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The Behavior of Architectural (Non-Structural) Building Components During Earthquakes

Final Technical Report

RACKING TESTS OF NON-STRUCTURAL BUILDING PARTITIONS

By
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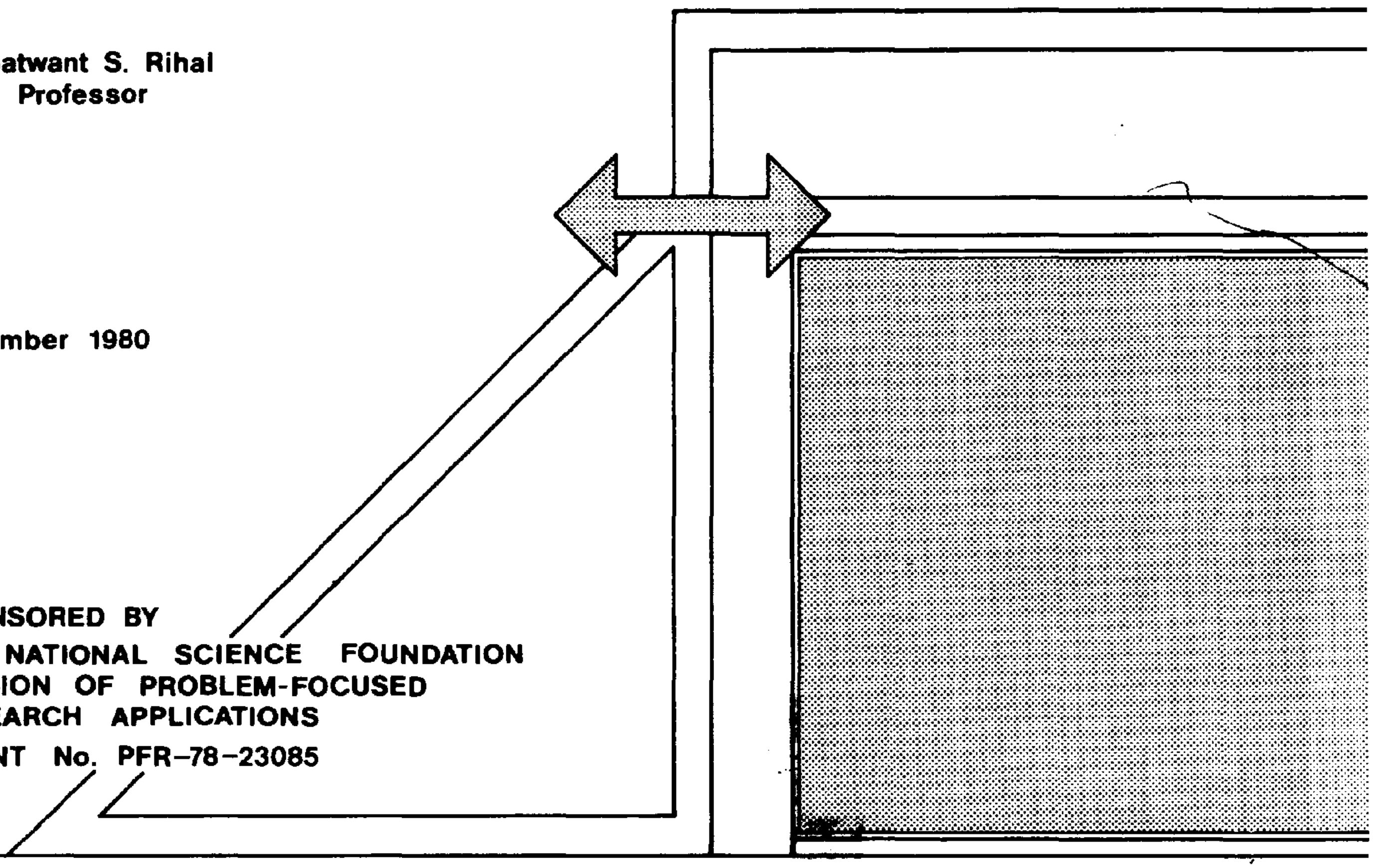
December 1980



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16. Abstract (Limit: 200 words)

The effects of inter-story displacement (drift) during earthquake-like conditions are reported. A series of experiments were conducted (1) to study the correlation between inter-story relative displacement and building partition behavior under horizontal racking loads; (2) to assess the threshold levels of partition damage during horizontal racking actions; and (3) to determine the fundamental characteristics of non-structural building partitions (stiffness and energy absorption capacity and strength) under horizontal racking actions simulating earthquake motion. Parameters in this study consist of geometry of partition configuration and placement of gypsum wallboard panels. Development of the testing program is described and test results, sources of error, and future research plans are presented. Included in the appendices are drawings of test frame and partition test specimens, results of racking tests, and photographs.

