NATIONAL BUREAU OF STANDARDS

NBS BUILDING SCIENCE SERIES 58

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

State-of-the-Art of Structural Test Methods for Walls, Floors, Roofs and Complete Buildings

The Building Science Series

The Building Science Series disseminates technical information developed at the National Bureau of Standards on building materials, components, systems, and whole structures. The Series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

These publications, similar in style and content to the NBS Building Materials and Structures Reports (1938-59), are directed toward the manufacturing, design, construction, and research segments of the building industry, standards organizations, and officials responsible for building codes.

The material for this Series originates principally in the Center for Building Technology of the NBS Institute for Applied Technology. The publications are divided into three general groups: Building Systems and Processes; Health, Safety and Comfort; and Structures and Materials. For further information regarding these publications please contact the Scientific and Professional Liaison Section, Center for Building Technology, Institute for Applied Technology, National Bureau of Standards, Washington, D.C. 20234.

[See mailing list announcement on last page]

State-of-the-Art of Structural Test Methods for Walls, Floors, Roofs and Complete Buildings

C. W. C. Yancey and L. E. Cattaneo

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

NBS Building science series no. 58

Prepared for

Office of Policy Development and Research
Department of Housing and Urban Development
Washington, D.C. 20410

U.S. DEPARTMENT OF COMMERCE, Frederick B. Dent, *Secretary*
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, *Director*

Issued November 1974

Library of Congress Cataloging in Publication Data

Yancey, C. W. C.

State-of-the-Art of Structural Test Methods
Walls, Floors, Roofs, and Complete Buildings.
(National Bureau of Standards Building Science Series 58)
Supt. of Docs. No.: C13.29/2:58
1. Buildings—Testing. 2. Structural Frames—Testing.
I. Cattaneo, L. E., joint author. II. United States. Dept. of Housing and Urban Development. Office of Policy Development and Research. III. Title. IV. Series: United States. National Bureau of Standards. Building Science Series 58.

TA435.U58 No. 58 [TH845] 624'.171 74-23735

National Bureau of Standards Building Science Series 58

Nat. Bur. Stand. (U.S.), Bldg. Sci. Ser. 58, 139 pages (Nov. 1974)

CODEN: BSSNBV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1974

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
(Order by SD Catalog No. C13.29/2:58). Price $2.00

State-of-the-Art of Structural Test Methods for Walls, Floors, Roofs and Complete Buildings

by
C. W. C. Yancey and L. E. Cattaneo
Structures Section
Structures, Materials, and Life Safety Division
Center for Building Technology, IAT
National Bureau of Standards

ABSTRACT

As part of a comprehensive research program concerned with the structural testing of building components, conducted for the U. S. Department of Housing and Urban Development (HUD), a search for information was conducted. This search was undertaken in order to document existing information pertaining to structural testing of wall, floor and roof assemblies. Various information sources were consulted to trace the evolution of structural testing of building construction from the 1930's to the present time. This task was a prerequisite to defining the state-of-the-art and to identifying the test areas requiring fundamental research.

Based on information obtained from a review of the literature and from liaison with committees concerned with the development and revision of voluntary standards, it was found that there is a dearth of research information contributing directly to the development of test methods. Most of the research conducted on building components has been carried out either to observe the behavior of a sample of a particular type of construction or to evaluate the performance of a specimen against some performance requirements. However, helpful inferences can be made on the basis of some of the documentation, especially that contained in reports of full-scale tests on housing.

As a result of comparing the test methods used by the National Bureau of Standards in HUD project Operation BREAKTHROUGH with American Society for Testing and Materials (ASTM) Standard methods, several recommendations have been made by the authors for improving present structural test practice.

An up-to-date status report of voluntary test standards activities (in the U.S.) was prepared through verbal and written communication with members of the technical subcommittees of ASTM Committee E-6 on Performance of Building Construction.

Key Words: Building construction; complete buildings; floors; roofs; standardization; test methods; walls.

1.0 INTRODUCTION

A study of available information was undertaken for the purposes of documenting information applicable to structural test method development and determining what fundamental research is needed for the improvement of present test practice. To obtain the background of the present state of practice, the evolution of structural testing of building construction has been followed from its early stages to the present time. The information sources consulted are: indexes of governmental agency publications; Engineering Index; NTIS Search; libraries; lists of proceedings of symposia, colloquia and conferences; indexes of publications by standards associations; technical indexes; regulatory documents and codes of practice; individual researchers and committees concerned with the promulgation of voluntary test standards.

Chapter 2 presents a review of existing information as found in publications; a Bibliography containing all of the references cited is presented in Appendix A of the report. Included in the review are both publications of a general nature and material of specific reference to walls, floors, roofs or complete buildings. The principal findings of this part of the study are summarized at the end of the chapter.

The present status of standards for structural performance testing is discussed in Chapter 3. The most commonly-used standard methods are tabulated. The current activities of both domestic and international association are discussed, and a summary of standards under revision, as well as new standards in various stages of preparation, is presented.

A critique of some adopted test methods based on the experience of the National Bureau of Standards (NBS) with the structural testing of industrialized building components is presented in Chapter 4. There are 7 separately published test reports that provide material for Chapter 4. Five reports pertain to the testing of panels representative of proposed building systems in the Department of Housing and Urban Development Operation BREAKTHROUGH. The remaining two reports are of experimental studies of full-scale houses, one under field conditions and one under laboratory conditions. The test methods used in the NBS test program are discussed and compared with corresponding ASTM E72 standard methods. Several recommendations are made for improving the standard methods.

A review of requirements stated in codes, standards and performance criteria documents with respect to structural testing is summarized in Chapter 5. Typical clauses have been excerpted or paraphrased from a representative sample of foreign and domestic documents.

2.0 LITERATURE REVIEW

In order to document existing information pertinent to structural testing of building components, a review of the literature was undertaken. Thirty publications, spanning from 1937 to 1973, have been studied and are discussed in this chapter. To establish a framework for the review of reports of technical studies, several items of information were identified as being of uppermost importance. These items were: objective of the investigation, scope, main parameters considered, type of materials and construction and the main conclusions and recommendations presented.

It is intended that the summaries that follow supply this key information as well as convey the historical and technical significance of the work that is described. The summaries are sequenced in chronological order to aid in fulfilling the historical objective.

The summaries are arranged into five sections. The classification of the principal structural elements being investigated (i.e. walls, floors, roofs and complete buildings) provides the headings of four sections. The fifth section covers publications of a general nature which do not strictly fit any of the other four headings. The review of general publications is presented first. Table 2.1.1 illustrates the distribution of the subjects covered in the review by charting the types of construction in relation to specific test categories. The coded entries (G, general information; W, walls; F, floors; R, roofs; S, complete structures) refer to the accompanying lists (table 2.1.2) of publication titles which are arranged in the same order as the reviews appear in the report.

TABLE 2.1.1 – DISTRIBUTION OF SUBJECTS COVERED IN LITERATURE REVIEW

Bldg. Component		Compression	Flexure	Concentrated Load	Impact Load	Racking	Horizontal Diaphragm	General Information
WALLS	General	G-1, G-3, G-4	G-1, G-3, G-4	G-1, G-3, G-4	G-1, G-3, G-4	G-1, G-3, G-4		G-2, S-1, G-4
	Wood	S-4	S-4, S-6			W-2, W-3, W-7, W-8 S-3, S4, S6		
	Masonry	W-6	W-1			W-4, W-5, S-8		
	Concrete	S-5	S-5			S-5		
	Metal							
	Stressed Skin	S-9	S-10			S-7, S-9, S-10		
FLOORS	General		G-1, G-3, G-4, G-5	G-1, G-3, G-4	G-1, G-3, G-4		F-1, G-4	G-2, G-4, S-1, G-5
	Wood		S-6		S-6		F-2	
	Masonry							
	Concrete							
	Metal						F-3	
	Stressed Skin		S-10					
ROOFS	General		G-1, G-3, G-4, G-5	G-1, G-3, G-4			F-1, G-4	G-2, G-4, S-1, G-5
	Wood		R-2, S-4, S-6				F-2, R-1	
	Masonry							
	Concrete							
	Metal		S-2				R-3	
	Stressed Skin		S-10				S-10	
COMPLETE STRUCTURE	General		G-4, G-5			G-4, G-5		G-4, S-1, S-11, G-5
	Wood	S-4	S-4, S-6		S-6	S-3, S-6		
	Masonry		W-1, S-8			S-4, S-8		
	Concrete	S-5	S-5			S-5		
	Metal	S-2	S-2					
	Stressed Skin	S-9	S-7, S-9, S-10			S-7, S-9, S-10	S-10	

G-GENERAL INFORMATION
W-WALLS
F-FLOORS
R-ROOFS
S-COMPLETE STRUCTURES

(SEE ALSO ATTACHED LIST OF PUBLICATIONS, TABLE 2.1.2)

Table 2.1.1 - Distribution of subjects covered in literature review.

Table 2.1.2 - Publications referenced in table 2.1.1 on structural testing grouped by types of construction.

GENERAL INFORMATION

G-1 "Structural Properties of Low-Cost House Construction [43]*
by National Bureau of Standards

G-2 "Research on Building Materials and Structures for Use In Low-Cost Housing" [20]
by H. L. Dryden

G-3 "Methods of Determining the Structural Properties of Low-Cost Housing Constructions" [49]
by H. L. Whittemore, and A. H. Stang

G-4 "A Philosophy of Loading Tests" [19]
by D. B. Dorey and W. R. Schriever

G-5 "The Testing of Structures" [38]
Report of a Committee set up by the United Kingdom Institution of Structural Engineers

STRUCTURAL EVALUATION OF WALLS

W-1 "Transverse Strength of Masonry Walls" [30]
by C. B. Monk, Jr.

W-2 "The Racking Resistance of Frame Wall Construction [24]
by M. W. Isenberg, R. M. Branoff and R. R. Mozingo

W-3 "Guides to Improved Framed Walls for Houses" [4]
by L. O. Anderson

W-4 "Shear in Grouted Brick Masonry Wall Elements" [7]
by J. A. Blume and J. Proulx

W-5 "Structural Behavior of Masonry Infilled Frames Subjected to Racking Loads" [13]
by C. Carter and B. S. Smith

W-6 "Experimental Determination of Eccentricity of Floor Loads Applied to a Bearing Wall" [47]
by D. Watstein and P. V. Johnson

W-7 "Racking Resistance of Timber Framed Walls" [35]
by T. Ramstad, V. D. Reyers and E. B. Espiloy, Jr.

W-8 "Racking Strengths and Stiffnesses of Exterior and Interior Frame Wall Construction" [34]
by NAHB Research Foundation, Inc.

Table 2.1.2 continued - Publications referenced in table 2.1.1 on structural testing grouped by types of construction.

STRUCTURAL EVALUATION OF FLOORS

F-1 "Testing of Large Diaphragms" [14]
by R. D. Cousineau

F-2 "1966-Horizontal Plywood Diaphragm Tests" [45]
by John R. Tissell

F-3 "Deflections of Light-Gage Steel Floor System Under Action of Horizontal Loads" [32]
by A. H. Nilson

STRUCTURAL EVALUATION OF ROOFS

R-1 "Lateral Tests on Full-Scale Lumber and Plywood Sheathed Roof Diaphragms" [42]
by J. R. Stillinger

R-2 "Loading Tests on Full-Scale House Roofs" [44]
by H. J. Thorburn and W. R. Schriever

R-3 "Strength and Behavior of Light-Gage Steel Shear Diaphragms" [27]
by L. D. Luttrell

STRUCTURAL EVALUATION OF COMPLETE HOUSES

S-1 "Strength of Houses" [48]
by H. W. Whittemore, J. B. Cotter, A. H. Stang and V. Phelan

S-2 "Evaluation of 40-ft by 100-ft Frameless Straight-Sided Prefabricated Metal Utility Building" [29]
by the U.S. Naval Civil Engineering Research and Evaluation Laboratory

S-3 "Rigidity and Strength of Houses Built of Plywood Stressed Cover Panels" [28]
by R. F. Luxford and E. C. O. Erickson

S-4 "Structural Tests of a House Under Simulated Wind and Snow Loads" [18]
by D. B. Dorey and W. R. Schriever

S-5 "Full-Scale Tests of Pre-Cast Multi-Story Flat Construction"[21]
by A. J. Francis, W. P. Brown and S. Aroni

S-6 "The Wood-Frame House as a Structural Unit" [50]
by National Forest Products Association

S-7 "Effect of Wind Pressure on the Racking Strength and Stability of a One-Story, Gable-Roof Building of Sandwich Panel Construction" [17]
by Simon H. Diskin, Consulting Engineer

Table 2.1.2 continued - Publications referenced in table 2.1.1 on structural testing grouped by types of construction.

S-8 "Model and Full-Scale Tests on a Five-Story Cross-Wall Structural Under Lateral Loading" [40]
by B. P. Sinha, H. P. Maurenbrecher and A. W. Hendry

S-9 "Test and Evaluation of the Prefabricated Lewis Building and Its Components-Phase 1, Part 2-Full Scale Building Tests" [36]
by T. W. Reichard and E. V. Leyendecker

S-10 "Tests and Evaluation of the Prefabricated Lewis Building and Its Components-Phase II" [26]
by E. V. Leyendecker and T. W. Reichard

S-11 "A Facility to Evaluate Three-Dimensional Performance of Modules of Houses" [8]
by K. H. Boller

2.1 General Information

"Structural Properties of Low-Cost House Construction" [43]*
by National Bureau of Standards

This Letter Circular, LC-502-A, is a leaflet produced for public distribution by the National Bureau of Standards in 1937 that contains descriptions of test methods. This was possibly the first reference to test methods forming the basis of ASTM Test Method E72 (originally issued in 1947). The Letter Circular is the forerunner of National Bureau of Standard-Building Materials and Structures Report BMS 2 [49] which is more widely known. Circular LC-502-A is supplementary to LC-502 which discussed generally, the then current federal research program related to a study of building materials and structures for use in low-cost housing.

The Circular describes test procedures to be used in determining the structural properties of walls, partitions, floors and roofs. The description includes requirements for size and number of specimens. The types of test loads described include compressive, transverse, impact, racking and concentrated loads for various structural elements, and, lastly, vertical shearing load at a butt joint between prefabricated floor panels.

Requirements are also given for maximum load capacities of specimens and for allowable permanent deformations after application of specified loads. However, these requirements were offered, not for use in building codes, but only as a guide in the selection of constructions for further study. If the performance of a construction did not comply with certain minimum requirements, no further tests were made.

Although the Circular considers numerous categories of structural test methods, it is very brief in its descriptions of these methods. It was intended to be a preliminary documentation of procedures that were being planned for use, therefore, it lacks some of the details to be found in BMS2 [49] which superseded it; hence it is primarily of historical interest.

"Research on Building Materials and Structures for Use In
Low-Cost Housing" [20]
by H. L. Dryden

This was the first (BMS1) of a series of publications--the National Bureau of Standards Building Materials and Structures (BMS) Reports--originated in 1938 to deal with the technical aspects, procedures and results of tests associated with a federally-funded research project. In this first report, however, the content is devoted to a general explanation of the intent of the research program that was being formulated with the advice of various government housing agencies by a committee of NBS division chiefs under the chairmanship of the author. The program was funded by Congress for the purpose of assisting progress in the building industry to attain the goal of satisfactory housing within the means of those in need of it.

The stated objective of the investigation was "to furnish government agencies, the building industry and the public, technical information from every available source on the engineering properties of building

*The bracketed number corresponds to the publication's listing in the Bibliography in Appendix A.

materials as incorporated in the structural elements and equipment of a house, with particular reference to low-cost housing, and including new materials, equipment and methods of construction as well as those already in use."

In discussing the procedure and scope of the program the author points out that, for simplicity, structural testing was to be limited to laboratory investigation of structural elements. These elements were to be suitable for detached houses, new houses and low-cost apartments. New as well as conventional constructions were to be included in the study, but their selection was narrowed by a cost limitation to restrict the investigation to constructions (and equipment) suitable for a low-cost house. The report closes on the note that in the BMS reports which are to follow, NBS is to serve as a fact-finding agency and that reports are not to be construed as "approvals."

In retrospect, 152 BMS Reports were published. Of the 45 that involved structural testing, almost all presented performance data on particular types of construction. The testing methods used in obtaining the data contained in these reports are referenced to BMS 2 [49], which is devoted to the descriptions of such procedures.

"Methods of Determining the Structural Properties of Low-Cost Housing Constructions" [49]
by H. L. Whittemore, and A. H. Stang

This is the first formal publication (BMS2) that describes methods in use (in 1938) in the NBS laboratories for measuring the strength, stiffness and resistance to local damage of types of construction intended for walls, partitions, floors and roofs of low-cost housing construction. The tests which are described were designed to provide information on 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 is also described and includes the description of a loading procedure for determining permanent deformation (set) at progressively higher load levels.

Unlike its predecessor, NBS Letter Circular LC-502A, this report does not suggest acceptable levels of performance, but is restricted to the various procedures for testing, all of which formed the basis for ASTM Method E72 (originally issued in 1947). It promotes the structural testing of elements such as floors, walls and roofs rather than complete houses, for the sake of efficiency and economy. The authors cite house testing as being too expensive, time consuming and limited by the response of the weakest element in providing information on performance of the whole structure. Recommendations are made for the size and number of specimens and the method of loading. Instrumentation suitable for the measurement of deformation and displacement is described and consideration is given to using modified procedures for specimens of different types of construction.

It is interesting to note that the Foreword of the report contains one of the earliest references to the probability of performance requirements and performance tests finding their way into building codes to replace prescriptive clauses for conventional construction.

"A Philosophy on Loading Tests" [19]
by D. B. Dorey and W. R. Schriever

This paper, presented at the 58th Annual Assembly of the American Society for Testing and Materials, in June 1955, addresses the need for a systematic approach to formulating structural performance test specifications. Two critical shortcomings in the building codes of 1955 were found to be in the areas of test load determination and test result determination. As a requisite to the derivation of a philosophy on structural testing, several important factors to be considered in such a formulation were discussed on the basis of the then current state of knowledge. The distinguishing characteristics of three structural test categories were given in the following order: 1) an "acceptance test", 2) a "rating test", and 3) a "research test". The authors concluded the paper with two significant proposals based on their assessment of the existing state of knowledge. First, they derived a proposed method for determining the magnitude of the test load. Secondly, they suggested some guidelines for developing a criteria to be used in assessing structural adequacy on the basis of the test results.

From a review of the specifications for structural performance tests included in building codes from various parts of the world, the authors concluded that the "specifications differ in principle, detail and procedure". The results of the code review were summarized in a table which listed the requirements for the following factors: type of test, time of test, superimposed test load, duration of loading, requirements after loading and requirements on removal of loading. Five of the thirteen specifications so summarized pertained to concrete exclusively, and five others pertained generally to all construction materials. The lack of a standard set of descriptions for expressing the <u>type of test</u> was indicated by the use of a common label such as "strength", by a number of codes to express significantly different structural requirements. For example, one code stated a qualitative "no signs of failure" in a specification for concrete strength testing while another one cites the requirement for concrete strength quantitatively, in terms of limiting deflections. It is of interest to note that a similar survey was conducted in 1964 by a committee charged by the United Kingdom Institution of Structural Engineers. A tabular summary of this survey can be found in reference [38]. A summary of a 1973 survey conducted for this report is presented in Chapter 5.

In reviewing the discussions of the three structural test categories named by the authors, it is observed that the categories are delineated on the basis of circumstances in practice that dictate the test. For example, an <u>acceptance test</u> is one performed on a completed structure or part thereof to determine the structure's acceptability to some designated set of requirements. On the other hand, a <u>rating test</u> is one performed on a number of specimens to determine the acceptability of a commercially produced type of construction. A <u>research test</u> is one performed to investigate the structural behavior of a type of construction. In contrast to the rating and research tests, the acceptance test serves to establish that a minimum allowable level of strength or stiffness is achieved by the structure in question. Both the rating test and the research test may have as one of their objectives the determination of a load factor by safety applicable to the type of construction in question. In which case they possess the common characteristics of requiring the load to increase until failure has occurred. It should be emphasized that the standardization of test categories is a very important prerequisite to the development of structural test specifications.

The lack of a common understanding of the relationship between the test requirements and the structural performance of actual structures renders the testing profession to relatively the same position it was in nineteen years ago. The current use of such terms as "proof-load testing", "acceptance testing", "prototype testing" "quality-control testing" and "ultimate strength testing" to indicate in many instances the same set of test circumstances is symptomatic of the problem.

Before presenting their suggested approach to determining test loads and to interpreting test results the authors briefly discussed eleven factors to be considered in test formulation. These factors are listed below and each item is followed by a comment whose purpose is to inform the reader of the nature of the discussion.

A. Classification of Structures

The structures referred to in the paper were classified as statically determinate or statically indeterminate.

B. Intended Use of Structure

"The risk of failure, that is, the losses in human lives and valuable property which would result from failure depends upon the use and occupancy of the structure."

C. Materials of Construction

The physical and chemical properties of a given material determine the use for which that material is most suited.

D. Standard of Workmanship

The variability of workmanship is critical to the structural performance of some types of construction (e.g. concrete).

E. Design Loads and Actual Loads

Consideration should be given to the probability of overloading with respect to the recommended design loadings.

F. Overdesign for Special Reasons

The excessive loads anticipated to occur during construction may warrant the overdesigning of a structure.

G. Types of Failure

Failures are classified into three types: 1) those without warning, 2) those occurring after yielding has taken place at a certain load, and 3) those that are marked by a state of unserviceability at a certain <u>safe</u> load.

H. Factor of Safety

The distinction is made between "stress factor of safety" and "load factor of safety"

I. Risk of Failure

This factor is concerned with potential danger to human life and valuable property during the structure's service life.

J. Duration of Loading

The discussion centers on the effects of long-term loading on the deformations of certain types of construction. (e.g. wood)

K. Repeated Loading and Vibration

The discussion touches on only the subject of fatigue strength considerations for some design considerations.

From the above listing it is observed that all of these factors are of concern to the structural designer and the structural evaluator.

In the proposed method of test load determination, the authors explained that the magnitude of test loading in an acceptance test may be made up of three parts which are directly additive. The first part consists of the total design live load plus any necessary dead load additions. The second part is expressed as a certain percentage of the design live load, based on the intended use or occupancy and on the type of failure (see the three classes of failure mentioned above). The applicable percentage could be determined from any one of three curves depending on the type of failure usually experienced by the type of structure in question. The third portion is expressed as a percentage of design live load and it is determined by summing percentages of design live load attributed to such factors as workmanship, deterioration and fatigue. Although a tabular format was suggested for presenting the percentages based on the latter factors, no attempt was made by the authors to establish such values. For the rating test the magnitude of test loading may also be composed of three parts. However, the third part would contain an additional percentage based on the variability of test results for various materials and on the relative sample size.

The proposed criteria for evaluating structural performance on the basis of test results are fundamentally sound, but remains too general to offer sufficient guidance in actual test applications. A good point for test specification writers to keep in mind is the recommendation that a combination of criteria be used in specifying strength requirements in an acceptance test. That is, a combination of maximum deflection and minimum deformation recovery, coupled with the absence of any signs of distress in the primary structural components should be used in strength requirements.

This paper expounded on some important fundamental subjects related to structural performance testing and this in itself was a rarity. It took an active, rather than passive, position in that certain recommendations were made to implement the then current state of knowledge. The future development of new and improved standard test methods is dependent on additional energies being expended to establish a standard set of terms to express certain concepts and to systematically establish the magnitude of test loading for different test conditions.

"The Testing of Structures" [38]
Report of a Committee set up by the United Kingdom Institution
of Structural Engineers

In 1962, an ad hoc committee was charged by the United Kingdom Institution of Structural Engineers with the mission of examining various code requirements for structural behavior as they relate to acceptance testing and of developing some recommendations for a rational basis for structural tests in general. This report, published in 1964, presents the Committee's findings and advances some guidelines for the practitioner who must devise and execute tests to satisfy code requirements.

The guidelines are aimed mainly at the testing of new structures; however, testing of bridges, liquid-containing structures, foundations, piles and materials are specifically excluded from the scope. The Committee notes that some modifications of the test guidelines may be necessary to deal with proof testing of old structures. Although no provisions are stated for implementing dynamic testing, the authors acknowledge the limitations of static loading tests and alert the engineer to consider other design forces such as fatique loading.

Initially, the report defines two general types of tests- an acceptance test and a test to destruction to determine ultimate strength- and summarizes the circumstances which usually make testing necessary. The section on Testing Procedure points out some factors to consider in applying and recording the load and in measuring the resulting deformation and stress. For example, when considering a procedure for load application, it is recommended that the test load be applied in stages or increments. Often it is desirable to follow the same procedure for load removal (i.e. by load decrements). Specifically, the authors recommend "that the number of load increments (or decrements) should be about ten and not less than five."

Another section of the report discusses test requirements with respect to load factors, duration of loading, acceptable deformations and acceptable defects. On the subject of duration of loading, the main conclusion is that "the test load on a structure need not be maintained longer than required to ensure that its effects are fully realized." The time required for a test specimen to adjust to applied loading is mainly influenced by the type of materials involved; to emphasize the point the Committee compares the time needed by metal structures (a few minutes) for settling down to that necessary for adjustment by timber structures (several hours). One of the several milestones in this report is the set of recommendations for minimum times to be allowed for load application or load removal, prior to making measurements and observations. These quantitative recommendations are stated for several stages of test, with a distinction being made between "elastic" and "non-elastic" materials. In order to establish a set of limits for acceptable deformation and recovery, a survey of current practice was executed. Several codes were reviewed in relation to their requirements for deflection limits and the limits are summarized in a table. Then some recommendations are made for deformation limits to be observed during testing as well as for acceptable rates of recovery. A table summarizing the code requirements for acceptance tests, similar to the one prepared by the Committee, can be found at the end of Chapter 5 (see table 5.5).

2.2 Structural Evaluation of Walls

"Transverse Strength of Masonry Walls" [30]
by C. B. Monk, Jr.

In the general absence of design code provisions for the transverse strength of unreinforced masonry walls, the author set out to provide some basis upon which design requirements could be established. The investigation was primarily aimed at evaluating the transverse strength of 6-in brick walls. Starting about 1951, this study was comprised of three distinct stages: 1) transverse tests were performed in the laboratory on nine -ft x 8-ft brick wall specimens, 2) the exterior walls of an 18-ft by 22-ft by 8-ft high model house were tested to check the laboratory forecast of strength and 3) another set of 4-ft by 8-ft brick walls were tested in the laboratory under different end conditions from those in stage 1. In order to provide a basis of comparison for the 6-in brick walls with conventional wall construction (for that period) tests paralleling stages 2 and 3 were performed for 8-in brick block wall and 10-in brick cavity wall specimens.

In the first stage of testing, the type of mortar was a variable while the same type of brick was used for all nine specimens. Three wall specimens each were prepared from three types of mortar. Following the recommendations for transverse loading presented in "Building Materials and Structures Report, BMS No. 2 [49], quarter-point loading was applied to the walls, placed in a vertical position. The support condition at the ends of the 7-ft 6-in-span and the support at the base of the wall conformed to the recommendations of BMS No. 2. The specimens were loaded to failure and the average maximum load and modulus of rupture were tabulated for each type of mortar. The recommendations for determining the allowable load for masonry walls given in Building Materials and Structures Report, BMS No. 109 [48] were consulted to derive allowable loads for the nine specimens for an 8-ft span.

To check the laboratory prediction of transverse strength of 6-in brick walls, a model single-story, brick house was tested. The mortar used in constructing the model house was identical to one of those used in the first stage of testing. Since uniform pressure was held to be more representative of the lateral forces to which walls are subjected in service, an air bag system was used for applying the load sequentially to each exterior wall. Hence, the method of loading and the boundary conditions of the walls were differed in stage 2 from the corresponding parameters in stage 1. The air pressure was measured by using the average of three manometers and the desired lateral pressure was obtained by adjusting the head of water above the bottom of two standpipes. According to the author, the pressure was maintained reasonably constant during the time required for reading deflections. To provide a check on the manometer readings, the connections of the reaction framework were instrumented with electrical strain gages. The framework was so designed that the strain readings could be used to determine the total reaction force. A grid system was employed on the inside of each wall to locate the dial gages used for measuring the lateral deflections.

Typically, load-deflection curves starting with an initial zero load and terminating at the failure load were drawn for each data point. It was noted that the curves generally were characterized by an initial straight portion, indicative of a linear relationship between load and deflection. A method for determining the "yield strength load" was developed. This "yield strength load" corresponded to the ordinate of the point of intersection of a line parallel to and offset from the initial slope of the load-deflection curve. The amount of offset was equivalent to the deflection at the point of transition from linearity to non-linearity. This method could be useful in comparing the performance of different types of masonry walls, provided there is close correlation between the test parameters for any two cases. It was noted that tests identical to the stage 2 testing were performed on an 8-in brick-block, and a 10-in cavity, wall model for the purpose of comparing performance.

It was because of a high percent difference between the results of stages 1 and 2 that it was decided to test additional 6-in brick walls in the laboratory, with the air bag system. The "yield strength loads" obtained in stage 2 suggested considerably higher strengths than the average maximum loads obtained for identical construction in stage 1. Three 4-ft by 8-ft brick-wall specimens, 6 in thick, were subjected to uniform pressure and at the same time the field boundary conditions were more nearly simulated. Contrary to the base support treatment in stage 1, these three walls were tested flat-ended without the benefit of base rollers. An identical procedure was performed for three 8-in brick-block and three 10-in cavity wall specimens. The test results for stage 3 did indicate, for the 6-in walls, a closer prediction of the field strength than was obtained from the results of stage 1. To justify the apparent higher transverse strengths obtained by using the air bag system, as opposed to the quarter-point loading the author performed some calculations based on the so-called "Statistical Theory of Rupture." To quantify the influence of method of loading on mean strength the author concluded that "theoretically, on the average, the uniform loading, depending on end conditions, will yield mean strengths 8.8 to 17.1 percent greater than the quarter-point loading for the case discussed* [masonry construction with a coefficient of variation of 16.8]." It is interesting to note that although ASTM Standard E72-68 [5] does include both methods of loading, there is no related commentary pertaining to the possible influence of the loading method on the test results.

"The Racking Resistance of Frame Wall Construction" [24]
by M. W. Isenberg, R. M. Barnoff and R. R. Mozingo

The report done by Pennsylvania State University for FHA in 1963 contains the results of a limited study and its main contribution is a survey of existing information on the racking resistance of frame wall construction. The survey was made to determine what research was required to arrive at a procedure for the determination of racking strength. A pilot testing program was conducted to evaluate existing test procedures and examine the feasibility of performing racking tests by a diagonal compression procedure.

One output of the survey, a bibliography of 72 references, provides background on the racking test for wall panels and documents the need for its improvement. The authors express the opinion that the literature available to them was, in general, rather limited in depth since most laboratories had confined their work to tests of panels rather than basic research on the racking problem. In addition, the survey included documentation of opinions on the racking test and associated problems given by researchers in 36 laboratories and institutions. In discussing the merits of the then existing techniques of racking testing and the needs of the racking evaluation problem, the authors consider such topics as manner of load application, participation of wall anchorage in resistance to racking, the extent to which undesirable racking effects are developed, and limitations on racking distortion imposed by various regulatory organizations. The existing ASTM E72 standard racking tests, including those of specimens conditioned by wetting, are discussed and a proposal is made for an alternative method of loading employing diagonal compression.

A laboratory comparison of the existing standard method and the proposed method made use of panel specimens of one height (8 ft) and three different widths (8 ft, 4 ft and 2 ft). A total of 7 comparative tests were performed. These comprised an 8-ft x 8-ft control specimen and 3 sets of duplicate specimens of the above sizes. The control specimen used 2 x 4 wood stud framing with horizontal 1-in x 8-in board sheathing and a 1-in x 4-in diagonal let-in brace; the other specimens used similar framing with 5/16-in plywood sheathing and no brace.

One group of tests was performed in accordance with ASTM Method E72. The instrumentation for measuring displacements met the requirements of the ASTM procedure and was augmented by additional instruments for measuring other, unspecified deflections and loads for correlation with similar observations made in the proposed method.

The diagonal load tests were performed with the plane of the specimens in a horizontal position. The diagonal compression load was applied between two opposite corners of the specimens by a hydraulic jack through tie-rods. Load was indicated by strain gages on the tension bars and deformation

*The portion in brackets is not part of the quotation.

of the specimen was measured by a single dial gage mounted along the diagonal joining the unloaded corners of the specimen.

The authors discuss the additional information needed for the development of a satisfactory racking test and outline a plan for future research. For this interim period of research, recommendations are made to extend and standardize the existing requirements for adequate racking resistance stated in FHA Circular 12 [41] and determined by ASTM Method E72. One major departure from those existing requirements involves the recommendation of an alternate test involving panels in a wetted condition.

The report is not only a useful guide to testing by racking but is also helpful in that many of the problems discussed are common to other test methods. The major contribution of the report is its state-of-the-art survey of racking resistance and its documentation of the strong need for improvement of existing racking test methods and criteria.

"Guides to Improved Framed Walls for Houses" [4]
by L. O. Anderson

As indicated in its summary, the paper itself is a summary of work reported by the Forest Products Laboratory (FPL), U.S. Department of Agriculture during the period 1934 to 1958. Comparisons are made of the relative racking rigidity and strength of sheathed framed walls, with and without openings, and ranging in size from 8 ft x 8 ft to 12 ft x 18 ft. Relative values are based on the performance of a control, conventional frame wall without openings made up of nominal 2 x 4-in studs spaced at 16 in on center and sheathed with horizontal 1 x 8-in lumber fastened to each stud with two eight penny common nails.

Of particular interest to the present survey, however, is a photographic illustration of an FPL racking apparatus. This fixed steel frame has the capability of racking an 8-ft x 8-ft panel in opposite directions in one setup. The reversible feature of the equipment was used in testing panels constructed with diagonally placed board sheathing. Although no details are given about this equipment, its reverse loading feature makes it desirable as a prototype reference in the event of any development of a proposed standard cyclic racking test.

"Shear in Grouted Brick Masonry Wall Elements" [7]
by J. A. Blume and J. Proulx

At the request of the Western States Clay Products Association, John A. Blume and Associates conducted a research testing program in 1964-68 to study the shear capacity of grouted brick masonry wall panels. Tests were made on 84 4-ft by 4-ft grouted masonry panels to explore the effects of various parameters (including reinforcement, grout, core thickness, brick strength and brick absorption rate) on shear strength and energy capacity. Although some tests were also made to evaluate the damping of 4-ft-square wall panels, made to vibrate freely in a transverse mode by impact loads, the major effort deals with "shear" as measured by diagonal tension--the usual control in seismic design and response of walls and wall elements. The test procedure finally selected after preliminary study was one of compression loading across two diagonally opposite corners of a square panel to develop tension normal to the loaded diagonal. The report is included here primarily for its consideration and discussion of the diagonal tension test method used to evaluate racking shear capacity of brittle wall panels.

The authors selected the diagonal loading technique as most appropriate for obtaining the desired results (shear capacity) with masonry elements. Their reasons for choosing this method over others, such as a pure shear technique, ASTM-E72, or certain modifications of ASTM-E72, were that the diagonal test was easier to perform and developed a state of stress in the panel that was known with greater clarity. Equations are given for average shear stress on a test wall panel section parallel to its base and top edges, as well as for maximum diagonal tensile stress acting normal to the load line at the center of the panel. Although all of the shear tests involved only a diagonal compressive force, there are also presented stress equations for cases of (a) a diagonal compressive force plus uniform pressure normal to a parallel pair of panel edges and (b) an applied shear plus triangularly-distributed counteracting pressure normal to a parallel pair of panel edges.

Aside from the particular values determined for the constructions tested, this report presents what appears to be a favorable method for obtaining shear strength, energy capacity and ductility related to racking in brittle materials. However, appropriate though it might be for materials which fail in diagonal tension, it would also appear necessary to investigate the adaptability of the method to testing materials for which the critical factor is not diagonal tension, but rather compression which would be developed in the vicinity of the loading corners of a specimen.

"Structural Behavior of Masonry Infilled Frames
Subjected to Racking Loads" [13]
by C. Carter and B. S. Smith

Chapter 27 on <u>Designing, Engineering and Construction with Masonry</u> reports on a three-year investigation, begun in 1965, into the stiffness and strength of masonry infilled frames subjected to in-plane racking loads. Laboratory investigations prior to this study had already succeeded in describing the three modes of failure which can occur in masonry infilled frames as a result of racking loads:

"1. local crushing of the masonry or mortar close to the applied load or at its reaction.

2. tension cracking along the mortar joints or through the masonry.

3. shear cracking along the mortar joints."

This investigation was concerned primarily with deriving a method of predicting the shear failure of the infill panel. Mode 3 was considered the most probable for "mortar-jointed masonry" because of the reduced shear strength along the mortar joints.

Two secondary derivations were obtained as a result of the elastic stress analysis performed by the authors. Infill panels of different stiffnesses and length-height proportions were analyzed for an assumed edge-load distribution and length of contact between the surrounding column and the infill panel. As a result of a finite difference solution of the biharmonic equation, normal and shear stresses were obtained throughout the panels. These stress analysis results were used to determine the magnitude and orientation of the principal shear and tensile stresses. The principal shear stress computations provided the basis for deriving a formula for predicting the magnitude of diagonal load necessary to cause shear failure in the infill panel. The principal tensile stress values provided a basis for the prediction of the diagonal load necessary to cause a diagonal tension failure (refer above to the description of mode 2).

A means of estimating the lateral stiffness of infilled frames was also obtained. It was conceived that the infill panel could be replaced by an equivalent diagonal strut whose effective width could be ascertained once the diagonal strains in the panel were known. The diagonal strains were calculated from the stress analysis results. By comparing the theoretical values of the effective widths with experimental values obtained from model testing, it was found that the former were excessive. Nevertheless, a rough estimate of the lateral stiffness can be obtained by assuming the frame to be pin-jointed, replacing the infill with equivalent struts and using a conventional pin-jointed frame analysis.

The authors compared the predictions of shear failure as determined by their derived method with several published test results. The percent of correlation varied over a wide range, but is not entirely reflective of the accuracy of the method. The necessity for estimating the value of the coefficient of internal friction of the various masonry composites was one factor contributing to the disparity.

This study of the behavior of masonry-infilled frames has resulted in substantial progress toward the development of a reliable design and analytical tool. There is a need for refining the proposed methods of strength prediction to achieve closer correlation with available test results.

"Experimental Determination of Eccentricity of Floor Loads Applied to a Bearing Wall" [47]
by D. Watstein and P. V. Johnson

An exploratory study was conducted by the Structural Clay Products Institute Research Fellowship to determine the feasibility of measuring the eccentricities of axial loads applied to load-bearing masonry walls. The research was performed at the National Bureau of Standards during 1968. The principal investigatory tool was a specially-designed, stress-sensitive, steel strut, which was assumed to simulate a load-bearing brick wall.

The steel strut was a rectangular tube 4 by 8 inches in cross section with a wall thickness of 0.187 in. The strut was 18 in high and had a 3/8-in welded steel plate insert at the top providing a closed end. A 1- by 4- by 8-in cold-rolled steel plate was bonded to the top welded plate insert with expoxy cement. The entire steel assembly was capped with a solid extruded clay brick which served to receive the load. This assembly was judged to simulate the bearing conditions at the top of a brick masonry wall. The open bottom end was machined normal to the axis of the strut and was supported on a machined steel plate 4 in thick. The strut was instrumented with two wire strain gages on each of the 4-in wide faces.

The underlying thesis of the study was that a calibration curve could be obtained for the steel strut by applying an axial load of known eccentricity and measuring the resulting maximum and minimum strains on the opposite faces of the compressed strut. The calibration load was applied through a steel knife edge seated in a suitable V block. It was reported that the eccentricity of the load could be measured with an accuracy of about 1/32 in. The eccentricities were measured over a range of 3 in on each side of the strut's center line. In this manner, an experimental curve, relating eccentricity and maximum and minimum strain was obtained. Using the conventional equations for computing maximum and minimum stress for combined axial and bending loading and the stress-strain relationship expressed by Hooke's Law, it was possible to derive a theoretical linear relationship expressed as:

$$e = \frac{r^2}{c} \left[\frac{\varepsilon\ max - \varepsilon\ min}{\varepsilon\ max + \varepsilon\ min}\right]$$

where

e = eccentricity of applied load, in

r = radius of gyration, in

c = distance from neutral axis to the outer fiber, in

ε max, ε min = maximum and minimum strain, respectively

Although the experimental calibration curve departed from the theoretical curve, there was reasonably close agreement between the two.

Once the calibration curve was established, two series of five tests each were conducted in which a 6-in deep I-beam was loaded with one of its ends bearing on the calibrated strut. Throughout these ten tests, measurements were taken of the rotation of the beam end at the strut and the corresponding maximum and minimum strains on the strut. The experimental strain values were used in the theoretical relationship mentioned above to obtain eccentricities. Then an eccentricity ratio (eccentricity divided by depth of strut) was plotted against the rotation, in radians, of the beam end.

The first series of five tests was conducted to study the effect of bonding a high strength gypsum plaster to the brick bearing surface atop the steel strut. To study this parameter the tests were separated into two groups: 1. In the first two tests, constituting the first group, the I-beam was bedded in unbonded plaster and the responses were measured. 2. In the three tests of the second group, the I-beam was bedded in bonded plaster. It was observed that while the eccentricity ratio increased with load in group I, the opposite behavior resulted for the tests in group II. In fact, at the maximum recorded rotation the average eccentricity in group II was 42% less than that in group I. Because high strength gypsum plaster is not a practical bedding material for floor beams, this phase of the investigation is primarily of academic value.

The second series of five tests was performed to determine the eccentricity ratio for the same 6-in I-beam supported on varying thicknesses of neoprene rubber pads. In addition to varying this thickness parameter, two other variables were introduced. There were two bearing lengths used, 4 inches in three tests and 2 inches in the other two tests. In order to observe the effect of intimacy of contact between the supporting strut assembly and the flange of the I-beam, the two neoprene pads were coated with gypsum plaster on both sides while the remaining three pads were uncoated. In the latter case it was specifically noted that intimate contact was not achieved. As in the first series of tests, five eccentricity-ratio-versus-rotation curves were obtained and their characteristics were compared.

The final stage of this investigation involved studying the feasibility of measuring the eccentricity of the reaction at the base of a wall subjected to an eccentric loading. The "wall" consisted of a brick pier 3 9/16 by 7 7/8 inches in cross section. The steel strut used in the first stage was used as a base for the brick wall. Then, upon applying a load of known eccentricity, the strains were again measured on the faces of the strut. In this manner, the eccentricity of the reaction at the base of a simulated bearing wall was obtained.

Although this research effort resulted in a procedure specifically applicable to measuring the eccentricity of either the load applied to the top of, or the reaction at the base of a load-bearing masonry wall, the same approach can conceivably be used for other types of construction. Some research would be required to test the validity of the assumption associated with simulating a given wall construction with a steel strut.

"Racking Resistance of Timber Framed Walls" [35]
by T. Ramstad, V. D. Reyers and E. B. Espiloy, Jr.

