirror scale; *B*, wire; and *C*, frame.

(*b*) *Procedure*

The test procedure is identical with that for transverse load on walls described in section VI–2 except that the span is 14 feet and the loads are applied only to the upper (weatherproofed) face of the specimen.

2. Concentrated Load

(*a*) *Specimen*

Tests are made on each of the transverse specimens after the transverse tests.

(*b*) *Procedure*

The test procedure is identical with that for concentrated load on walls described in section VI–3, except that the loads are applied only to the upper (weatherproofed) face of the specimen.

X. PRESENTATION OF RESULTS

The results of the tests are shown graphically. A typical graph for transverse loading of a wall, floor, or roof, is shown in figure 18. Results for the other tests are presented in a similar way. For all tests the loads are plotted as ordinates and the deformations as abscissas. For all specimens the load is applied in increments so chosen that a sufficient number of readings is obtained to determine definitely the load-deformation curve. The initial reading of the load and the reading of the deformation is recorded either with no load on the specimen or under a small initial load as at *a*, figure 18. The load is increased to the first increment, *b*, and the deformation recorded. The load is then decreased to the initial load, *a*, and the set (sometimes designated "permanent set") recorded. This set is plotted at *c*, the ordinate being the load which, when released, caused this set. The load is then increased to two increments, *d*, and the set when it is released to the initial load, *a*, plotted at *e*. This sequence of readings and points on the graph is then followed for three increments, four increments, etc. of load. There are three duplicate specimens for each test and the results for each specimen are shown on the same graph. Although the particular specimen for each point on the graph is not designated, they were recorded on the laboratory data sheets. The points for deformation under load are

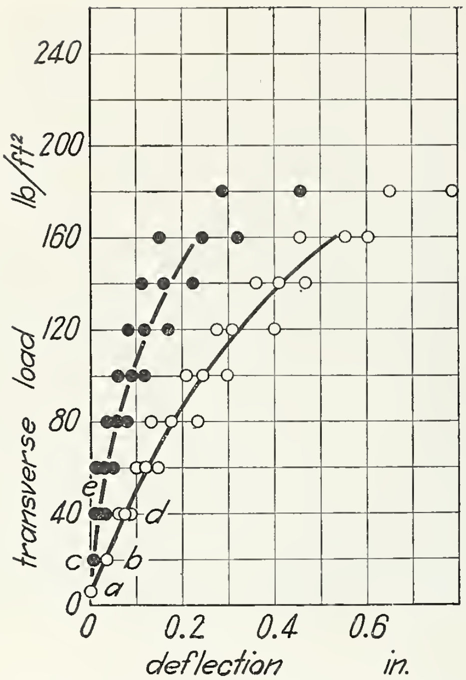

FIGURE 18.—*Typical graph showing results.*

Open circles—deformations under load; solid circles—sets after loads removed; continuous line—load-deformation curve; and broken line—load-set curve.

shown by open circles and those for set by solid circles. The three values for either the deformation or the set are averaged and this average value plotted in pencil on the graph. A smooth curve is drawn among the average points to show the average behavior of the construction. The load-deformation curves are continuous lines and the load-set curves are dashed lines. If readings are obtained under greater loads for some specimens than for others, all the values are plotted, but the curves are only drawn to the average values for which there are three valucs. When for each specimen the behavior of the specimen under load indicates that the specimen might fail suddenly and damage the deformation-measuring apparatus, this apparatus is removed from the specimen and the load increased continuously until the maximum load which can be applied to the specimen is determined. The maximum loads are not plotted on the graph but are given in the report. This method of testing by applying the loads in increments and measuring the deformation, then the set under the initial load, simulates, to some extent, repeated loading under service conditions. Therefore, results by such a method of loading may be more useful than those obtained by increasing the load continuously. They may show whether different portions of a construction act as a unit under load, whether the fastenings or bonds have adequate strength, or whether they rupture under repeated loads. For any engineering structure, including low-cost houses, it is necessary not only that the strength be adequate, but also that the deformation under load shall not appreciably decrease the usefulness of the structure. If the working load and the allowable deformation for an element for a house are known, constructions complying with these requirements may be selected by inspection of the graphs, provided the construction was included in this program.

A structure is elastic if, after a load has been applied and then removed, the set is inappreciable. If the set is small for an element of a house it may be assumed that the construction has neither been damaged nor appreciably deformed by the load. The set, therefore, is another property which may be used when comparing different constructions and may be useful when selecting a construction for a particular purpose.

Obviously, the differences between the points and the curve are a measure of the variations in the properties of the construction.

The variations in the properties of a construction as used commercially for houses, in all probability, are greater than the variations for the three specimens tested in this program because these specimens were all fabricated at the same time by the same workmen and from the same lot of material.

Building codes and specifications for house construction might logically give definite maximum values for either the deformation or the set, or for both, when the available information is adequate for determining these values. It is believed that the graphs and the maximum loads for the constructions included in this program for the determination of the structural properties of house constructions will give information which has not heretofore been available. This information should be of value to the construction industry and the public.

WASHINGTON, May 5, 1938.

The program of research on building materials and structures undertaken by the National Bureau of Standards is planned with the assistance of the following advisory committee designated by the Subcommittee on Design and Construction of the Central Housing Committee:

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