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1. INTRODUCTION

This report documents the exploratory experimental studies carried out to study the behaviour of non-structural building partitions under horizontal racking loads.

The detailed background, scope and objectives of this research program were described in a previous report (14)[1]. The main purpose of the research program is to attempt to understand the behaviour of non-structural building partitions during earthquakes. The fundamental characteristics of building partitions governing their seismic behaviour are their mass, lateral stiffness, energy-absorption capacity and strength. These basic properties, once determined, then provide the necessary data for developing rational methods of assessing the effect of non-structural building partitions on the seismic response behaviour of buildings. Studies of building damage during recent earthquakes clearly indicate that the participation of non-structural partitions can significantly alter the lateral stiffness and energy absorption properties of the building earthquake resisting system. These effects then change the building seismic response behaviour and the time history of damageability.

The two major factors affecting the seismic behaviour of non-structural building partitions including their interaction with the primary lateral force resisting system during earthquakes are:

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[1]Numbers in parenthesis refer to list of references on page 30.

- o Relative Inter-story Displacement (Drift) Effects
- o Vibrational Effects

The role of drift limits in the seismic design of buildings, including their relation to non-structural damage, has been reported by Teal (16) and recently by Freeman (8).

The emphasis in this investigation is on the study of the effects of relative inter-story displacement (drift) on partition behaviour during earthquakes.

2. SCOPE AND OBJECTIVES

The objectives of this experimental research program are as follows:

a. To study the correlation between horizontal inter-story relative displacement (drift) and building partition behaviour under horizontal racking loads.

b. To attempt to assess the threshold levels of partition damage during horizontal racking actions.

c. To determine the fundamental characteristics of non-structural building partitions, e.g., stiffness, energy absorption capacity and strength, under horizontal racking actions, similar to those imposed upon these components during earthquakes.

Parameters included in this study are as follows:

(i) Geometry of partition configuration
- o Height/width ratio
- o Full-height vs. Partial-height partition
- o Door openings (wood door frame vs. metal door frame)
- o Window opening

(ii) Placement of gypsum wallboard panels:
- o vertically
- o horizontally

(iii) Connection details at boundaries and @ openings

(iv) Taped vs. untaped joints between gypsum wallboard facing panels

(v) History of loading

(vi) Joint-slip at interface between gypsum wallboard facing panels

3. DEVELOPMENT OF TESTING PROGRAM

The building partitions selected for this investigation are those typically representative of non-load bearing partitions in buildings of different occupancies. Temporary partitions for dividing interior spaces in buildings are excluded from this study.

3.1 Review of Current Design and Detailing Practices

According to current design practice, the bare structural system of a building is designed to resist the entire earthquake forces with the objective that the building should survive a moderate earthquake with minor damage and a severe earthquake without catastrophic structural collapse.

Non-structural building partitions are considered to contribute only to the gravity load of the building and their contribution, if any, to the stiffness, damping and other properties of the primary structural system, is neglected.

According to current design practice, detailing of architectural building partitions is based on the objective of dynamically uncoupling them from the primary structural system. The two systems are then treated separately in the building seismic design process.

Building partition assembly configurations are at present based on the following:

- o architectural requirements
- o fire-resistance rating criteria
- o sound control criteria

Fisher (5) and others (2), (11), (3) have presented architectural details of building partition assemblies currently in use in multi-story buildings.

A survey of building partition detailing and installation practices indicates a wide variability in these practices. For instance, gypsum wallboard panels may be placed vertically or horizontally. Connection details also vary considerably. This is due to a general lack of codes and regulatory standards governing the seismic design and detailing of architectural building partitions and other non-structural components. The few codes and standards governing the earthquake resistant design of architectural (non-structural) building components are as follows:

- o Uniform Building Code, 1979 Edition (20)
- o Lateral Force Requirements of SEAOC (15)
- o Title 21 Requirements - Schools (17)
- o Title 24 Requirements - Hospitals (18)
- o Tri-Services Manual (19)
- o Tentative Provisions for the Development of Seismic Regulations for Buildings ATC 3-06 (1)
- o Veterans Administration Handbook H-08-8 (24)

Two buildings under construction on this University campus, the five-story R. E. Kennedy Library Building and the new Faculty Office Building were also visited during the initial phase of this investigation to obtain additional first-hand information on the installation details of non-load bearing partitions in buildings.