Based on work done at the Norwegian Building Research Institute, this report was presented at a CIB international symposium on low-rise lightweight construction held in Budapest in 1971. The paper presents the results of 24 racking tests of timber framed walls with different panel-type sheathing nailed to the frame. Wall section specimens of 2.4 x 2.4 metres with no openings were investigated using the ASTM E-72 test method. The sheathing consisted of 1.2 x 2.4 metre vertical panels which were butt-jointed and glued, or shiplap-jointed. A calculation method to determine the strength and stiffness of nailed timber framed walls with panel sheathing is given and compared with test results. The calculation method requires the results of an auxiliary lateral nail resistance test which is also presented. In the supplementary test, the lateral resistance of a single nail driven through the sheathing material into a wood block (frame sample) is determined by pulling apart the test specimen components transversely to the nail while measuring load with a load cell and slip with an inductive displacement transducer.

In considering the correlation between experimental results and theoretical analysis of the sheathed, timber framed wall specimen performance, the nailed joints between studs and sills are assumed to be totally hinged so that stiffness is attributed entirely to fastenings of the sheathing panels to the frame members. Calculations are based on the theory that the deformation and lateral force on each nail is proportional to its distance from a line of symmetry of the total panel deformation. This line of symmetry is observed to be the panel vertical centerline. Equations are given relating: (a) lateral force on the wall with maximum force on a nail, (b) shear deformation with shear stress and (c) slip deformation with wall geometry and data from auxiliary nail resistance tests.

The calculation method showed satisfactory agreement between computed and measured maximum loads. However, the method appears to be less useful for computing horizontal deformations of walls with glued lapjoints than for those with butt joints. Also the method is limited to wall sections without openings and to wall sections which are not much longer than the tested walls.

Although the calculations for predicting the racking performance of the tested constructions apparently needs to be improved, it is encouraging to find a treatment of the racking test which concerns itself with an analytical interpretation of the results. Unfortunately, this aspect of the problem of improving racking design has not, generally, been examined as much as the physical test procedures. Such analysis should obviously be carried along with any development of improved test methods.

"Racking Strengths and Stiffnesses of Exterior and
Interior Frame Wall Construction" [34]
by NAHB Research Foundation, Inc.

The primary objective of this research, conducted in 1971, was to develop recommendations for performance criteria for racking resistance.

The basis for the recommendation was to be the experimental results for several types of wood-frame wall construction. Another objective of the investigation was to determine the comparative racking performance of commonly-used exterior wall constructions, permitted in FHA-Minimum Property Standards* (MPS) and several exterior wall constructions, not permitted in FHA-MPS. Also, the results of earlier racking tests (conducted by NAHB Research Foundation) on typical interior partitions were included and compared with the test results for exterior walls.

A total of 11 exterior walls were tested in accordance with paragraph 15 of ASTM Standard E72-68 [5], with one exception; the specimens were tested in a horizontal position. All frames were built in accordance with ASTM E72-68. Of the total sample, 4 walls were representative of those permitted by FHA-MPS, in that they utilized let-in bracing as the principal means of providing racking resistance. The remaining 7 walls would not be permitted by FHA-MPS because they contained no let-in bracing. There were 11 interior partitions tested in the earlier program. A sample size of 3 was used for each of the 22 specimens.

For the purpose of comparing the performance of different types of construction, the tabulated summaries of the test results were quite effective. One table summarized the results for the exterior walls and another summarized the results for the interior partitions. Because all the results were to be compared with the performance requirements of FHA Technical Circular 12 [41], the average deflection and residual deflection at loads of 1200 lb. and 2400 lb. were listed in the table. The average maximum load obtained for each specimen was also listed. Another useful presentation of results is the inclusion of "relative stiffness at 1200 lbs" and "relative strength" values. These values were obtained by calculating the ratio of the results for all other types of construction divided by the lowest average deflection and the maximum load, respectively.

The "Discussion" section cited three widely used criteria for evaluating racking resistance of exterior walls: provisions of the Uniform Building Code, Housing and Home Finance Agency Performance Standards and HUD's Operation BREAKTHROUGH Guide Criteria. Based upon the racking test results the consideration of these three criteria and FHA Technical Circular 12, the authors have offered some recommendations for evaluation criteria to be used in judging ASTM E72 racking test results. The format for these recommendations is similar to that found in FHA Technical Circular 12. The new criteria would require a minimum ultimate load of 3600 lb. (vs 5200 lb.) and a maximum allowable average racking deflection (at 1200 lb or one times design wind, whichever is greater), of 0.25 in (vs 0.2 in). The maximum allowable average residual racking deflection, upon load removal, (i.e., 1200 lb) would be raised from 0.10 in to 0.12 in.

The evaluation approach used in this study illustrates the importance of establishing relevant performance requirements that can serve as a basis for comparing the results of structural testing. While the relevance of the requirements in FHA Technical Circular 12 to specific structural attributes of a house in service may be questioned, this document does provide a means of interpreting test results that can be commonly understood. For this purpose, the use of the ASTM Standard E72 was quite appropriate. The major shortcoming of the recommendations presented in this report is that they are predicated upon the same rationale that underlies the existing FHA Technical Circular 12. No new insights are gained as to the correlation between these requirements and the behavior of an erected house and the influence

---

*Minimum Property Standards for Multi-family Housing, FHA No. 260, Federal Housing Administration, Washington, D. C., June 1969, Para. M718-3.7.

of cyclical loading on the house's structural performance. The authors of the report qualified their recommendations by stating that "The Foundation does not wish to recommend use of the above structural criteria without some evaluation of the effect of cyclical loading on some of the exterior wall construction types tested herein."

2.3 Structural Evaluation of Floors

"Testing of Large Diaphragms" [14]
by R. D. Cousineau

This paper presents some guidelines to be applied to testing diaphragms. The four test parameters elaborated on are: test apparatus, size of test panels, measurements and presentation of data. At the time of the paper's presentation, 1959, there had been considerable increase in the use of new materials for roof sheathing and floor decking as compared to the practice of 10 years before. This introduction of new technology was accompanied by questions about the value of these new types of construction as horizontal diaphragms to transmit lateral loads to shear walls. Since the methodology for testing diaphragms was not standardized, these guidelines represented a contribution toward the unification of test methods.

Following a listing of some of the types of construction that had been tested to date by organizations such as the U. S. Forest Products Laboratory and by researchers at universities, the point is made that the type of construction will generally be a determining factor in selecting panel sizes and shapes. It is stated that test panel selection is also influenced by the "span and spacing of supporting members and the thickness and strength of covering materials." This statement is specifically applicable to frame-wall construction. A more general factor influencing the selection of test panels is the "usual size of panels in building construction." Reflecting on the absence of a performance standard on which to base the evaluation of a test panel's performance, it is mentioned that the desire to compare the results with the performance of the same or similar materials often dictates the selection of the test panel. Consequently, to compare the performance of a test panel with that of previously-tested wood-frame construction it is necessary to test full-scale diaphragms in the range of 15 to 20 ft wide and 40 to 60 ft long.

Three types of testing apparatus then in common use are described, with a note about their respective applications. One type of rig is completely independent of the test panel while another rig depends on certain elements of the test panel to develop the load. The third rig illustrated is a permanent reinforced concrete test frame useful in testing small diaphragms. The size limitation on the diaphragm is dependent on the bending moment capacity of the concrete members comprising the frame.

There are some guidelines presented to aid in the selection of instruments used for measuring deflections. But, there is no mention of instrumentation used for measuring loads. Furthermore, there is no discussion of other important test parameters such as rate of loading, duration of loading and the type of boundary conditions for the diaphragm.

Although this paper does not go far enough, it is a worthwhile undertaking to review the existing state of knowledge before developing a standard test method for any type of component. The review in this paper of commonly-used apparatus for diaphragm testing is a good example of what should be done for other important test parameters.

"Shear Diaphragms of Light Gage Steel" [32]
by A. H. Nilson

In this paper the author first presents a description of a series of full-scale diaphragm tests, on light gage steel systems, conducted at Cornell University's Thurston Testing Laboratory. The test description is followed by a general analysis of the test results with regard to safe working values of shear, limits to horizontal deflection and the effect of varying several test parameters on the panels' behavior. The first of these diaphragm tests was conducted in July 1955 and there followed more than fifty tests, utilizing many types of panels, steel thicknesses, patterns of welding, panel spans and panel depths. Using the categories of testing recommended by Dorey and Schriever (see reference [19]), this series of tests could be categorized as both "rating tests" and "research tests". The rating test category applies because the establishment of working strength values for many different steel systems resulted from this program. On the other hand, the research test category applies because one of the principal objectives of the testing was to catalog the structural performance of such diaphragms.

During the first year of testing a three-bay steel frame was used to test the corrugated panels made of 16-, 18- and 20-gage steel. The steel frame can best be described by quoting the paper. "Three 10 ft x 12 ft bays were established, forming a deck area 12 ft x 30 ft. 12 WF 27 beams framed in the short direction of each bay, into 10 WF 33 jacking beams running east-west at the third points of the test area, and into 10 WF 21 reaction beams running east-west at the extreme ends. The frame was supported on eight short columns located at the ends of the 10-in beams. The columns under the two jacking beams were set on rollers to minimize frictional resistance. A 24 WF 84 beam was provided, to the east of the decked area, running in the north-south direction, and set with the web horizontal. Loads were applied to the test structure by jacking between the 24-in beam and the jacking beams previously described, using two 50-ton hydraulic jacks. The reaction beams at the north and south ends of the deck area were connected to the 24-in beam, and in turn to the laboratory columns at the extreme ends. The deck panels were laid on top of the beams, suitably interconnected along the seams and welded to the beams to form a diaphragm."

Prior to the installation of the corrugated steel deck, the bare frame was loaded to a level of 500 lb per jack and the third-point deflection was measured. This step was performed to establish a baseline of stiffness, from which the resistance to horizontal movement provided by the deck could be determined.

Loads were then applied to the complete diaphragm in increments, and at each increment, observations were made of horizontal displacement at several points along the span, tensile and compressive strains in the marginal beams (i.e. the top and bottom chord of the hypothetical plate girder), and relative movement between the adjacent panels.

After completion of the stage in which the multibay frame was used, it was decided to test diaphragms with longer spans. It was desired to increase the bay spacing from the 10-ft dimension of the first stage to a maximum of 30 ft. After considering the prohibitive expense and difficulty of handling associated with a multi-bay test frame of dimensions 30 ft x 90 ft, a more simplistic test scheme was developed. During the first stage of testing it was concluded that due to the presence of both symmetrical loading and geometry the center bay did not contribute to the resistance to horizontal shear. Hence, its function was to resist bending moments, not to provide shear strength. On the basis of this analysis, it was proposed that a single "end bay, loaded as a cantilever, would yield the same strength values as provided by the three-bay frame". Furthermore, it was proposed that the maximum deflection of an equivalent three-bay frame could be computed after two corrections were made to the deflection results obtained from the single-bay frame. The first correction would be a negative one to account for movement of the cantilever support points. Secondly, an additive correction would have to be introduced to account for the effects of the missing center bay.

In order to obtain experimental verification for this proposal, a series of single-bay frames, 10 ft by 12 ft, were tested as a cantilever. The details of these frames were identical to those of some three-bay, 12-ft by 30 -ft frames that had been tested previously. As a result of the close agreement obtained from the two series of tests, it was decided that subsequent testing of long-span panels would employ the single-bay, cantilever load test method. From the standpoint of test method development, this evaluative process contributed significantly to the state-of-the-art as regards diaphragm testing. The three-bay frame test was quite useful for short-span diaphragms while the single-bay frame test provided a practical and economic solution to the problem of testing full-scale, long-span diaphragms.

The latter part of the paper is devoted to an analysis of the test results. The following subjects are discussed: 1) safe working values of shear, 2) deflection, 3) effect of panel depth, 4) effect of panel span, 5) relation of material thickness to strength, 6) effect of acoustic perforations, and 7) panel orientation relative to load. The author suggests a direct application of the test results to the establishment of criteria for safe working strength values of light-gage steel diaphragms. Recognizing that the ultimate strength value for a diaphragm system is a definitely established quantity, one simply has to apply an appropriate load safety factor to arrive at a working strength value.

This paper, representing one part of an extensive series of diaphragm tests, is notable in that the test procedures described therein have been used successfully for the past eighteen years. In fact, modifications of both methods are presently being considered for adoption as standard test methods by the American Society for Testing and Materials.

"1966-Horizontal Plywood Diaphragm Tests "[45]
by John R. Tissell

The report on a program conducted by the American Plywood Association presents information from 19 tests of 16-ft x 48-ft diaphragms of plywood sheathing as used for roofs and floors. Tests included some diaphragm constructions not previously tested, such as preframed plywood roof panels applied over trusses, plywood applied over trusses placed more than 4 ft on centers, and plywood applied directly over open-web steel joists. The tests were performed to determine the validity of existing design shear values as applied to Douglas-fir plywood and to determine previously unestablished values for plywood panels made of veneers other than Douglas fir. Other parameters which were investigated included veneer grade, workmanship, manner of joining panel edges, lateral bearing strength of different nails and amount of minimum bearing of plywood panel edges on the framing.

The diaphragms were tested in a horizontal position by loading them laterally along a 48-ft side using 16, equally-spaced, hydraulic jacks. Observations included deflections measured in-plane and out-of-plane, and deformations of the diaphragm tension and compression chords. Instrumentation for measuring displacements included dial gages and machinist scales, the latter used in conjunction with taut wires. Strain gages were attached at the center of the tension chord to measure strain. The loading procedure consisted of applying six cycles of designated design load followed by six cycles of double design load and a final loading to the point of failure.

Observations were also made of general performance at various locations in the specimen. Load-deflection curves are given for the first, seventh and thirteenth cycles of each test.

Conclusions are presented which are based on observations of the various features of construction tested and are directed toward the development of design values. A summary of the ultimate-to-design load factors exhibited by the specimens is tabulated. Recommended design shears for horizontal plywood diaphragms are derived from the test results, with reference to all previous tests of horizontal plywood diaphragms and shear walls. The recommended shear values are related to plywood grade and thickness, width of framing member, nail size, nail/frame penetration and types of diaphragm construction. An example also shows how design shears may be derived for fasteners, spacings or framing species not included in the report or its references. Although the report is oriented toward the evaluation of specific materials and construction, the test loading procedure contains features worth considering in examining methods suitable for improved tests. The use of full-scale, large size specimens clearly demonstrate their desirability when there is need to develop service conditions for evaluating inter-panel joint performance of multipanel construction.

2.4 Structural Evaluation of Roofs

"Lateral Tests on Full-Scale Lumber and Plywood Sheathed Roof Diaphragms" [42]

by J. R. Stillinger

This report summarizes the results of research conducted during 1952 and 1953 at the Oregon Forest Products Laboratory to study the behavior of full-scale wood-frame, roof diaphragms subjected to in-plane forces. The primary objective was to obtain experimental data that could serve as a basis for developing rational design methods for the use of structural engineers. Ten diaphragms, each 60 ft long and 20 ft wide were loaded to failure in order to determine their strength and stiffness characteristics. There were ten variables included whose influence on strength and stiffness was determined. Among the variables cited were: the type of sheathing, the presence or absence of skylight openings, and the construction of the boundary members. A secondary objective was to determine the effects of scale as indicated by comparing previously-obtained (by the same laboratory) results of testing quarter-scale wall and roof diaphragms with those obtained from testing the ten full-scale roof diaphragms.

Each diaphragm was positioned with its plane horizontal and was supported along the 60-ft chords on nominal 4-in by 6-in timbers, which were laid flatwise on concrete blocks spaced on 10-ft centers. There were no supports along the 20-ft chords. The loading equipment consisted of two 30-ton hydraulic jacks that were centered at the third points of the 60-ft span. The jacks acted against timber loading beams. These beams transferred the load to one chord of the diaphragm through four steel rocker bearings that bore against four 1/2-in by 10-in by 48-in steel distributing plates. The steel plates were centered on the fifth points of the span. Thus, the load was distributed over 16 ft of the 60-ft chord. This was thought to be the most practical representation of a uniformly distributed load. A reaction assembly was located at each end of the unloaded 60-ft chord. The connection between the chord and the reaction assembly was effected by a hardwood block whose one end bore against the end post at the diaphragm and other end was equipped with a steel plate that bore on a solid steel roller.

The diaphragms were loaded in predetermined increments and at each load level, the load was maintained for a short time and then returned to zero. Seven of the diaphragms were subjected to five additional cycles of loading and unloading at each load level. According to the author "the purpose of the repetitive loading was to determine the level at which repeated loadings would cause significant increases in set or deflection and thus aid in determining practical working loads."

In order to comprehensively describe the overall structural behavior numerous deformation measurements were necessary: in-plane deflections and strains of the unloaded chord, buckling in the framing members located in maximum shear stress areas, strains in the endpost members, and buckling in the sheathing material were measured in all diaphragms. There is no discussion in the report about the adequacy of the number of instruments used to measure deformation. For the purpose of testing a diaphragm against some performance standard it would be useful to obtain a recommendation of the number and placement of instruments. The conclusions section neglected any discussion of a comparison of the results from full-scale testing with those from the quarter-scale testing. It is a commonly-held opinion that reduced-scale models are inapplicable to wood-frame construction primarily because the connections cannot be satisfactorily modelled.

As a result of the cyclical loading tests it was generally concluded that the first cycle at each load level was the most influential of the six cycles with respect to set. This conclusion has also been reached in research conducted on full-scale, wood-frame houses by Yancey [51] and Yokel [53].

"Loading Tests on Full-Scale House Roofs" [44]
by H. J. Thorburn and W. R. Schriever

The behavior of eight typical wood-frame gable-roof structures under simulated roof gravity loading was studied in laboratory conditions. The observed strengths of these roofs were to be compared with the results of tests previously conducted on single frames of identical construction. The objective of the study was to determine the influence of the sheathing on the roof's strength. To provide a basis for comparison, the procedure for the full-scale roof tests was similar to that for the single frame tests. It is indicated that both test programs were executed at the Division of Building Research of the National Research Council of Canada, but it is not stated exactly when the tests occurred.

The geometry was identical for each of the eight roofs; each frame had a span of 24 ft and a slope of 5 in 12, and consisted of a pair of rafters, a pair of joists (spliced at mid-span) and a collar tie. The length of the roofs was held constant at 30 ft. Despite these similarities, each of the roofs constituted a sample size of one since they differed in construction details. The type of roof sheathing was one of the test variables. The sheathing, which was nailed to the rafters, was either 4-ft by 8-ft sheets of 3/8-in plywood or 3/4-in by 6-in square-edge boards. Another variable was the rafter size, which was either 2 in by 4 in or 2 in x 6 in. All joists were 2 in by 6 in and the collar ties were 2 in by 4 in. Since timber is a material with a relatively high variability in strength, the sample size is too small to afford quantitative conclusions about the structural behavior. Therefore, the immediate value of the results lies in the qualitative conclusions that are drawn. If the strength data obtained for the eight roofs tested were supplemented by additional test results for similar structures, a statistically reliable prediction of strength for typical roof constructions could be derived.

The testing was aimed at assessing the ultimate strength of the roofs and the test loading was applied in only three steps. The roofs were first loaded to the equivalent of one-half the design load (25 lb per sq ft) and then the load was removed. In the second step, the load was increased to the full design load (50 lb per sq ft) and then removed. In the third step, the load was increased until the roof failed.

The test method used was necessarily ad hoc because no standard test method for full-scale roofs existed. Judging by the list of equipment required to conduct these tests on 30 ft-long roof structures, it is concluded that too few facilities are so equipped to justify a standardization effort. In this test program, two bridge trusses, supported at each end by columns, were used for the reaction frames. Six hydraulic jacks, which provided the actual loading force, were suspended from the lower chord of each of these trusses. The load from each jack was divided by a whiffletree into four equal live loads. Although the laboratory dimensions are not stated specifically in this report, it is concluded that the minimum space requirement was 45 ft by 35 ft by 14 ft. Thus, only a few laboratories in the U. S. can satisfy the space requirements, not to mention the loading capacity and equipment needs. It therefore seems desirable to provide a basis for testing a smaller roof specimen. As a first step toward developing a test method for relatively small specimems, the effects of scale must be studied in some detail.

"Strength and Behavior of Light-Gage
Steel Shear Diaphragms" [27]
by Larry Luttrell

This research bulletin reports on a laboratory investigation conducted at Cornell University to observe the response of light-gage steel diaphragms to in-plane shear force and to determine the influence of certain variables on the response. This investigation was part of an extensive research program sponsored by the Americal Iron and Steel Institute (A.I.S.I.), for the study of light-gage, cold-formed steel structures. The results of the constituent investigations provided the bases for an A.I.S.I. publication entitled "Design of Light-Gage Steel Diaphragms."

The author noted that the state of the art with respect to predicting the behavior of diaphragms by purely analytical means was impeded by the large number of variables and parameters that must be considered. Hence, there is a need for structural test data to augment the existing analytical tools. The scope and objectives were defined to provide some of the needed information. The scope of the investigation included the testing of 73 full-scale (of dimensions 12 ft by 10 ft, 6 ft by 6 ft and 10 ft by 12 ft) and 13 smaller (from 17 3/4 in to 28 in long and 24 in wide) diaphragms. The investigation was limited to diaphragms made from open fluted and standard corrugated panels. No attempt was made to consider cellular panel diaphragms nor diaphragms with filler material. The structural characteristics under consideration were shear strength and shear rigidity with respect to in-plane forces. The test objectives were: 1) to establish shear strength values for typical light-gage steel diaphragms; 2) to determine the variation of shear deflection with load; 3) to determine the maximum reliable strength under cyclic load and 4) to determine the influence of diaphragms in a building.

In general the diaphragms consisted of a steel test frame, covered on one side with the light-gage steel ribbed or corrugated panels. The panels were fastened to the frame with screws, welds or back-up fasteners such as lock rivets. The size of the perimeter framing members and of the purlins was included in the list of variables. The large diaphragms were tested as horizontal cantilevers with two point reactions. The reaction at one corner simulated a theoretical pinned connection while a greased bearing plate at the opposite support corner represented a roller support. The load was applied through the use of two 50-ton hydraulic jacks, whose axes were in line with the plane of attachment between the panels and the frame. The 13 smaller frames were all tested in a 400,000 lb testing machine as vertical cantilevers. Except for this difference in setup, the testing procedure was the same for both the larger and smaller diaphragms.

In view of the first two test objectives, various diaphragms were statically loaded either by one of the hydraulic jacks or in the testing machine in increments from zero to failure. To measure the effect of cyclic loading on the ultimate strength of the diaphragms, either pulsating or reversed loads, with amplitudes equivalent to chosen percentages of the expected ultimate load, were applied for various numbers of cycles. The expected ultimate load was based on the results of an identical diaphragm loaded statically to failure. The pulsating loads cycled between zero and +0.4 of the expected ultimate load for 5 cycles. The reversed loadings were applied through the alternate use of the two hydraulic jacks. The loading sequence was performed by first increasing from zero to some percentage of the expected ultimate, unloading, and then loading to the same percentage in the opposite direction. The numbers of cycles of reversed loading were 5,25 or 29 and the three percentages of ultimate were 30, 40 or 60. After the specified cyclic loading had been applied, the diaphragm was loaded statically to failure by one of the hydraulic jacks.

Dial gages were attached to three corners of the respective test frames to measure the in-plane deflections. Four gages were sufficient to account for support movement in the process of determining the total diaphragm deflection. The assumption was made that the total corrected deflection is composed of two components, namely bending deflection and shear deflection. A method was derived for computing the stiffness of a given diaphragm, based on the characteristics of the resulting load-deflection curves. The author defines the stiffness as the slope of the load-deflection curve in the nearly linear region below approximately 0.4 of the ultimate load.

The author also illustrates, by numerical example, the use of cantilever test results in predicting the shear deflection of a diaphragm. While the author does not provide any commentary on the evaluation of the cantilever test method, its limitations are alluded to in the American Iron and Steel Institute (New York City) publication, "Design of Light-Gage Steel Diaphragms". In Section 3.2 (Methods of Tests) of that publication, it is stated that either the cantilever test or a simple beam test (involving two-point concentrated loading) is acceptable for obtaining the necessary test results. However, it is implied that although the simpler cantilever method is acceptable for predicting the shear strength of multibay structures, it may not yield reliable results for predicting the deflection of those structures. The problem of predicting the deflection for multibay structures is more complex because of the kinematic indeterminacies introduced by the interior frames. Hence, equations must be generated to account for the deflection compatibility that must exist between the diaphragm and the interior frames.

One example is presented in the appendix of the report to illustrate the use of the experimental value of the modulus of rigidity in the determination of diaphragm deflection. It is seen that a general approach to predicting the total in-plane deflection of a diaphragm in a structure would involve obtaining the experimental value of the modulus of rigidity and subsequently using existing analytical methods to determine the shear and bending deflection components.

2.5 Structural Evaluation of Complete Houses

"Strength of Houses" [48]
by H. L. Whittemore, J. B. Cotter, A. H. Stang and V. Phelan

This report, issued in 1949, was the forerunner of practically all domestic attempts at explaining the structural behavior of houses by physical testing. This analytical study resulted in some recommendations for a comprehensive design procedure for one- and two-story frame houses based on engineering principles.

Basic information on wind forces, snow load, dead load and floor live load was synthesized prior to the determination of a full set of design loads for the structural components of two typical house constructions. This was done for three geographic locations of diverse environmental characteristics. A procedure for determining the "allowable" (working) loads applicable to different types of construction was discussed. The determination of an allowable load from the laboratory data was based on considerations of strength and safety only. This procedure was applied in assessing the allowable compressive, concentrated, racking and impact loads for 100 house constructions that had been previously documented in National Bureau of Standards series of Building Materials and Structures (BMS) reports. For example, allowable racking loads were expressed in terms of "racking moduli," as computed from the test results reported in other BMS reports. The design loads assigned to the walls, floors and roofs of the two houses were compared with the allowable loads and the comparisons were discussed.

In order to simplify the analysis of load distribution to the various components, four basic assumptions about component behavior are stated in the report. These simplifying assumptions relate to the assumed action of floors as rigid diaphragms in resisting in-plane loads, and of floors and walls and roofs as simple beams in resisting transverse loads; the underlying premise is that a house can be considered as a statically determinate structure for all load conditions except racking. None of the assumptions have been substantiated by test results. Nevertheless the analyses presented in this report constitute a substantial effort toward the understanding of the interactions that occur between various components and their connections in house construction. Unfortunately, since this study, little basic research has been undertaken for the development of rational design methods for houses.

"Evaluation of a 40-ft by 100-ft Frameless Straight Sided
Prefabricated Metal Utility Building" [29]
by the U. S. Naval Civil Engineering
Research and Evaluation Laboratory

This report presents the results of an evaluation test conducted in 1952, on a frameless, metal utility building submitted to the U. S. Naval Civil Engineering Research and Evaluation Laboratory (now called the Naval Civil Engineering Laboratory). The evaluation was with respect to performance requirements related to naval activities. One of the requirements was that a standardized utility building must be structurally adequate. The report dealt with the structural performance of the building under simulated snow loading.

The prototype structure was 40 ft-0 in by 100 ft-6 in in plan, 14 ft-0 in high at the eave and 19 ft-4-1/2 in high at the peak of the gabled roof. The building was designed to be anchored to a concrete footing or slab with anchor bolts. The roof and wall panels, consisting of corrugated galvanized steel, were all 41 inches wide and 7-1/2 inches deep. Each end wall contained 2 windows, a metal louver and a sliding door.

The design snow load was 20 psf according to the appropriate military specifications. The overload factor was established as two for the test. Thus, the structure was expected to perform adequately for the application of vertical loads equivalent to 40 psf. The loading was provided by hydraulic rams and effected by a whiffletree assembly located on the underside of the roof.

A number of electrical resistance strain gages were used to obtain data for stress calculations, while deflections were measured by deflectometers developed at the laboratory. The roof was loaded in 10 percent-of-design increments until the occurrence of a buckling failure in the roof panels at a load equivalent to 60 percent of the design load. Failure of the roof panels was attributed to the lack of a structural member for transmitting the forces from the ridge channel to the end walls. Also the center of the ridge channel underwent a relatively high vertical deflection, thereby tending to pull the end walls inward. Subsequent to the release of the failure loading, some wooden columns were placed under the ends of the ridge channels. The loading was then applied to a level equivalent to 100 percent of the design load.

On the basis of the test results it was concluded that there were three structural factors in the building contributing to the support of the loading. These three factors were identified as rigid-frame action, roof-beam action and roof-diaphragm action. The configuration of the structure was held to be too complex to afford a determination of the relative contribution of these factors in distributing the load, despite the use of considerable instrumentation.

There is one feature in this evaluation that warrants consideration when developing a test method for full-scale prototype testing. The use of a whiffletree assembly to transfer the load from loading devices such as a hydraulic ram to the surface of the strucure is cited in several other reports [18], [44]. None of the authors discusses the advantages and disadvantages of employing such a system. But, a study of alternative loading methods would include a comparison of trade-offs.

Several other similar evaluation tests were conducted by the same laboratory during the same period. However, they do not offer any additional information about structural behavior or test methodology.

"Rigidity and Strength of Houses Built of Plywood Stressed Cover Panels" [28]
by R. F. Luxford and E. C. O. Erickson

This report presents details of a racking test performed on one full-scale, single-story house at the U.S. Forest Products Laboratory. The outside dimensions of the test unit were 29 ft-4 in by 21 ft-0 1/2 in. There was one partition parallel to the side walls that was continuous between the end walls. To one side or the other of this long partition there was a total of four partitions parallel to the two end walls, having a total length of 36 ft. The structure was formed of wood, stressed-skin panels. Each wall panel was 4 ft by 8 ft in size and consisted of two 1/4-in faces of 3-ply Douglas fir plywood glued to 3/4-in by 1 3/8-in studs spaced on approximately 12-in centers. Panels were fastened to each other using vertical mullions with parallel grooves, but this was not a positive connection. Floor and roof panels utilized 2-in by 6-in joists spaced on 24-in centers with an upper face of 5/8-in plywood and a lower face of 3/8-in plywood.

The experiment was conducted about 1954 to evaluate the structural behavior of the house when subjected to simulated wind forces. Based on the results of this field test it was believed that predictions could be made for the performance of panelized houses in high winds. The design wind pressure cited was 20 lbs per sq ft, which is associated with a wind velocity of 80 mph. There were no performance requirements for structural stiffness or strength that provide a basis for evaluating the results. Furthermore, the authors acknowledged that they knew of no data from similar tests performed on more conventionally constructed houses with which to compare the results they obtained.

The method of loading was dictated by an unrepresentative construction detail. The prototype house was connected to a "temporary" foundation and hence did not have sufficient anchorage or resistance to overturning to permit the application of external lateral forces. Therefore, a method of applying diagonal, in-plane forces to the 21-ft shear walls was used. Loading was effected by systematically tightening a nut on each of four diagonally-installed threaded rods two of which were attached outside of the end walls. The other two rods , placed inside the house, were spaced equidistantly from the exterior rods. A dynamometer was inserted into the lower 1/3-length of the rods to measure the force. The equivalent wind pressure could be calculated from the measured forces and known geometry.

The lateral deformation was determined by measuring diagonal shortening in the two 21-ft end walls. For this purpose a telescoping wooden rod, to which a "scale" (interpreted to mean a graduated ruler) was fastened to the corner mullions at each end of the building in "approximately the same plane as that of the four loading rods." Relative vertical movement between the end wall panels and the respective mullions that connected them was also measured. Starting at an equivalent wind pressure of 34 lbs per sq ft, the horizontal movement of the roof was measured by fastening a scale to one corner of a roof panel and reading the change from a known initial point on the scale with a transit.

The in-plane loading method and the indirect method of measuring horizontal deflection (drift) constituted a practical approach to field-testing a full-scale prototype structure. However, the details of the deflection-measurement device are too scant to assess the reliability of the deflection data. The smallest graduation of the scale is not stated and the degree of accuracy of the telescoping wood device cannot be ascertained. These shortcomings notwithstanding, the use of more accurate instrumentation may not have been justified because of the increased cost and complexity.

"Structural Tests of a House Under Simulated Wind and Snow Loads" [18]
by D. B. Dorey and W. R. Schriever

Using a one-story wood-framed house (36 ft by 24 ft), built in 1948, a field test program was undertaken by the Division of Building Research of the National Research Council of Canada. The two main objectives of this study were: "(1) to obtain information on the strength and stiffness of a full-scale single-story house without exterior sheathing; and (2) to obtain experience in full-scale testing and in evaluation of the strength of houses." The design loads for wind and snow, as indicated in the 1953 edition of the National Building Code of Canada, were applied. This testing did not strictly fit into either of the categories of: proof testing (i.e. testing to a factored load equal to or greater than the design load, but less than the required ultimate load) or ultimate load testing because it was decided that the maximum loading would be limited by the occurrence of "relatively minor damage."

In discussing the loading apparatus, the authors state that two loading methods were considered well suited for the field conditions. The possible use of steel cables with one end anchored to the ground and directed over a column to a load mechanism on the other was compared with the possible utilization of a rigid reaction framework that envelopes the test house. It was concluded that the latter method was more desirable. In discussing the merits of the two methods the authors do point to the relative design and assembly simplicity of the first method. However, it has the disadvantage of being difficult to adopt for the application of outward thrusts normal to moderately sloping roof surfaces. It is stated that "with a rigid reaction framework spanning the test house, simultaneous inward or outward thrusts may be applied and controlled from a central position without altering the test house very much." A whiffletree assembly was positioned over the roof and on the side walls to reasonably effect the uniform load assumed in design. This means of representing the design load was decided upon in lieu of a system employing concentrated loads; with the latter system, the maximum shear and bending moment obtained in the design can be represented.

The loading phases were ordered so that each subsequent phase was more severe than the preceding one. The four design conditions simulated were:

(a) wind load acting alone - with internal suction

(b) wind load acting alone - with internal pressure

(c) combination of wind load and one-half design snow load.

(d) snow load acting alone.

The simulated wind forces were derived by transforming the wind velocities into equivalent static pressures acting on equal areas of the side walls and roof slopes. The initial simulated wind force corresponded to a wind velocity of 70 mph. The subsequent simulated forces corresponded to wind velocities of 80 mph and 90 mph, the latter being the design velocity. After the force associated with the design velocity had been sustained for 1 hour it was released and reapplied. The loading was further increased, in increments of 10 mph, up to a value corresponding to a wind velocity of 120 mph.

A system of pulleys and wires was used inside the house to measure the resulting deformations. Horizontal and vertical displacements along four deformation planes were measured by running piano wire over a system of low-friction aircraft pulleys. The practice of instrumenting so-called deformation planes with vertical and horizontal deflection recorders has also been employed by Yancey [51] in laboratory racking tests performed on a wood framed housing unit. This technique constitutes an efficient use of a limited number of instruments in that relatively complete deformation data can be obtained for discrete planes through the test structures. These planes can be selected to correspond to the perimeter of shear walls or they may be located at other points of interest along the structure. Using the deformation values obtained from these data points, the behavior of the entire test structure can usually be interpolated. To facilitate the detection of cracks as evidence of structural distress, thirteen plaster telltales (i.e. "returned layers of gypsum plaster") were used at the junctions formed by intersecting walls and the ceiling.

The test structure possessed one distinguishing feature in that the exterior sheathing was purposely omitted. Thus, its stiffness and strength performances can be compared with those of sheathed, wood-framed houses to gain insight into the contribution to racking resistance offered by the sheathing.

A summary is given on the structural test results relating to the effect of the sheathing on racking strength and resistance to snow loads. The authors point out that before definite conclusions can be reached, numerous similar tests are necessary because structural evaluation of house structures is made difficult by such factors as complexity of form, and variations in materials, workmanship and methods of construction. It is likely that future tests would be conducted in laboratories rather than in the field, because of the time and cost required in constructing test equipment around an existing house, as done in this instance.

"Full-Scale Tests of Pre-Cast Multi-Story Flat Construction" [21]
by A. J. Frances, W. P. Brown and S. Aroni

A single specimen of three-story, pre-cast concrete housing was tested in Melbourne Australia in 1956 as a part of a feasibility study for the Housing Commission of Victoria. The central question underlying the experiment was; "could the height limits on Commission-sponsored housing be extended from conventional two-story construction to three or more stories?" The authors investigated the behavior of a prototype three-story unit under a combination of lateral loading and gravity load equivalent to the contribution of 4-1/2 stories. The magnitude of the gravity load was limited by the bearing stress capacity at the base of the ground story walls. Field testing measures of an ad hoc nature were employed since no standard test method existed.

The test specimen was constructed according to the current practice to a height of three stories (28.5 feet). Then, the effect of an additional 1-1/2 stories of dead load was simulated by superimposing five complete layers of floor slabs onto the uppermost story bearing walls. The test structure measured 27 ft by 26 ft in plan.

The investigators acknowledged that it was necessary to compromise with the test loading since the design shears and moments for a five-story structure could not be identically matched in the three-story prototype. It was decided that the lateral loading in the test structure be applied in a manner to represent the overturning moment calculated for the ground floor level in a five-story structure using the design loads specified in the Uniform Building Regulations of Victoria. The maximum lateral force applied during the test program was equivalent to 1.5 times the design wind load. Force was applied to a loading beam at 12 equally spaced locations along the top of the designated windward side of the structure through turnbuckles attached to high-strength stainless steel wires. The load in each wire was measured by a device consisting of a short length of high-strength silver steel rod, with gage points 8 in apart, to which a demountable mechanical strain gage was attached. In the authors' opinion, the error in reading the load in each wire was probably $\pm$ 5 percent or less. The temperature during the testing exceeded 90°F and so that it was necessary to apply a correction factor to compensate for its effect on the load measurements.

Lateral deflection along the top of the structure was measured at three points by deflectometers with dial gages. The lateral movement between the base of the windward and leeward walls and the adjacent floor slabs was measured at each corner of the building, on the second and third floors by the use of dial gages.

An analysis of the structural behavior, based on the measurements obtained and the visual observation of cracking patterns, provided the bases for some recommendations on the use of this type of construction for taller buildings. Some understanding of the lateral stability of buildings of this type was also gained.

For the purpose of loading a three-story structure at its top, under field conditions, the loading method used was a practical selection. It seems relatively easy to apply the load in increments as well as to release the load quickly when necessary. However, it is doubtful that the accuracy of load measurement was less than ± 5 percent. Instead of measuring the strain values in the steel rod, better accuracy could probably have been achieved by using a load indicating device operating on the same principle as a load cell.

"The Wood-Frame House as a Structural Unit" [50]
by National Forest Products Association

A full-scale house was subjected to several combinations of simulated gravity and lateral wind forces to evaluate its structural performance. The one-story, three-bedroom unit was constructed with trussed roof framing and wood wall and floor framing over a full-story height basement constructed with 8-in concrete block walls. The testing program was conducted during 1963 and 1964 at Virginia Polytechnic Institute. The 1963 phase of the program consisted of three parts.

Part I involved the measurement of floor deflections, under simulated gravity live loading, for 14 stages of construction. The performance of the floor system was measured while several components like partitions and structural elements such as 1 in by 8 in scabs (ties) were added to the assembly.

In part II, floor vibration tests were performed on 43 joists for the same 14 stages of construction as specified in part I. The response was induced by suddenly releasing a 688-pound force, which was applied equally to two adjacent joists. Results were presented for the frequency, amplitude and duration of response.

Part III dealt with a study of the interaction of the various components and their contribution to overall structural stiffness with respect to simulated wind loading. Racking tests were performed during seven stages of dismantling. By means of hydraulic rams, acting in tension, cycles of simulated wind loading were applied to all four exterior walls and on the roof surfaces. All surfaces were loaded to the same equivalent pressure in 4 psf increments up to 16 psf. Each increment was repeated twice during a 6-minute period before going to the next level. Horizontal deflection was measured on the two leeward walls for each increment of load. A simulated gravity load equivalent to the simulated wind pressure at a given increment was applied and maintained for five minutes. Then the vertical movement at the crown was measured. Results were presented for leeward wall movement, 4 feet above the floor, for each stage of dismantling.

It was necessary to correct the measurements of horizontal deflection because the deflection recorders were mounted on the steel reaction frame to which the hydraulic rams were attached. By using transits, the horizontal deflection of the reaction frame was measured at points where the deflection recorders were mounted. The corrected horizontal deflections were obtained from these two sets of data. The authors have attempted to quantify the degree of inaccuracy of the deflection-measurement procedure. "The degree of accuracy for the horizontal measurements is considered ± 0.05 inch because some transit readings could only be read to the nearest millimeter, or 0.04 inch. The deflection recorder has an experimental error of $\pm$ 0.01 inch." Their conclusion about the effectiveness of the measurement procedure to fulfill one of the test objectives is stated as follows. "While this degree of accuracy would not be acceptable for experiments with small test specimens under controlled atmospheric conditions, it is considered accurate enough for the full-scale house tests. Greater accuracy is always desirable, but the difficulty and cost of attaining it in this case did not seem to be justified."

The results of part III suggested that a typical wood-framed house may resist racking in several ways. The contributions of the roof sheathing and ceiling diaphragm to resist horizontal movement were evaluated, but the additional resistance supplied by the partitions could not be distinquished.

In 1964, the house was disassembled and part I (i.e. testing the floor for gravity loading) was repeated for 2 of the original 14 stages of construction. The time lapse between the corresponding 1963 and 1964 tests ranged from 9 to 15 months. The objective of the re-testing was to observe the repeatability of test results after short-term exposure to the effects of the environment.

Several aspects of this test program are cases-in-point of recommended procedure for any test method. By repeating a given load several times it is generally possible to determine if a test specimen exhibits elastic response. The application of three cycles should be sufficient for wood structures. It is good practice to instrument for the measurement of possible movement of the datum line so that a correction factor can be applied to the results. While the re-testing of a structure for all stages of construction seems impractical, some re-testing is warranted when a single sample is used. The reliability of the test data is dependent on its reproducibility.

"Effect of Wind Pressure on the Racking Strength
and Stability of a One-Story,
Gable-Roof Building of Sandwich Panel Construction [17]
by Simon H. Diskin, Consulting Engineer

The performance of a prototype structure as manufactured by Panelfab, Inc., was evaluated under racking loads in 1966. Field-testing techniques were used to subject the single-story structure to simulated horizontal wind forces. A series of concentrated loads were applied at the eave line on one side of the building and the resulting horizontal and vertical deflections were measured at several locations.

The primary purpose of the test was to observe the racking behavior of the end walls and to determine their strength and in-plane stiffness. The test structure consisted of a shell constructed of panels; it contained no interior partitions.

A secondary purpose was to study the behavior of the structure as a complete unit. The objective was to establish a rational design method for individual panels.

The test structure was 20 ft-4 in by 35 ft-4 in with an 8 ft- 0-in-high wall and a gable roof that sloped 3 in 12. The wall panels were of 2-inch nominal thickness with 26-gage steel facings adhesive-bonded to a honeycomb core. The roof panels were 3-inch nominal thickness with 24-gage steel facings and a honeycomb core. The wall base channels were anchored to an 18-in thick concrete wall footing placed continually around the building. J-type anchor bolts were used at the four corners and lag bolts with expansion shields were used for intermediate anchorage.

The loading system consisted of four loading cradles suspended by vertical steel cables which passed over pulleys. Each pulley was located on top of a pipe column whose axis was oriented 45 degrees to the vertical. The cables transmitted the vertical dead weight from the cradle to a horizontal force at the eave line. Incremental forces were effected by adding solid concrete block units to the cradles. After applying a pre-load, the load was increased by increments to a test load equivalent to two times the specified design wind pressure. The test load was maintained for 24 hours and then removed.

Horizontal deflection measurements were obtained at eight eave line stations for each increment of load. The deflections were also obtained at the end of a 24-hour period during which the test load was held constant. The deflection recovery, expressed as a percentage of the deflection under test load, was determined 24 hours after the removal of the test load. Vertical deflections at the ridge were also measured.

The simulated wind load was derived from a static analysis of the designated windward wall for the design wind pressure. The portion of the assumed uniform pressure that is reacted at the base of the wall was disregarded in computing the test load. Therefore, the simulated wind load applied at the windward eave of the test house was equivalent to one-half the total design wind force acting on the structure. This simulation was justified by the fact that the wind pressure on the lower half of the windward wall did not contribute to the racking force at the top of the end walls. Also, the overturning moment caused by the test load was equivalent to that attributed to the design pressure acting on the entire windward wall. However, the base shear in the test arrangement was only one-half the design base shear. This shortcoming in the load simulation was inconsequential to the objective of evaluating the racking performance of the end walls. The report contains an analysis of the distribution of forces through the structure to the end walls and this analysis is followed by a simple design method for individual panels.

The use of dead weight as the source of the test load was apparently justified by the nature of the test. This was essentially a proof test, consisting of a static overload sustained for a relatively short period of time. Although, the load was applied in increments up to the test load there were no cycles of load-removal and reapplication involved. When such is the case, handling the deadweight material may become a substantial problem. The total test load was relatively low, less than 8000 lb, thereby further justifying the loading method used. This report provides good information on the distribution of lateral forces through a simply-constructed sandwich panel building.

"Model and Full-Scale Tests on a Five-Story Cross Wall Structure Under Lateral Loading" [40] by B. P. Sinha, H. P. Maurenbrecher and A. W. Hendry

The authors' primary objectives were to compare test results from a full-scale multi-story masonry building with those from a one-sixth scale model test and those obtained from existing theories. Prepared in 1970, the report presents an unusual, yet economical, means of providing large horizontal load reactions over a great height by using the face of a stone quarry. Such a choice, of course, requires the test structure to be built at the quarry site. The walls were built of brick masonry according to cited British specifications. The five floor slabs were of precast reinforced concrete with a cast-in-place reinforced topping.

A portion of the quarry face was surfaced with concrete for a height of 46 ft against which lateral loading jacks reacted at each floor and roof line. All jacks were operated from a central pump; roof-line jacks exerted half the load applied by floor-line jacks. Each jack load was measured by a load cell.

Scaffolding was erected around the building for access and for mounting instrumentation (although no access was permitted during testing). The scaffolding was free of the structure and tied firmly to the quarry face. Wind effects on scaffolding and instruments necessitated calm weather for testing. All deflections at slab level were measured by dial gages. On the loaded side of the structure, dial gages were attached to the scaffolding and read by means of theodolites; on the opposite side, a pulley and wire system transferred deflections to dial gages mounted at ground level. Strains were measured at locations on ground floor walls by hand-held mechanical gages with 12-in or 24-in gage lengths. The maximum lateral loading corresponded to a 106 mph wind speed.

The full-scale testing was primarily intended as research for confirmation of results obtained from the model tests. As such it was designed as a detailed single undertaking rather than as a repeatable standard procedure. Nevertheless, consideration of certain of its features is helpful in the development of improved test methods. For example, comparison of the results with results from earlier single-story tests shows clearly the increased rigidity caused by the precompression due to additonal stories, a factor to be considered in recommending standarized procedures.

"Test and Evaluation of the Prefabricated Lewis Building and Its Components-Phase 1, Part 2-Full Scale Building Tests" [36]
by T. W. Reichard and E. V. Leyendecker

This report was prepared to document erection problems and the load capacities of a relocatable building assembled of prefabricated sandwich panels. The report serves as a good illustration of full-scale structural testing in the laboratory.

The test structure was a 20-ft x 32-ft one-story building having a gable roof. The major components of the building were 4-ft wide panels constructed with aluminum skins and paper honeycomb cores, aluminum extrusions for framing and rigid vinyl cleats for joining; sheet metal screws and bolts were also used for fastening.

The building was erected on a reinforced concrete test frame that was cast on the floor of a large environmental test chamber (chosen for thermal tests). This foundation-type test frame was constructed to simulate the pier support called for by the building design. Erection of the test building was performed as a field operation in an attempt to expose and subsequently eliminate assembly problems.

Loading of the building simulated the effect of roof loads and lateral wind forces. Pressurized air bags applied load normal to the roof. Because of the flat slope of the roof (2.5 in 12) the vertical roof pressure was 98 percent of the normal roof pressure. The vertical pressure was, therefore, assumed equal to the normal pressure. The air bags reacted against an overhead timber framework that was tied down to the laboratory floor by vertical steel tie rods passing through holes in the test building. Air pressure in the bags was recorded with a low-pressure, strain gage, pressure transducer. Vertical movements of the roof were measured with a surveyor's level by sighting on lightweight leveling rods suspended from the roof ridge line.

Wind forces on the building were simulated by concentrated loads applied at the eave line on the leeward side. These loads were developed by tension-type hydraulic rams operated from a common manifold, and a combination of cables and pulleys arranged to pull with equal forces at four points on the leeward eave. The load on the building was calculated from the ram pressure which was measured by a high-pressure, strain gage, pressure transducer. Lateral movements of the windward and leeward walls were measured by linear variable differential transducers (LVDT), whose signals were fed into a data processor and recorded as perforated tape as well as printed copy.

Separate racking tests were performed to determine performance of the building under design load, loads greater than design load, and finally, a designated ultimate load. The racking test procedures utilized both cyclic and increasing, gradually applied (i.e. static) loadings. The roof vertical load test was performed with an increasing, static loading procedure to determine load capacity.

Results of the various tests are discussed in detail and the discussion illustrates well the completeness with which information can be derived from such tests. Some of the tests described also serve to show that reasonably accurate information related to performance of the whole structure was obtained even though only part of the structure was loaded.

Although very complete in its approach, the overall test included several procedures that were devised as expedients in this instance and could readily be improved. Because of its very completeness and detail, however, it is questionable that such a test lends itself to recommended standardized practice. Nonetheless, the discussions of structural failures, in relation to the procedures used, provide helpful background for developing improved test methods.

"Tests and Evaluation of the Prefabricated Lewis Building and Its Components-Phase II" [26]
by E. V. Leyendecker and T. W. Reichard

This account deals with structural tests of a relocatable building which differed in layout from that reported in reference [36]. This building was 20 ft by 48 ft, erected in two 24-ft long modules and tested without the 20-ft wide end walls in place. This open-ended arrangement of the 2-module structure was used to determine the behavior of an elongated building consisting of an indefinite number of modules. Besides full-scale structural tests, numerous other tests of structural components and of material coupons are described. The latter used ASTM Recommended Methods C393, C273, C297, and C365 to determine, respectively, flexural, shear, tensile and compressive strengths of structural sandwich construction. These tests were performed in duplicate sets with specimens that had been conditioned at 73°F and 50%RH or 100%RH. The structural test procedures have many innovative features, thus making the report a particularly useful reference.

Since the full building was used in performing numerous tests, a determination of load capactiy was not included. The series of tests was conducted with the building erected on, and attached to the tie-down floor of a structures testing laboratory. Again, the supporting piers simulated those of field installations. Tests included the simulation of wind forces using concentrated loads along one eave line; and the testing of the roof as a diaphragm. For the latter, a horizontal concentrated load was applied at the mid-length of the eave line on one side and reactions were supplied at the two ends of the opposite eave. All loading of the full-scale structure was accomplished by hydraulic rams (connected to a common manifold when necessary) and all displacements were measured by linear variable differential transducers (LVDT's) with signals recorded by an automatic data processor as perforated tape and as printed copy.

Sandwich panels, measuring 4 ft x 8 ft were simply supported and loaded uniformly, using air bags. The panels were flexed with the air bag between the specimen and the tie-down floor. The test floor was used to hold down the ends of the panels with simple supports. Additional flexure tests were performed using specimens made of three panels (each 4 ft x 14 ft) cleated side by side and bridging the same span. The manner of loading and the instrumentation were similar to those of preceding tests except that only the two outer panels were loaded. This was done to determine the load that could be transferred through the joining cleats to an unloaded panel. A third group of flexure tests made use of individual 4-ft by 8-ft panels, simply supported as beams, but uniformly loaded by a vacuum on the tension surface rather than by air bag pressure on the compression surface. This loading technique was used to determine if the tension facing would part from the core material before the panel could develop the maximum load determined by air-bag flexure loading. Again, LVDT's and strain gages were used to measure deformations.

Before installation into the test building, a 24-ft ridge beam was tested in flexure in a novel way. This prefabricated component contained a 24-in deep web of honeycomb sandwich panel construction and continuous flanges made of aluminum extrusions riveted together. The beam was loaded by applying air pressure to a fire hose placed between the beams in an inverted (from actual use) position and the test floor. The beam was held to the floor at the ends through simple supports applied to the tension flange.

Descriptions of many testing techniques in this reference make it useful for evoking ideas to improve structural test methods. However, even certain of these need deliberation if considered for adoption. For example, the use of a fire hose for loading, presents the problem of a changing pressure-contact-area as it inflates with specimen deflection -- a factor which is more critical in this case than in using wide, large area air bags.

"A Facility to Evaluate Three-Dimensional Performance of Modules of Houses" [8]
by K. H. Boller

The report describes a facility at the U. S. Forest Products Laboratory by which the strength and stiffness of house modules up to 8 x 12 x 24 feet can be evaluated. The facility consists of a structural steel framework; a system to apply loads by air bags and hydraulic rams simulating service conditions; and an electronic system for acquiring data.

Although it is primarily a description of equipment, the report contains opinions on the desirability of three-dimensional testing of structures. In this regard, it contributes to what should be an impartial approach in considering the problem of improving test methods. The author stresses the need for adopting a composite approach to structural testing of houses to seek out much-needed efficiency and economy. Such an approach involves the study of structural elements performing as parts of a building system in order to evaluate their three-dimensional interactions.

2.6 Summary and Conclusions

The foregoing review has covered a representative sample of the literature pertaining to structural testing of building components. It is intended to convey the nature and scope of the information which must be drawn from to determine the present state of knowledge and the immediate research needs. Whereas more publications were consulted for this phase of the study, their review has been omitted to avoid redundancy. The literature contributing to this review spans the 26-yr period between 1937 and 1973 and therefore, traces the recent history of domestic structural testing.

Structural test methods in the United States, had their origin with a congressionally funded research program--intended to assist the building industry in providing adequate, lowcost housing for all who needed it. A set of test methods was developed at the National Bureau of Standards, in conjunction with this research program to provide a means of evaluating the strength, stiffness, and resistance to local damage inherent in various types of construction which were intended for use in walls, floors, partitions and roofs in low-cost housing construction. As was reported in Building Materials and Structures (BMS) No. 2 [49], the scope of the test methods provided NBS with the wherewithal to determine the structural properties of wall specimens under compressive, transverse, concentrated, impact and racking (i.e., lateral in-plane) loading; of specimens representing partitions under the application of impact and concentrated loading; of segments of floors under the application of transverse, concentrated and impact loading; and of roof specimens under transverse and concentrated loading. The literature implies that the principal types of construction at the time of publication of BMS No. 2 were wood-framed and masonry construction.

Variations of the two main types of construction, as well as less widely accepted types of construction, were tested by these structural test methods during the following decade and the results were published in subsequent Building Materials and Structures Reports by NBS and in reports by Forest Products Laboratory. In 1947, the ASTM Committee E-6, On Performance of Building Construction, adopted the structural test methods in virtually their original form (i.e., name, scope, format, procedure, and content) as a Tentative Standard, E72, Standard Methods of Conducting Strength Tests of Panels for Building Constructions. Subsequent additions to, and revisions of the Tentative Standard were made to reflect the changing demands of the building industry and the updating of the state-of-the-art. The E72 test methods were adopted as a Standard Method in 1954 and underwent revisions in 1961 and 1968.

The second standard test method developed pertained to the testing of roof truss assemblies. This standard, ASTM E73-70, "Standard Methods of Testing Truss Assemblies," was first issued with a Tentative status in 1948 and, after being revised in 1952, it was adopted as a Standard in the same year.

The literature indicates that for the past 25 years structural testing usually has been performed with the objective of evaluating the performance of a sample of components, which were representative of some type of building construction. Furthermore, the majority of the structural testing has been performed in accordance with, or as a modification of ASTM Standards E72 and E73. The further advancement of test method development and standardization has been impeded by the lack of programs whose purpose is to correlate the results of tests of prototype buildings with those of building components. As a result, designers, builders and evaluators are not provided with sufficient reliable data to rationally predict the contribution to structural resistance made by the different components that comprise houses and small industrial buildings. The authors of BMS No. 109 [48] undertook a comprehensive research program which resulted in the cataloging of allowable loads for all the components tested in accordance with the recommendations of BMS No. 2 [49] and reported on in other BMS reports. There have been no similar programs documented since that publication was issued in 1948.

There have been several other notable efforts to review information from various sources with the objective of establishing general guidelines for structural testing. Dorey and Schriever [19] surveyed the specifications for structural testing contained in various building codes in existence in 1955. The authors discussed generally the purpose and scope of structural testing and then discussed in detail eleven factors to be considered in the formulations of test specifications. Noting the lack of principles reflected in the diversity of the then current test specifications, they attempted to utilize the present state of knowledge to derive a method for determining the appropriate test load magnitude. A suggested criteria to be used in evaluating a structure's adequacy on the basis of the structural test results was also discussed. The ad hoc committee charged by the United Kingdom Institution of Structural Engineers [38] culminated a two-year study of code requirements as they relate to structural testing for acceptance purposes, with several significant general guidelines useful in development of test methods. Cousineau [14] drew from the body of information covering 10 years of testing diaphragms to advance some guidelines for the future testing of diaphragms. Although this paper may have made some contribution toward the unification of diaphragm test methods, there is still no standard test method available. The assessment of diaphragm stiffness and strength is quite germane to predicting the lateral stiffness and strength of buildings subjected to lateral environmental forces. This area of deficiency is currently being addressed by ASTM Committee E06 (see table 3.2 of Chapter 3).

As a prerequisite to determining what research was required to arrive at a procedure for the evaluation of racking strength, Isenberg et al [24] undertook a survey of existing information on the racking resistance of frame wall construction. While their bibliography of 72 references provides some background on racking tests for framed wall construction, the authors point to the lack of basic research work supporting the development of racking test methods. After conducting a pilot testing program to evaluate the existing racking test procedures, the authors discuss the additional information needed for the development of a satisfactory racking test. The recommendations for future research, made in 1963, have not been implemented at this writing. The advent of new materials, construction practices and manufacturing techniques in the 10-year interim has amplified the deficiencies cited in that report.

As the section pertaining to tests on full-scale houses (Section 2.5) indicates, there have been complete houses tested in the United States, England, Canada and Australia for various combinations of lateral and vertical loading. In general, the primary purpose has been to quantify the stiffness in terms of measured deformations and the strength in terms of the total load being applied at the time of failure or extreme deformation. Such considerations as determining the share of the total structural resistance contributed by the building components and the manner of load distribution through the structure were secondary. These shortcomings notwithstanding, there is some useful data contained in these nine reports. This data must be augmented with that from testing additional full-scale prototypes in the laboratory. The systematic observation of force distribution patterns and deformation behavior of the prototype components is a necessary task before bases for recommending improved test methods can be established.

Another area of deficiency observed from reviewing the literature is that there is no known correlation between the results of full-scale building tests and those of associated tests on building elements. Desirably, one needs a kind of "transfer function" to relate the results of component testing to the predicted behavior of complete buildings. The transfer function (s) could make it possible to evaluate the structural attributes of a given building on the basis of the data obtained from reliable test methods.

3.0 Present Status of Standard Structural Performance Testing

3.1 Activities of Domestic Associations

The development and promulgation of national standards for testing and evaluation of building materials, elements and components is within the purview of several voluntary standards associations. The various technical committees, subcommittees and task groups are composed of representatives of various interests and backgrounds. The utilization of successive ballots to obtain consensus approval for a proposed standard is the most common approach.

The American Society for Testing and Materials (ASTM) is the largest and most widely recognized domestic organization involved in the development of voluntary standards. Likewise, ASTM Committee E-6, On Performance of Building Construction, comprises the largest group addressing priorities in the area of structural performance test methods for building construction. ASTM Standard E72, Standard Methods of Conducting Strength Tests of Panels for Building Constructions, is the most widely used document in this country for testing building components. To illustrate the point more graphically, table 3.1 lists the standard structural performance tests currently used by test practitioners. The test methods are listed as they pertain to one of three categories of building components: walls, floors, and roofs.

Most of the previously mentioned test methods were adopted as standards on the basis of research work conducted at the National Bureau of Standards and Forest Products Laboratory during the 1930's. In fact, much of the original wording in one published report, BMS No. 2 [49] was incorporated verbatim into the Tentative E72 Standard in 1947. A review of the latest version of the same standard, E72-68 will show that only relatively minor revisions have been made during the subsequent 25 years.

The principal objective of the test standards - as for practically any product-oriented standard - was the promotion of safe and economic use of materials through the establishment of bases for comparing the performance of building components and structural details. Of course, the conventional construction materials and building technology were considered in the adoption of the standards. As new developments in construction practice, in design standards, in manufacturing processes and in materials applications have evolved, most segments of the structural profession have acknowledged the need for updating the testing practice as it pertains to building components. Consequently, many of the existing standards are currently undergoing some degree of revision. Just as significant an activity is the development of new standard methods to satisfy heretofore unfulfilled evaluation requirements.

What follows immediately is a status report of current (as of December 1973) activities by ASTM Committee E-6, in the area of standard development and revision. The report includes a mixture of proposed revisions and new test standards. The name (proposed name in the case of a new standard) of the standard is cited between quotation marks, followed by a short commentary and a status statement of the current activities based on subcommittee correspondence, minutes of meetings and liaison with subcommittee and task group chairmen. Table 3.2, located at the back of this section, summarizes the current activities of ASTM Committee E-6.

Table 3.1 - List of standard test methods currently (December 1973) in use

Type of Component	Standard No. or Identifier	Name of Standard	Remarks
WALLS	ASTM E72-68- Section 7	Compressive Load	Eccentric loading is standard.
	ASTM E72- Section 9	Transverse Load - Specimen Horizontal	Quarter-point loading is standard but uniformly distributed load may be used.
	ASTM E72- Section 10	Transverse Load - Specimen Vertical	Quarter-point loading is standard but a vacuum pressure may be used.
	ASTM E72- Section 11	Concentrated Load	This test is made after the transverse load test (sect. 10), on the same face of the specimen.
	ASTM E72- Section 12	Impact Load - Specimen Horizontal	The specimen is tested as a simple beam.
	ASTM E72- Section 13	Impact Load - Specimen Vertical	This method is intended for constructions to which impact loads cannot satisfactorily be applied with the specimen horizontal.
	ASTM E72- Section 14	Racking Load - Complete Assemblies	This test is for measuring the racking resistance of "Standard" wood frames.
	ASTM E72- Sections 15&16	Racking Load - Evaluation of Sheathing Materials on a Standard Wood Frame	Sect. 16 is identical to sect. 15 except that for the former the specimen is tested wet.
FLOORS	ASTM E72-68- Section 18	Transverse Load	The test is performed on the upper face of the floor in accordance with Sections 9 & 10.
	ASTM E72 - Section 19	Concentrated Load	This test is performed in accordance with Sect. 11.
	ASTM E72- Section 20	Impact Load	This test is performed in accordance with Sect. 12.
	ASTM E196-66	Load Tests of Floors and Flat Roofs	Static loads are applied for either proof testing or ultimate load testing.

Table 3.1 continued - List of standard test methods currently (December 1973) in use

Type of Component	Standard No. or Identifier	Name of Standard	Remarks
FLOORS	American Iron & Steel Institute. "Design of L.G. Steel Diaphragm" 1969 Edition	Cantilever Diaphragm Test	This test method is intended to obtain shear strength and stiffness data for light-gage steel diaphragms.
	American Iron & Steel Institute. 1969 Edition	Simple Beam Diaphragm Test	This test method has the same objective as the "Cantilever Diaphragm Test" but results are more reliable for diaphragms intended for multibay construction.
ROOFS	ASTM E73-70	Testing Truss Assemblies	This standard was originally entitled "Standard Methods of Testing Heavy Truss Assemblies".
	Truss Plate Institute TPI-70	Load Test on Full Size Trusses	The test can be performed on either single truss specimens or double truss specimens.
	ASTM E196-66	Load Tests on Floors and Flat Roofs	Static loads are applied for either proof testing or ultimate load testing
	ASTM E72-68-Section 22	Transverse Load	The test is performed in accordance with Sect. 9.
	ASTM E72-68-Section 23	Concentrated Load	This test is made after the transverse load test (Sect. 22) on the same face of the specimen, in accordance with Sect. 11.
	Appendix B of American National Standard A119.1, 1972	Test Procedure for Roof Rafters or Roof Trusses	These test recommendations are similar to those in the Test Method by Truss Plate Institute.
	American Iron & Steel Institute. 1969 Edition.	Cantilever Diaphragm Test	See Remarks stated for "Floors" above.
	American Iron & Steel Institute. 1969 Edition.	Simple Beam Diaphragm Test	See remarks stated for "Floors" above.

*Table 3.2 - Summary of standards currently under development or revision by ASTM Committee E-6**

BUILDING COMPONENT	NAME OF STANDARD	TYPE OF LOADING	COMMENTARY	STATUS
WALL SHEATHING	Evaluation of Materials on a Standard Wood Frame (R) ASTM E72-68	Static; Short-Term; Racking; Concentrated	Method intended to determine the relative shear stiffness and strength of various sheathing materials.	Grading specifications of frame lumber being revised. Task group assigned to draft a new standard method.
WALLS OR WALL SEGMENTS	Test for Flexural Strength of Walls (R) ASTM E72-68	Static; Short-Term; Flexural; Uniform or Concentrated	Method intended to determine the flexural stiffness and strength of walls or wall segments under simulated wind force. To be a replacement for Sections 9 and 10 of ASTM E72-68.	A revised draft is expected prior to the June 1974 meeting. Adoption of the test method as a standard by ASTM, is projected for 1974.
SHEAR WALLS AND PARTITIONS	Test for Framed Shear Walls and Partitions for Buildings (N)	Static; Short-Term; Racking	Proposed method represents a modification of the proposed "Standard Method of Test for Framed Floor or Roof Diaphragm Constructed for Buildings". (See ASTM E196 below).	Task Group is studying first draft for possible improvements. Subcommittee E06.12 is also reviewing the first draft.
BEAMS AND GIRDERS	Flexural Tests on Beams and Girders for Building Construction (N)	Static; Short-Term; Flexural; Uniform	Method intended primarily for construction whose predicted behavior does not conform to the assumptions used in flexural analysis.	Has been approved by Committee E06 and its adoption by ASTM as a standard is iminent.
FLOORS AND ROOFS	Load Tests of Floors and Flat Roofs (R) ASTM E196-66	Static; Short-Term; Flexural; Uniform	Procedures can be used for either proof testing or ultimate load testing of horizontal components. This method is often referred to in model codes. (e.g. ACI 318-71)	A revised draft of the standard is forthcoming from the assigned task group.
FLOORS AND ROOFS	Tests for Framed Floor or Roof Diaphragm Construction of Buildings (N)	Static; Short-Term; In-Plane Flexural or In-Plane Shear; Concentrated	Method involves use of either cantilever frame or simple span frame to determine the response of diaphragms to in-plane concentrated loads. Based on test method by A.I.S.I.	Task group is preparing a new draft for simultaneous review by Subcommittee E06.11 and Committee E06 prior to June 1974.
ROOF TRUSSES	Methods of Testing Truss Assemblies (R) ASTM E73-70	Static; Short-Term; Flexural; Concentrated	Procedures are intended for testing single truss specimens; loading may be applied either at the panel points or between the panel points.	Currently under task group study. Has been subject of significant criticism in a recent preliminary report. A draft of revised standard to be presented at the June 1974 meeting.
EXISTING BUILDING AND FULL-SCALE PROTOTYPES	Recommended Practice for Load Tests on Existing Buildings and Full-Scale Prototypes (N)	Static or Dynamic; Short-Term; Flexural; Shear; Impact; Uniform or Concentrated	The sixth draft of the proposed Recommended Practice encountered many difficulties and conflicting requirements The Task Group concluded that rather a "guide" should be undertaken jointly by ASCE & ASTM.	A joint committee has been appointed. A committee report is to be presented at the June 1974 meeting.
TRUSS CONNECTORS	Test for Tensile Strength Properties of Steel Truss Plates (N)	Static; Short-Term; Tensile; Concentrated	Method intended to evaluate the tensile strength of steel truss plates used to fasten wood members together.	The sixth draft has been balloted among the entire membership of Committee E06. Proposed method should become a standard in near future.

SYMBOLS

(R)-Existing Standard Being Revised
(N)-New Standard Being Proposed.

*As of December 1973.

"Standard Method of Test for Framed Floor or Roof Diaphragm Construction for Buildings"

Commentary:

This proposed standard test method is intended to have general applicability to framed diaphragm assemblies representative of floor and roof construction used in buildings. The proposed standard describes two alternative test methods:

(1) uses a cantilever test frame and

(2) uses a simple span frame with third-point loading.

The test setup, loading procedure, spatial details and associated calculations are all based on test methods described by the American Iron and Steel Institute in the publication, "Design of Light Gage Steel Diaphragms" (1969 edition). By recording the deflection of discrete points within the diaphragm for successive levels of static loading to failure, it is possible to determine the ultimate shear strength and the in-plane shear stiffness of the test assembly.

Status:

The task group for this proposed standard test method prepared a new draft and circulated it to the subcommittee concerned with the performance of horizontal components and to Committee E-6 prior to the June 1974 meeting.

"Standard Method for Load Tests of Floors and Flat Roofs"

Commentary:

This standard (ASTM E196-66) was originally issued by Committee E-6 in 1962 and was subsequently revised in 1966. This method provides for the evaluation of floor or flat roof assemblages (slope of less than 1 in 12) for strength and stiffness characteristics, under actual or simulated service conditions. The procedure involves the measurement of deflections at key locations as the test component is subjected to successive increments of superimposed static load. This standard, or some variation of it, is often referred to in model codes as a method for proof testing or ultimate load testing.

Status:

A revised draft of the standard is forthcoming from the task group assigned to make recommendations.

"Racking Load - Evaluation of Sheathing Materials on a Standard Wood Frame" ASTM E72 Sections 15 and 16.

Commentary:

The results of this test method provide a measure of the racking resistance of wall panels composed of a standard frame covered with any specified sheathing material. The standard frame being a test constant, it is possible to assess the relative racking resistance contribution of the various sheathing materials. Section 15 of E72 describes the procedure for testing specimens with a moisture content ranging between 12 and 15 percent $\pm$ 3 percent. Section 16 of E72 cites an identical procedure but the specimen must undergo simulated environmental conditioning prior to testing. The prescribed conditioning involves two successive cycles of spraying the sides of the specimen with water and allowing it to dry in laboratory air, preferably at a temperature of $75°\pm 5°F$. Then a third cycle of wetting is performed. The panel is to be tested in racking no more than two hours after the third wetting stage. The test method described in these two sections is designated in the requirements of FHA Technical Circular 12 [41] as the physical means by which the performance of various sheathing materials can be compared with that of a "standard" sheathing.

Status:

These two sections, along with the other 21 sections of E72 were last accepted in September 1968. The original version was issued in 1947. The membership of Committee E-6 is currently voting on a revision which changes the specification for the lumber constituting the standard frame. Furthermore, a task group has been assigned to draft a revised standard method which will reflect the present state of knowledge.

"Standard Methods of Test for Flexural Strength of Walls"

Commentary:

This is a proposed revision intended to replace the existing standards found in Sections 9 and 10 of ASTM E72-68. The intent of these flexural test methods is to determine the strength and stiffness characteristics of walls or wall segments as they are influenced by a static-load simulation of perpendicular design wind forces. Either proof-load testing or ultimate-load testing can be accomplished by following the prescribed incremental force-application and deflection-measuring procedure.

Status:

Substantive comments were made at the December meeting as to improvements that could be made in a draft sent to the subcommittee concerned with performance components prior to that meeting. Also, the subcommittee concerned with the performance of vertical components discussed the pros and cons of adopting a standard method for testing for the strength of curtain walls (ASTM E330-73), which was prepared by another subcommittee (E06.51) as the method for testing for the flexural strength of walls. The task group was charged with determining the feasibility of making such an adoption. The task group's recommendations are to be presented in the form of another draft of a proposed revision to the standard method in ASTM E72.

"Method of Test for Diagonal Tension (Shear) in Masonry Assemblages"

Commentary:

The proposed standard consists of a procedure for determining the shear resistance of 4-ft by 4-ft masonry specimens which are loaded in diagonal compression, normal to the mortar bed joints. The applicability of the test method is supported by considerable test experience; it has been used by the Structural Clay Products Institute (now Brick Institute of America) for several years and it is referred to in Section 4-3 (Allowable Stresses in Non-Reinforced Brick Masonry) of the Second Edition of their publication Recommended Practice for Engineered Brick Masonry. This method has also been employed by C.B. Monk at Purdue University, John Blume and Associates Co., and the National Bureau of Standards. The size of the specimen, as compared to the 8-ft by 8-ft dimension designated in the ASTM E72 racking test, is an important parameter in that it permits the use of a type of testing machine that is common to many laboratories. Furthermore, by using smaller scale specimens, four samples can be produced for about the same effort as one 8-ft by 8-ft sample. In the opinion of the task group, the recommended size is the smallest that would be representative of a full size masonry assembly.

Status:

The proposed standard method has been approved by the subcommittee concerned with the performance of vertical structures and Committee E-6. It will subsequently be sent to the society (ASTM) for final approval before publication.

"Standard Method of Test for Framed Shear Walls and Partitions for Buildings"

Commentary:

This method was proposed by some of the technical staff of the American Plywood Association as a generalized racking test for wall construction. The first draft indicates that the test method has been derived by modifying the procedure for the cantilever frame setup described in the proposed "Standard Method of Test for Framed Floor or Roof Diaphragms for Buildings." The task group assigned to prepare additional drafts will be studying the proposed standard to evaluate its applicability to different types of construction and different geometric configurations.

Status:

The development of this standard is in its preliminary stages. The first draft has been circulated to members of the subcommittee on performance of vertical components, for their review and comments.

"Standard Methods of Testing Truss Assemblies"

Commentary:

The general recommendations in this standard are applicable to either proof load or ultimate load tests of single-truss specimens. The original version of this standard, then entitled "Standard Methods of Testing Heavy Truss Assemblies," was issued in 1948 with a Tentative status. A revised version was approved in 1952 and adopted as a Standard in the same year. The emphasis of the test method was on "heavy" assemblies with purlins or concentrated panel point loading or both. The current edition, ASTM E73-70, contains the same recommendations as the 1952 edition, except that a procedure has been added for loading the top chord of the truss--while it is in the in-service position--between the panel points.

Status:

A task group has been studying this standard for areas of possible revision. It is the preliminary finding of the task group that: the existing standard test method fails to include all applicable loading techniques (e.g. vacuum loading); there is the implication that other loading techniques are not adequate, although there is no stated justification for this implication; there is a lack of safeguard against the possible use of test gimmicks intended to produce more favorable test results; and the method as it presently exists is inapplicable to testing light trusses. It was recommended that the test standard have its status changed to a Standard Recommended Practice. The task group will continue to study this test area and then begin preparation of a draft of a revised test method. The proposed revisions will be presented at the June 1974 committee meeting.

"Recommended Practice for Load Tests on Existing Buildings and Full-Scale Prototypes"

Commentary:

The planning and execution of load tests on existing buildings or on full-scale prototypes is presently handled on an ad hoc basis, since no standard procedures have been adopted. The absence of a standard methodology in this area constitutes a significant deficiency in that there is substantial rationale for executing tests on full-scale assemblies. The results of full-scale testing can be applied during the design and analysis stage as well as during the evaluation stage. Despite the apparent merits of promulgating recommended practices to be employed when testing full-scale structures, the task group has concluded that the significance of professional judgement in the planning and execution stages is too great to render the process to generalized procedures. It was noted that the sixth draft of the proposed Recommended Practice encountered many difficulties and conflicting requirements. The task group recommended that a "guide" for engineers be prepared by a joint ASTM-ASCE Committee.

Status:

A joint committee has been appointed and a report of the proceedings of a committee meeting will be presented at the June 1974 E-6 committee meeting.

"Standard Methods of Flexural Tests on Beams and Girders for Building Construction"

Commentary:

The scope of this proposal is stated as follows: "These methods provide for the flexural testing of beams and girders under simulated service conditions to determine their structural performance characteristics. In some cases, they are also suitable for determining the structural performance adequacy of the design, materials, connections, and fabrication techniques. They are intended primarily for construction that may not conform with the relatively simple assumptions upon which well known flexural theories are based. The methods are not intended for use in routine quality control tests."

Status:

At the June 1973 meeting the Subcommittee on Horizontal Building Construction (E06.11) unanimously agreed that this proposed standard test method be recommended to the main committee for submittal to ASTM members for ballot as a Standard.

"Standard Method of Test for Tensile Strength Properties of Steel Truss Plates"

Commentary:

This proposed standard addresses the need for a method of evaluating the tensile strength of steel truss plates used to fasten wood members together. The method calls for testing the steel truss plates, testing control plates of the same material as the truss plate and then comparing the performance of the two types of specimens.

Status:

The sixth draft is presently being balloted by the full E-6 Committee.

"Standard Method of Test for Flexural Bond Strength of Masonry"

Commentary:

The two methods comprising this proposed standard are intended for the determination of flexural bond strength of masonry assemblages. Through the application of these procedures, the bond strength of prisms composed of different types of masonry units and mortar can be compared. Also, the relative quality of workmanship during construction can be determined.

Status:

This proposed standard method has been approved by Committee E-6 and hence must be sent to the society for total ASTM membership approval, prior to being published.

3.2 Activities and Publications of Foreign and International Associations.

3.2.1 Foreign Standards Associations

A search has been conducted through the index of standards published by several foreign standards associations and by one international association to determine if there are references to existing standard test methods which may be consulted in attempting to improve domestic test practice. In this effort, the standards index of the following standards associations have been consulted: Standards Association of Austrialia, Canadian Standards Association, British Standards Institution, German Standards Institution (DNA), The Standards Institution of Israel, Japanese Standards Association, and International Organization for Standardization (ISO). The standards pertaining to the structural performance of building construction, as developed by these associations, generally provide design data and include recommended design and construction practice similar to that in the American Concrete Institute's Standard 318-71 [2].

Contained in the standards published by all the previously mentioned associations except one, are some general guidelines for planning and executing test programs, but no standardized test procedures applicable to evaluating building components. The Japanese Standards Association has issued standard test methods, similar in format and scope to ASTM Standard E72, for testing building components. English versions of two typical Japanese standard test methods have been prepared and reviewed for this report (refer to Appendix C). Their titles (see reference [39]) are: (1) "Test Method for Bending Resistance to Local Concentrated Load" and (2) "Test Method of Loading Resistance for Loading Normal to Surface." The procedure recommended in these standards for rating the performance of test specimens seems to be an improvement over the strictly subjective approach to interpreting test results that is necessary when using most domestic standards. The Japanese standards include a 10-point rating scale from which one can obtain a basis of comparison for the performance of two or more types of construction.

3.2.2 International Associations

Although there are several international associations (i.e. CIB and RILEM) whose main functions are to serve as a medium of exchange of technical ideas, research experiences and expert opinion, and to promote development of standards, there is only one organization (i.e. ISO) authorized to promulgate international standards. The work of that organization and two other international associations will be discussed briefly. Special attention has been given to those collective committees, symposia (or similar gatherings) and publications that may be relevant to structural performance testing and the associated conditioning of test specimens.

3.2.2.1 The International Organization for Standardization

The International Organization for Standardization (ISO) is a federation of the national standards institutes of 73 countries from all parts of the world. As a means to promoting international cooperation in the development of standards and in the exchange of scientific, technological and economic information the ISO may: (a) set up international standards; (b) encourage and facilitate the development of new standards having common requirements for use in the national or international spheres; and (c) cooperate with other international organizations interested in related matters, particularly by undertaking, at their request, studies relating to standardization projects. The work of developing International Standards is carried out through technical committees. There are 146 technical committees, which are subdivided into various subcommittees and working groups. Prior to January 1, 1972, the ISO published ISO Recommendations as a result of the work of the technical committees, subcommittees and working groups. Since that time what have been issued are called International Standards.

A close scrutiny of the list of technical committees and the scope of their activities produced the identification of one committee of particular interest. The committee on Enclosures and Conditions for Testing, TC 125, seeks to develop ISO standards in relation to conditioning environments for test and/or test environments for materials and equipment for any application. It is also concerned with the requirements for enclosures in which these environments are obtained and maintained.

3.2.2.2 The Union of Testing and Research Laboratories for Materials and Structures

The Union of Testing and Research Laboratories for Materials & Structures (RILEM) is an international, non-profit association governed by Swiss law. The two main functions of this organization are to serve as a medium of exchange of ideas, information and experience with respect to the study of building materials and building elements and to act as a catalyst in the improvement and unification of testing methods.

Through the issuance of publications, the distribution of surveys and the organization of symposia the association promotes international dissemination of information and discussion of developments and experiences. The second function is performed through the establishment of technical committees, the members of which are selected on the basis of their interest and expertise in the particular field of study. The respective committees then engage in activities appropriate to the production of recommendations for international standards. The recommendations are eventually transmitted to ISO which is the only organization authorized to promulgate international standards. There are 25 standing technical committees at the present time.

There are four technical committees whose stated scopes and objectives indicate that their activities may be of interest to the study of current practice of test methods conducted on walls, floors, and roofs. Those names are listed below and referenced according to the symbols assigned by RILEM.

1) 3-TT Testing Methods of Timber (established in 1967),

2) 20-TBS Testing Building Structures in Situ (established in 1970),

3) 21-IL The Effect of Impact Loading on Buildings (established in 1970) and

4) 24-BW Methods of Testing the Mechanical Properties of Load Bearing Walls and Masonry.

RILEM has organized about 35 international symposia since 1954 and the full proceedings have been published. Several of the symposia topics warranted a thorough search of the publications for pertinent information. The lists of proceedings reviewed are as follows: (1) "Effects of Repeated Loading of Materials and Structural Elements," Mexico, 1966, (2) "Testing Methodology and Technique of Full-Scale and Model Structures, under Static and Dynamic Loads," Bucarest, 1969, (3) "Testing and Design Methods of Lightweight Aggregate Concretes, Budapest 1967, and (4) "Performance Concepts in Buildings," United States, 1972.

3.2.2.3 The International Council of Building Research, Studies and Documentation

The International Council of Building Research, Studies and Documentation (CIB) is an organization comprised of representatives of large public building research organizations and large industrial bodies or departments involved in building research. The scope of the organization's concern ranges from the study of various aspects of construction to consideration of the social aspects of the total built-up environment. The encouragement of international collaboration between all types of research bodies and the promotion of exchange of comprehensive research reports are two principal functions undertaken by CIB. To this end, CIB has currently adopted several working methods:

1. Public congresses on themes of general interest are held every three years. There have been five congresses convened since the organization was established in 1953, with the first one being held in 1959.

2. A General Assembly attended by members and specially invited guests is held at least in three-year intervals to discuss selected topics.

3. The organization of symposia and colloquia is undertaken on different scales depending on the interest in a special theme. These sessions are sometimes jointly organized with other associations such as RILEM and ASTM.

In order to effect international research and study projects, working commissions, made up of experts from different national institutes, are organized. (The delegation of research duties to committees, subcommittees, etc., is common to all three international associations, ISO, RILEM and CIB.) The results of the research work or study project are published by the working commission and distributed to the membership. CIB also publishes an international periodical, BUILD International, that attempts to inform the practitioners of research results as to the latest findings, recommendations and trends.

Of the 30 listed CIB Working Commissions there are 4 whose programs of work have at least a remote connection with test method development. Those relevant working commissions are listed below, according to number and name, along with a condensed version of their respective purposes.

W18 Timber Structures - Improvement of structural uses, jointing, testing and stress grading of timber; comparison and unification of national timber design codes.

W23 Basic Structural Engineering Requirements - Development of recommendations on standarized calculation methods of structures.

W23A - Safety of Load Bearing Walls - Development of scientific bases for building codes, particularly related to calculations and testing of stresses in load-bearing walls.

S56 - Lightweight Lowrise Construction - Symposia on various aspects of lightweight constructions, e.g., technical trends and solutions.

None of the 10 CIB reports published addresses the subject of structural test method development of walls, floors or roofs. Likewise, a search of the proceedings of CIB congresses and of CIB symposia did not produce any significant sources of information. Presently, Working Commission W23A, with RILEM Technical Committee 21-IL The Effect of Impact Loading on Buildings, is conducting an international survey among research institutions as a means of finding out what research is currently underway or has been completed relating to load-bearing walls. The National Bureau of Standards has a United States National Committee Corresponding Membership on CIB W23A. The findings of the survey will be distributed at some future date.

4.0 Review of Operation BREAKTHROUGH Structural Testing Performed at the National Bureau of Standards

4.1 Introduction

4.1.1 Purpose and Scope

In this chapter the test methods employed by the National Bureau of Standards (NBS) during the evaluation of industrialized building components, for the Operation BREAKTHROUGH housing program, are compared to the methods contained in ASTM Standard E-72-68[5]. This comparison is done for the purpose of contributing to the evaluation of improved standard methods that may be effectively used in the evaluation testing of innovative housing systems.

The comparison of test methods is confined to a critical review of the deviations from, and extensions to, the adopted standard test methods. It was not felt necessary to describe the standard test methods to fulfill the stated purpose. Furthermore, it is not within the scope of this chapter to address the overall effectiveness of the respective standard methods referred to in the comparisons.

Also, tests on housing systems are summarized and reviewed for the purpose of making recommendations toward the development of standard test methodology for full-scale housing units.

A separate section of this chapter is devoted to each of the three groups of tests: roof and floor; wall; and full scale systems. Included in the section covering each group of tests is a summary of the test, a review and recommendations for improving the test, based on NBS experience with the BREAKTHROUGH testing.

4.1.2 Objectives of the Operation BREAKTHROUGH Testing Program

Innovative uses of materials and methods of fabrication and construction were features of housing systems proposed by several Housing Systems Producers (HSP's) for the HUD-sponsored housing program. Where the evaluation of such features could not be accomplished by rational analysis, it had to be supported by structural tests (as well as fire and acoustic tests) of critical components. Thus, the knowledge gained about the structural behavior of the specimens was to be applied in the evaluation of housing systems for structural safety and serviceability. Also included were panels representative of certain conventional constructions for which engineering data was either non-existent or inadequate for the performance of an effective evaluation.

In general, physical simulation was used to represent the support and loading conditions for the building components so that the test results could be used directly in the evaluation process. For the cases where direct evaluation through testing was not feasible or necessary, the testing provided structural data such as material strength, elastic modulus and component stiffness, any one of which an evaluator may need to perform an analysis.

4.1.3 Scope of Operation BREAKTHROUGH Structural Testing

The types of wall, floor and roof panels and systems tested, and the nature of the tests conducted at NBS for the Operation BREAKTHROUGH program are listed below.