A broad overview of development of building systems and components has been provided by Merritt (12). Graphic presentation of fire-resistive details of building component assemblies in accordance with the provisions of the Uniform Building Code, Gypsum Association and I.C.B.O. Research Committee recommendations has been presented by Przetak (13).

It is observed that at this time the connection details and for installation of non-structural building partitions are based on local building trade practices and do not take into account dynamic effects of earthquakes.

3.2 Partition Test Specimens

3.2.1. General

The partitions selected for this testing program are typical non-load-bearing metal-stud partitions with fire-rated gypsum wallboard as facing material. The partition assembly, in addition, consists of horizontal metal runners at base and at top, with the bottom runner connected to the structural floor. The metal runner at top is also attached to the structural floor (in case of full height partitions without suspended ceiling) or fastened to a braced suspended ceiling assembly. A schematic diagram of a non-structural building partition is shown on page 8.

The numerous interface conditions between building partitions and ceilings, as well as those between such building components and the primary structural system, have been documented by McCue et al. (11) in their recent research into the development of conceptual models of interaction of building components during earthquakes.

Recommendations of U.S. Gypsum for steel-framed drywall systems (10), (23) have also been used as an important source of guidance for selection of connection details and installation of building partitions.

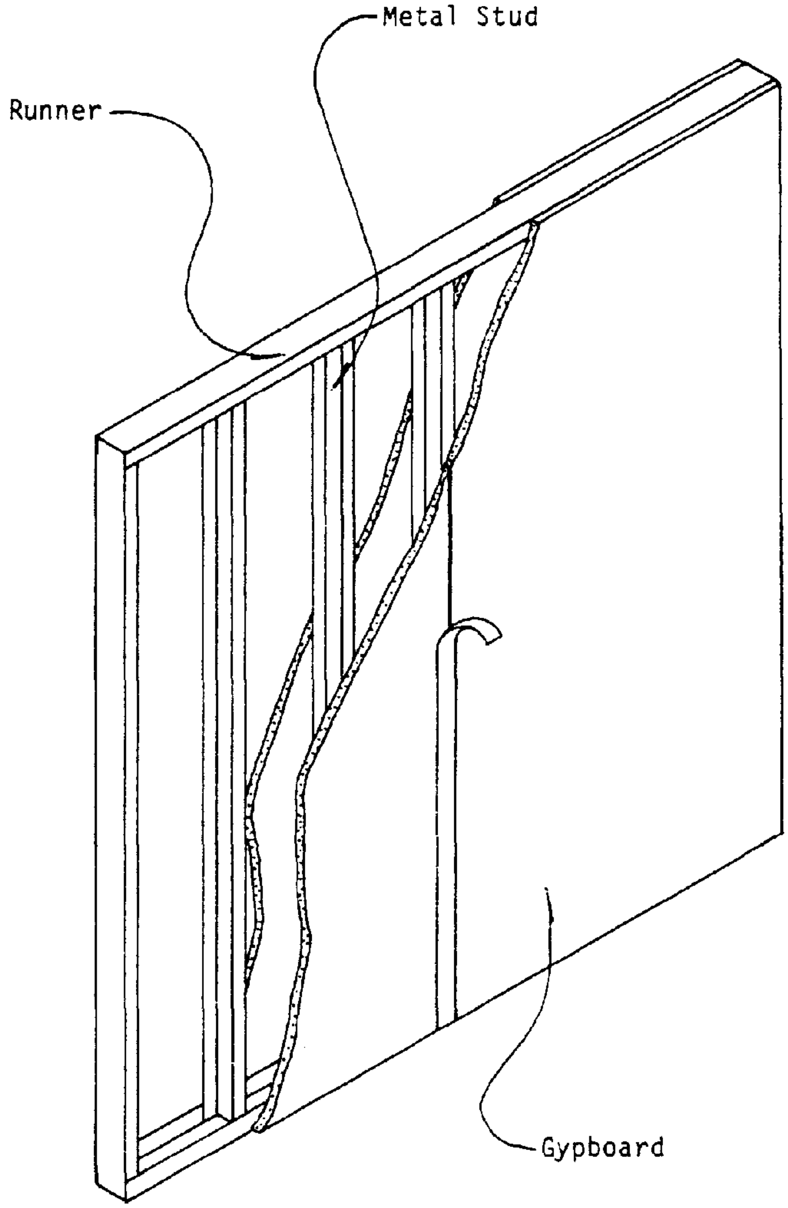

DIAGRAM I

SCHEMATIC DIAGRAM OF BUILDING PARTITION ASSEMBLY

It should also be noted that installation details recommended by the Gypsum Association (9) provide for perimeter relief systems at top and at structural column/wall junctions.