1. Floor and Roof Tests

   a. Impact and subsequent concentrated static loading on plywood subflooring supported by wood joists [25]

   b. Local resistance of conventional plywood subflooring to concentrated load [52]

   c. Static uniform load on sandwich panels with gypsum board facings [22]

   d. Static uniform load on panels fabricated from glass fiber-reinforced polyester laminate [37]

   e. Static uniform load on steel-faced sandwich panels [33]

2. Wall Tests

   a. Compressive loading on sandwich panels with gypsum board facings [22]

b. Racking load on panels fabricated from glass fiber reinforced polyester laminate [37]

c. Compressive loading on panels fabricated from glass fiber reinforced polyester laminate [37]

3. Full-Scale System Tests

a. Two story house subjected to lateral load [53]

b. A wood framed housing module [51]

Table 4.1.1 relates types of construction and tests conducted at NBS by indicating which of the seven representative reports contain certain topics.

4.2 Floor and Roof Tests

4.2.1 Impact and Subsequent Concentrated Static Loading on Plywood Subflooring Supported by Wood Joists [25]

4.2.1.1 Summary of Tests

A series of tests was made on floor specimens to establish a relationship between an impact load and the subsequent deflection of the impacted area, as it was subjected to a concentrated static load. The impact was first delivered to the floor specimen (see figure 4.2.1) by dropping a 60-lb bag from a given height as shown in figure 4.2.2; then a 400-lb concentrated load was applied in the manner depicted in figure 4.2.3. The latter load was applied through the end of a 5/8-in round steel rod to simulate large magnitude concentrated loads that may be transmitted through a caster of a crowded couch, or a piano caster. A description of the test specimens is presented in table 4.2.

4.2.1.2 Review of Tests

The setup and procedures employed in this test were similar to those recommended in ASTM E72 for impact and concentrated loading. However, the diameter of the loading rod used, was 5/8 in instead of the 1 in specified in ASTM E72 because it was concluded to be closer to reality (e.g. simulation of a couch leg). The use of the smaller rod will be discussed in Section 4.2.2.

Using curves such as those shown in figure 4.2.4, a limiting level of impact energy could be determined for a specific floor system provided that an acceptable deflection limit under the 400-lb concentrated load, was established. At present, no such limit is found in the design specifications and standards used in the United States. Based on results of tests conducted on 1/2-in plywood subfloors with wood joists spaced at 16 inches o.c., the Canadian Standards Association Standard- CSA0152-1964, "Performance of Construction Plywood", has a requirement for a maximum deflection limit for plywood subfloors. The deflection limit is 1/180 of the span between joists under a static concentrated load of 175 lb.

4.2.1.3 Recommendations

There exists a basic impediment to the development of an improved test method involving impact and concentrated loadings in that acceptable limits of localized deflection have not been determined through research. Such limits must be based on the various levels of perceptible discomfort

TABLE 4.1.1 ~ STRUCTURAL TEST DISTRIBUTION IN OPERATION BREAKTHROUGH

BUILDING COMPONENT ↓ / TEST DESCRIPTION →			ENVIRON. CONDIT.	COMPRESSION		FLEXURE		CONCENTRATED LOAD	IMPACT LOAD	RACKING	
				SHORT TERM	LONG TERM	SHORT TERM	LONG TERM			STATIC	CYCLIC
WALLS		WOOD FRAME								FH MO	FH MO
	STRESSED SKIN	STEEL FACED									
		GYPSUM SURFACE	GY	GY							
		POLYESTER LAM.		PO	PO					PO	
FLOORS		WOOD FRAME				WJ MO		WJ LY	WJ MO		
	STRESSED SKIN	STEEL FACED									
		GYPSUM SURFACE				GY	GY				
		POLYESTER LAM.									
ROOFS		WOOD FRAME				GY					
	STRESSED SKIN	STEEL FACED	ST			ST					
		GYPSUM SURFACE					GY				
		POLYESTER LAM.				PO	PO				
COMPLETE STRUCTURE		WOOD FRAME				FH				FH MO	FH MO
	STRESSED SKIN	STEEL FACED									
		GYPSUM SURFACE									
		POLYESTER LAM.									

WJ = WOOD JOIST LY = PLYWOOD MO = MODULE FH = FULL-SCALE-HOUSE ST = STEEL-FACED GY = GYPSUM SURFACE
PO = POLYESTER LAMINATE (SEE ALSO ATTACHED LIST OF PUBLICATIONS, TABLE - 4.1.2)

Table 4.1.1 - Structural test distribution in Operation Breakthrough.

Table 4.1.2 - Operation BREAKTHROUGH structural test reports referenced in table 4.1.1

(WJ) "The Effect of Impact Loadings on the Performance of Wood Joist Subflooring Systems", PB-221-188 [25]
by H. S. Lew

(LY) "Study of the Local Resistance of Conventional Plywood Subflooring to Concentrated Load" PB-220-432 [52]
by F. Y. Yokel

(MO) "Structural Tests of a Wood Framed Housing Module" COM-73-10860 [51]
by C. W. Yancey and N. F. Somes

(FH) "Full Scale Test on a Two-Story House Subjected to Lateral Load" BSS 44 [53]
by F. Y. Yokel et al.

(ST) "Structural Evaluation of Steel Faced Sandwich Panels" PB-213-240 [33]
by J. H. Pielert et al.

(GY) "Structural Tests for a Housing System Using Sandwich Panels with Gypsum Board Surfacings", PB-214-336 [22]
by W. E. Greene et al.

(PO) "Structural Tests on Housing Components of Glass Fiber Reinforced Polyester Laminate" PB-221-183 [37]
by T. W. Reichard et al.

Table 4.2 - Description of test specimen.

Group		Component of Specimens	No. of Tests
1		1/2 in. A-D INT, Group 1*	56
2		5/8 in. Underlayment C-C Plugged	44
3	a	1/2 in. C-D Plugged INT with 1/4 in. A-A Underlayment	25
	b+	1/2 in. C-D Plugged INT with 1/4 in. A-A Underlayment	28
4	a	1/2 in. C-D Plugged INT with 1/4 in. Hardboard Underlayment	36
	b+	1/2 in. C-D Plugged INT Split with 1/4 in. Hardboard Underlayment.	28

+These specimens had split sheets of plywood panel thus providing discontinuous edge at the center of test panel.

*For designation of plywood, refer to latest edition of U. S. Product Standard PS 1-66 for Softwood Plywood-Construction and Industrial, Product Standards Section, National Bureau of Standards, U. S. Department of Commerce.

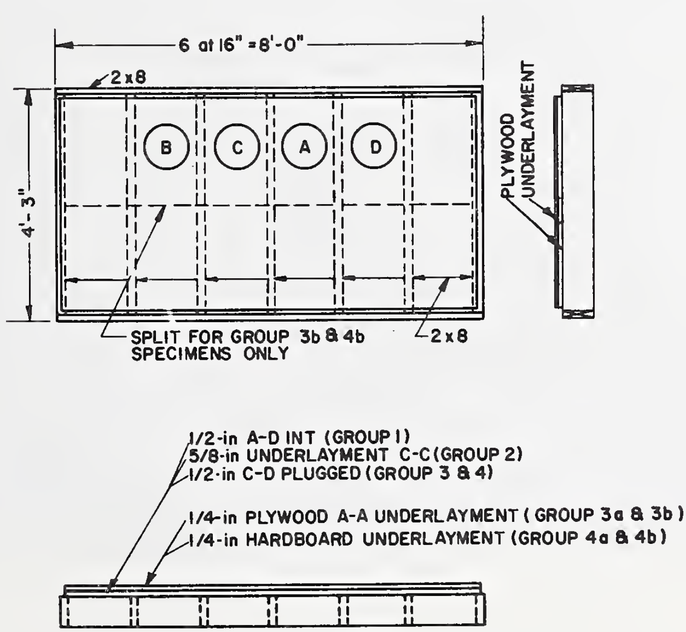


Figure 4.2.1 - Test specimen.

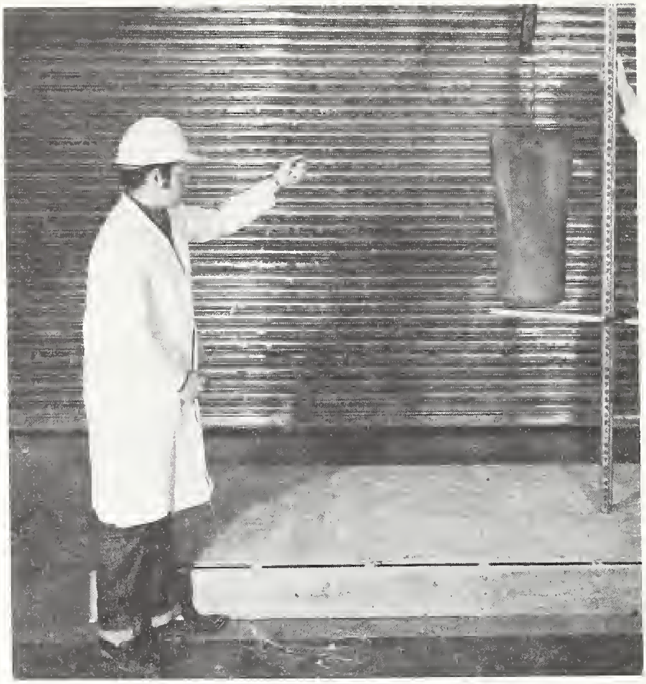


Figure 4.2.2 - Impact test setup.

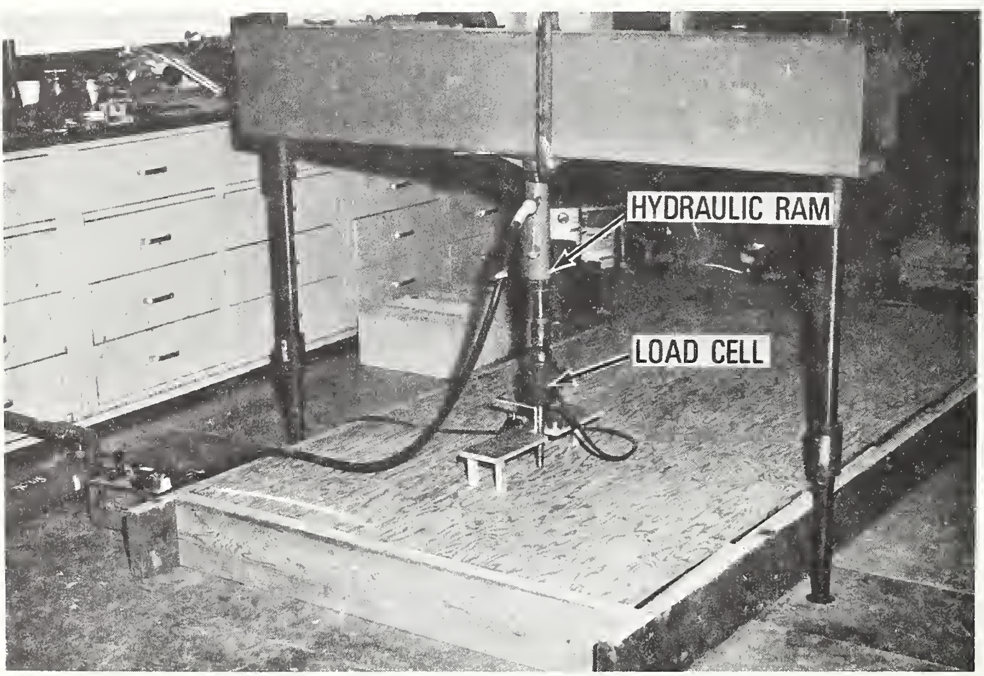


Figure 4.2.3 - Concentrated load test setup.

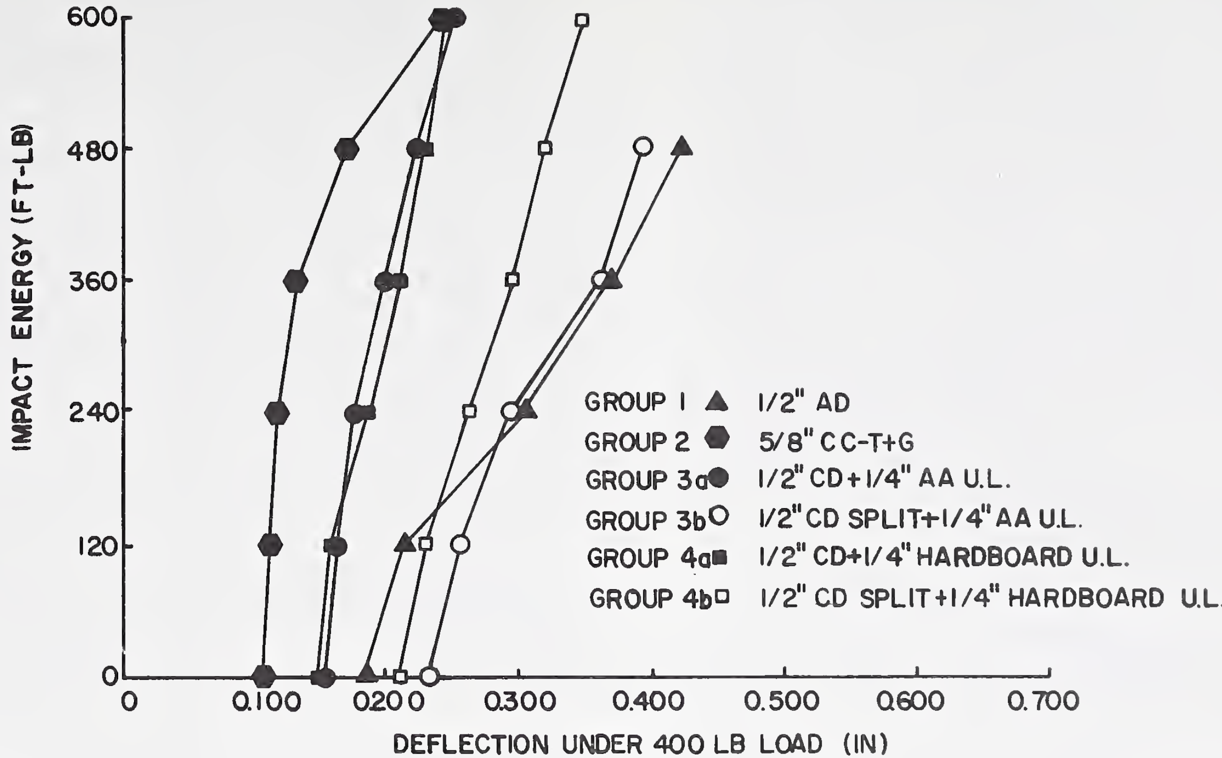


Figure 4.2.4 - Average deflections from 400-lb concentrated load applied after impact vs Impact energy.

experienced by a person walking over, or standing on, a localized area that has been subjected to impact loading. It is recommended that once deflection limits are established, a development program be conducted with the objective of deriving a test method that evaluates the response of the floor for its acceptability to human perception.

A recommendation regarding the area of the rod best suited to apply a concentrated load on a floor specimen will be expressed in the next section.

4.2.2 Local Resistance of Typical Plywood Subflooring to Concentrated Load [52]

4.2.2.1 Summary of Test

Five typical plywood subflooring assemblies, constructed in accordance with the requirements of the November 1966 edition of the FHA Minimum Property Standards, were tested under concentrated loading in order to compare their performance with performance criteria which had been developed on the basis of available data on anticipated occupancy loads. The test specimens were separated into two major groups, those with underlayment and those without underlayment (figures 4.2.5 and 4.2.6). Table 4.3 indicates the other test variables and the scope of the testing program. A typical test setup is shown in figure 4.2.7.

4.2.2.2 Review of Test

Concentrated loads on floors may be caused by heavy furniture or by human activity. Two possible critical conditions are identified and they are as follows:

1. A concentrated load of critical magnitude may cause damage to the entire floor or, as is more likely, to a portion of the floor, by exerting excessive bending moments and/or excessive shear forces.

2. A load may be concentrated over a very small area, therefore causing failure by excessive compressive stress and/or excessive punching shear. Typical heavy concentrated loads have been studied by Boyd [1/] and are summarized below:

1.	A person carrying a heavy load	.350-450 lb
2.	A crowded sofa (per front caster).	.300-350 lb
3.	An upright piano (1 caster).	200 lb
4.	A grand piano (1 caster)	280 lb
5.	Transportation of an upright piano (per wheel) . . .	.250-350 lb
6.	Transportation of a grand piano (per wheel). 2 . . .	.250-450 lb

Boyd concluded that since the presence of grand pianos in residences is relatively rare, the following design loads should be used:

(a) 400 lb for several seconds

(b) 350 lb for 1/2 hour

(c) 200 lb idefinitely.

1/ See the report by Boyd, J. D., "Minimum Strength and Stiffness Necessary for Wooden Floors and Houses", Paper No. 34, CSIRO, Division of Forest Product Technology, Melbourne, Australia, 1964.

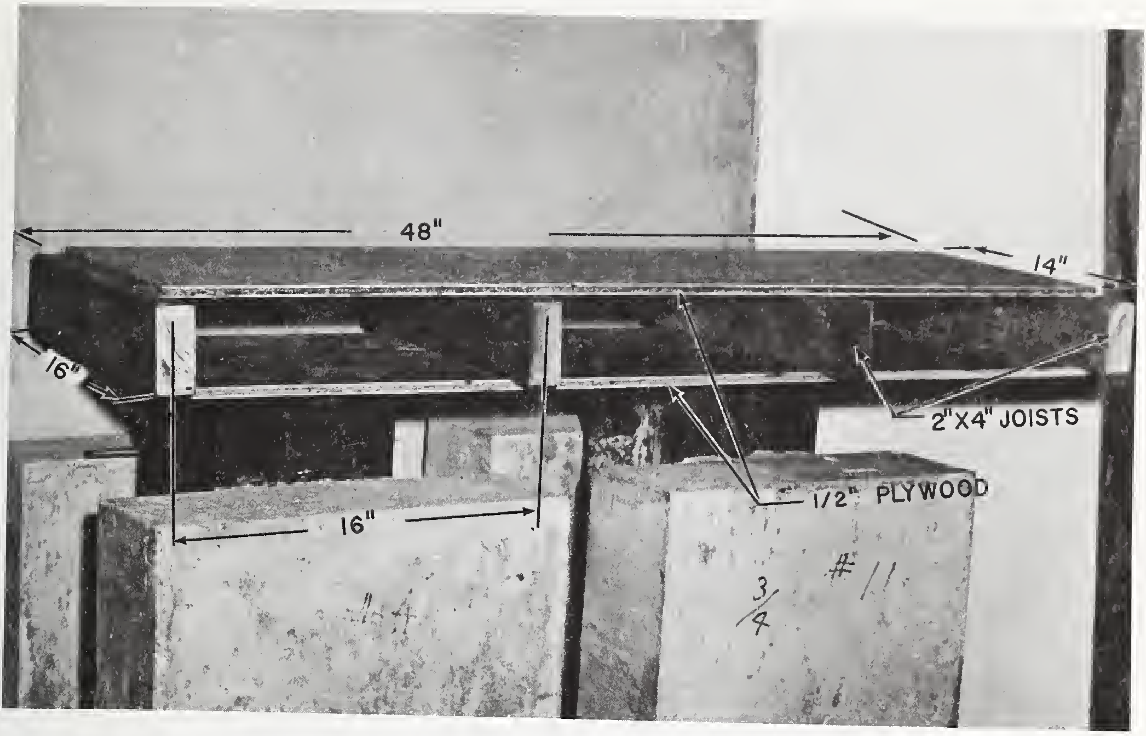


Figure 4.2.5 - Standard specimen without underlayment.

Figure 4.2.6 - Standard specimen with underlayment.

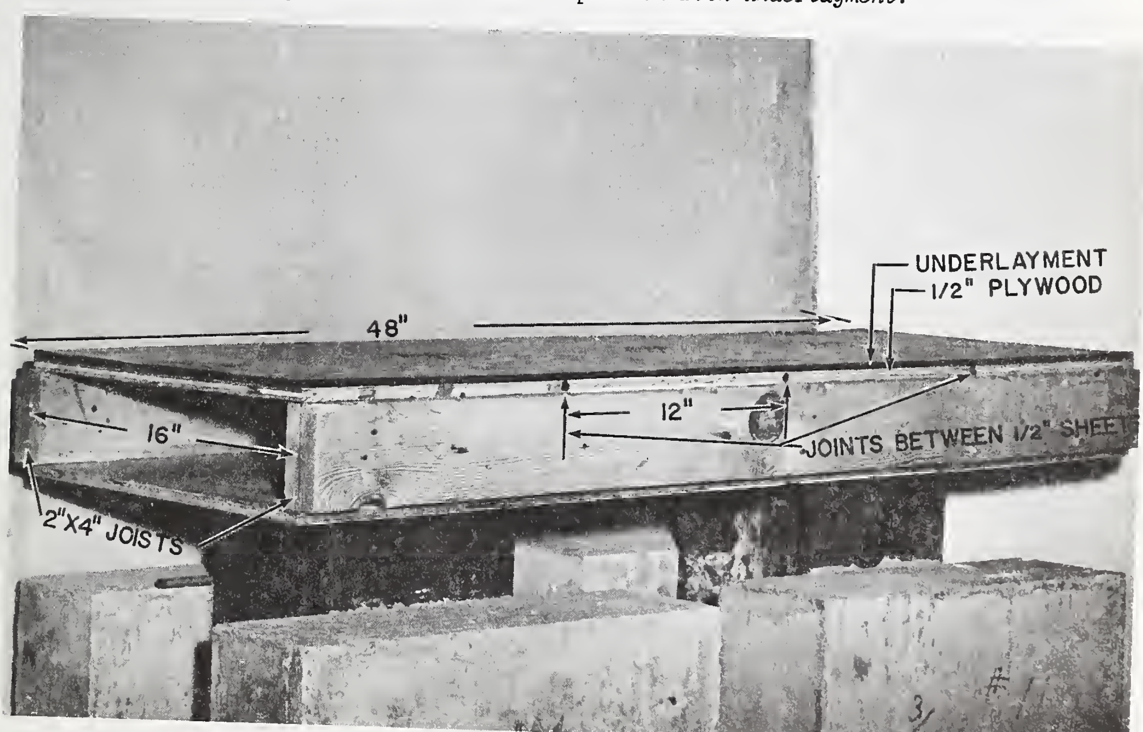


Table 4.3 - Number of tests performed.

Joist Spacing, in		16			24		20		10		6		
Diameter of Loaded area, in		1	5/8	1/2	1	5/8	1	5/8	1	5/8	1	5/8	TOTAL
Subflooring System	A	12	18			6	6	6	6	6	6	6	72
	B		18			12		6		11		6	53
	C	5	6	2									13
	D	14	7										21
	E	14	7										21
	F		6										6
	G		7										7
Total No. of Tests													193

SUBFLOORING SYSTEMS:

A: 15/32-in-thick underlayment grade Southern Pine interior-type, 5-ply plywood.

B: 1/2-in-thick standard grade Southern Pine interior-type with exterior glue, 5-ply plywood.

C: 1/2-in-thick C-D grade Dourlas Fir interior-type, 3-ply plywood.

D: 1/2-in-thick standard grade Douglas Fir interior-type, 3-ply[a] plywood under 7/32-in-thick hardboard underlayment.

E: 1/2-in-thick plywood as in D under 1/4-in-thick plywood underlayment.

F: 1/2-in-thick plyood as in C under 7/32-in-thick hardboard underlayment.

G: 1/2-in-thick plywood as in C under 1/4-in-thick plywood underlayment.

[a] The core of this plywood was laminated giving the interior ply double thickness.

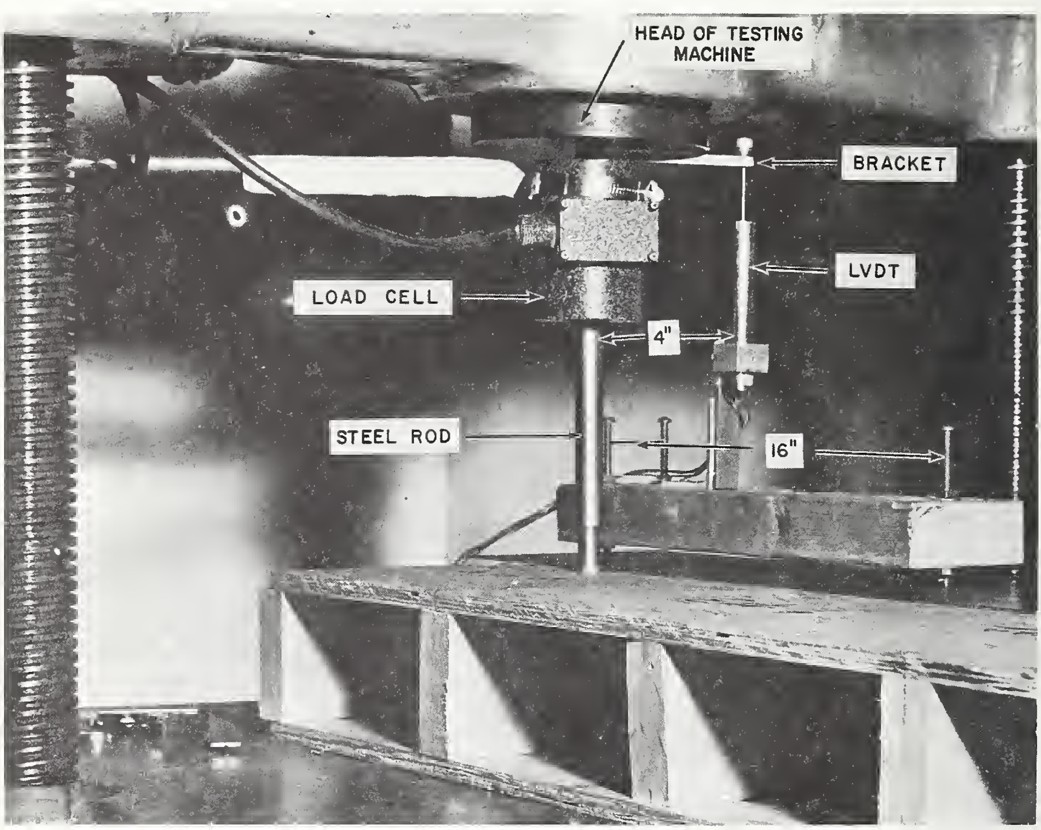


Figure 4.2.7 - Test setup.

Critical loading caused by load concentration over a small bearing area is also caused by stilletto heels. Even though these heels are not currently fashionable, their future use cannot be ruled out. A study of typical stilletto-heel pressure[2/] indicates a range of compressive stresses from 550 psi to 1390 psi, and one extreme value of 2260 psi. Values of punching shear computed from these data range from 80 lb/in to 117 lb/in. The case that produced the 2260-psi compressive stress produced a punching shear of 156 lb/in.

The concentrated load test described in Section 19 of ASTM E72-68[5] is intended to measure the structural capacity of the system, and the ASTM D2394 Test[3/] measures the strength of the finished flooring. These tests, with proper choice of load levels, could adequately evaluate most floor systems. A problem arises, however, with floor systems that consist of a thin structural skin supported by stiffening elements. In this case, the system may perform satisfactorily under the ASTM D2394 test, while under different support conditions the structural skin may fail by punching shear. On the other hand, in order to generate adequate stress under a 1-in diameter disc, the concentrated load would have to be increased to over 1000 lb, and in order to generate adequate punching shear the load would have to be increased to at least 500 lb. These heavier concentrated loads would be higher than the extreme concentrated loads that act on the floor in service.

The compressive stress caused by the 400-lb load, applied over a 5/8-in diameter circular area, is 1360 psi and the punching shear is 203 lb/in. Comparing the concentrated load, the compressive stress and the punching shear values with the concentrated loads data presented above for stiletto heels, it is evident that the effect of a 5/8-in diameter circular area more closely approximates these data than that of a 1-in diameter circular area.

4.2.2.3 Recommendation

In view of the above comparison, it is recommended that the standard ASTM E72 test be modified to reflect the findings of this test [52]. Hence, the standard would specify a 5/8-in diameter rod to apply the concentrated load.

4.2.3 Short Term Flexure Tests

4.2.3.1 Summary of Tests

A. Static Uniform Load on Sandwich Panels with Gypsum Board Facings [22]

One roof and one floor panel were tested, in a dry state with temperature and relative humidity conditions of approximately 73°F and 50% respectively. Figures 4.2.8 and 4.2.9 show the test setup and the details of the specimens. A complete load-versus-deflection plot could not be recorded because of the large deflections encountered and the need to protect the equipment from damage.

The results of these tests cannot be compared directly to generalized code requirements because of design changes which resulted in the roof

---

2/ Thornburn, H. T. "Flooring Damage by Heels," Materials Research Standards, ASTM, Vol. 2, No. 9, Phila., Pa., Sept. 1962.

3/ ASTM D2395-69 "Tests for Simulated Service Testing of Wood and Wood-Base Finish Flooring", American Society for Testing and Materials.

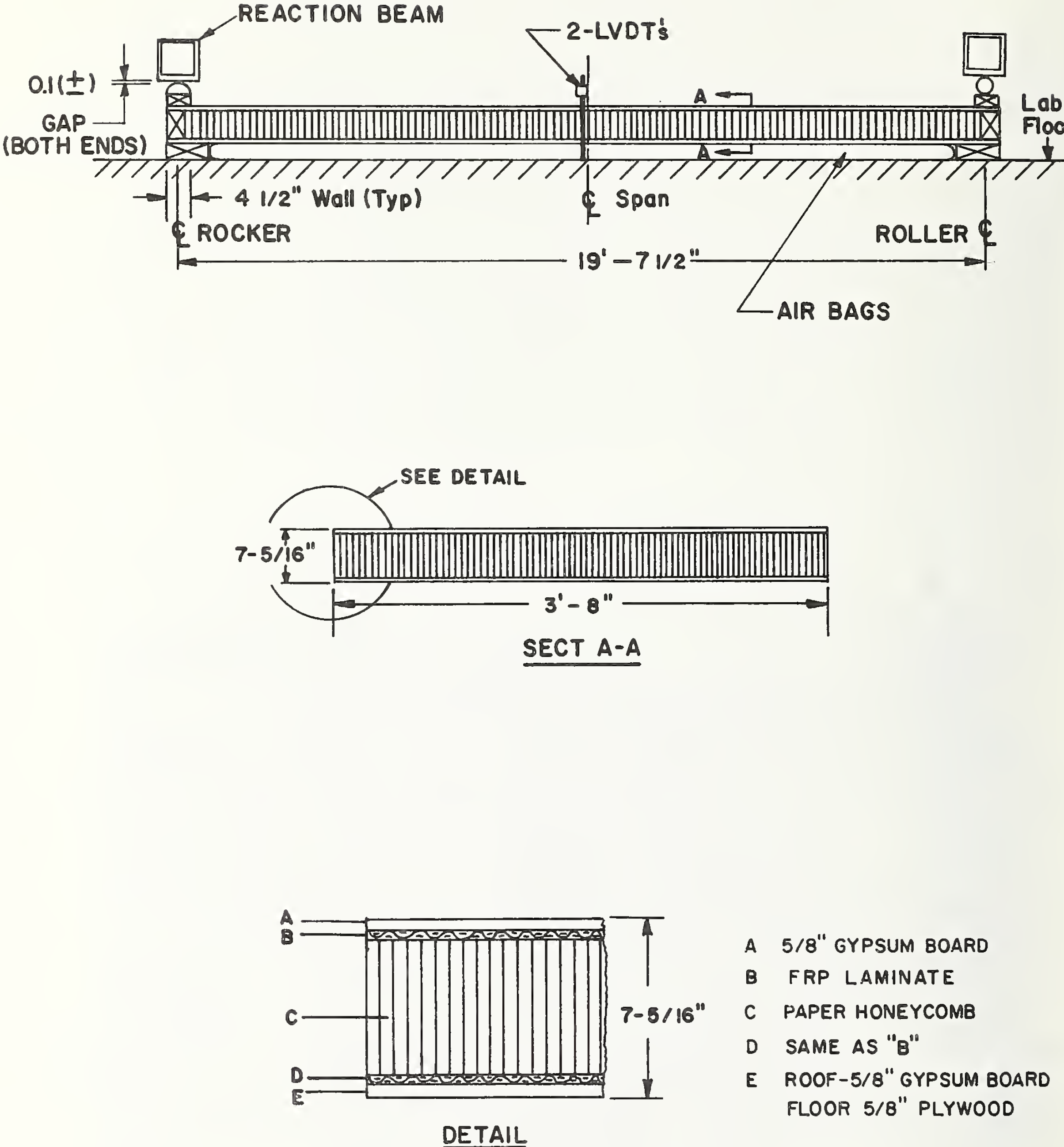


Figure 4.2.8 - Schematic of short term flexural test setup for safety and serviceability testing.

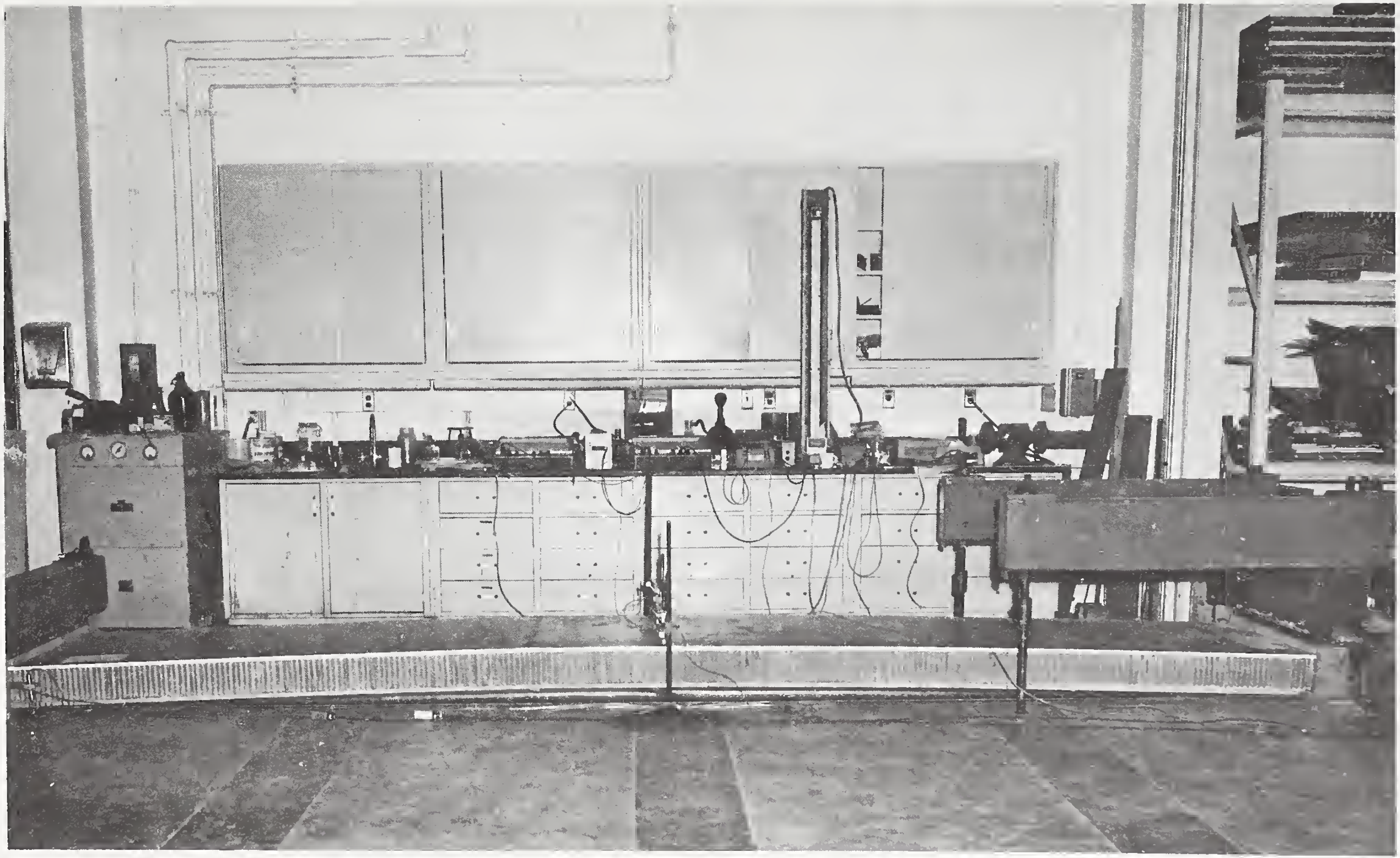


Figure 4.2.9 - Floor specimen under short term flexural test.

and floor components becoming flat plates, supported on all four edges. The specimens tested were elements which acted primarily as beams supported only on two opposite sides. However, the beam stiffnesses were determined from the load-versus-deflection plot by using the elementary beam deflection equation for the case of uniform loading.

From this, an estimate of the structural rigidities of the roof and floor plates were made. For the roof, the derived structural rigidity was used to calculate a maximum deflection for a uniform load of 20 psf. This afforded a comparison of the computed deflection-to-span ratio with the value allowed by the governing performance criterion.

The test results were also applied indirectly to determine a suitable limit for the design ultimate uniform load for the roof plate. In the test specimen, failure occurred in the compression facing, so that the strength was limited by bending. It was assumed that the strength of the roof plate would also be limited by bending and that the ultimate bending moment of the plate would equal the ultimate bending moment derived from the simple beam test performed. Substituting the test results into the equation for the maximum plate bending moment, and solving for an equivalent uniform load, yielded a load capacity for the roof. Based on this value, an allowable design ultimate loading for the roof was determined.

The floor was also a flat plate with the same dimensions and aspect ratio as the roof. Using the same analytical process as that applied to calculate the roof deflection, a maximum deflection was calculated for a design uniform floor load of 40 psf. As with the roof plate, this afforded a comparison of the computed deflection-to-span ratio with the value allowed by the governing performance criterion.

The same analytical procedures used in determining the load capacity of the roof were used to determine the load capacity of the floor. This value was used to establish an allowable design ultimate load.

B. Static Uniform Load on Panels Fabricated from Glass Fiber Reinforced Polyester (FRP) Laminate [37]

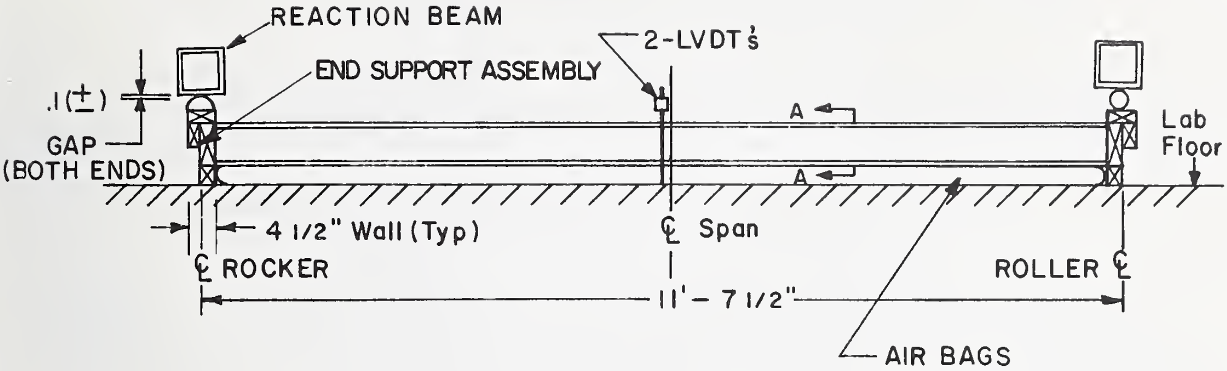
One roof panel was tested in a dry state with environmental conditions of approximately 75°F and 50% relative humidity. Figure 4.2.10 shows the test setup, dimensions and details of the cross section of the panel. The midpoint deflections measured during this test afforded a direct comparison of the deflection-to-span ratio with that permitted by the governing performance criterion since the physical simulation of the supports and loading were representative of actual conditions. The roof panel did not reach its flexural capacity because the air bag failed first. However, at this point, the load on the roof panel had exceeded the recommended ultimate design load by a factor of 1.8.

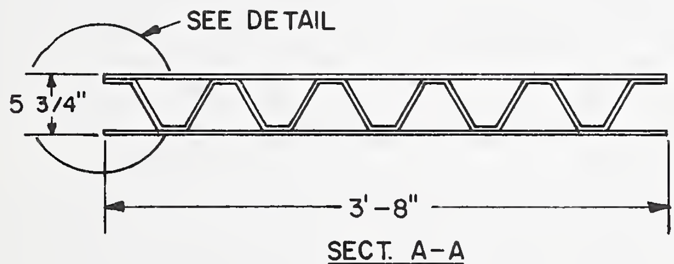
C. Static Uniform Load on Steel Faced Sandwich Panels [33]

Four roof panels were tested after each had been conditioned by one of the following procedures:

1. 50% relative humidity at 73 $\pm$ 3°F for five days

2. 95% relative humidity at 73 $\pm$ 3°F for five days





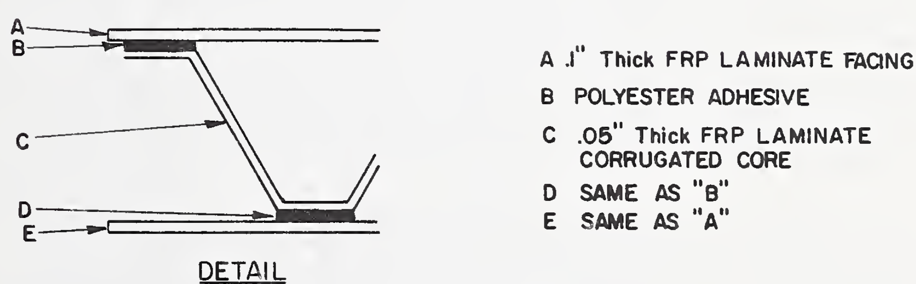


Figure 4.2.10 - Schematic of test setup for short term flexural test on roof panel.

3. Complete submersion in a water bath at 73 ± 3°F for seven days and a subsequent 9-day drying period at 73 ± 3°F and 50% relative humidity. Figures 4.2.11 and 4.2.12 show the test setup.

Again, as in the roof panel tests described (paragraph B) above, the midpoint deflection measured during this test permitted a comparison of the deflection-to-span ratio with that permitted by the governing performance criterion as the support condition and loading technique were representative of the design parameters.

4.2.3.2 Review of Tests

The test setup and procedures used for this series of tests, A through C, followed ASTM E72 recommendations except that the air bag was sandwiched between the laboratory floor and specimen instead of between the specimen and a reaction frame, as called for in E72. Also, no air bag containment plates were provided around the edges of the specimen; although in the test on steel faced sandwich panels, side containment was provided by the edge members of the panel (figure 4.2.11). It seems clear that reacting the applied load uniformly against an existing laboratory floor simplifies the test setup by eliminating the grid assembly from the reaction frame. The grid would have to be tailored for different sizes of specimen, while no alterations would be required for the laboratory floor. The advantages and disadvantages resulting from eliminating the containment plates around the edges of the specimen may not be quite as apparent as those resulting from eliminating the grid assembly from the reaction frame; therefore the effect of the former, warrants further discussion.

If edge-containment plates are provided, it still may not be possible to fully determine the loaded area of the specimen, since the air bag probably will not be able to fit exactly into the re-entrant corners along the edges of the specimen, where the direction of confinement changes from horizontal to vertical. If edge-containment plates are not provided, either the air bag will extend beyond (i.e. be outboard of) the edges of the specimen (except in cases where the edge members of the specimen protrude above its surface as described in Section 4.2.3.1B) or the extent of the area of contact between the air bag and the specimen's loaded surface will be inboard of the edges of the specimen (see Sections 4.2.3.1A and 4.2.3.1B for descriptions of specimens without edge-member protrusions). In the latter case, the absence of edge-containment plates allows the area not in contact to be observed. Consequently, measurements can be made to determine the amount of unloaded area, and an accurate assessment of the applied load can be made. This was the procedure followed during performance of the tests summarized in Sections 4.2.3.1A and 4.2.3.1B; the test summarized in Section 4.2.3.1C had confined edges due to the construction of the panel. Both procedures appeared to give satisfactory results.

The concept of allowing the air bag to extend outboard of the specimen's edges was not used in the test summarized in Section B due to weak longitudinal panel edges (see figure 4.2.10). Neither was the outboard air bag arrangement employed in the test summarized in Section 4.2.3.1A because of the risk that the sharp edges of the specimen would cut the air bag. Three other factors were also considered, the first one being that if the diameter of the outboard portion of the air bag became greater than the distance between the laboratory floor and loaded surface of the specimen, hoop tension forces would introduce additional loading along the edges of the specimen in the direction of the uniformly applied load. For example, if the diameter of the outboard portion of the bag was 6 in, and the distance from the laboratory floor to the loaded surface was 4 in, a force of 17.0 lbs per ft along the edges of the specimen could easily develop, for an

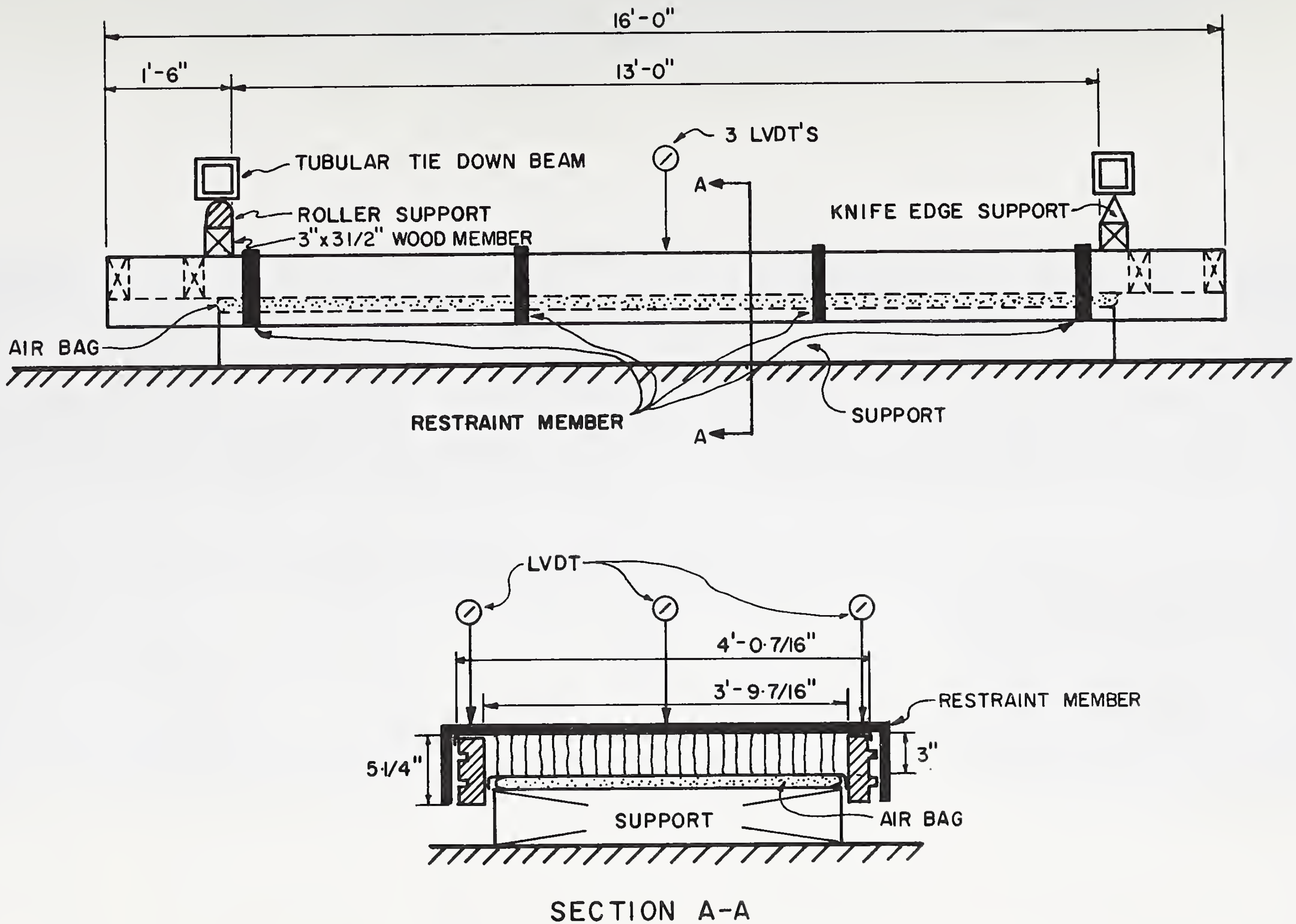


Figure 4.2.11 - Schematic of test setup for short term flexural test on roof panel.

Figure 4.2.12 - Short term flexural test on roof panel.

applied load of 72 psf. The second consideration was the air bag's membrane stress, which can be calculated from the internal pressure, membrane thickness, and radius of the air bag along the edges. However, this did not turn out to be a problem; the air bag used to test the floor specimen of sandwich panels with gypsum board facings attained an edge radius of almost 9 in without rupturing, corresponding to an 18-in midpoint deflection of the specimen. The third factor was the possibility of subjecting the panel to in-plane forces caused by the radial pressure within the air bag. As a result of these in-plane forces the panel would in effect become a beam-column and hence its true flexural strength and stiffness would be affected. (The following section contains some recommendations regarding the use of air bags). In addition to this stability consideration for the panel is the problem of local edge effects. Panels with weak edge construction could be adversely affected by crushing or buckling as the pressure is increased. All three of these factors should be considered according to the details of construction of individual specimens.

4.2.3.3 Recommendations

The ASTM E72 test method for floor and roof panels clearly needs to be modified to improve cost effectiveness and the capability of observing the structural behavior during the test without degrading the simulation of uniformly applied loading. This can be accomplished by employing methods similar to those employed during the Operation BREAKTHROUGH structural testing program for roof and floor panels. The major cost saving came from devising a method which eliminated the grid assembly from the reaction frame; also, with the elimination of the side containment plates, the specimen was completely uncovered, permitting structural behavior of the specimens to be more readily observed. An apparent drawback of this simplified method stems from the inability to fully load the surface of the panel. This certainly is not a drawback for panels with weak edges, such as those described in Section 4.2.3.1B. On the other hand, for many panels, it might seem desirable to load the entire surface. This is not possible unless some portion of the air bag extends outboard of the edge of the panel being loaded, which causes an undesirable edge loading and creates the risk of damaging the air bag when testing panels with sharp edges. Therefore, it is recommended that the structural test method employed in the Operation BREAKTHROUGH testing program for physically simulating support conditions and uniform loading of roof and floor panels be further developed for adoption as a standard test.

It will be shown that the inability to load the entire surface of panels, that are capable of resisting such loading without incurring local damage along the edges, need not be considered a drawback. There are several alternative ways to account for this condition. The area reduction, or its complement, the actual loaded area, can be observed during the test and then calculated if appropriate measurements are made during observation; or, the area reduction can be calculated prior to testing, using the geometry of the specimen, air bag and test setup (see Appendix B). Thirdly, the imposed uniform loading can be measured. This can be accomplished by using two reaction beams at each support, with load cells inserted between them as shown in cross-section B-B of figure B.2 in Appendix B.

The use of load cells provides the most accurate method of monitoring the simulated uniform loading of the panel; however the use of load cells adds to the complexity of the test setup, which will increase the cost of performing the test. This increase in complexity and cost may not be warranted if it can be shown that the other two approaches, (i.e. determining the reduction in area during the test by measuring the width of the unloaded area along the edge of the panel and calculating the reduced area from the geometry of the air bag, specimen, and test setup) which employ knowledge of only air bag pressure and contact area, do accurately monitor the simulated uniform load.

Caution must be exercised when evaluating the results of a test in which significant reduction in area occurred. It must be remembered that although the total load obtained from a partially loaded panel may be equivalent to the total load resisted by a panel that is fully loaded with a uniform distribution, the resulting moments, shears and deflections may be considerably different.

A test program should be devised to compare the results of the two test setups which do not contain load cells to those of the test setup which contains load cells. The scope of this test program should include:

a. evaluation of predicted loading using a single air bag to load panels.

b. evaluation of predicted loading using two or more air bags to load panels.

c. investigation over a full range of deflections from zero to 20 in, recalling that one of the panels tested in the Operation BREAKTHROUGH test program deflected nearly 20 in.

d. development of techniques for continuously monitoring large deflections efficiently and safely, (i.e. minimize the necessity for resetting deflection gages).

4.2.4 Long Term Flexure Tests

4.2.4.1 Summary of Tests

A. Static Uniform Load on Sandwich Panels with Gypsum Board Facing [22]

One roof and one floor panel were tested under environmental conditions of 70°F and 50% RH. The magnitude of the test load was 5 psf and 10 psf for the roof and floor panels respectively; the test setup, specimen size and details are shown in figure 4.2.13. The test results for the roof panel specimen are shown in figure 4.2.14 as a curve which describes the creep deflection as a function of time. Note that the time coordinate is plotted on a logarithmic scale. The solid line in the figure approximates the time-deflection relationship for an average relative humidity of 30%. The broken line is an estimated time-deflection curve for an average relative humidity of 50%; the latter RH value was judged to be the more realistic one for the specified design conditions. It is shown below that these data can be used to predict the time-dependent deflection of the actual roof system for its entire service life.

When the broken line in figure 4.2.14 is extrapolated from 300 days to 50 years (18,000 days), a creep deflection of 0.81 in is estimated for the roof panel. On the assumption that the data used to obtain the extrapolation is statistically reliable, the boundary (support) conditions of the test panel can be compared to those assumed for the actual roof system (i.e. rectangular plates supported along all edges) to provide an estimate of the creep deflection of the roof for the entire service life. For the design load combination of one times the dead load and 0.25 times the live load (which amounts to 5 psf superimposed load) the estimated creep deflection is 0.23 in. This procedure is also applicable to the results of the floor panel tests.

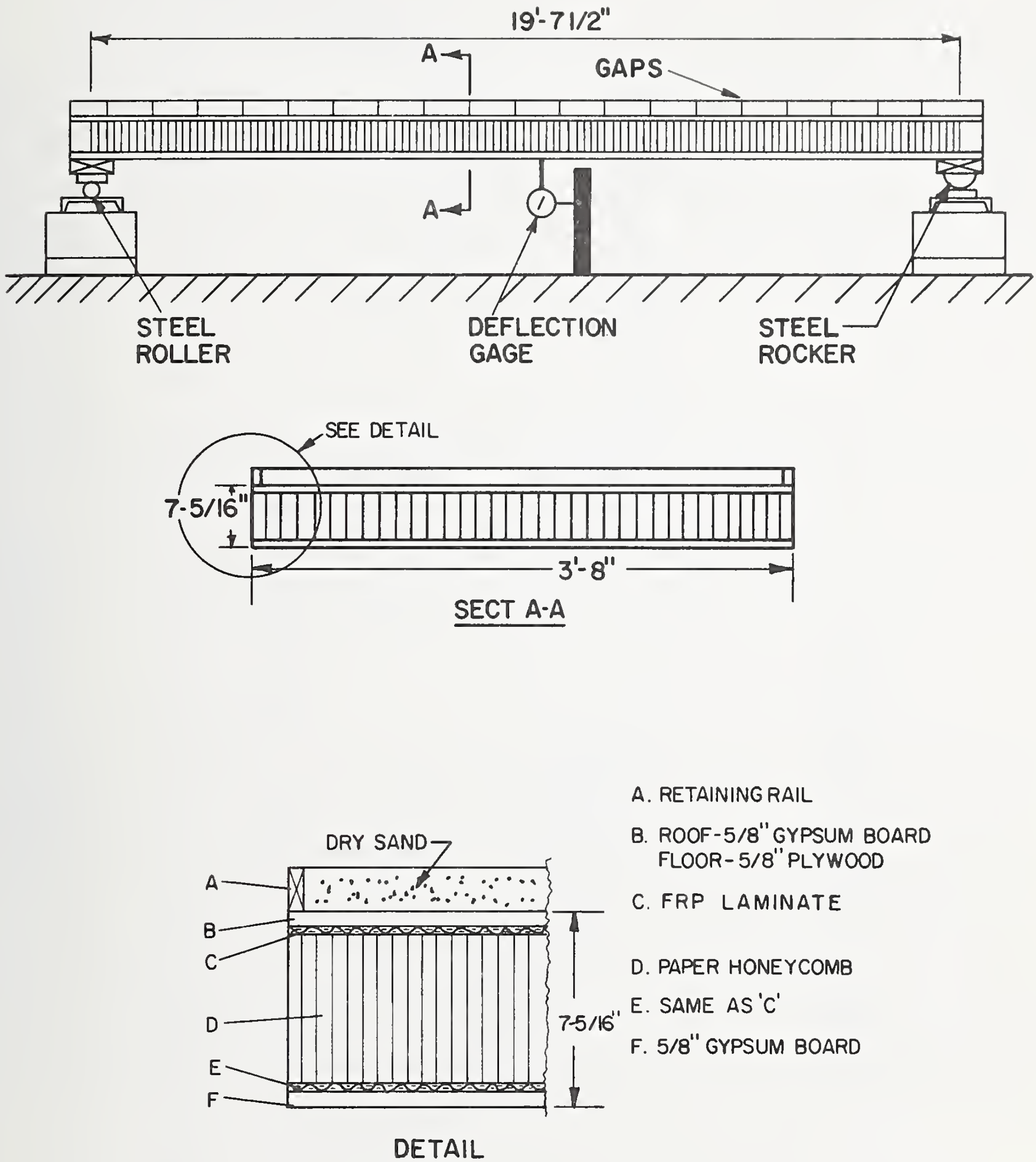


Figure 4.2.13 - Schematic of long term flexural load test setup.

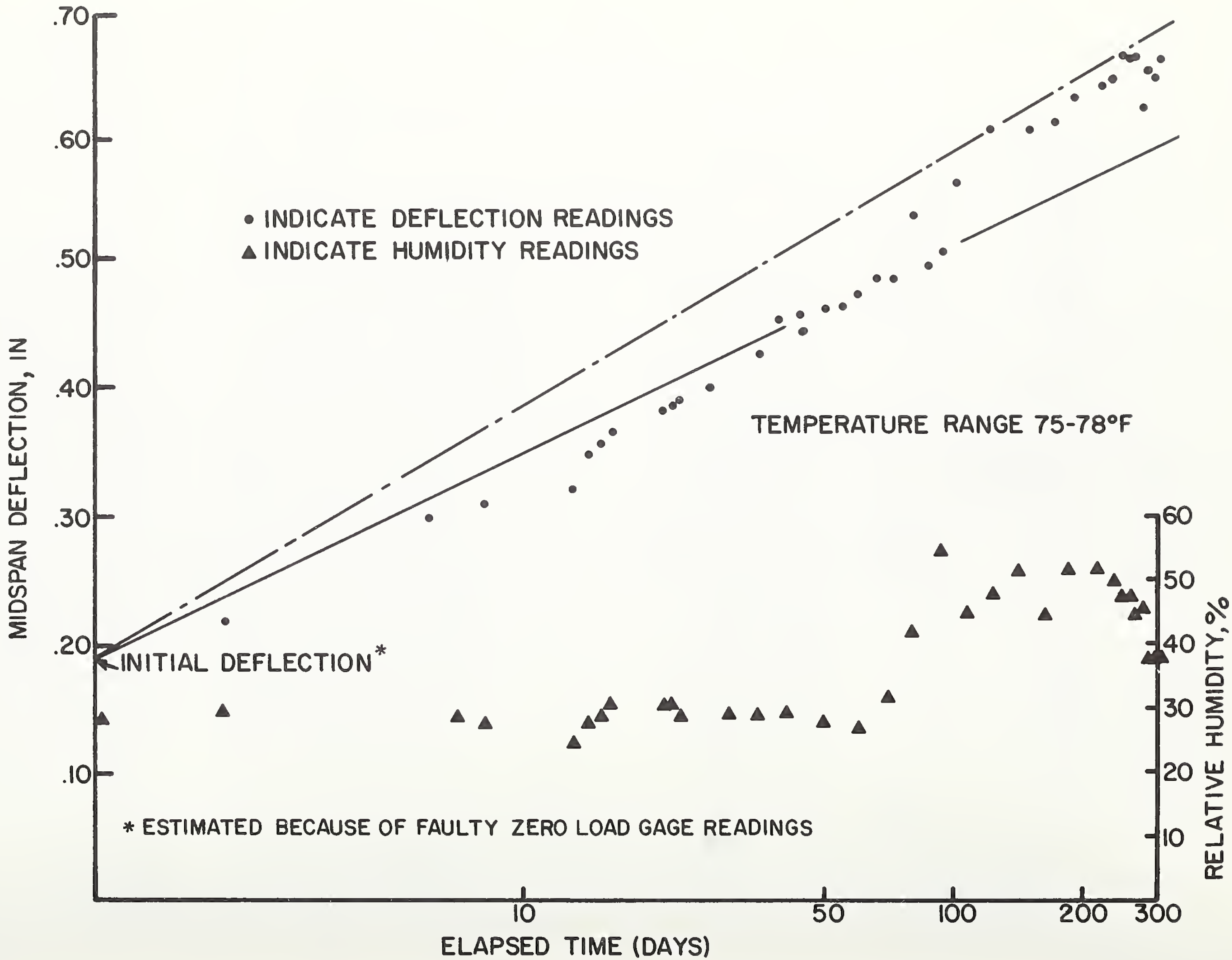


Figure 4.2.14 - Roof panel creep test results under a sustained load of 5 psf.

B. Static Uniform Load on Panels Fabricated From Glass Fiber Reinforced Polyester Laminate [37]

A single roof panel specimen was tested in flexure under controlled environmental conditions. Figure 4.2.15 depicts the test setup, dimensions and details of the specimen.

The results of this testing are presented in figure 4.2.16. Midspan deflections, temperature and humidity readings were taken for 280 days but only the data from the first 100 days of the test period were considered usable as a failure in the temperature and humidity control unit resulted in erratic environment conditioning after this period. The data points for days 12 to 100 lie approximately in a straight line when time is plotted on a logarithmic scale. If this line is extrapolated to 50 years, the maximum deflection due to creep can be calculated, assuming the reliability of the data on which the extrapolation is based. This deflection, when added to the instantaneous deflection caused by a live load yields a total deflection for a simulated long-term loading condition.

4.2.4.2 Review of Tests

The relatively small uniform load (25% of design live load), applied to the panels tested for BREAKTHROUGH resulted in a very low creep rate, causing the test to be prolonged. To be effective, test methods for obtaining data to evaluate creep should be obtained in a relatively short period of time, say two weeks. It is evident that 25% of the design live load sustained by a floor or roof specimen does not reflect service loading conditions over the expected service life of the structure. The actual loading is more a combination of a small-magnitude uniformly sustained load and large-amplitude cyclic loading.

4.2.4.3 Recommendations

It is recommended that a test method using a combination of uniform sustained and cyclic loading be developed to simulate service loading. The magnitudes of both loads can be determined through studying existing live load information. The test setup could be similar to the air bag setup used in BREAKTHROUGH testing, with an automatic cycling device to increase pressure to simulate temporary large-order loading superimposed on a small-order sustained load. The cycling could be accomplished, say, every ten or fifteen minutes. Starting with a low magnitude of uniform loading, the results of the test will provide data needed to plot load versus number of cycles, and load versus deflection increase. The latter could be accomplished by taking the difference between the first and last cycle at a particular load. Some reasonable number of cycles of loading must be determined; again, this can be determined through studying existing live load information. A physical testing program should be developed to verify the test procedures and the adequacy of the prescribed loading.

4.3 Wall Tests

4.3.1 Short Term Compression

4.3.1.1 Summary of Tests

A. Sandwich Panels with Gypsum Board Facings [22]

The aim of these tests was to evaluate the performance of full size wall panels of single-story height under the action of short-term compressive loads. Wall specimens were representative of exterior wall panels but

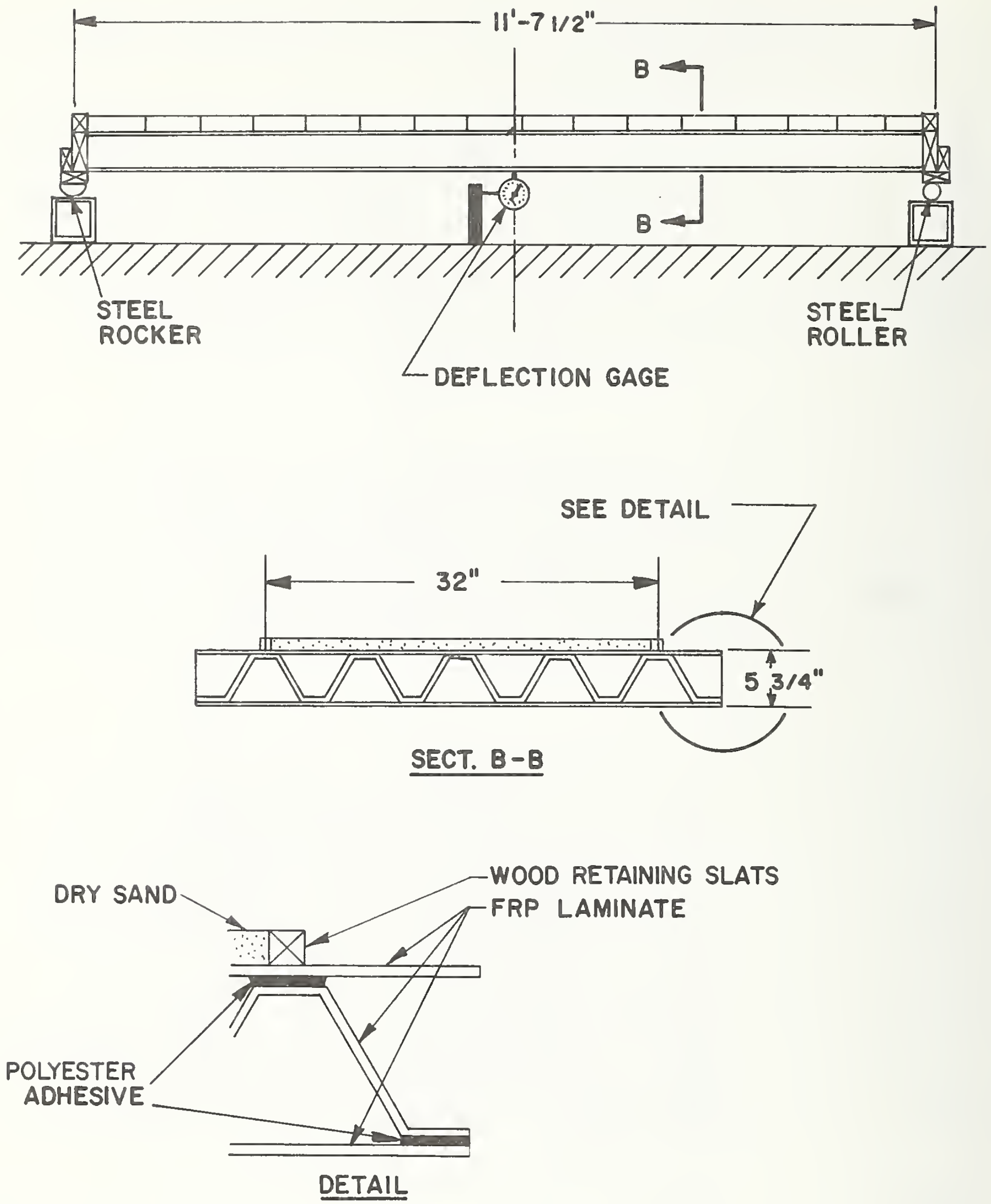


Figure 4.2.15 - Schematic of long term (creep) sustained flexural load test setup.

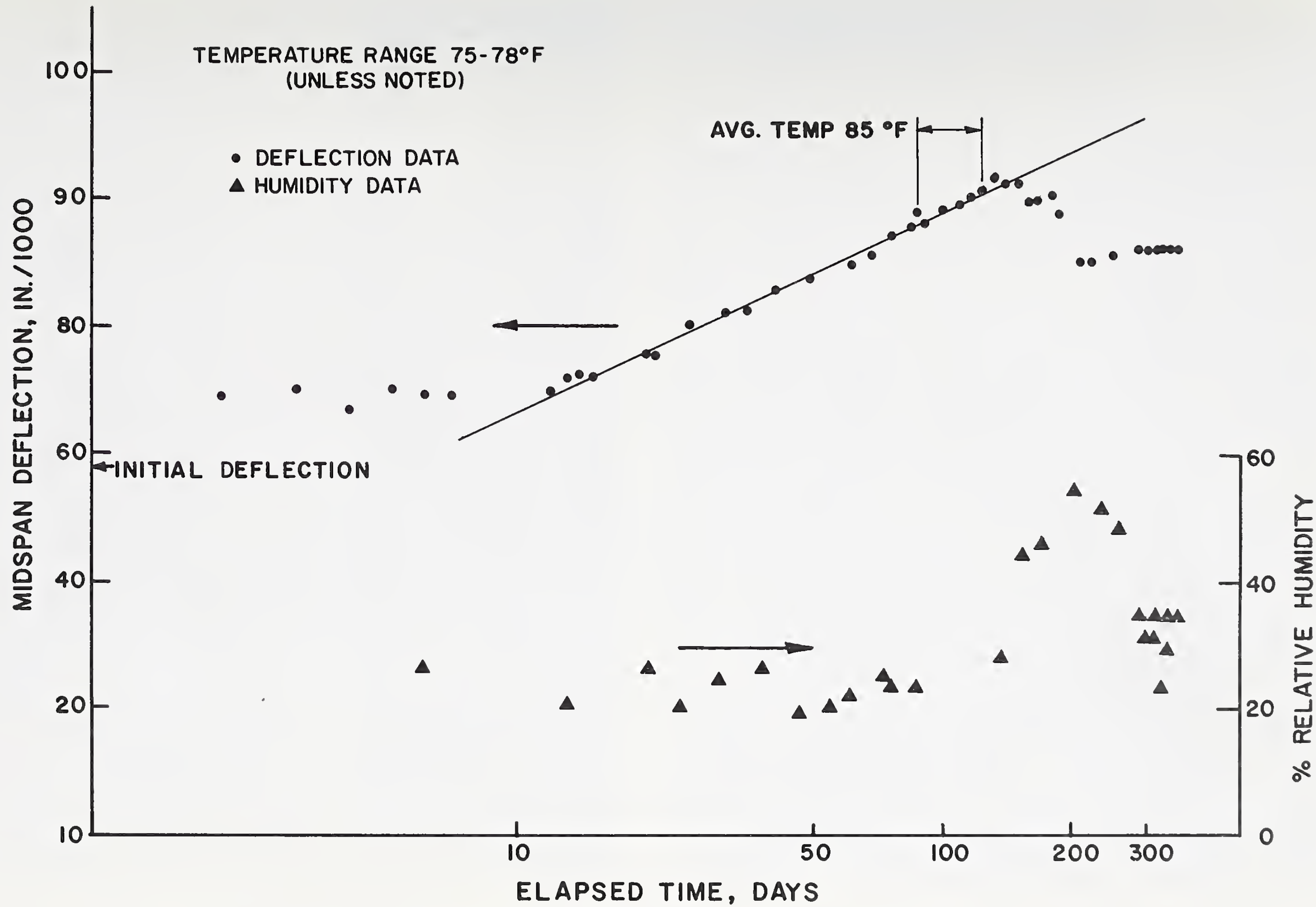


Figure 4.2.16 - Roof panel creep test results under a sustained load.

were of a width suited to test purposes; specimens were 4 3/8 in thick by 24 in wide by 96 in high. Figure 4.3.1 is a photograph of a wall specimen under test. The basic construction of the panels is shown schematically in figure 4.2.8. The upper and lower 3 in of the core in each panel consisted of laminated plywood bearing blocks bonded to the fiber-reinforced plastic (FRP) laminate and the honeycomb core. The design of the wall panels called for application of compressive loads to the walls through the wood bearing blocks without any load bearing on the gypsum board facing. Two panels, called "dry," were conditioned for 14 days in the testing laboratory-controlled atmosphere of 73°F and 50% relative humidity (RH) and tested immediately thereafter. Two other panels, called "wet," were preconditioned for 4 days in the same laboratory, then exposed to a controlled atmosphere of 160°F and 95% RH for 7 days, just prior to testing; all four specimens were tested in the laboratory atmosphere described above. A total of four tests comprised different combinations of "wet" or "dry" specimens, and concentric or eccentric (1/6 of the panel thickness) loading. Load application was substantially in accordance with ASTM E72-68.

B. Short Specimens of Sandwich Panels with Gypsum Board Facing [22]

These tests were performed to evaluate the edgewise compressive strength of the panel material without the effect of lateral deflections experienced by the full-height wall panel tests described above. The four specimens were 24 in high by 12 in wide by 4 3/8 in thick and were of the same construction as the full-height wall panels except for end conditions. The top and bottom of the specimens were bonded with an adhesive to 14-in.long, 2 x 6 wood bearing plates for test purposes. Figure 4.3.2 is a photograph of a short-wall specimen ready for test. Two specimens were conditioned for 11 days in air at 73°F and 50% RH. Two others were conditioned for 7 days in a steam-heated chamber at 160°F and about 95% RH. All specimens were tested at 73°F. The specimens conditioned at elevated temperature and humidity were cooled to 73°F but were not dried before testing. Specimens were loaded in a hydraulic testing machine by applying increasing concentric compressive load until failure occurred.

C. Sandwich Panels of Glass-Fiber Reinforced Polyester (FRP) Laminate [37]

Two wall panels, were tested in short-term compression to evaluate their performance under simulated service loading conditions. The panels were typical of those intended for use in service but also incorporated two additional wood members at the top and at the bottom edges to facilitate test simulation of service loading (figure 4.3.3). Each panel was 40 in wide, 96 in high and 3 7/8 in thick; except for these dimensions, the basic cross section details are the same as those shown in figure 4.2.10. Specimens were positioned in a compression testing machine so that the load was applied at an eccentricity ratio (fraction of panel thickness) equal to 0.26, as incurred in service. Generally, the rest of the test procedure followed ASTM E72.

4.3.1.2 Review of Tests

One of the departures from the ASTM E72 method was in the positioning of the test load on the specimen. In the case of the honeycomb-gypsum board panels (see Section 4.3.1.1A), concentric loading was included so that a comparison of its results with those caused by E72 loading would provide an indication of the relative effect of eccentric loading. In testing the corrugated FRP panels, sufficient details were known about service loading conditions to simulate them in the laboratory.

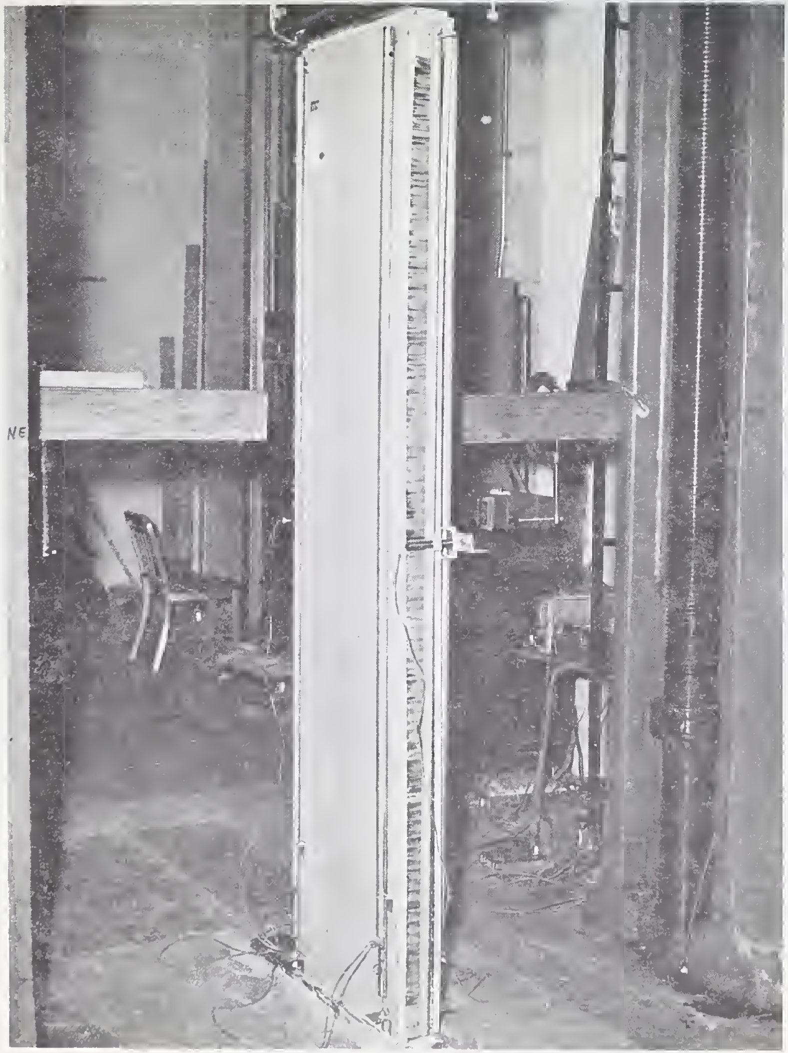


Figure 4.3.1 - Short term load test of large wall panel specimen.

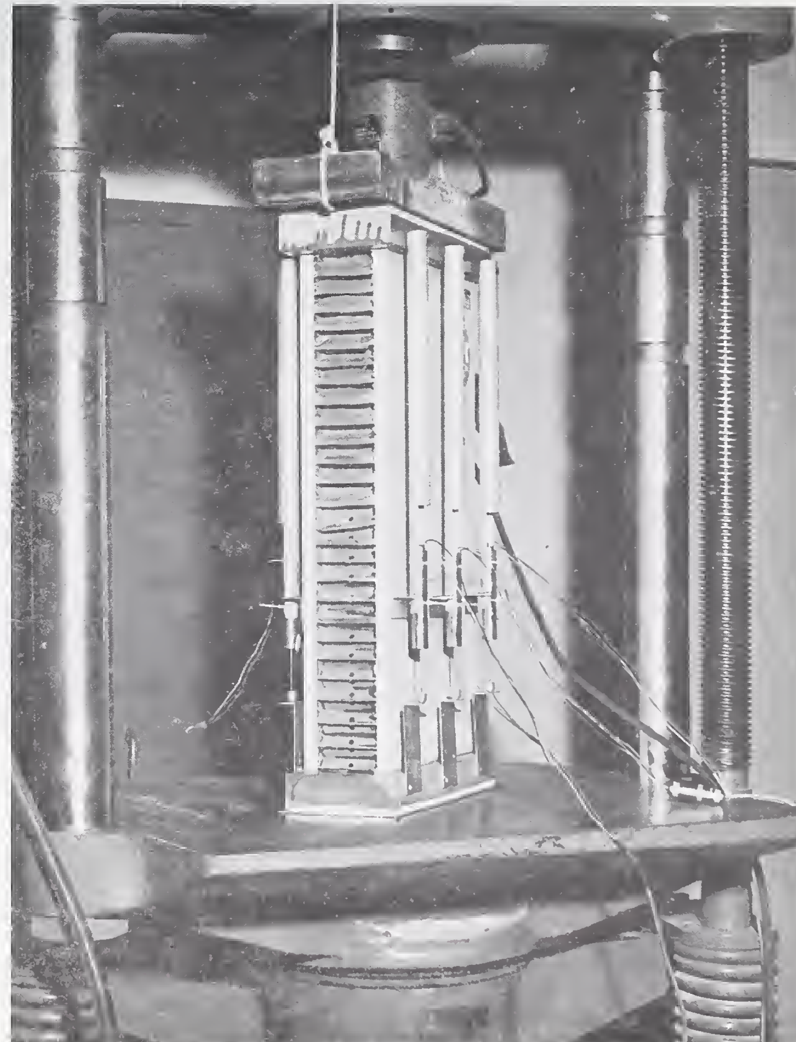


Figure 4.3.2 - Test setup for short-wall compressive tests.

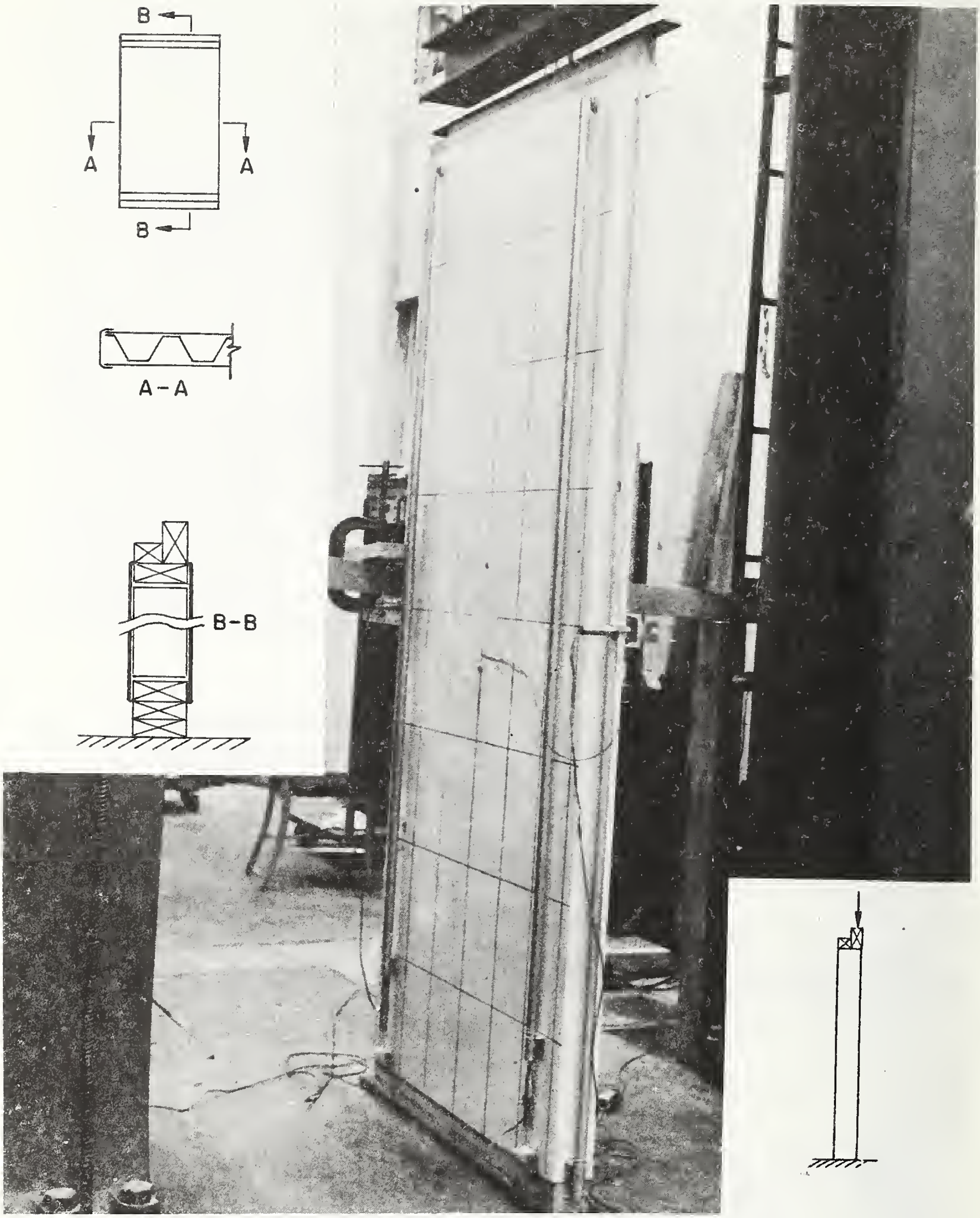


Figure 4.3.3 - Short term compressive load test.

The use of linear variable differential transformers (LVDT) as compressometers and deflectometers (figures 4.3.1, 4.3.2, 4.3.3) made it possible to automatically observe and record data for each load increment in a short time interval--a particularly important factor in testing constructions that creep readily. Moreover, in contrast with what is recommended by illustration in figure 2 of ASTM E72 [5], the deflectometers were located so that they spanned virtually the full length of the specimens, and measured the deflection of the neutral axis.

Another circumstance which influenced the test procedure was the involvement with materials that, even with little structural history, were known to be sensitive to high temperature and humidity. The need to know the percentage reduction in performance (especially of the paper honeycomb-gypsum board panels) caused by exposure to such conditions was quite evident. A less obvious aspect of this kind of procedure, however, was the choice of laboratory exposure conditions for a realistic simulation of service exposure.

Testing of the short specimens of sandwich panels with gypsum board facing (see Section 4.3.1.1B) elicits two observations. First, adhesive-bonded wood 2 x 6 plates provided satisfactory bearing at the loaded ends and prevented localized test-related bearing failure, thus permitting the determination of representative values of strength and stiffness. Secondly, the height-to-thickness ratio of the short specimens (approx. 5 1/2) was an arbitrary choice and therefore does not reflect sufficient systematic regulation.

4.3.1.3 Recommendations

Provision should be made in ASTM E72 for positioning the compression test load in its service location on the wall, if it is known. Similarly if the test is to be a realistic one, consideration should be given to requiring simulation of wall support and restraint conditions. If this kind of information is not known, then a generalized type of procedure could be employed. Furthermore, such a generalized test would need additional fundamental study. For example, location of test load, as well as manner of bottom edge support (flat or roller) should be reconsidered. Location of instrumentation on the specimen should be improved to minimize errors, and recommendations for instrumentation should be modernized to facilitate rapid observations and reduce manpower requirements.

A standarized compression test should take into account the detrimental effects of environment on the wall structure. Conditioning procedures for laboratory simulation will have to be established by research. These procedures should entail pre-conditioning as well as test conditions.

The testing of short compression specimens should be considered as a recommended complement to wall tests. These would provide strength and stiffness values for use in design calculations of load capacity and deflection to be compared with test observations. The choice of a height-to-thickness ratio for these short specimens requires study for standardization, however, since there is a diversity of values now in use.

4.3.2 Long Term Compression of Sandwich Panels of Glass-Fiber Reinforced Polyester (FRP) Laminate [37]

4.3.2.1 Summary of Test

Two wall panel specimens, identical to those used for short-term compression (Section 4.3.1.1 C), were tested under a sustained compressive design load as shown in figure 4.3.4; the load eccentricity was the same as in the short-term compression test of the panels. Two support conditions were used. Both specimens were originally loaded using the flat bottom bearing illustrated in figure 4.3.4. Later, the set-up of one specimen was changed to employ a roller bearing at the bottom providing the same eccentricity as at the top (figure 4.3.5). Both of the above-mentioned figures also show the springs used to sustain the test load, and the mirror-backed graduated scale and taut wire used for measuring deflection.

4.3.2.2 Review of Test

The basic set-up, shown in figure 4.3.4, for sustaining a constant compressive load on a wall panel functioned satisfactorily. Load can be monitored in such an arrangement either by measuring the length of the springs or the strain in the tie rods. Visually measured deflection was an adequate indication of creep experienced by the specimen under eccentric compressive load.

However, still open to question is the choice of test load magnitude and manner of application that can provide, in a relatively short time, creep data which are indicative of projected performance over a much longer period.

4.3.2.3 Recommendations

As in the recommendations for the short-term compression test, the same factors of load eccentricity, edge support and restraint, and environmental conditioning procedures must be studied and standardized for application to the long-term compression test.

A need which is peculiar to the long-term compression test is its particular standard procedure for applying the load. It is generally recognized that a wall probably does not bear a full design load for the entire period of its life. On the other hand, a reduced sustained test load, which is an estimate of a life time average, would not produce creep data soon enough for practical purposes of evaluation. Research is needed to develop a short-duration test procedure (possibly sustained load combined with cyclic loading) that will produce data which can be correlated with prolonged creep test data. It is likely that in the development of such a procedure, assistance can be gained from techniques resembling those used in obtaining curves which relate stress levels and number of cycles of loading (i.e. fatigue curves); data resulting from current structural live load investigations could also be used to further the stated objective.

4.3.3 Racking of Sandwich Panels of Glass-Fiber Reinforced Polyester (FRP) Laminate [37]

4.3.3.1 Summary of Test

To evaluate performance under the action of short-term racking loads, one wall panel specimen was tested in a normal vertical position by subjecting it to horizontal racking forces. The 3 7/8-in-thick specimen, of the same basic cross section as the compression specimens (Section 4.3.2), was nominally 7 ft wide by 8 ft high (figure 4.3.6). The height of the panel was extended by using two 2 x 4's nailed and adhesive-bonded along the top and bottom edges of the panel. These attached members were intended to distribute the racking load and its reaction horizontally along the top and bottom edges of the test panel. The specimen was made of two

Figure 4.3.4 - Long term compressive load test with flat bottom support.

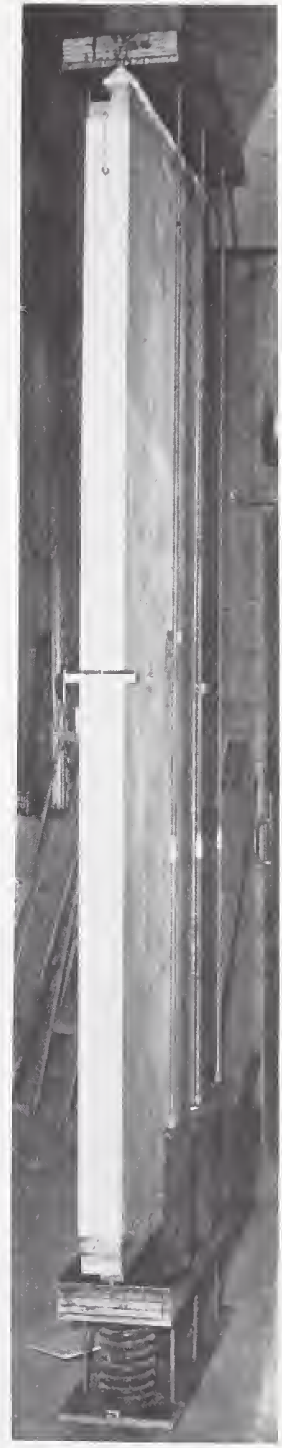


Figure 4.3.5 - Long term compressive load test with eccentric bottom support.

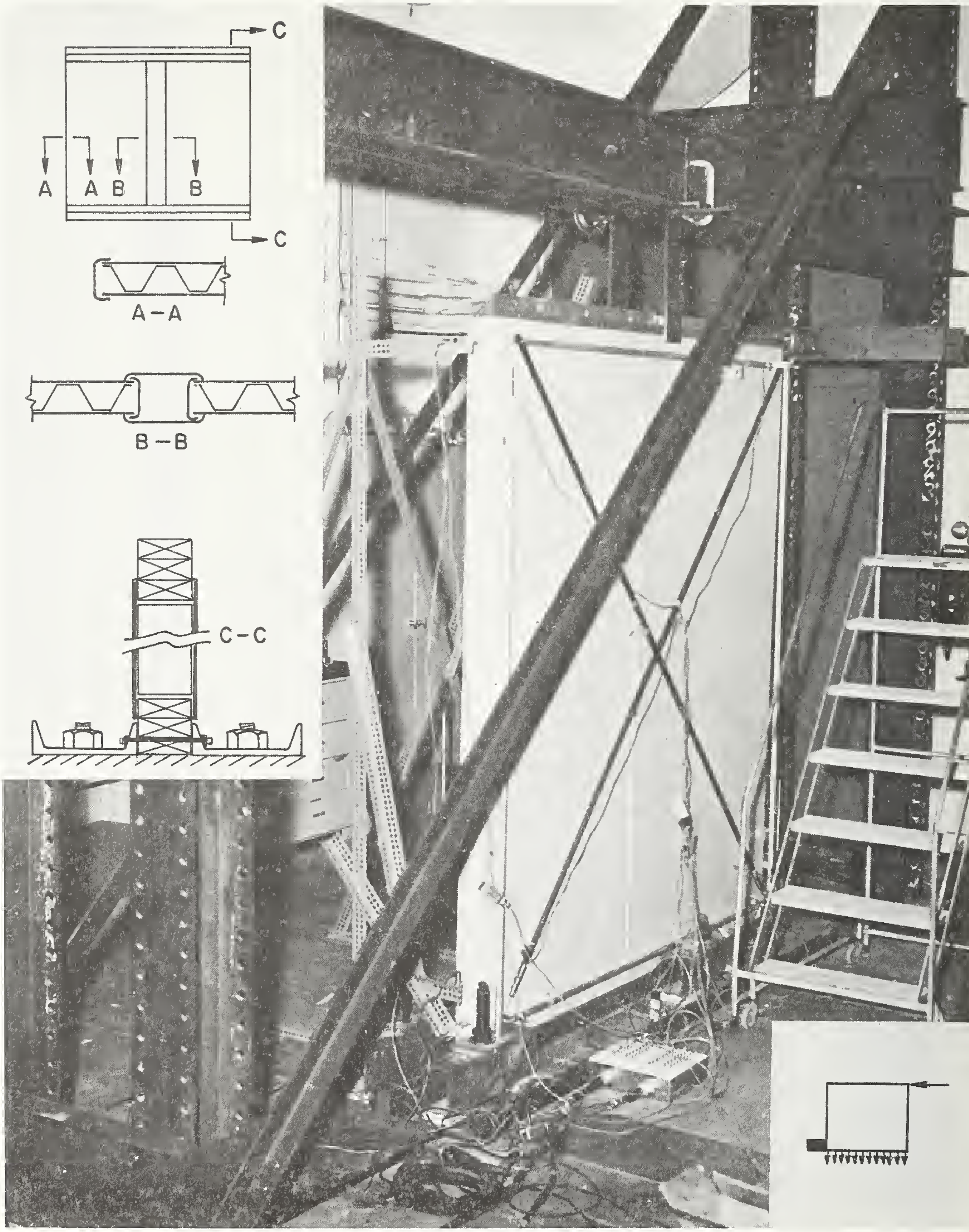


Figure 4.3.6 - Test setup for racking test No. 1.

panels, approximately 3'-6" wide; the panels were connected by the fabricator through the use of joint-cover plates made of the same FRP and adhesive as the panels.

Three racking tests were performed on the one specimen by re-setting the specimen between tests. The apparatus for the three different tests is shown respectively in figures 4.3.6, 4.3.7 and 4.3.8. Loading was accomplished by hydraulic rams attached to a structural steel framework connected to the laboratory tie-down floor. The specimen was bolted and clamped (by the two bottom 2 x 4's) between steel channels which were bolted to the test floor (figure 4.3.6) Lateral guides and a toe-stop, recommended in ASTM E72, were used. Vertical hold-down, used in some of the tests, was provided by hydraulic rams attached to the test frame.

In the first test (figure 4.3.6) the racking load was increased gradually until an indication of impending failure was observed. No vertical hold-down from above the wall was supplied in this test to allow possible rotational failure to develop at the bottom. Racking load was applied in increments.

In the second test the racking load was applied incrementally and reduced to zero after each additional increment was applied. The racking was increased until failure developed. Vertical hold-down was supplied at the loading corner by a hydraulic ram which was loaded to provide a restraining moment equal to that of the racking load (figure 4.3.7).

The third test was conducted in the same manner as the preceding test except that the vertical hold-down above the wall was provided by six equally spaced rams operated simultaneously by a common pump. The vertical resultant of these rams was always such as to develop a restraining moment equal to that of the racking load (figure 4.3.8).

4.3.3.2 Review of Tests

Although less desirable than using a new specimen for each test, it was possible to perform three variations of a racking test on the one available specimen because failure in each test was anticipated (and occurred) in different areas. This was so because, in each of the succeeding setups, the failure area of the preceding test was no longer a critical area for the type of loading used in the following test. The tests were expedient attempts to examine the resistance to racking forces on the wall offered under different circumstances: 1) by attachments near the floor alone, 2) by vertical reaction at the loading corner, and 3) by distributed vertical reaction along the top edge of the wall; each in conjunction with a toe-stop and an accompanying reaction at the corner diagonally opposite the loading corner. A consideration of such tests leads to the question of what a standard racking test should evaluate. Proposals might conceivably include a) performance of wall connections to adjacent structure, b) shear strength and stiffness of the wall construction alone, c) effect of superimposed live loads, or d) combinations of the foregoing.

4.3.3.3 Recommendations

An approach to developing a realistic standard test for measuring racking performance of walls must include studies of numerous factors. Probably the most important of these is the establishment of guidelines for imposing the proper edge conditions on the wall specimen. Such edge conditions include the manner of wall support and attachment at its base; the amount and distribution of restraint to be applied around its perimeter; and the manner in which the racking forces, themselves, should be distributed. For example, should a wall be tested in racking while under constant vertical forces simulating bearing loads, or, should it be tested in as nearly pure shear as possible? Should racking forces be applied along the entire

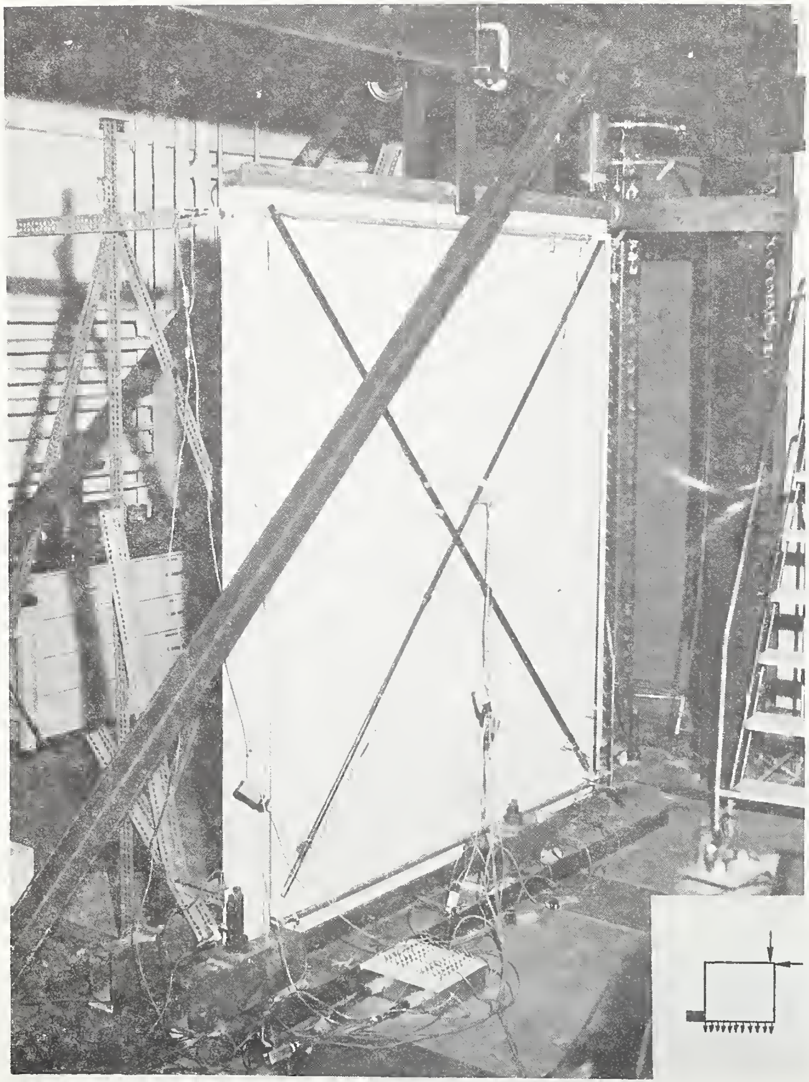


Figure 4.3.7 - Test setup for racking test No. 2.

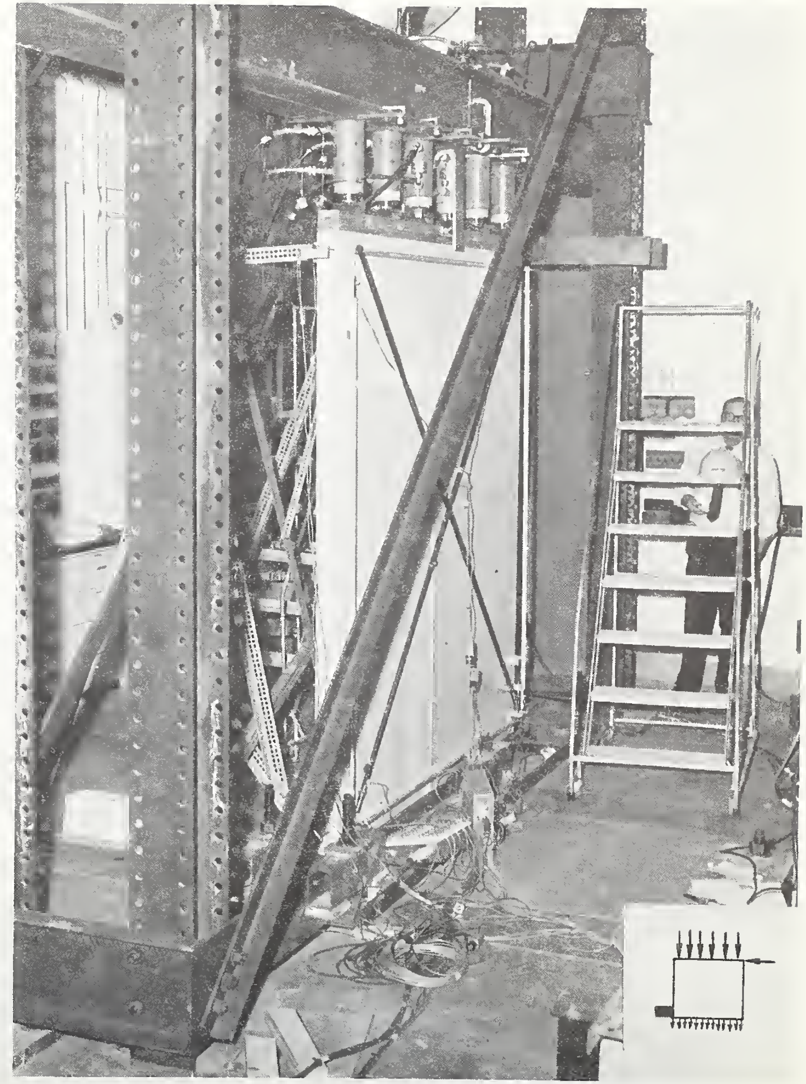


Figure 4.3.8 - Test setup for racking test No. 3.

height of the wall, and should they be cycled and reversed? These are some of the areas of recommended research.

Since racking is caused by short-term wind and seismic forces it is probably unnecessary to investigate creep test methods. However, as in other tests, the need for employing environmental conditioning of specimens exists here also, and should be considered for application to a standard racking test.

With regard to the purpose of conducting a racking test, very little information exists in the form of specifications to be met by racking performance of walls. Aside from developing testing techniques, therefore, much study is needed to determine limiting values of racking drift, caused by wind and seismic forces, that will provide safety and comfort for the occupants of a building.

4.4 Full-Scale House Tests

4.4.1 Summary of Tests

A. Full-Scale Test on a Two-Story House Subjected to Lateral Load [53]

The primary purpose of this field test program was to measure the lateral drift of a conventional, two-story, wood-framed house under simulated wind load to determine whether the drift limitation required in the design of medium- and high-rise buildings is applicable to low-rise housing units. A secondary purpose was to determine the dynamic response characteristics of the house under lateral impulsive load. A front view of the 47-ft by 26-ft house is shown in figure 4.4.1.

Table 4.4 summarizes the static tests performed; and figure 4.4.2 shows the location of loading points and the deflection transducers. Lateral forces were first applied at the second-floor level and then at the eave line. The separate effects of these forces were combined to compute a total effect, using the principle of superposition. The loading arrangement at the lower level is shown pictorially in figure 4.4.3. The measurements in this first experiment included loads, vertical deflection, horizontal deflection of floors and walls and racking deformation of walls. Thirty-two displacement transducers were used to measure deformation of the house and racking distortion of walls. All displacement transducers were placed inside the building to be maintained at a temperature of approximately 70°F and to protect the equipment against inclement weather. As a result of placing the supports for the deflection transducers inside the house, the reference for the measurements (i.e. the second-floor surface), made at the eaves line translated with respect to the ground floor. Thus, the movement of the reference for the upper story measurements had to be allowed for in determining the drift values for the house.

In the experiment to determine the dynamic response of the building, a 12-in-long piece of steel pipe was inserted between one of the loading rams and the corresponding loading plate located on the lower level. After a predetermined load was applied, the pipe was removed by a sharp hammer blow, and the deflection amplitude was recorded as a function of time. Two of the 32 deflection transducers were used to measure the dynamic response and the data were recorded by a strip-chart recorder.

B. Structural Tests on a Wood Framed Housing Module [51]

A series of six structural tests was performed on a wood-framed, volumetric, housing module, subsequent to a series of tests relating to

Figure 4.4.1 - Front view of the building.

Table 4.4 - Summary of static tests. (See figure 4.4.2 for locations of loads).

Test No.	Date	Loading Points	Loading Sequence kip	Conditions	Comments
1	2/5/71 pm	A,B,C,D	0 - 5.63 - 0.14 0.14 - 8.00 - 0 0 - 7.93 - 0	Cloudy 35°F	Loading was limited by frictional resistance of forklifts
2	2/6/71 am	A,B,C,D	0 - 10.00	Sunny 40°F	Horizontal resistance was increased by blocking of forklifts.
3	2/7/71 am	E,F,G,H	0 - 2.00 - 0 0 - 4.00 - 0 0 - 6.00 - 0 0 - 7.23 - 0	Rainy 36°F	"
4	2/7/71 pm	A,B,C,D	0 - 10.00 - 0	Rainy 36°F	"

ALL LVDT'S NEAR THE SIDE WALLS, EXCEPT THE LVDT'S AT THE CENTER VERTICAL PLANE, WERE SET 5.5" BELOW THE CEILING AND 9" AWAY FROM THE WALL.

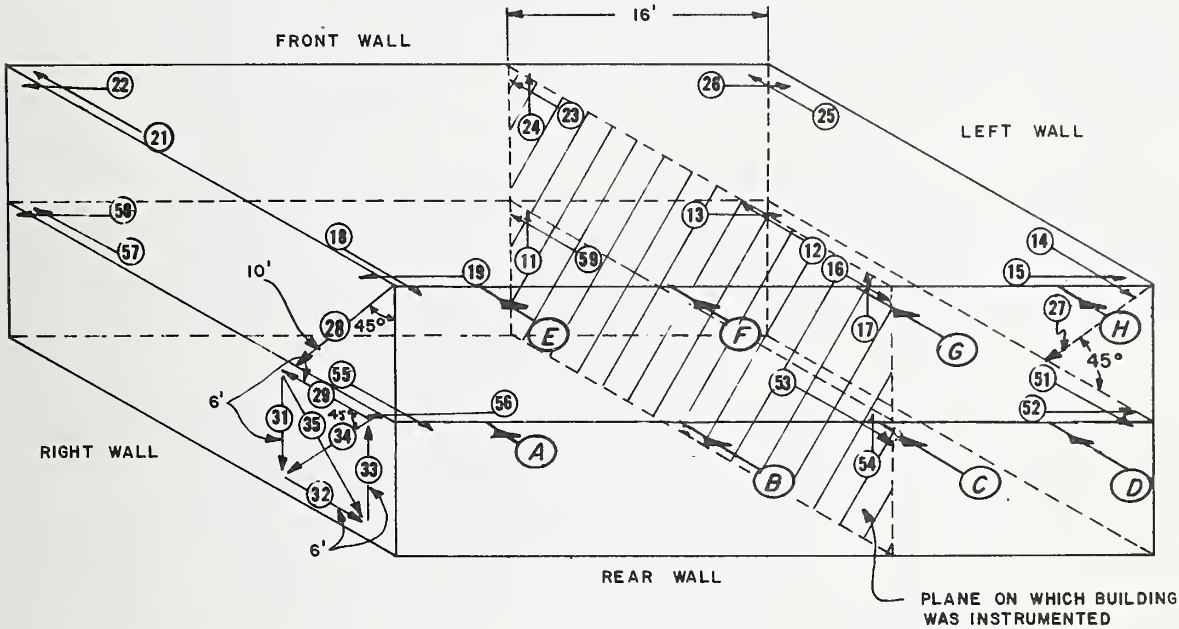


Figure 4.4.2 - Locations of transducers and loading points.

Figure 4.4.3 - Loading arrangement.

transportation by rail. The general objective of the structural tests was to quantify some of the structural characteristics (e.g. lateral stiffness, floor-vibration response and deflection-recovery behavior) of the module which were not conducive to analysis. The factory-built module is shown in the bold outline of the schematic drawing, figure 4.4.4. The six tests performed were: 1. Service Life Racking (Test 1), 2. Transient Floor Vibrations (Test 2), 3. Sustained Floor Load (Test 3), 4. Repeated Racking (Test 4), 5. Reversals of Racking (Test 5) and 6. Racking to Capacity (Test 6).

The module was visually inspected for damage or other evidence of structural distress, upon its arrival, via rail, at the laboratory. All cracks and other forms of local damage were systematically documented. Prior to lifting and transporting from the factory, reference points had been established on the exterior and interior wall surfaces and linear measurements were made between the reference points. These measurements were repeated in the laboratory, to determine any dimensional changes in the module caused by the handling and shipping operations.

In Test 1, the module was subjected to the static concentrated loads simulating wind forces normal to the front face of the house and the resulting horizontal and vertical deflections of selected points were measured. The loading ram locations are shown in figure 4.4.5 and the exterior deflection-measuring instruments are presented schematically in figures 4.4.6 and 4.4.7. From the results of this test, the drift at the second-floor level in the actual house was estimated for several values of design wind pressure. To obtain these estimates of second-floor drift, an analytical model was derived to provide a kind of "transfer function" between the results from the test module and the response of the actual structure.

The objective of Test 2 was to determine the damping behavior of the floor when subjected to vibrations of relatively short duration, such as those induced by human activities. This test recorded the decay of the deflection amplitude, with time, following a single-impulse excitation. An impact load was applied to the floor as a result of releasing a 25-lb bag which was attached to the head of a tripod at a height of 3 ft. The deflection amplitude was measured with a deflection transducer and recorded on an oscillograph.

In Test 3, a factored uniform load was applied by sand bags over the entire surface of one floor of the module and sustained for 24 hours. Vertical deflections at five points were recorded immediately after the proof load was applied and several times during the subsequent 24 hours. The ability of the floor to return to its initial position was quantified by recorded measurements made at the same points immediately upon unloading the floor and several times during the subsequent 24 hours.

To document any detectable decrease in serviceability, and to determine if a reduction in lateral stiffness resulted upon the module being subjected to repeated applications of lateral loading, Test 4 was performed. One-thousand cycles of simulated wind force, oscillating between zero and one-half the design wind pressure, were applied at right angles to the front face of the module. Figure 4.4.8 locates the two loading rams used for this test. The shortened version of the test structure resulted from severing a portion of the original module following Test 2. Following a single cycle of static loading, the 1000 cycles were applied automatically in twenty blocks of 50 cycles each, at a frequency of 1 Hz. The residual deflections at the end of each 50-cycle block were recorded to determine the ability of the module to recover its original geometry.

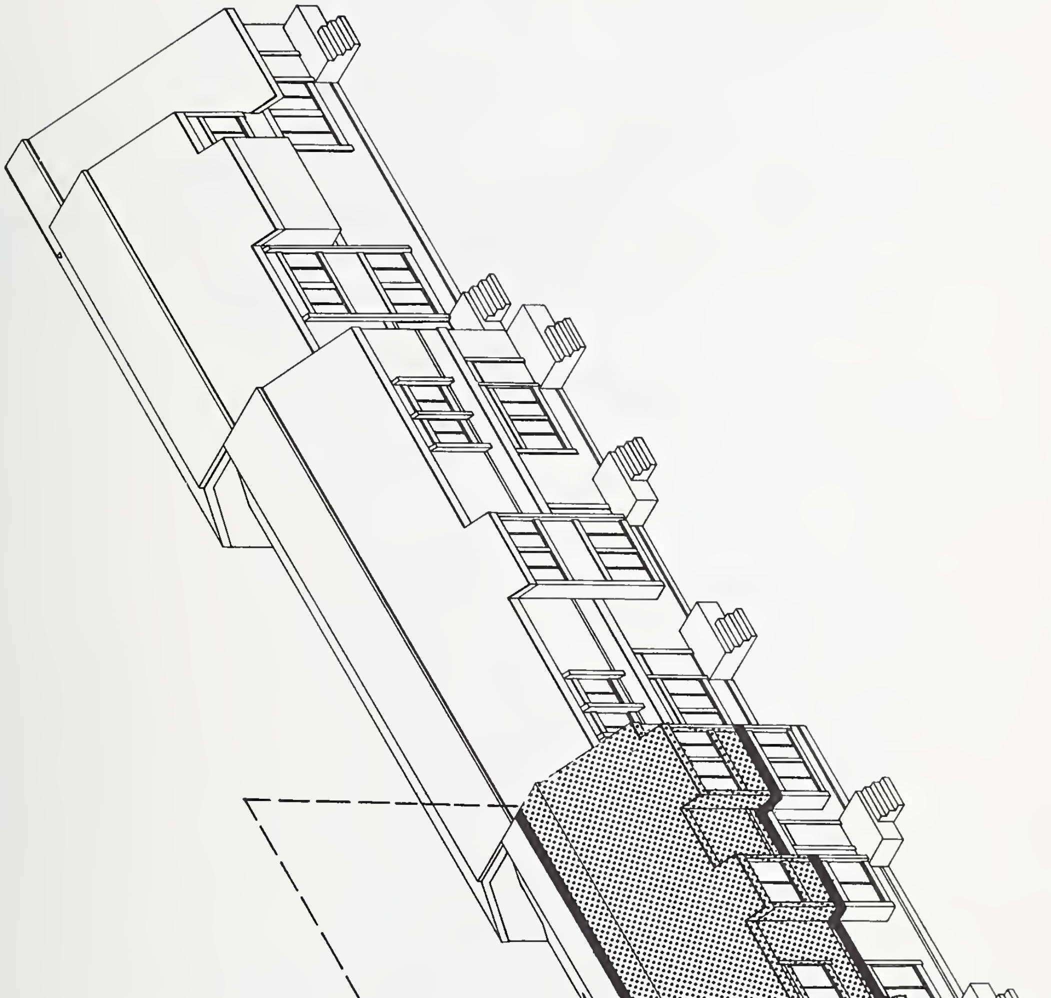


Figure 4.4.4 - Isometric view of typical townhouse cluster.

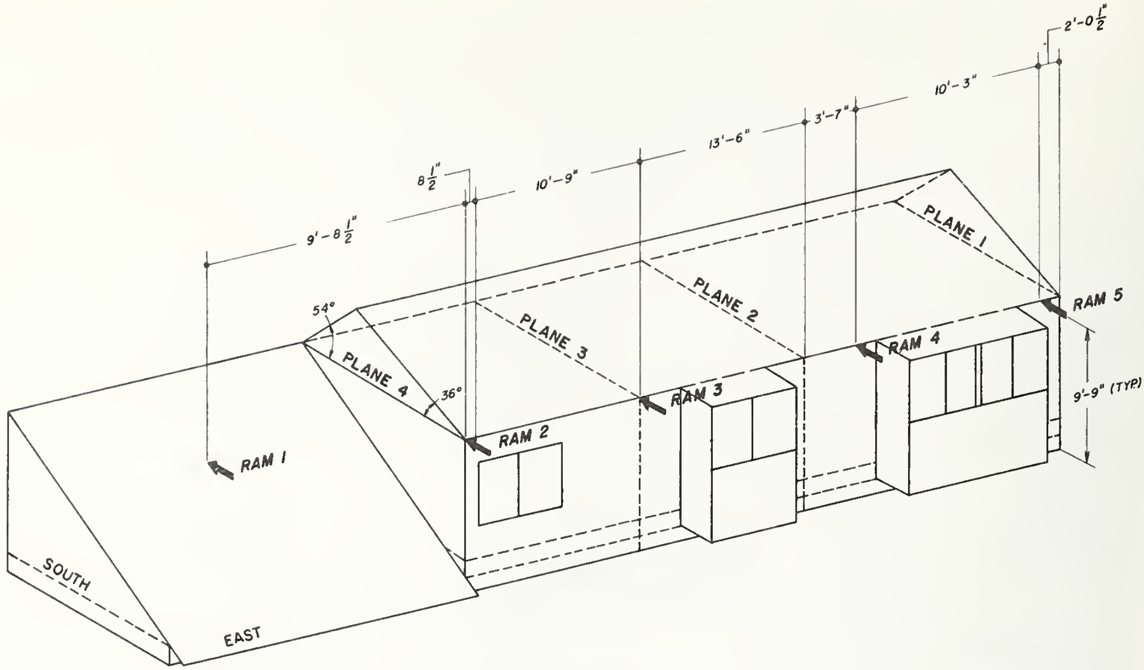


Figure 4.4.5 - Ram locations for Test 1.

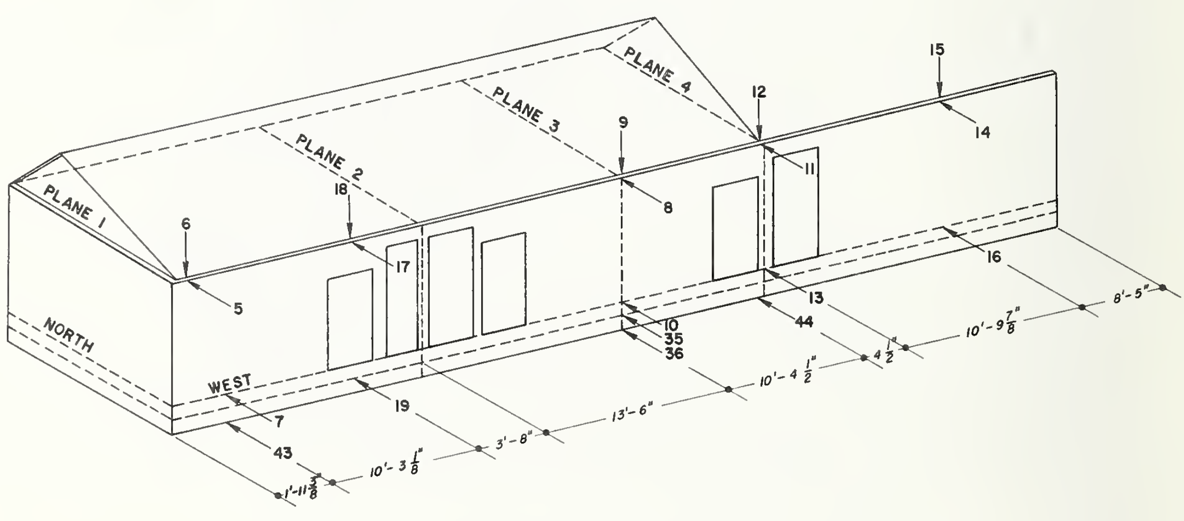


Figure 4.4.6 - Exterior instrumentation on the rear --Test 1.

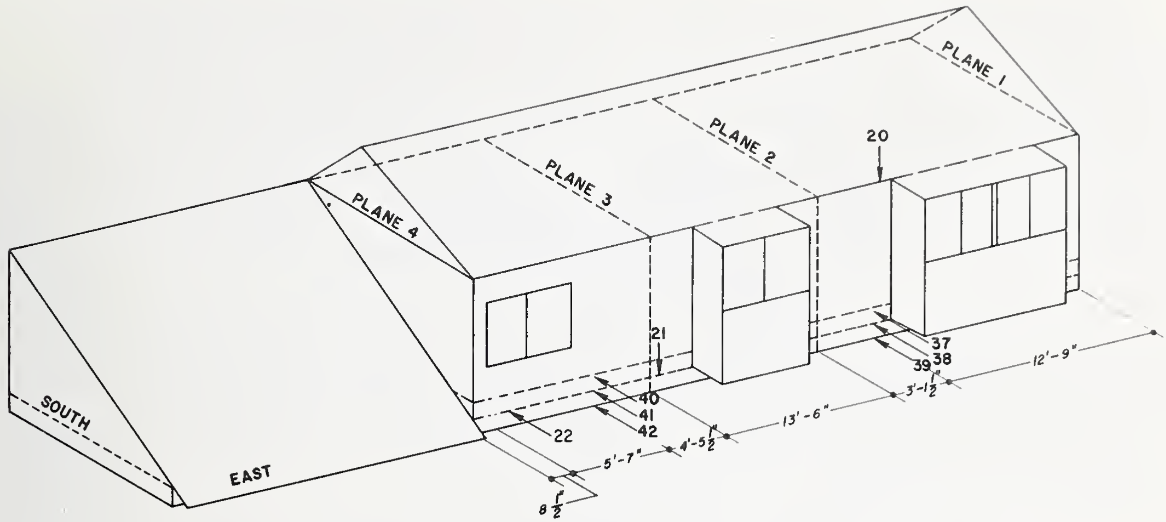


Figure 4.4.7 - Exterior instrumentation on the front --Test 1.

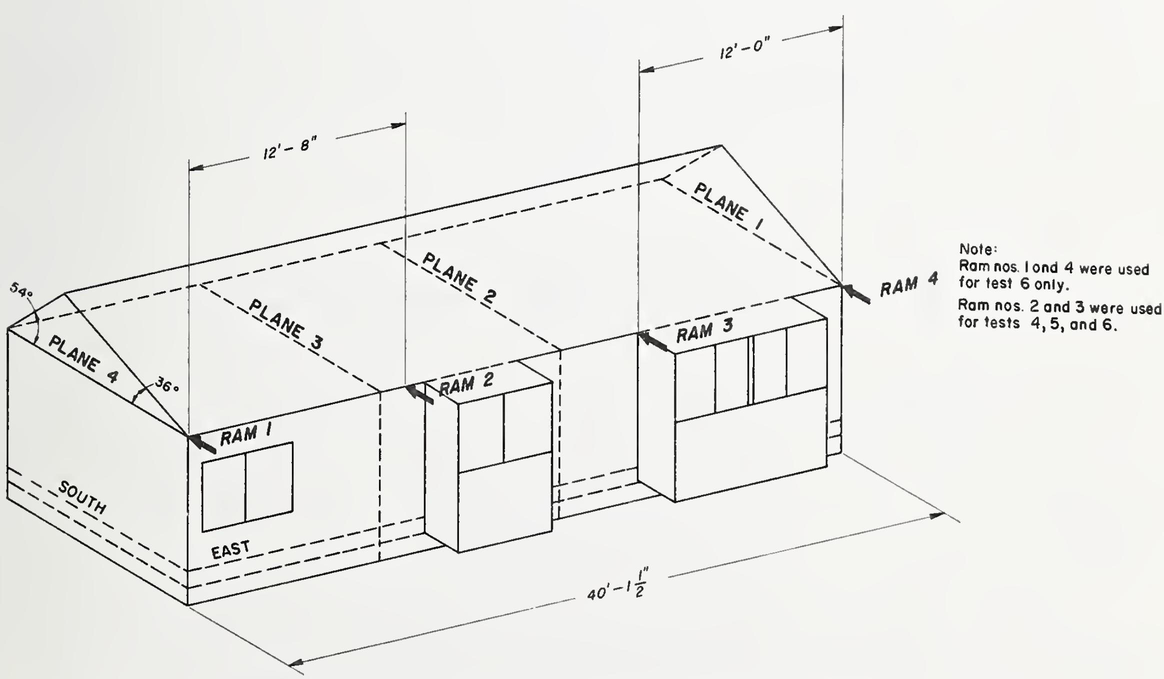


Figure 4.4.8 - Ram locations for Tests 4, 5 and 6.

The objective of Test 5 was to describe, qualitatively, the extent of distress and damage to all visible connections and exposed components as the module was subjected to loading that corresponded, in magnitude, to earthquake design provisions for two-story structures in the 1967 edition of the Uniform Building Code. Five cycles of reversed lateral load, oscillating between plus one times the design earthquake load and minus one times the design earthquake load, were applied to the front face of the module. Since there is no known requirement for deflection limitation of a structure subjected to such loading, the main consideration was the effect on the visible joints in the module and the change in lateral stiffness. Figure 4.4.8 locates the two loading rams used for this test.

Test 6 was an ultimate load test intended to assess the maximum lateral load which the module could withstand. Four hydraulic rams (see figure 4.4.8) were used to apply concentrated forces in increasing magnitude until failure occurred. Deflection data were periodically recorded and the module was visually examined for signs of distress and damage.

4.4.2 Review of Tests

A. Full-Scale Test on a Two-Story House Subjected to Lateral Load [53]

There is no standard test method for field testing of full-scale houses with which to compare the two experiments which comprised this test program. As was stated in Chapter 3, the development of a set of guidelines by a joint ASTM-ASCE Committee, for use in testing complete houses is in the planning stage. Nevertheless, the investigation can be discussed with respect to its treatment of key test parameters and the possible value of the test results.

In the general field of structural performance testing, the method of load application should be chosen to represent, as closely as practicable, the known or assumed design load characteristics. Likewise, the manner of the test structure's resistance to the test loading should closely represent the actual service reactions. While the simulation of component-to-component and component-to-foundation connections is often a difficult and expensive undertaking in laboratory testing, this parameter is inherently accommodated in field testing of existing houses. On the other hand, the simulation of a uniform wind pressure, which is usually assumed in design of low- and medium-rise buildings, is generally more difficult to accomplish in field testing.

As described in summaries of previous tests of full-scale houses (see Section 2.5), the application of a series of concentrated loads at approximately the eave line and/or the floor of a test house, has been the most commonly used field method for representing the effect of an equivalent static wind pressure acting normal to one face of the erected building. Assuming that the test house has the same dimensions as the building, this loading arrangement effects a simulation of both the design overturning moment at the top of the foundation and the racking forces distributed to the tops of the shear walls. These two representations are accomplished at the expense of not simulating the design base shear. Depending on the geometry and type of construction being investigated, the consideration of the latter detail may be more important than the other two.

The technique of loading the house one level at a time and combining the two sets of responses was justified in that the requirements for the application of the principle of superposition were satisfied. The results confirmed the assumption of linearly elastic response of the house. Also, the resulting deflections were sufficiently small to allow all measurements to be referenced to the original geometry.

Typical of field testing procedures, the loading method was not readily adaptable to either reversals of loading or relatively rapid repetition of one-directional loading. However, the use of hydraulic rams did afford a couple of test advantages: the rate of loading could be easily controlled and the relatively slow repetition of one-directional racking loads, for a small number of cycles, could have been accomplished. It is likely that the use of two separate and redundant systems (a pressure transducer and two load cells) for measuring the load produced a degree of accuracy of less than the 2% maximum recommended in reference [38].

The placement of all deflection-measuring instruments inside the house, in lieu of using a series of two-story-high frames for supporting the instruments outside, was a practical solution to the anticipated problems posed by inclement weather and inadvertent jolting. Furthermore, this technique of measuring displacements is a good illustration of the necessity for compensating in the observed results for expected movement of the datum point. Since the second floor was expected to translate as a result of the lateral load, its displacement had to be added to that measured at the eave line to determine the magnitude of drift.

It is desirable that a test method be practically reproducible in order to establish a basis for comparing the structural performance of similar structures. Furthermore, the structural performance can be evaluated against a standard of performance as specified in a code, standard or criteria document. To these ends, this investigation has made a contribution since the results seem to be reproducible and the test was performed on a common type of house construction.

B. Structural Tests on a Wood Framed Housing Module [51]

The fact that six separate structural tests were performed during this investigation does illustrate the point that a relatively large number of non-destructive tests can be performed on a single prototype specimen. Furthermore, for serviceability tests such as floor flexural and vibration tests, the evaluation is effectively supplied with several full-scale specimens whose test boundary conditions are identical to the in-service boundary conditions.

Most of the test methods comprising this investigation probably do not represent practical models for the development of standard laboratory test methods, since the laboratory facilities and the test equipment were atypical of the US population of test organizations. Nevertheless, some of the prevailing concepts and the manner of handling some of the test parameters warrant discussion.

By referring to the test setup for the four racking tests (1, 4, 5 and 6), it is seen that a relatively large number of deflection-measuring instruments is required by a module of this size and the data acquisition task becomes tedious if there is no automatic data-recording equipment. The technique of instrumenting the structure along discrete planes seems to be an efficient way to employ the deflection gages. Sufficient information can be obtained to define the deformation pattern of several planes in the structure. The planes may coincide with actual end walls and interior partitions or they may be imaginary. Subject to the qualifications imposed by a straight-line approximation between the data points, the response of the entire prototype can be interpolated or extrapolated.

Considering the length of the test module, the use of a series of concentrated loads at the eave line seems to be a practicable representation of the uniform wind pressure assumed in design. For laboratory test purposes, the loading simulation probably could have been improved by using loading beams between the rams and the surface of the module to further distribute the ram loading. The degree of improvement has not been quantified by research results, so it is not possible to assess the compromise involved.

The repeated lateral loading test (Test 4) and the test involving reversal of loading (Test 5) were performed using ad hoc procedures which manifested the evaluators' interpretation of applicable performance requirements with respect to the effects of wind and earthquake, respectively. In effect they were pseudo-dynamic, proof-load tests, in which the predetermined peak loads were certain factors times the assumed design load and the number of cycles was designated to conservatively simulate the structural effect of repeated applications of wind pressure during service life and of load reversals during a major earthquake. Since the main consideration was the effect on the visible joints and the change in lateral stiffness of the structure, the simulation of actual boundary conditions was a very important test parameter. Specifically, the predicted line of weakness, the joint located at the base of the prototype, had to be prepared in strict accordance with the design specifications for the housing system.

A notable shortcoming of applying a cyclic loading within a relatively short period (conversely, high frequency) was that the response data (from about 40 channels) could be recorded only at the zero load occurring at the ends of a predetermined number of cycles; or else a "static cycle," in which the load was manually controlled, was necessary. Ideally, the rate of scanning for the recording device should be about two times the frequency of loading to insure the acquisition of reliable, continuous data. Then, any changes in the response characteristics of the structure can be associated with a particular cycle and amplitude of loading. As was the case for Tests 4 and 5, it may be necessary to compromise the ideal to the extent of obtaining data at some point when the load is stationary. Thus, it is seen that the scanning rate capability of the data acquisition equipment may be a controlling factor in establishing a test procedure for cyclic loading.

The importance of achieving a close simulation of the design load characteristics and the field boundary conditions (i.e. anchorage and joining) as well as the benefit of performance criteria related to acceptable structural performance was emphasized at the conclusion of Test 1. It was then that it became necessary to determine the significance of the deformation in relation to the prediction of lateral stiffness for the erected house. In the absence of an accepted maximum allowable drift for low-rise buildings and houses, the conventionally accepted value for medium- and high-rise buildings (height/500) was used. Since the anchorage conditions for the prototype were held to be congruous with the joining and anchorage conditions in the erected house the analytical model was effective in yielding an estimate of drift. The exercise of comparing this estimate with a lateral deflection limit accepted for high-rise buildings, can be considered academic until such time as a maximum allowable drift for low-rise construction is reconciled with occupancy and serviceability requirements.

The development of performance criteria pertaining to transient vibration response of floor assemblies is in a preliminary stage, at present. For this reason, the significance of a vibration test such as Test 2 cannot be fully assessed. It is first necessary to determine the relative importance of such vibration parameters as damping and natural frequency on human perception. Such is the nature of one of the phases of a long-range research program being conducted at NBS, entitled Structural Deflections. For the purpose of comparing frequencies and percentages of critical damping among various types of floor construction, the test method seems effective. The test equipment requirements are not extensive and the test setup is simple enough to encourage uniformity of procedures.

The procedures used in Test 3 were similar to those recommended in ASTM Standard E196-66, "Load Tests of Floors and Flat Roofs", and only one feature warrants some discussion. Due to the inaccessibility of the underside of the test floor, it was necessary to attach the deflection-measuring instruments to the top surface of the floor. To eliminate the effect of a person's weight being superimposed on the sand bags during testing, it was necessary to record the deflection data remotely. The use of a strip chart recorder (for two of the five data points) served this function adequately, and provided a time-record of the test load and zero load deflection as well.

4.4.3 Recommendations

Based on the review of these two full-scale house tests, a partial list of research needs is suggested:

- A co-ordinated national effort is required to collect and correlate structural performance data relative to the lateral resistance of existing houses and low-rise buildings. This data would probably have to be supplemented with the results from further field testing of both traditional and industrialized housing. The principal objective to be served by such an effort would be to establish a basis for code requirements for the maximum allowable drift of houses and low-rise buildings.

- A comprehensive set of guidelines is needed to promote the unification of both field- and laboratory-testing procedures as they pertain to full-scale houses or modules. As is mentioned in Section 3.1, it is planned that a joint ASTM-ASCE Committee be established for the purpose of drafting a set of guidelines. Perhaps this activity should be paralleled with a study of alternative ways to accommodate certain test parameters. Typical subjects for investigation are "effective techniques for measuring deflections" and "advantages and disadvantages of various load simulation practices."

- A laboratory test method encompassing repeated, one-directional lateral loading and reversals of loading should be developed for industrialized housing prototypes. As a prerequisite to the test method, it will be necessary to reconcile such test parameters as 1000 cycles of repeated loading and 5 cycles of load reversal (requirements stated in the HUD Operation BREAKTHROUGH Guide Criteria) with the state-of-the-art as it pertains to earthquake and wind effects on houses.

- Basic research is needed to determine the limits of floor vibrations which are perceptible by humans as well as to identify the vibration parameters which contribute to the perception. Once this information is known, an improved test method which will assist in the evaluation of a floor's vibrational performance can be devised. It is anticipated that these objectives will be fulfilled by the structural deflections program in progress at NBS.

The continued use of the method employed in Test 2 is recommended, since it does yield worthwhile information about floor damping. There are substantial test data available with which to compare future test results.

- Before the development of more representative racking and diaphragm test methods can be realized, it is necessary to obtain a better understanding of the interaction of building components and the stiffness and strength of joints and anchorages. Contributions to this effort can be made by existing information such as that reviewed in Section 2.5 and that discussed in Section 4.4. However, this information must be augmented by data obtained from laboratory tests on segments of full-scale buildings and full-scale prototypes. It is recommended that laboratory tests be conducted on several full-scale assemblies, representative of building construction types for which existing information is insufficient.

5.0 Review of Codes, Standards and Criteria with Respect to Structural Test Requirements

The primary reason for undertaking practically all structural performance testing is that many requirements in design standards or codes dictate proof of compliance in the form of test results. The provision for the acceptance of building components; new construction techniques and materials applications; and entire buildings on the basis of some form of load testing is made, either implicitly or explicitly, in many design regulations. As a prerequisite to the development of standards for structural testing, it is necessary to identify those requirements which dictate testing and to examine the intent of the requirements relative to the built structure. To this end a representative sample of codes, standards and performance criteria, both domestic and foreign, were reviewed by the authors. To provide a convenient reference the principal requirements of these documents have been summarized in table 5.5.

According to a report [38] by an ad hoc committee on the testing of structures, set up in 1962 by the United Kingdom Institution of Structural Engineers, "There are two general types of tests, either of which may be carried out in situ or under laboratory or other special conditions:

(i) An acceptance test to check the behavior of a structure or part of a structure, under a load equal to or greater than the known working load, so as to assess its adequacy for service.

If a structure fails to meet the acceptance test requirements in regard to recovery of shape after load removal, it may sometimes still be accepted if it meets the special requirements of a re-test.

(ii) A test to destruction to determine the ultimate strength of a structure and hence either the load factor or, conversely, the working load that will be permissible with a given load factor."

Most of the testing suggested by the following standard and code requirements pertain to the first general category.

5.1 Review

ACI Standard 318-71 - "Building Code Requirements for Reinforced Concrete" [2]

Chapter 20 - Strength Evaluation of Existing Structures

The circumstance dictating a static-load strength test is the existence of a structure or part of a structure whose margin of safety is suspected by the "Building Official" in charge of approving the structural system. The essence of the testing is that a proof load or overload is applied and maintained on the designated test area for a specified period of time. If the structural performance of the test area is acceptable under the loaded condition and also upon removal of the proof load, the structure or part of the structure passes. One retest is permitted if the performance requirements are not met on the first trial, provided there is no visible evidence of failure. It is emphasized that the scope of this testing does not include considerations of serviceability (e.g., stiffness), quality control or ultimate strength.

There are no recommendations made relative to test setup, apparatus or procedure. However, the load factors to be used for the superimposed load, as well as the duration of loading, are given in (ACI-318) Section 20.4 (paragraphs 20.4.3 and 20.4.4). The total load on the designated section of the structure, including the existing dead weight, shall be equivalent to 0.85 times the quantity (1.4 times the dead load + 1.7 times the live load). At least four approximately equal increments should be used to reach the maximum load; the critical deflections shall be measured 24 hours after its removal. Provided the structure does not exhibit signs of failure, its deformation behavior must satisfy several quantitative criteria. If the limit established for maximum deflection is not exceeded, the recovery characteristics are not to be measured. For relatively flexible construction, where the maximum deflection does exceed the limit prescribed in paragraph 20.4.6, the deflection recovery must be at least 75 percent of the maximum deflection for non-prestressed concrete (80 percent for prestressed concrete) within the 24 hours after load removal.

The provisions in Chapter 20 are common to several other domestic codes and to foreign codes in which the behavior of concrete structures is under consideration.

American National Standard A119.1, 1974 "Standard for Mobile Homes" [3]

Part B - Section 6.6 - Walls

The strength requirements for the walls are such that tests applying axial loading, transverse loading or racking loads may have to be conducted to demonstrate the adequacy of a component's strength. No test methods are explicitly suggested, but the standard methods found in ASTM E72 would generally be appropriate.

Part B - Section 6.9 - Floors

"Floor assemblies shall be designed in accordance with accepted engineering practice to support a uniform live load of 40 lb/ft^2, plus the dead load of the materials. In addition (but not simultaneously), floors shall be able to support a 200-pound concentrated load on a 2-inch diameter disc at the most critical location with a maximum deflection not to exceed 1/8 inch relative to floor framing."

Part B - Section 6.11 - Structural Load Tests

"Every structural assembly shall be capable of sustaining its dead load plus superimposed live loads equal to 1.75 times the required live loads for a period of 12 hours without failure. Failure shall be considered rupture, fracture, or residual deflections which are greater than the limits in 6.10 of this part."

Australian Standard CA 65-1972, "The SAA Timber Engineering Code" [6]

Section 9. Testing of Timber Structures or Elements

Two types of load tests are considered. "One is a 'proof' load test which shall be applied to every structure of a population of structures for them to be accepted. The other is a 'prototype' load test which needs to be applied only to a portion of a population of structures for all structures of that population to be accepted." In both of these types of tests it is necessary to apply a load factor to account for variability in structural strength. The circumstances under which testing is required are the same ones cited in section 5 of British Code of Practice CP 118 [11].

A two-stage procedure is prescribed for determining the test load for the proof testing. First, the critical combination of design loads is specified by the design engineer or is determined from appropriate codes and specifications. Secondly, the equivalent test load (ETL) is calculated from the following formula:

$$ETL = \frac{2.1\ K_{26}\ K_{27}}{K_1} (P_1 + 1.4\ (P_2 + P_3 + P_4 + \ldots))$$

where

P_1 = known permanent load on the structure such as its self weight

$P_2, P_3, P_4, \ldots$ = all other imposed loads

K_1 = the factor from Table 5.1 appropriate to the design load of shortest duration included in the critical combination

K_{26} = factor obtained from Table 5.2 to compensate for effect of duration of load on strength of special components

K_{27} = factor obtained from Table 5.3 to compensate for the fact that test load is not of 15 minutes' duration."

Several factors are incorporated into the formula to compensate for the effect of duration of loading on timber components. The uniform rate of loading and a 15-minute duration of the ETL are required. Some guidelines for acceptance criteria for strength and stiffness are also included, such as the possible requirement for a retest should the load-deflection curve show any discontinuities or non-linearity.

The provisions for prototype testing include some requirements for the materials used in the prototype. Only that grade of timber which is specified for production can be used in the prototype. Furthermore, the material used for the prototype should contain the upper limit of imperfections permitted for a given stress grade, as far as practicable.

Table 5.1 - Duration of load factor for strength

(Table 2.4.1.1 in CA-65)

Duration of load	Multiplying factor K_1	Duration of load	Multiplying factor K_1
Permanent	1.0	1 day	1.4
5 years	1.1	6 hours	1.5
6 months	1.2	1 hour	1.6
2 months	1.25	10 minutes	1.7
2 weeks	1.3	1 minute	1.8
5 days	1.35	5 seconds or less	2.0

Table 5.2 - Compensation factor K_{26}

(Table 9.4.1 in CA-65)

Structural Component	Factor K_{26}
Columns, beams and arch elements with slenderness coefficients greater than 10 -	
Timber initially dry	1.1
Timber initially green	1.4
Metal connectors -	
Failure in timber that is initially green	1.2
For failure of steel	0.6

Table 5.3 - Compensation factor K_{27}

(Table 9.4.2 in CA-65)

Time to reach ETL	15 min	30 min	1 hr	2 hr	6 hr
Factor K_{27}	1.00	0.98	0.96	0.93	0.90

The equivalent test load is found by another formula, which includes an additional factor, K_{28}, (see table 5.4 for a list of values for this factor) in the numerator to account for the number of units to be tested and the estimated coefficient of variation of strength for the total population from which the test units are selected. Furthermore, the constants 2.1 and 1.4 in the formula for proof testing are changed to 2.2 and 1.0 respectively for prototype testing.

The test procedure calls for a preload, equal to the design long-term load, to be maintained for a five-minute period and then removed. Subsequently, the prototype is to be loaded, at as uniform a rate as practicable, until either failure or the ETL is reached, whichever comes first. Guidelines for acceptance of the strength and stiffness characteristics of the prototype are also given. For example, no specimens may show any sign of failure before reaching the ETL; nor may any residual deflection or deformation exceed 5% of the acceptable amount under short-duration loading.

British Standard Code of Practice, CP 112 (1967) "The Structural Use of Timber" [9]

Section 6 is entitled "Inspection, Testing and Maintenance." Paragraph 602 sets down the provisions for testing of timber structures, with no specific components being designated. The circumstances dictating the testing of timber structures or parts of such structures are substantially the same as those cited for aluminum structures (see reference [11]). There is no method indicated for the application of loading or the points at which to measure the deflections, for these decisions would depend upon the specific structure or components to be tested. As close an approximation of the actual loading and support condition as possible is required.

A loading and deflection recording sequence is outlined for a stiffness evaluation test and the duration of loading is specified. For a period of 30 minutes prior to performing a given load test, a preload equal to the design long-term load, should be maintained on the structure or structural component. This preload should cause a settling-down of the test specimen. Subsequent to testing for stiffness characteristics, the strength of the test specimen is assessed by loading at a uniform rate until 2-1/2 times the design load is applied or failure is induced.

British Standard Code of Practice, CP 114 (1957) "The Structural Use of Reinforced Concrete in Buildings" [10]

Section 605. Load Testing of Structures

There is no specific procedure fully outlined in this section, but the load levels, duration of loading and relaxation requirements suggest the application of a static load test. The conditions dictating testing are requirements by the specification or the presence of reasonable doubt about the adequacy of the strength of the structure. A curing period of 56 days before testing is recommended.

The specified superimposed test loading is one and a quarter (1-1/4) times the design superimposed load. The test load should be maintained for 24 hours and then removed. If within 24 hours after the removal of the load the structure does not show a recovery of at least 75 percent of the maximum deflection reached during the 24-hour loading period, the test loading should be repeated. Acceptance of the adequacy of the structure is then dependent upon a recovery of at least 75 percent of the maximum deflection during the second loading test.

Table 5.4 - Sampling factor K_{28}
(Table 9.5.4 in CA-65)

Number of Similar Units to be Tested	Value of sampling factor K_{28} for estimated coefficient of variation (per cent) of strength of individual units of -		
	15	25	35
1	1.8	2.8	4.3
2	1.6	2.4	3.5
3	1.5	2.2	3.0
4	1.5	2.0	2.8
5	1.5	1.9	2.6
10	1.3	1.7	2.1
100	1.0	1.0	1.0

Note: For intermediate coefficients of variation use linear interpolation on log-log plot of coefficient of variation against K_{28}

British Standard Code of Practice, CP 118 (1969)
"The Structural Use of Aluminium" [11]

No specific test is required in Section 5 (Testing). The conditions under which an acceptance test is appropriate are indicated and they are repeated below:

"(1) The structure is not amenable to calculation or calculation is deemed impracticable;

(2) Design methods other than those specifically referred to in Section 4 (Design) of this code are used;

(3) There is doubt or disagreement as to whether the structure has been designed in accordance with Section 4 (Design), or whether the quality of material or workmanship is of the required standard."

There are two classes of tests described. The Static Acceptance Test applies to structures or parts of structures which are not subject to fluctuating loads likely to cause fatigue failure. The appropriate load factors are given as well as the duration of loading, for each loading increment. Prior to the actual test, it is recommended that a "settling-down" of the test structure be accomplished through the application, for 15 minutes, of the combination of live and dead loading determined to cause the severest effect. The criterion for acceptance is that the structure must sustain the test loads without excessive deformation and without development of deleterious effect.

It is required that the recovery of deformation, measured 15 minutes after removal of the test loads, be at least 95 percent, to prevent retesting of the structure.

The second test, Fatigue Acceptance Test, is intended for structures or parts of structures that may experience fatigue failure as a result of fluctuating loads. A sequence of loading must be decided upon and the test specimen should not fail until at least 30 repetitions of the loading sequence have been executed.

Canadian Standards Association Standard A23.3-1970 "Code for the Design of Plain or Reinforced Concrete Structures" [15]

Section 4. Load Tests of Structures

Reliable load test data is recommended as a basis for demonstrating the safety of either innovative or special systems of design or construction of concrete structures or structural elements not directly covered by the standard. A time limit for obtaining the data subsequent to placing the concrete in the structure is imposed. The period should not be greater than the minimum age at which the structure is to be put into service or is assumed to possess the specified strength.

When there is reasonable doubt about the safety of an existing structure, static load testing may be ordered (Clause 4.3). This field testing of the designated portion should not begin until the structure is at least 56 days old. Roof and floor components are explicitly mentioned in this standard. The superimposed test load (Clause 4.4) equivalent to 0.3 times the dead load plus 1.7 times the live load shall be applied without shock to the structure and maintained for 24 hours. The standard spells out criteria for evaluating the performance of floor or roof construction when subjected to the prescribed proof test. The five criteria cited in Clause 4.5.1 are almost identical to those stated in Section 20.4.6 of the ACI Code, 318-71 [2].

Canadian Standards Association, S157, "The Structural Use of Aluminium in Buildings" [16]

Clause 4.3 provides for the establishment of structural adequacy by direct load tests in lieu of approved design calculations. Clause 20 includes provisions for the testing of prototype structural units and of portions of existing structures. A basic test load is established for application to the prototype units which is equivalent to the design load. The design load includes dead weight and impact allowances where applicable.

The loading sequence is comprised of three stages. First, the basic test load is applied, the deflections are measured and compared with the limits given in Clause 6. After removing the basic test load, the prototype is reloaded to 1.4 times the basic test load. After removal of the factored load the recovery of deflection shall be at least 90 percent. The prototype is then to be subjected to a load of 1.75 times the basic test load without failure.

The stiffness characteristics of existing structures are evaluated by loading the test portion of the structure with a required working load, including impact allowances where applicable. The live load is removed after the measured deflections are compared with the limits cited in Clause 6. Then the test portion is reloaded to 1.5 times the total dead plus live loading mentioned above. Subsequent to load removal the recovery of deflection shall be at least 90 percent.

"A Standard for Testing Sheathing Materials for Resistance to Racking" [41]

Federal Housing Administration (FHA) Technical Circular 12

This circular was issued October 5, 1949, by FHA in an effort to establish a common method of evaluating the contribution to overall racking resistance made by sheathing materials not specifically allowed by FHA-Minimum Property Standards for One- and Two-Family Living Units (U.S. Dept. of Housing and Urban Development, FHA No. 300). The standard size, 8-ft by 8-ft, test panels were to be subjected to racking forces, applied according to the recommendations given in NBS report BMS No. 2 [49]. It is noted that the recommendations in BMS No. 2 were adopted as a Tentative Standard by ASTM in 1947.

The established basis for acceptance of test panels was the observed load-deflection relationship exhibited by a wood-framed wall sheathed with horizontal wood boards and stiffened at the corner with diagonal let-in bracing. Demonstration of comparable performance by other sheathing materials as well as by many new types of panel construction is still the requirement for gaining acceptability by FHA.

In addition to stipulating the critical load levels for the test panels, the requirements for conditioning of the samples prior to testing are described. Specimens are to be supplied in sufficient numbers to allow for test in both a "dry" and a "wet" condition.

There have been no significant revisions to the content of this circular since it came to existence but the document is currently under review and should undergo some changes. The nature and extent of those changes are not known at this writing.

Uniform Building Code, 1973 Edition, [46]

Chapter 24 - Masonry, Section 2404 - Tests

This section states the load factors to be used in a flexural proof test of masonry components in an existing structure. For evaluation purposes, the superimposed static load shall be equal to two times the design live load plus one-half of the dead load. This loading shall be maintained for a period of 24 hours. There are no recommendations for the loading apparatus, rate of loading or positioning of instruments for measuring deflection. The maximum deflection measured at the end of the 24-hour period is limited to the lesser of L/200 or $L^2/4000t$ (L is the span in feet and t is the thickness or depth of the component in feet). During the 24 hours after the removal of the proof load the component must exhibit a recovery of 75 percent of the maximum deflection.

Chapter 26 - Concrete, Section 2620 - Load Tests of Structures

The provisions in Section 2620 are identical to those given in Chapter 20 (Strength Evaluation of Existing Structures) of ACI Standard 318-71 [2].

5.2 Summary

An examination of table 5.5 will show that these requirements differ in principle, scope and detail. Some requirements are intended for general application while others are addressed to a specific material or type of construction. The structural performance of horizontal concrete components is the most widely covered subject in the listing. A majority of the tests fall into the category of "acceptance" tests, but only the Australian Standard CA65-1972 makes a distinction between the testing of existing structures or components and that of prototype structures or components. The distinction between existing and prototype structures is important when one contemplates the significance of the test results from one specimen. When testing an existing structure (or part of a structure) for proof of compliance, a single proof load application is generally sufficient for making a judgement on acceptance. However, the results obtained from testing one specimen or a small sample, may be practically useless if the variability of performance is high. It was also observed that the specifications generally do not clearly distinguish between a "stiffness" and a "strength" test.

6.0 Summary of the Report and Recommendations for Research

6.1 Summary of the Report

In order to establish the present state of knowledge and to identify specific research needs various sources of information were consulted. A collection of test reports, technical papers, symposium proceedings and other publications were reviewed, leading to the preparation of thirty extensive abstracts for this report. The abstracts are intended to show the nature and utility of the available publications. In addition to the literature review, the activities of several voluntary standards associations concerned with structural test methods were monitored. The current status of the activities of ASTM Committee E-6 (On Performance of Building Construction) has been discussed according to specific test method categories. The performance requirements cited in various codes and standards were studied with respect to test method requirements, implied or explicit, and a summary of that study was included herein. The details of test methods used by NBS to evaluate industrialized building components for the HUD Operation BREAKTHROUGH housing program were compared with the details of methods contained in ASTM Standard

TABLE 5.5 – SUMMARY OF CODE AND STANDARD PROVISIONS FOR STRUCTURAL TESTING

CODE OR SPECIFICATION	MATERIALS	BUILDING COMPONENTS	TYPE OF TEST	TYPE OF LOADING	RATE OF LOADING	LOAD OR LOAD FACTORS	TEST LOAD DURATION (HRS.)	PRELOADING: MAGNITUDE	PRELOADING: NO. OF CYCLES OR DURATION (HRS)	ALLOWABLE DEFLECTION	MIN. RECOVERY % OF MAX. DEFLECTION: 1ST TEST	MIN. RECOVERY: RE-TEST	REMARKS
ACI 318-71	REINFORCED CONCRETE	FLOOR AND ROOF ELEMENTS FLOORS, ROOFS	ACCEPTANCE	STATIC FLEXURAL	N. S. (1) FOUR STEPS MINIMUM	0.85 (1.4D+1.7L) (2)	24	DESIGN DEAD LOAD	48	$h^2/20{,}000\,t$ (3)	75% WITHIN 24 HRS AFTER LOAD REMOVAL	80%	CONCRETE – 56 DAY MIN. CURE
AMERICAN NATIONAL STANDARD A119.1-1972	GENERAL	COMPONENTS IN MOBILE HOMES	ULTIMATE STRENGTH	STATIC FLEXURAL	N. S.	(1.0D + 1.75L)	12	N. S.	N.A. (4)	N. S.	N. A.	N.A.	
	GENERAL	FLOORS	ACCEPTANCE	STATIC CONCENTRATED	N. S.	200 LBS.	N. S.	N. S.	N.A.	1/8 IN.	N. S.	N.A.	
	GENERAL	WALLS	ACCEPTANCE & ULTIMATE STRENGTH	REFER TO ASTM E72					REFER TO ASTM E-72	N. S.	N. A.	N.A.	
AUSTRALIAN STANDARD CA65-1972	TIMBER	FLOORS, WALLS ROOFS AND COMPLETE STRUCTURES	ACCEPTANCE ON EXISTING STRUCTURES	DEPENDS ON COMPONENT BEING TESTED	UNIFORM	EQUIVALENT TEST LOAD (ETL) (5)	1/4	N.S.	N. A.	N.S.	N.A.	N.A.	
			ACCEPTANCE ON PROTOTYPE STRUCTURES		UNIFORM – 6 STEPS MIN.	EQUIVALENT TEST LOAD (ETL) (6)	N.S.	DESIGN LONG TERM LOAD (7)	1/12	N. S.	95%	N.S.	SPECIMEN TO HAVE MAX. IMPERFECTIONS
BRITISH STANDARD CODE OF PRACTICE CP112-1967	TIMBER		TWO PART ACCEPTANCE		PART 1: 30-45 MIN. TO APPLY TEST LOAD FROM ZERO	(1D + 1L)	24	DESIGN LONG TERM LOAD	1/2	80% AMT. SPECIFIED IN DESIGN	N. S.	N.A.	
					PART 2: UNIFORM	(1D + 2 1/2 L)	1/4	N. S.	N.A.	N.S.	N.A.	N.A.	
BRITISH STANDARD CODE OF PRAC. CP114-1957	CONCRETE		ACCEPTANCE	DEPENDS ON COMPONENT BEING TESTED	UNIFORM	(1D + 1 1/4 L)	24	N.S.	N.A.	N.S.	75% WITHIN 24 HRS AFTER LOAD REMOVAL	75%	CONCRETE – 56 DAY MIN. CURE
CANADIAN STANDARD ASSOC. (CSA) A23.3	ALUMINUM	A) FLOORS, WALLS ROOFS & COMPLETE STRUCTURES	A) STATIC ACCEPTANCE TEST	A) N. S.	A) UNIFORM 5 STEPS MAX.	A) EITHER OF 1.25 W + 1D + 1.5 L, 1D + 1.5L, 1D + 1.25W	1/4	TOTAL DEAD LOAD + LIVE LOAD THAT CAUSES WORST EFFECT	1/4	N.S.	95% WITHIN 15 MIN. AFTER LOAD REMOVAL	N.S.	
		B) COMPONENTS SUBJECT TO FATIGUE FAIL.	B) FATIGUE ACCEPTANCE TEST	B) N. S.	B) FREQUENCY NOT SPEC. ~ 30 REPETITIONS OF EST. LOAD. SEQUENCE	B) COMBINATION OF LOADS EXPECTED IN-SERVICE	N.A.	N.S.	N.A.	N.A.	N.A.	N.A.	

Table 5.5 - Summary of standard and code provisions for structural testing.

TABLE 5.5 CONT'D.- SUMMARY OF CODE AND STANDARD PROVISIONS FOR STRUCTURAL TESTING

CODE OR SPECIFICATION	MATERIALS	BUILDING COMPONENTS	TYPE OF TEST	TYPE OF LOADING	RATE OF LOADING	LOAD OR LOAD FACTORS	TEST LOAD DURATION (HRS.)	PRELOADING: MAGNITUDE	PRELOADING: NO. OF CYCLES OR DURATION (HRS.)	ALLOWABLE DEFLECTION	MIN. RECOVERY % OF MAX. DEFLECTION: 1ST TEST	MIN. RECOVERY: RE-TEST	REMARKS
CANADIAN STANDARDS ASSOC. (CSA) A 23.3	PLAIN OR REINFORCED CONCRETE	BEAMS, FLOORS ROOFS	ACCEPTANCE	STATIC, FLEXURAL	UNIFORM	(1.3D + 1.7L)	24	DESIGN DEAD LOAD	48	$h^2/20{,}000\,t$	75% WITHIN 24 HRS. AFTER LOAD REMOVAL	80%	CONCRETE - 56 DAY MIN. CURE
CSA S157	ALUMINUM	BEAMS, FLOORS, ROOFS	A) THREE PART ACCEPTANCE TEST OF PROTOTYPES	A) STATIC, FLEXURAL	A) UNIFORM	A.1) (1D+1L) A.2) (1.4D+1.4L) A.3) (1.75D+1.75L)	A) LONG ENOUGH TO GET DATA	A) N.S.	N.A.	A) REFER TO CLAUSE 6 OF THE STANDARD	A.1) N.S. A.2) 90% A.3) N.S.	A.2) N.S.	
			B) ACCEPTANCE TEST OF PART OF EXISTING STRUCTURES	B) STATIC, FLEXURAL	B) UNIFORM	B.1) (1D+1L) B.2) (1.5D+1.5L)	B) LONG ENOUGH TO GET DATA	B) N.S.	N.A.	B) REFER TO CLAUSE 6 OF THE STANDARD	B1) N.S. B.2) 90%	B2) N.S.	
F.H.A. TECHNICAL CIRCULAR 12	GYPSUM BOARD, PLASTICS, PLYWOOD, FIBERBOARD, HARDBOARD,	WALL SHEATHING	TWO PART ACCEPTANCE	STATIC, RACKING	REFER TO ASTM E72	PART 1: LEVEL 1-1200# LEVEL 2-2400# LEVEL 3-5200#	← REFER TO ASTM E72 →			PART 1: LEVEL 1-.2 IN. LEVEL 2-.6 IN.	LEVEL 1-.1 IN. LEVEL 2-.3 IN.	N.S.	SPECIMENS "DRY" WHEN TESTED
						PART 2: LEVEL 1-1200# LEVEL 2-2400# LEVEL 3-4000#	← REFER TO ASTM E72 →			PART 2: LEVEL 1-.28 IN. LEVEL 2-.8 IN.	LEVEL 1-.14 IN. LEVEL 2-.4 IN.	N.S.	SPECIMENS "WET" WHEN TESTED
UNIFORM BUILDING CODE	MASONRY	N.S.	ACCEPTANCE	STATIC, FLEXURAL	N.S.	(1.5D + 2.L)	24	N.S.	N.S.	LESSER OF h/200 OR h^2 4000 t	75% WITHIN 24 HRS. OF LOAD REMOVAL	N.A.	
	CONCRETE	BEAM, FLOORS, ROOFS	ACCEPTANCE	STATIC, FLEXURAL	N.S. - FOUR STEPS MIN.	.85(1.4D+1.7L)	24	DESIGN DEAD LOAD	48	$h^2/20{,}000\,t$	75% WITHIN 24 HRS. OF LOAD REMOVAL	80%	CONCRETE - 56 DAY MIN. CURE

FOOTNOTES:
(1) N.S.-NOT SPECIFIED IN CODE
(2) D-DESIGN DEAD LOAD; L-DESIGN LIVE LOAD; W-DESIGN WIND LOAD
(3) h= SPAN OF A FLEXURAL MEMBER UNDER LOAD TEST (IN INCHES); t= TOTAL THICKNESS OR DEPTH (IN INCHES)
(4) N.A.- NOT APPLICABLE
(5) FORMULA FOR DERIVING THE ETL IS FOUND IN SECTION 9.4 OF THE STANDARD
(6) FORMULA FOR DERIVING THE ETL IS FOUND IN SECTION 9.5 OF THE STANDARD
(7) LONG TERM LOAD INCLUDES DEAD PLUS PERMANENT IMPOSED LOAD. IT IS DISTINGUISHED FROM MEDIUM-TERM AND SHORT-TERM LOAD.

Table 5.5 continued - Summary of standard and code provisions for structural testing.

E72-68, "Standard Methods of Conducting Strength Tests of Panels for Building Construction". This was done to derive some recommendations intended to make standard test methods more effective tools in evaluating the performance of innovative housing systems.

6.1.1 Literature Review

It was found that there is a scarcity of research information contributing directly to the development or revision of structural test methods. Most of the testing of building components has been carried out to study the performance of a sample of components representative of a particular type of construction or to evaluate the performance of specimens relative to certain requirements cited in codes or standards. Hence, the literature does not contain substantial discussion or commentary on the merits or shortcomings of the various test setups and procedures which are described. Such subjects as the simulation of boundary conditions, the interpretation of test results in terms of the predicted performance of the actual structure, the feasibility of measuring critical deformations, the validity of certain test assumptions and the proper method of loading are generally not discussed in any detail, if at all.

The review showed that the early predominance of wood-framed and masonry construction in housing influenced the objectives, scope and procedures of the testing methods that were then used. As a result, there evolved several test methods which eventually were widely accepted as standard test procedures (e.g., ASTM E72). Yet, the test methods reflected the influence of this prevailing background which on occasion rendered them inappropriate for application to innovations which were being introduced. The lack of subsequent test method development resulted in housing technology that was not provided with sufficient reliable data to predict rationally the performance of a wide variety of structural concepts being used in houses and small industrial buildings.

Another deficiency made evident in the review of the literature, was the lack of correlation between the results of full-scale building tests and those of associated building components. Shortcomings such as these help to form the bases for conclusions drawn about the research needed for component test methods which can be effective in the evaluation of the structural attributes of a building.

6.1.2 Activities of Voluntary Standards Associations

As new developments have evolved in construction practice, design standards, manufacturing processes and material applications, most segments of the structural engineering profession have acknowledged the need for updating testing practice as it pertains to building components. Consequently, many of the existing standard test methods are currently undergoing some degree of revision. Just as significant an activity is the development of new standard methods to satisfy previously unfulfilled evaluation requirements.

Because ASTM is the largest voluntary standards association and its Standard E72-68, Standard Methods of Conducting Strength Tests of Panels for Building Construction, is the most widely used methodology in this country for testing building components, this association's current activities are reported and summarized in table 3.2.

It was found that ISO is the only international organization which is authorized to develop and promulgate international standards. The scope of this organization's activities encompasses the development of structural test methods for building components. However, to the present time, the technical committees have not produced any material germane to this area.

It was found that the standards pertaining to the structural performance of building construction, as developed by the six foreign associations reviewed, generally provide design load information and include recommended design and construction practice. The exception to this generality is the Japanese Standards Association (JSA), which has issued standard test methods for evaluating building components. These standards, while being similar in format and scope to ASTM Standard E72-68, include a 10-point rating scale which serves as a basis for comparison of the performance of two or more materials or types of construction. English versions of two typical JSA Standards have been prepared for this report and are presented in Appendix C.

To provide the reader with a capsule account of the state-of-the-art of structural test methods for building components, table 6.1 has been prepared. The information included in this table was derived from a review of the publications of domestic, foreign and international standards associations and of several domestic technical associations. It should be noted that the scope of this investigation precluded coverage of test methods whose purpose is to evaluate the performance of structural connections and joints. Due to the relative significance of the joints and connections in building systems a comprehensive study of test method availability and deficiency in this area is warranted.

6.1.3 NBS Testing for HUD Operation BREAKTHROUGH Housing Program

The test methods employed by NBS to evaluate industrialized building components for the HUD Operation BREAKTHROUGH Housing Program have been compared with those contained in ASTM Standard E72. The main emphasis was placed on the deviations from and extensions of accepted standard methods with a view toward improving these standards. The following list of items summarizes the recommendations generated by this comparison exercise:

- develop a low-frequency repeated loading test in combination with static loading to supplant static creep tests of extremely long duration.
- establish guidelines for the simulation of boundary conditions and loading procedures (re: distribution, cycling and reversing) in compression, flexure and racking tests.
- improve instrumentation in order to minimize errors and expedite observations.
- establish guidelines for employing environmental conditioning of test specimens.
- use small-specimen, complementary tests for determining strength and stiffness parameters unaffected by the size proportions of structural test specimens.
- develop guidelines to correlate field and laboratory testing practices for houses.
- conduct tests to study and better understand the interaction of building components, joints and anchorages for improved correlation of component evaluation with full-structure performance.

6.2 Recommendations for Research

On the basis of the literature review, the other sources of information which are summarized in a general state-of-the-art by table 6.1 and the

Table 6.1 — State-of-the-art Summary of Test Methods for Building Components

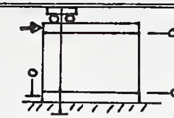
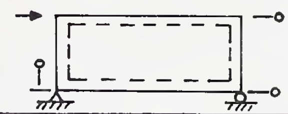
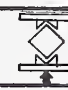
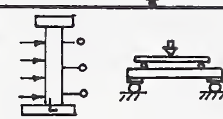
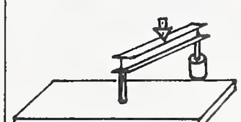
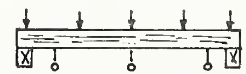
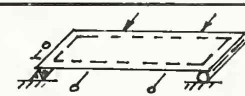
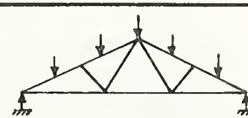
Building Component	Test Description	Type of Loading	Applicable Materials	Applicable Construction	Typical Test Configuration	State-of-the-Art Summary: Test Method Existing	A Standard Method Existing	Revision to Standard Necessary	Revision Considered or Underway	New Standard Being Developed
WALL SHEATHING	RACKING	(a) STATIC	PLYWOOD HARDBOARD FIBERBOARD GYPSUM BOARD WOOD & PLASTIC	WOOD-FRAMED		(a) YES	ASTM E72 SECT. 15&16 SEE TABLE 3.1	YES	YES, SEE TABLE 3.2	
		(b) CREEP				(b) NO	NO			NO
WALLS	RACKING ~ FULL SCALE	(a) STATIC	GENERAL **	** GENERAL		(a) YES	ASTM E72 SECT.14 SEE TABLE 3.1			BY ASTM
		(b) PULSATING	GENERAL			(b) NO	NO			NO
		(c) REVERSED	GENERAL			(c) NO	NO			NO
		(d) CREEP	PLASTICS, CONC. WOOD			(d) NO	NO			NO
WALLS	COMPRESSION	(a) STATIC	GENERAL	GENERAL		(a) YES	ASTM E 72 SECT. 7 SEE TABLE 3.1	YES	YES BY N.B.S.	
		(b) CREEP	WOOD, PLASTICS CONCRETE			(b) NO	NO			NO
WALLS	RACKING — SMALL SCALE	STATIC	BRICK, BLOCK AND TILES	MASONRY		YES BY B.I.A.	NO			YES, BY ASTM
WALLS	FLEXURE	STATIC	GENERAL	MASONRY, WOOD-FRM., METAL-FRM., SANDWICH PANELS, STRSD. SKIN, CONC.		YES	ASTM E72 SECT. 9 & 10 SEE TABLE 3.1	YES	YES, SEE TABLE 3.2	
WALLS AND FLOORS	IMPACT	IMPACT	GENERAL	GENERAL	 WALLS; WALLS & FLOORS	YES	ASTM E72 SECTS. 12,13&20 SEE TABLE 3.1	YES	NO	
FLOOR & WALL SURFACES	CONCENTRATED LOAD	STATIC	PLASTICS, GYPSUM BRD., PLYWOOD, HARDBOARD, FIBERBOARD, METALS	GENERAL		YES	ASTM E-72 SEE TABLE 3.1	YES	NO	
							J.I.S. A5708*	UNKNOWN	NO	

Table 6.1 - State-of-the-art summary of test methods for building components.

TABLE 6.1 CONTINUED – STATE-OF-THE-ART SUMMARY OF TEST METHODS FOR BUILDING COMPONENTS

Building Component	Description	Type Of Loading	Applicable Materials	Applicable Con-struction	Typical Test Configuration	State-Of-The-Art Summary: Test Method Existing	A Standard Method Existing	Revision To Standard Necessary	Revision Con-sidered Or Underway	New Standard Being Developed
FLOORS AND FLAT ROOFS	FLEXURE	(a) STATIC	GENERAL	GENERAL		(a) YES	ASTM E196 SEE TABLE 3.1	YES	YES, SEE TABLE 3.2	
		(b) CREEP	PLASTICS, WOOD, CONCRETE			(b) NO	NO			NO
BEAMS AND GIRDERS	FLEXURE	STATIC	GENERAL			NO	NO			YES, BY ASTM, SEE TABLE 3.2
ROOFS AND FLOORS	HORIZONTAL DIAPHRAGM	(a) STATIC	METALS, WOOD, PLASTICS	FRAMED		YES, BY A.I.S.I.	NO			YES, BY ASTM
		(b) PULSATING				NO	NO			NO
		(c) REVERSED				NO	NO			NO
ROOF TRUSSES	FLEXURE	STATIC	METALS, WOOD	HORIZ. CHORD ROOF TRUSSES OR SLOPED CHORD ROOF TRUSSES		YES	ASTM E73 SEE TABLE 3.1	YES	YES, SEE TABLE 3.2	
						YES	TRUSS PLATE INSTITUTE SEE TABLE 3.1	UNKNOWN	NO	

LEGEND:

→ LOAD OR REACTION.

—o DEFLECTION GAGE.

* J.I.S. ~ JAPANESE INDUSTRIAL STANDARD.

** GENERAL ~ IMPLIES THAT THE METHOD IS APPLICABLE TO A VARIETY OF MATERIALS OR CONSTRUCTION TYPES.

Table 6.1 continued - State-of-the-art summary of test methods for building components.

Operation BREAKTHROUGH testing, seven structural test categories for which basic and development research is needed have been identified. The categories are divided into two groups: (1) those for which no standard test method has been adopted and (2) those for which procedures have been accepted as a Standard by ASTM Committee E-6 but are in need of substantial modifications.

The seven categories are listed below in accordance with these two groupings. The order in which they occur is arbitrary and should not be construed to be a recommended ranking of priorities. The brief discussion presented for each category is intended to convey the nature and scope of the problem.

6.2.1 Categories for which a Standard Test Method Exists but Needs Modification

6.2.1.1 Horizontal In-plane Loading on Shear Walls* - Static Racking Load

As a prerequisite to the development of an improved racking test, it is necessary to gain insight into force distribution patterns and deformation behavior by consulting existing information and supplementing this information with data obtained from laboratory tests on prototype segments of full-scale houses. To make the test method an effective evaluation tool, the degree of correlation between the test results and the predicted lateral response of the building must be determined.

6.2.1.2 Transverse Loading on Floors and Roofs - Short-duration, Static, Uniform Load

There are modifications needed to improve the cost effectiveness of the test and to make the test setup more easily adaptable to specimens of different sizes. Section 4.2.3 of this report elaborates on one possible alternative to the existing standard method.

6.2.1.3 Vertical Loading on Walls and Partitions - Short-duration, Static, Compressive Loading

It is necessary to study such parameters as wall support and restraint condition simulation, positioning of the compressive loading and location of instruments. The testing of short specimens should be considered as a recommended complement to full-height wall tests.

6.2.1.4 Local Transverse Loading on Walls, Partitions and Floors - Impact Loading and Subsequent Short-duration Concentrated Loading

As a prerequisite to developing an improved test method, acceptable limits of deflection under the concentrated load must be established. Model U.S. codes do not state requirements for this serviceability consideration.

6.2.2 Categories for Which No Standard Test Method has been Adopted

6.2.2.1 Vertical Loading on Walls and Partitions - Simulation of Creep in Compression

The need to evaluate the creep performance of new construction materials and techniques warrants the development of a standard test method. It is

*The expression "shear walls" refers to those walls which are subjected to shear forces in their plane, as a result of horizontal forces. This distinction does not preclude the likelihood of other types of loading acting concurrently.

desirable to develop a relatively short-term test procedure that will produce data which can be correlated with long-term performance that occurs in service. The most important determination to be made is the required duration of test loading to effect the desired correlation. Other factors to be considered are: the type of conditioning required prior to and during the test; the amount of eccentricity for the load; and the simulation of edge support and restraint conditions.

6.2.2.2 Transverse Loading on Floors and Roofs - Simulation of Creep in Bending

It is desirable to develop a technique that in a relatively short term will produce data which can be correlated with long-term performance that occurs in service. In Section 4.2.4 of this report there is a suggested loading method that warrants further investigation. Other test parameters must be studied as well.

6.2.2.3 Lateral Loading on Complete Prototype Houses - Racking Induced by Cyclic Load Reversal and Rapid Repetition of One-Directional Loading

A laboratory testing procedure is needed for the purpose of evaluating the load-cycle relationship for industrialized building prototypes. Of primary interest is the structural integrity of joists, anchorages, and other points of potential weakness. As a prerequisite to the test method, it will be necessary to reconcile such test parameters as 1000 cycles of repeated loading and 5 cycles of load reversal with existing information on earthquake and wind loading histories for houses.

APPENDIX A

BIBLIOGRAPHY

The following is an alphabetical listing of specific references noted by number in the text and the appendices of the report.

1. ACI Standard 318-63, "Building Code Requirements for Reinforced Concrete," American Concrete Institute.

2. ACI Standard 318-71, "Building Code Requirements for Reinforced Concrete," American Concrete Institute.

3. American National Standard A119.1, 1974, "Standard for Mobile Homes," American National Standards Institute.

4. Anderson, L. O., "Guides to Improved Framed Walls for Houses," Research Paper FPL 31, Forest Products Laboratory, U.S. Department of Agriculture, Madison, Wis., August 1965, 28 pp.

5. ASTM E72-68, "Standard Methods of Conducting Strength Tests of Panels for Building Construction," American Society for Testing and Materials.

6. Australian Standard CA65-1972, "SAA Timber Engineering Code," Standards Association of Australia.

7. Blume, J. A. and Proulx, J., "Shear in Grouted Brick Masonry Wall Elements," Western Clay Products Association, San Francisco, Calif., August 1968.

8. Boller, K. H., "A Facility to Evaluate Three-Dimensional Performance of House Modules," Research Note FPL-0025, Forest Products Laboratory, U.S. Department of Agriculture, Madison, Wis., 1972.

9. British Standard Code of Practice, CP112 (1967), "The Structural Use of Timber," British Standards Institution.

10. British Standard Code of Practice, CP114 (1957), "The Structural Use of Reinforced Concrete in Buildings," British Standards Institution.

11. British Standard Code of Practice, CP118 (1969), "The Structural Use of Aluminium," British Standards Institution.

12. Canadian Structural Design Manual 1970, Supplement No. 4 to the National Building Code of Canada, NRC No. 11530, National Research Council of Canada, Ottawa, Canada.

13. Carter, C. and Smith, B. S., "Structural Behavior of Masonry Infilled Frames Subjected to Racking Loads," Chapter 27 of Designing, Engineering and Construction with Masonry, Gulf Publishing Company, Houston, Texas, 1969, pp.226-233.

14. Cousineau, R. D., "Testing of Large Diaphragms," ASTM Special Technical Publication No. 282, presented at ASTM Symposium on Methods for Testing Building Construction, San Francisco, Calif., October 12-14, 1959.

15. CSA Standard A23.3-1970 "Code for the Design of Plain or Reinforced Concrete Structure," Canadian Standards Association, Ottawa, Canada.

16. CSA Standard S157, "The Structural Use of Aluminium in Buildings," Canadian Standards Association, Ottawa, Canada.

17. Diskin, S. H., "Effect of Wind Pressure on the Racking Strength and Stability of a One-Story, Gable-Roof Building of Sandwich Panel Construction," Panelfab Technical Series Engineering Test Report No. 113, (Panelfab, Inc.), North Miami, Florida, April 1968, 11 pp.

18. Dorey, D. B. and Shriever, W. R., "Structural Test of a House Under Simulated Wind and Snow Loads," ASTM Special Technical Publication No. 210, presented at ASTM Symposium on Full-Scale Tests of House Structures, Los Angeles, Calif., Sept. 18, 1956.

19. Dorey, D. B. and Schriever, "A Philosophy on Loading Tests," presented at the 58th Annual Assembly of ASTM, Atlantic City, N. J., June 29, 1955.

20. Dryden, H. L., "Research on Building Materials and Structures for Use in Low-Cost Housing," Nat. Bur. Stand. (U.S.), Building Materials and Structures Report (BMS) 1, June 1938.

21. Francis, A. J., Brown, W. B. and Aroni, S., "Full-Scale Tests of Pre-Cast Multi-Story Flat Construction," ASTM Special Technical Publication No. 210, presented at ASTM Symposium on Full-Scale Tests of House Structures, Los Angeles, Calif., Sept. 18, 1956.

22. Greene, W. E. et al, "Structural Tests for a Housing System Using Sandwich Panels with Gypsum Board Facings," NTIS PB 214-336, National Bureau of Standards (U.S.), Nov. 20, 1972, 75 pp.

23. Hendry, A. W., "Shear Tests on Full-Scale Single-Story Brickwork Structures Subjected to Pre-Compression," (research conducted at University of Edinburgh), Paper presented at the RILEM International Symposium on Methodology and Technique of Testing Structures, Topic III, Bucharest, 1969, pp. 95-110.

24. Isenberg, M. W., Barnoff, R. M., and Mozingo, R. R., "The Racking Resistance of Frame Wall Construction," a report prepared for the Federal Housing Administration, (College of Engineering and Architecture, The Pennsylvania State University), April 1963, 112 pp.

25. Lew, H. S., "The Effect of Impact Loadings on the Performance of Wood Joist Subflooring Systems," National Bureau of Standards (U.S.), Building Science Series 52, May 1974, 28 pp.

26. Leyendecker, E. V. and Reichard, T. W., "Test and Evaluation of the Prefabricated Lewis Building and Its Components, Phase II," National Bureau of Standard (U.S.) Report No. 10 568, unpublished report prepared for Naval Civil Engineering Lab., Port Hueneme, Calif., April 1971, 66 pp.

27. Luttrell, L. D., "Strength and Behavior of Light-Gage Steel Shear Diaphragms," Cornell Engineering Research Bulletin No. 67-1, Cornell University, Ithaca, N. Y., July 1967, 41 pp.

28. Luxford, R. F. and Erickson, E. C. O., "Rigidity and Strength of Houses Built of Plywood Stressed-Cover Panels," ASTM Special Technical Publication No. 210, presented at ASTM Symposium on Full-Scale Tests of House Structures, Los Angeles, Calif., Sept. 18, 1956.

29. Mason, W. R., Rush, P. J. and Bruck, A. B., "Evaluation of a 40-ft by 100-ft Frameless Straight-Sided Prefabricated Metal Utility Building," Final Technical Memorandum M-050, U.S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, Calif., April 1, 1952.

30. Monk, C. B. Jr., "Transverse Strength of Masonry Walls," ASTM Special Technical Publication No. 166, presented at ASTM Symposium on Methods of Testing Building Constructions, Chicago, Ill., June 17-18, 1954.

31. National Building Code of Canada 1970, NRC No. 11246, National Research Council of Canada, Ottawa, Canada.

32. Nilson, A. H., "Shear Diaphragms of Light Gage Steel", Journal of the Structural Division, Vol. 86 ST 11, ASCE, Nov. 1960.

33. Pielert, J. H. et al, "Structural Evaluation of Steel-Faced Sandwich Panels," NTIS PB 213240, National Bureau of Standards (U.S.) Revised Sept. 27, 1972, 47 pp.

34. Racking Strengths and Stiffnesses of Exterior and Interior Frame Wall Constructions, Report No. CR-486, NAHB Research Foundation Inc., Rockville, Maryland, May 1971, 88 pp.

35. Ramstad, T., Reyes, V. D. and Espiloy, E. B. Jr., "Racking Resistance of Timber Framed Walls," CIB Publication S56, presented at CIB International Symposium on Low-Rise Lightweight Constructions, Budapest, Hungary, April 26-29, 1971.

36. Reichard, T. W. and Leyendecker, E. V., "Test and Evaluation of the Prefabricated Lewis Building and Its Components, Phase I, Part 2," (Full-Scale Building Tests), National Bureau of Standards (U.S.) Report No. 10 164, unpublished report prepared for Naval Civil Engineering Lab., Port Hueneme, Calif., February 1970, 46 pp.

37. Reichard, T. W. et al, "Structural Tests on Housing Components of Glass Fiber Reinforced Polyester Laminate," NTIS PB 221-183, National Bureau of Standards (U.S.), April 1973, 90 pp.

38. Report on the Testing of Structures, Series No. 40, United Kingdom Institution of Structural Engineers, London, September 1964, 15 pp.

39. Research Group of Systematic Methods for Selecting Building Materials, "On the Systematic Method for Selecting Materials - Third Report - Standard Testing Methods," Report No. 56, The Building Research Institute, Ministry of Construction, Tokyo, Japan, January 1970, 179 pp.

40. Sinha, B. P., Maurenbrecher, A. H. P., and Hendry, A. W., "Model and Full-Scale Tests on a Five-Story Cross-Wall Structure Under Lateral Loading," Proceedings of the Second International Brick Masonry Conference (SIBMAC), Stoke-on-Trent, England, April 12-15, 1970, pp. 201-208.

41. A Standard for Testing Sheathing Materials for Resistance to Racking, FHA Technical Circular No. 12, Federal Housing Administration, Washington, D. C., Oct., 1949.

42. Stillinger, J. R., "Lateral Tests on Full-Scale Lumber- and Plywood-Sheathed Roof Diaphragms," ASTM Special Technical Publication No. 166, presented at ASTM Symposium on Methods of Testing Building Constructions, Chicago, Ill., June 17-18, 1954.

43. Structural Properties of Low-Cost House Construction, National Bureau of Standards (U.S.), Letter Circular LC-502A, August 1937.

44. Thorburn, H. J. and Schriever, W. R., "Loading Tests on Full-Scale House Roofs," ASTM Special Technical Publication No. 312, presented at ASTM Symposium on Methods of Testing Building Constructions, Washington, D. C., November 15, 1960.

45. Tissell, John R., "1966--Horizontal Plywood Diaphragm Tests," American Plywood Association Laboratory Report 106, American Plywood Association, Tacoma, Washington, 48 pp.

46. Uniform Building Code, 1973 Edition, International Conference of Building Officials, Whittier, Calif.

47. Watstein, D. and Johnson, P. V., "Experimental Determination of Eccentricity of Floor Loads Applied to a Bearing Wall," National Bureau of Standards (U.S.), Building Science Series 14, June 1968, 6 pp.

48. Whittemore, H. L., Cotter, J. B., Stang, A. H. and Phelan, V. B., "Strength of Houses," National Bureau of Standards (U.S.), Building Materials and Structures Report (BMS) 109, April 1948, 133 pp.

49. Whittemore, H. L. and Stang, A. H., "Methods of Determining the Structural Properties of Low-Cost Constructions," National Bureau of Standards (U.S.), Building Materials and Structures Report (BMS) 2, August 1938, 18 pp.

50. The Wood-Frame House as a Structural Unit, Technical Report No. 5, National Forest Products Association, Washington, D. C., 1965.

51. Yancey, C. W. and Somes, N. F., "Structural Tests of a Wood Framed Housing Module," COM 73-10860, National Bureau of Standards (U.S.), March 26, 1973, 101 pp.

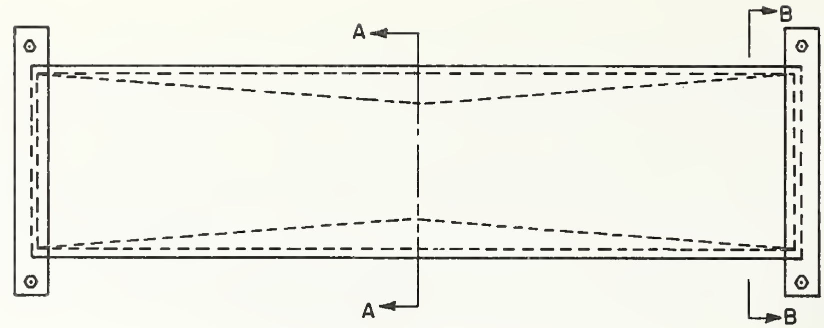
52. Yokel, F. Y., "Study of the Local Resistance of Conventional Plywood Subflooring to Concentrated Load," National Bureau of Standards (U.S.) Building Science Series 53, May 1974, 36 pp.

53. Yokel, F. Y., Hsi, G. and Somes, N. F., "Full Scale Test on a Two-Story House Subjected to Lateral Load," National Bureau of Standards (U.S.), Building Science Series 44, March 1973, 23 pp.

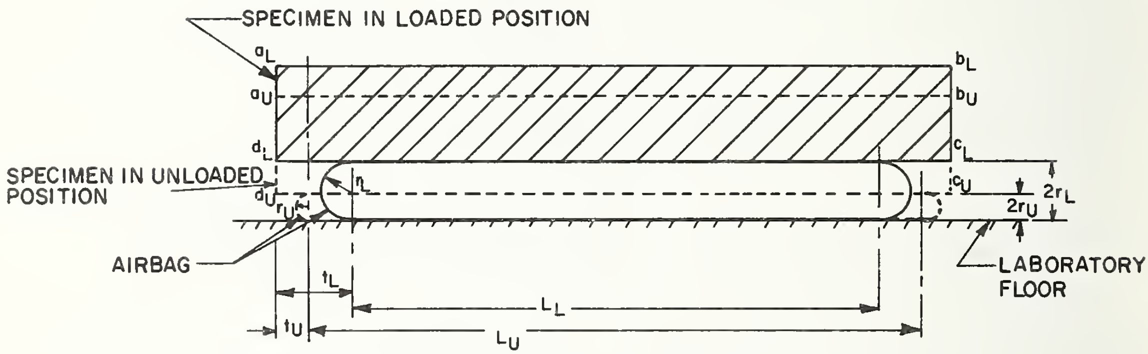
APPENDIX B - Air Bag Contact Area - Flexure Tests

In section 3.2.3.3 there are three alternative ways of accounting for the fact that under some circumstances the air bag used in a flexural test does not load the entire surface of the test panel. Described herein is the second of those three ways; this procedure is based on the original geometry of the specimen and the air bag. Figure B.1 schematically shows the specimen and the air bag in their unloaded (i.e. original and loaded positions. The symbols shown in this figure are subsequently explained and used in performing the necessary calculations.

Figure B.2 is a schematic representation of the third way in which to account for the stated condition. The actual uniform load imposed on the specimen can be determined by measuring the reaction at each support with a set of load cells sandwiched between two reaction beams.

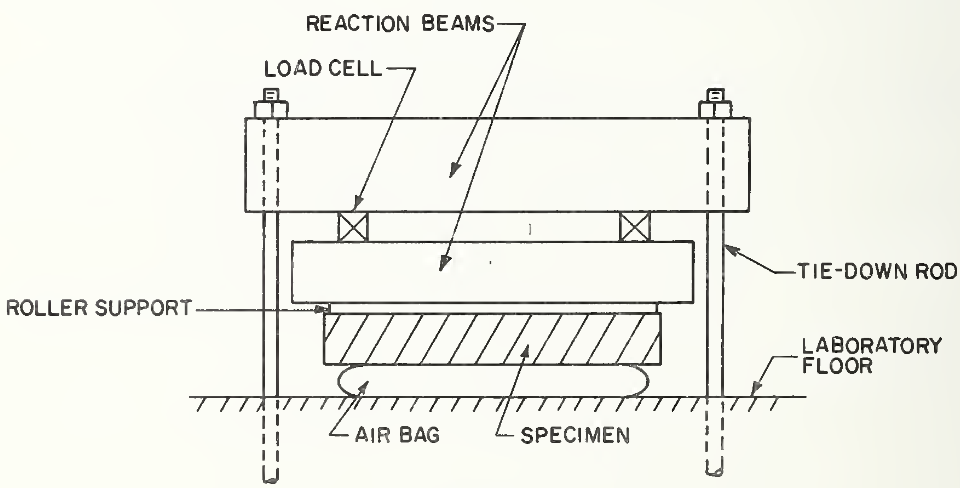


PLAN VIEW - FLEXURE TEST



SECTION A-A

Figure B.1 - Plan and section of flexural test setup.



SECTION B-B

Figure B.2 - Section of flexural test setup at reaction beams.

Calculation of Contact Area

Symbols

L_u = transverse length of air bag contact at the centerline when the specimen is unloaded.

L_L = transverse length of air bag contact at the centerline when the specimen is loaded.

r_u = edge radius of air bag at the centerline when the specimen is unloaded.

r_L = edge radius of air bag at the centerline when the specimen is loaded.

c = circumference of air bag

t_u = edge distance of the unloaded specimen.

t_L = edge distance of the loaded specimen.

Using the plan view and section A-A in fig. B.1 and the symbols listed above, several geometric relationships can be derived. It is assumed that the circumference remains constant throughout the longitudinal length of the air bag.

$$2L_L + 2\pi r_L = c \qquad [B.1]$$

$$2L_u + 2\pi r_u = c \qquad [B.2]$$

Eliminating c from the two equations and transposing terms yields the following relationship at the centerline.

$$L_L = L_u - \pi(r_L - r_u) \qquad [B.3]$$

Since the transverse deflection of the specimen follows a circular arc, with the maximum deflection (i.e. the distance between the chord and the arc) occurring at midspan, the edge profile of the air bag's contact area against the specimen will also follow a circular arc of large radius. Assuming that the edge profile of the air bag's contact area can be approximated by a straight line, as shown in the plan view of figure B.1, an expression can be derived for the average transverse length of air bag contact, L_{avg}:

$$L_{avg} = L_u = \frac{\pi}{2}(r_L - r_u) \qquad [B.4]$$

L_u can be calculated from equation B.2 as follows:

$$L_u = \frac{c}{2} = \pi r_u \qquad [B.5]$$

Using equations B.4 and B.5, the following example is presented:

Given: c = 12 in, r_u = 1.0 in

L_u = 60 = π(1) = 56.84 in.

Table B.1 - AVERAGE TRANSVERSE LENGTH REDUCTION FOR AIR BAG CONTACT

r_L (in)	L_{ave} (eqn. B.4) (in)	Average Percent of Length Reduction $100(L_u - L_{ave})/L_u$	Midspan Deflection $(r_L - r_u)$
1.25	56.46	0.7	0.25
1.50	56.06	1.40	0.50
1.75	55.66	2.07	0.75
2.00	55.27	2.76	1.00
2.25	54.88	3.45	1.25
3.00	53.70	5.52	2.00
4.00	52.13	8.28	3.00
6.00	48.99	13.81	5.00
10.00	42.71	24.86	9.00
15.00	84.86	38.66	14.00

APPENDIX C - Translation of Two Japanese Standard Test Methods

The two standard test methods presented on the following pages were selected as being typical, in format and content, of a series of standard test methods included in [39]. Among the other structural performance tests included in this reference are the following titles: 1) "Standard Method of Test for Impact Strength by Steel Ball Pendulum System", 2) "Standard Method of Test for Bearing Resistance in Dynamic Pressure" and 3) "Standard Method of Test for Bearing Resistance in Compression by Concentrated Load".

These test methods are to be used in evaluating specific building components against various structural performance requirements. It should be noted that the designated performance requirements are stated at the beginning of the test method. After following the details of the test procedure, the user is supplied with some guidelines for quantitatively assessing the resistance of the test specimens and for establishing a rating of the components performance.

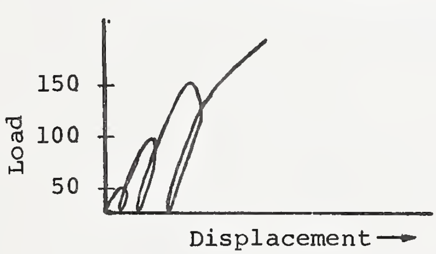
(1) Name of Test Method (2) Performance Requirements		601T-2 "Test of Method of Loading Resistance (Test Method of Pressure Resistance for Vertical Loading Normal to Surface)" [501] To be safe against live load and snow loading
(3) Purpose of Test		To find the degree of safety against uniformly distributed loading which is acting on the horizontal members, subjected to live and snow loading.
(4) Test Specimens		1. Type: Building Element and Joint - Various types of panels and joints 2. Dimension: Shall be the smallest unit of the structure, but it should include the entire span length 3. Quantity: Three specimens
(5) PROCEDURES	(5-1) Summary	In principle this should be a uniformly distributed load test. However, if deemed appropriate, many equally spaced concentrated loads or a single concentrated load at the center may be applied to the Building element.
	(5-2) Test Setup	1. Test setup for uniformly distributed loading (Refer to Figs. 1, 2, and 3 and photo. 1) 2. Test setup for many concentrated points of loading 3. Test setup for compression (airbag) loading 4. Instruments for Deflection Measurement (e.g., Dial Gages)
	(5-3) Conditioning Prior to Test	Moisture Content -- For air-dried specimens the temperature-moisture condition is class 2.
	(5-4) Details of Test Method	1. Uniformly distributed load shall be used -- In principle, only both ends are to be supported, although in real structure all four edges may be supported. Load increments are as follows: 50, 100, 150, 200, 300, 400, 500, 1000, 1500 kg/m^2 2. Increase load gradually; load at a rate of about 1 kg/5 sec, and at each load level maintain load for 10 minutes. Then release load to zero. Repeat process at next highest load. (Sketch on next page) 3. The test shall be conducted until failure or until severe displacement occurs. (Severe displacement in actual practice would be the point beyond which the deflection is irrecoverable.) 4. If necessary, perform the same steps again.

<table>
<tr>
<td>(6)
Method of
Evaluation</td>
<td>
To determine the least loading capacity, use one of the following three:

1. Two loading steps before the level at which failure or severe displacement occurs.
2. Loading step at which deflection reaches supported span divided by 150 (L/150).
3. The loading step (in the step by step loading procedure) at which the surface of the Bldg. Element will fail.

Table 1 - Grading of Loading (Perpendicular to the Surface) Resistance
<table>
<tr><td>Grade</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Unit Pressure (kg./m²)</td><td>50</td><td>100</td><td>150</td><td>200</td><td>300</td><td></td></tr>
</table>
(Table 1 - cont.)
<table>
<tr><td>Grade</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr>
<tr><td>Unit Pressure (kg./m²)</td><td>450</td><td>700</td><td>1000</td><td>1500</td><td></td></tr>
</table>
</td>
</tr>
<tr>
<td>(7)
Test
Results</td>
<td>Indicate the loading capacity in units of kg/m² which was determined by above techniques</td>
</tr>
<tr>
<td>(8)
Remarks</td>
<td>No remarks</td>
</tr>
</table>

LOAD - DISPLACEMENT CURVE



Commentary on Test Method of Loading Resistance (601 T-2)

(1) Live load capacity so determined is usually used for structural calculations in satisfying building code requirements. Normally the value ranges between 60 and 550 kg/m^2. In [501] live loading and snow loading, quantitative grading is divided into ten levels from 50-1500 kg/m^2.

(2) Test Setup for Uniformly Distributed Loading

By filling the compressed air into several air bags, the uniformly distributed load is applied. The equipment used in the building research lab. is shown in Figures 1, 2 and 3 and in Photograph 1.

(3) Loading Technique

Repeat the loading for each loading step and continue until bending failure or shear failure occurs. But, if increase of deformation is large and no increase of load is possible, in this case it is not necessary to continue increasing the loading until failure.

(4) Evaluation

Following the three evaluation methods in section (6), bending strength performance of the Bldg. Element can be obtained.

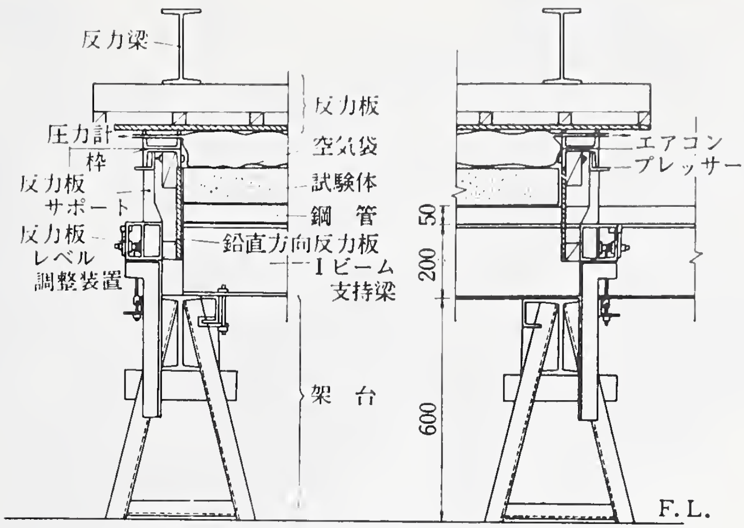


Figure 1 - Cross Section View of Test Setup for Uniformly Distributed Loading (for the case of two edges supported)

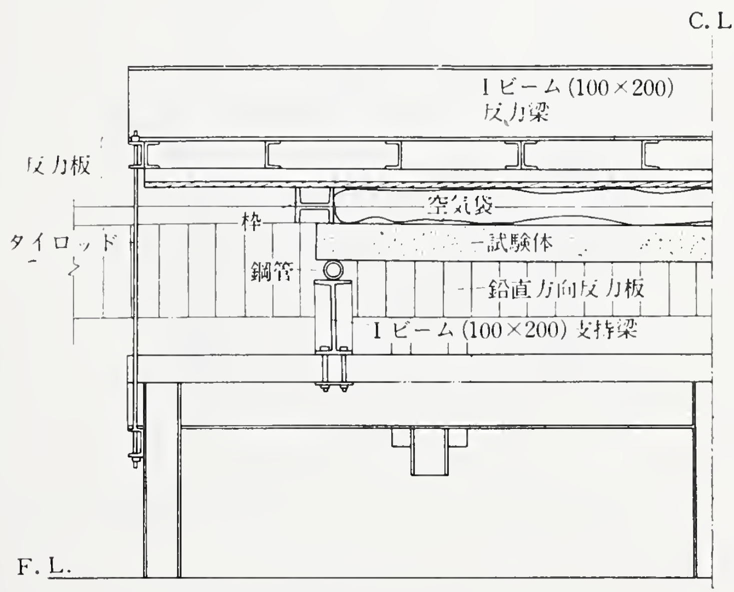
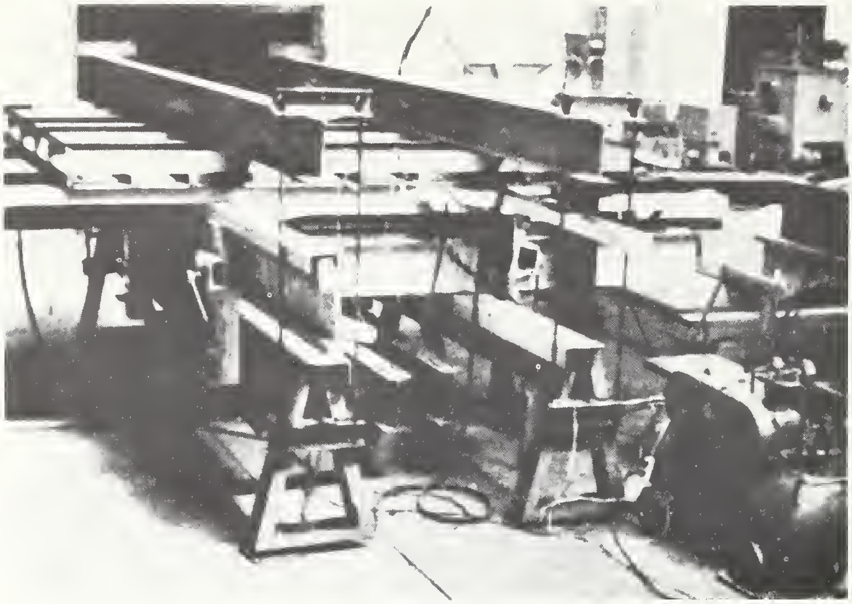


Figure 2 - Section Along the Span (for the case of two edges supported)



Photograph 1 - Test Setup for Uniformly Distributed Loading

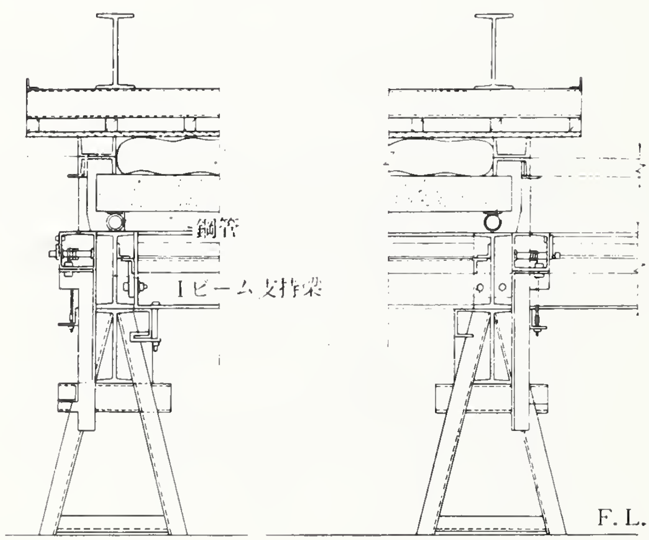


Figure 3 - Cross Section View of Test Setup for Uniformly Distributed Loading (for the case of four edges supported)

<table>
<tr><td colspan="2">(1)
Name of the
Test Method</td><td>608T-2 Test Method for Bending Resistance to Local Concentrated Load</td></tr>
<tr><td colspan="2">(2)
Performance
Requirements</td><td>[507] To be safe against locally concentrated loading
[708] Locally concentrated compression</td></tr>
<tr><td colspan="2">(3)
Purpose of
Test</td><td>To find the characteristics of a Bldg. Element and its surface material under the locally concentrated loading, simulating actual design conditions.</td></tr>
<tr><td colspan="2">(4)
Test
Specimens</td><td>1. Type: Various kinds of Bldg. Elements
2. Dimension: The dimensions shall conform to the dimen. of the actual structure. Typically the longer side is approx. 90-250 cm and the shorter side is approx. 60-120 cm.
3. Quantity: More than two samples or such quantity that will yield two test results.</td></tr>
<tr><td rowspan="3">(5)

PROCEDURES</td><td>(5-1)
Summary</td><td>Test specimen shall be supported at both ends by horizontal line supports. Center of concentrated load is to be applied perpendicular to the upper surface of test specimen at its geometric center. Measure the change in deformation of the Bldg. Element as well as the deformation of the surface of the Bldg. Element.</td></tr>
<tr><td>(5-2)
Test
Setup</td><td>1. The panel bending strength test machine -- to have a maximum capacity of more than 1 ton.
2. Load is applied to the surface of the test specimen through either a 10 cm diameter disc or a 10 cm square block. A 10 mm thick hard rubber pad is placed between the surface of the specimen and the disc or block. The method of attaching the above assembly to the panel bending strength test machine depends on the machine's construction.
3. Dial gage or displacement detector with automatic recorder.
4. Load cell and automatic recorder.</td></tr>
<tr><td>(5-3)
Conditioning
Prior to Test</td><td>Store the test specimen more than 7 days under constant temperature and relative humidity of 5" - 35"C and 45 - 85%, respectively.</td></tr>
</table>

(5-4) Details of Test Method

1. Span Length - the span length depends on the span (L) in the actual design conditions but it is usually about 180 cm in standard size. Condition of support fixity is dependent on actual design.
2. Location of the Loading - Principally, one point in the center of the test specimen such as in Figure 1.
3. Location of the Displ. Meas. Points - Deformations to be measured at least at the following three locations shown in Figure 1.
   (1) Edge Defl. at 1/4 span (δ_1, δ_2, δ_3, δ_4)
   (2) Edge Defl. at Center Span (δ_5 & δ_6)
   (3) At Center of Specimen (δ_7)
4. Loading Method - Increase load until failure occurs in the Bldg. Element or in the surface material or until load reaches 1 ton. In case the displacement is meas. by dial gages, the loading rate is to be based on the gage which shows the most movement. And also the loading rate should be based upon the behavior of the specimen. When using automatic recorder the average loading rate is about 100 kg/min.

(6) Method of Evaluation

When failure occurs before the center deflection at mid-span (δ_7), reaches L/150 the local bending resistance is expressed by 2/3 of the loading at which failure occurred. In other case, the bending resistance is expressed for the point at which δ_7 reaches L/150 and then the grading is based on Table 1.

Table 1 - Grading of Local Bending Strength

Grade	0		1		2		3		4		5		6		7		8		9
Load (kg)		1.0		2.1		4.5		10		21.5		45		100		215		450	

(7) Test Results

1. Detailed information of test specimen;
2. Location of load and displ. meas. points;
3. Load-deflection curve;
4. Failure load (kg);
5. Local load bending strength (kg) and grade.

(8) Remarks

When there is a displacement at the top of support, measure this displ. along the support and take it into account. The original draft of this method was a Japanese Industrial Standard for local load testing of Bldg. Elements.

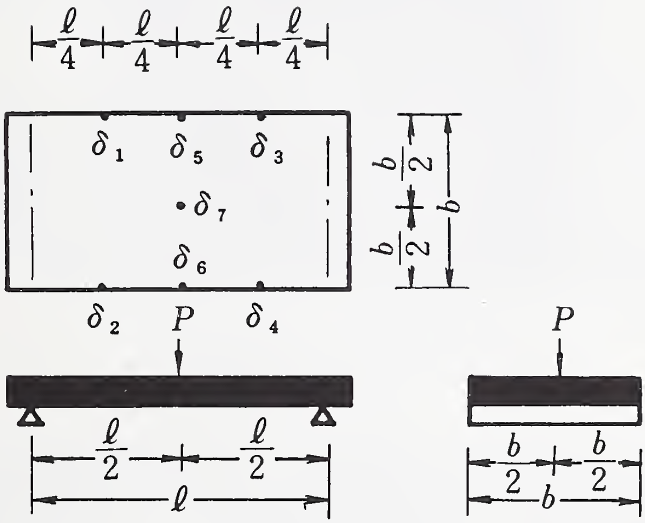


Figure 1 - Location of Loading and Observation Points of Displacement

Commentary on Test Method for Locally Concentrated Loading Bending Strength (608 T-2)

(1) Locally Concentrated Loading

Here, the locally concentrated loading, applied to a relatively small area of the surface, acts perpendicular to the surface of the sample. As such, this concentrated loading can be applied to floors as well as to walls. In the case of loading on the floor of a building, the loading is caused by human occupancy and by household goods. Sources of localized loading include such items as spiked heels, desk legs and chair legs. Although the following items are not defined as loading, the local pressure due to humans leaning on to objects is herein considered to be local loading.

(2) Local Load Bending

The structure experiences bending when local loading is applied. This particular loading state is called local load bending. The local bending of surface material should be considered in relation to the path of loading. Such a case is local loading action on the surface material of a panel made of cellular structures with voids. However, the test method presented herein considers only the local bending strength of surface material, the Local Compression Test Method (test no. 608T-1) should be consulted.

(3) Loading Method

(a) Loading Assembly

In the Local Compression Test method the leg of a chair or a desk is simulated by a 25 mm-diameter sphere attached to the bottom of the assembly. However, this assembly is not suitable for the evaluation of bending resistance of a building element. It is necessary to provide for the loading assembly to contact the surface of the specimen over a certain area. Photograph 1 shows an example of such an arrangement. A wooden block attachment with surface dimensions of 10 cm x 10 cm, with a 10 mm-thick hard rubber pad on the entire contact surface, of the wooden block, is reinforced by a steel band which is wrapped around it. This assembly is usually employed with the panel bending test machine (described in another test method). But, it can also be applied to the Local Concentrated Loading Bending Test. An improved steel assembly is shown in figure 2. The part which contacts the specimen is a steel disc 10 cm in diameter and there is a steel sphere between the disc (see Attachment B in figure 2) and the supporting bar of the panel bending machine.

(b) Span Between Supports and Location of Loading Points

The test span should be the same as that of the real structure. The test span should be the same as the span of the main members of the building element or multiplies of it.

Load should be applied at the center of the test specimen. Usual Panel Bending Test Machine can be used for this purpose. This type of testing machine can present problems when two-point loading across the width of the specimen is assumed to simulate the line loading on the specimen in that direction.

Photograph 1 - Local Loading Bending Test

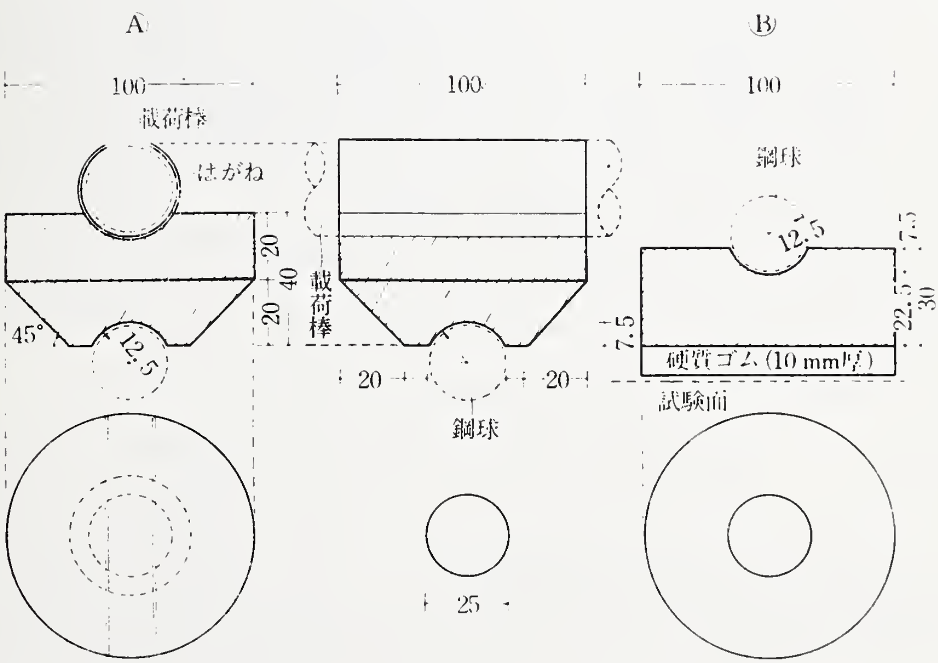


Figure 2 - An Example of Attachment for the Local Loading Bending Test (Units in mm)

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS BSS-58	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE State-of-the-Art of Structural Test Methods for Walls, Floors, Roofs and Complete Buildings			5. Publication Date November 1974 6. Performing Organization Code
7. AUTHOR(S) C.W.C. Yancey and L.E. Cattaneo			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 4618491 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* Office of Policy Development and Research Department of Housing and Urban Development Washington, D. C. 20410			13. Type of Report & Period Covered Final 14. Sponsoring Agency Code
15. SUPPLEMENTARY NOTES			

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

As part of a comprehensive research program concerned with the structural testing of building components, conducted for the U.S. Department of Housing and Urban Development (HUD), a search for information was conducted. This search was undertaken in order to document existing information pertaining to structural testing of wall, floor and roof assemblies. Various information sources were consulted to trace the evolution of structural testing of building construction from the 1930's to the present time. This task was a prerequisite to defining the state-of-the-art and to identifying the test areas requiring fundamental research.

Based on information obtained from a review of the literature and from liaison with committees concerned with the development and revision of voluntary standards, it was found that there is a dearth of research information contributing directly to the development of test methods. Most of the research conducted on building components has been carried out either to observe the behavior of a sample of a particular type of construction or to evaluate the performance of a specimen against some performance requirements. However, helpful inferences can be made on the basis of some of the documentation, especially that contained in reports of full-scale tests on housing.

As a result of comparing the test methods used by the National Bureau of Standards in HUD project Operation BREAKTHROUGH with American Society for Testing and Materials (ASTM) Standard methods, several recommendations have been made by the authors for improving present structural test practice.

An up-to-date status report of voluntary test standards activities (in the U.S.) was prepared through verbal and written communication with members of the technical subcommittees of ASTM Committee E-6 on Performance of Building Construction.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Building construction; complete buildings; floors; roofs; standardization; test methods; walls.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[XX] Unlimited [ ] For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	139
[XX] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13. 29/2:58 [ ] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $2.00

(cut here)

ANNOUNCEMENT OF NEW PUBLICATIONS IN BUILDING SCIENCE SERIES

Superintendent of Documents,
Government Printing Office,
Washington, D.C., 20402

Dear Sir:

Please add my name to the announcement list of new publications to be issued in the series: National Bureau of Standards Building Science Series.

Name --

Company --

Address --

City ---------------- State ---------------- Zip Code ----------------

(Notification key N-339)

NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH reports National Bureau of Standards research and development in physics, mathematics, and chemistry. Comprehensive scientific papers give complete details of the work, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Illustrated with photographs, drawings, and charts. Includes listings of other NBS papers as issued.

Published in two sections, available separately:

• Physics and Chemistry (Section A)

Papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. Annual subscription: Domestic, \$17.00; Foreign, \$21.25.

• Mathematical Sciences (Section B)

Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly. Annual subscription: Domestic, \$9.00; Foreign, \$11.25.

DIMENSIONS/NBS (formerly Technical News Bulletin)—This monthly magazine is published to inform scientists, engineers, businessmen, industry, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on the work at NBS.

DIMENSIONS/NBS highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, DIMENSIONS/NBS reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing.

NONPERIODICALS

Monographs—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

Handbooks—Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications—Include proceedings of high-level national and international conferences sponsored by NBS, precision measurement and calibration volumes, NBS annual reports, and other special publications appropriate to this grouping such as wall charts and bibliographies.

Applied Mathematics Series—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a world-wide program coordinated by NBS. Program under authority of National Standard Data Act (Public Law 90-396).

Building Science Series—Disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

Technical Notes—Studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NBS under the sponsorship of other government agencies.

Voluntary Product Standards—Developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The purpose of the standards is to establish nationally recognized requirements for products, and to provide all concerned interests with a basis for common understanding of the characteristics of the products. The National Bureau of Standards administers the Voluntary Product Standards program as a supplement to the activities of the private sector standardizing organizations.

Federal Information Processing Standards Publications (FIPS PUBS)—Publications in this series collectively constitute the Federal Information Processing Standards Register. The purpose of the Register is to serve as the official source of information in the Federal Government regarding standards issued by NBS pursuant to the Federal Property and Administrative Services Act of 1949 as amended, Public Law 89-306 (79 Stat. 1127), and as implemented by Executive Order 11717 (38 FR 12315, dated May 11, 1973) and Part 6 of Title 15 CFR (Code of Federal Regulations). FIPS PUBS will include approved Federal information processing standards information of general interest, and a complete index of relevant standards publications.

Consumer Information Series—Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

NBS Interagency Reports—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Service (Springfield, Va. 22151) in paper copy or microfiche form.

Order NBS publications (except Bibliographic Subscription Services) from: Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

BIBLIOGRAPHIC SUBSCRIPTION SERVICES

The following current-awareness and literature-survey bibliographies are issued periodically by the Bureau:

Cryogenic Data Center Current Awareness Service (Publications and Reports of Interest in Cryogenics). A literature survey issued weekly. Annual subscription: Domestic, \$20.00; foreign, \$25.00.

Liquefied Natural Gas. A literature survey issued quarterly. Annual subscription: \$20.00.

Superconducting Devices and Materials. A literature survey issued quarterly. Annual subscription: \$20.00. Send subscription orders and remittances for the preceding bibliographic services to the U.S. Department of Commerce, National Technical Information Service, Springfield, Va. 22151.

Electromagnetic Metrology Current Awareness Service (Abstracts of Selected Articles on Measurement Techniques and Standards of Electromagnetic Quantities from D-C to Millimeter-Wave Frequencies). Issued monthly. Annual subscription: \$100.00 (Special rates for multi-subscriptions). Send subscription order and remittance to the Electromagnetic Metrology Information Center, Electromagnetics Division, National Bureau of Standards, Boulder, Colo. 80302.

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

OFFICIAL BUSINESS

Penalty for Private Use, $300

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-215

U.S.MAIL

AMERICAN REVOLUTION BICENTENNIAL 1776-1976