3.2.2. Description of Partition Test Specimens

A detailed description of the partition specimens tested is presented in Table I.

The details of the partition test specimens, as built, are given in Appendix A (Fig. 3 to Fig. 14). All the specimens included in this testing program were 8'-0" wide and 8'-0" high. Trial specimen P1 was a plywood partition with 2x4 wood studs with 3/8" plywood as facing material on both sides of the partition. Testing of this trial specimen was intended to check out the load application and measurement systems used in the racking tests of building partitions.

Partition test specimens P2 through P9 were constructed with 3-5/8 inch wide-25 gage metal studs while specimens P10 and P11 were built using 2-1/2 inch wide-25 gage metal studs. The facing material in all specimens was a single layer of 5/8 inch thick type X-fire-rated gypsum wallboard, on both sides of the partitions. The fasteners used for attachment of the gypsum wallboard to the partition framing were 1 inch type S drywall screws (10),(23).

Typically, all the specimens were attached at base, free at the vertical sides, whereas the connection details at top varied from specimen to specimen. Partition test specimens P2 through P3A, P5 and P6 were all partitions without openings, with gypsum wallboard placed vertically. Unique features of this group of specimens may be identified as follows:

TABLE I. DESCRIPTION OF PARTITION TEST SPECIMENS.

No.	Partition Size/Ft.	Facing Material	Studs	Opening	Remarks	Date of Test
P1	8 x 8	3/8" plywood	2 x 4 wood	None	Trial specimen only.	8/79
P2	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Facing panels placed vertically. Taped joints. Connection of studs to runner at top by friction only.	10/79
P2A	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Same as P2, except connection between gypboard and runner at top by drywall screws at 16" o.c.	10/79
P3	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Same as P2, except no gap between studs and runner at top. Joints not taped.	10/79
P3A	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Same as P2A, except no gap between studs and runner at top. Joints not taped.	10/79
P4	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Facing panels placed horizontally. Connection between gypboard and runner at top by drywall screws at 16" o.c. Joints not taped.	10/79
P5	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Facing panels placed vertically. Joints not taped. Different drywall screw layout.	11/79
P6	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Same as P5 except joints are taped and different screw layout is used.	11/79
P7	8 x 8	5/8" gypsum wallboard	3-5/8" metal	Door opening	3'-0" x 6'-8" door opening. Wooden door frame.	1/80
P8	8 x 8 overall	5/8" gypsum wallboard	3-5/8" metal	None	Partial height partition. Height of gypboard = 6'-0". Facing panels placed vertically. Taped joints. Connection of studs to runner at top by friction only.	1/80

No.	Partition Size/Ft.	Facing Material	Studs	Opening	Remarks	Date
P8A	8 x 8	5/8" gypsum wallboard	3-5/8" metal	None	Condition similar to P8 except studs fully covered. Joints taped.	2/80
P9	8 x 8	5/8" gypsum wallboard	3-5/8" metal	Window	3'-0" x 3'-0" window opening: wooden frame.	3/80
P10	8 x 8	5/8" gypsum wallboard	2-1/2" metal	Door	2'-8" x 6'-8" door opening: metal door frame: gypboard placed horizontally.	5/80
P11	8 x 8	5/8" gypsum wallboard	2-1/2" metal	Door	2'-8" x 6'-8" door opening: metal door frame: gypboard placed vertically.	4/80

- o small gap (1/8 inch) between the ends of studs and top runner (P2 and P2A only)
- o connection of studs to top runner by friction only (P2 and P3)
- o connection between gypboard and top runner by drywall screws at 16" o.c. (P2A and P3A only)
- o taped joints between gypboard facing panels (P2, P2A)
- o untaped joints between gypboard facing panels (P3, P3A)

Starting with partition specimen P3A it was decided to provide uplift restraint steel straps at base at each end of partition. See Figure 2 for details.

Partition specimen P5 was similar to specimen P3A, except for different screw fastener layout at edges and at joint between gypboard facing panels. Partition P6 was similar to specimen P5 except the joints were taped. Partition Specimen P4 was similar to P3A except that gypboard is placed horizontally.

Partition specimens with openings were P7, P9, P10 and P11. In all these specimens joints were taped. Partition specimens P7 and P9 had wood-framed door and window openings, respectively, and 3-5/8 inch wide-25 gage metal studs. Gypboard was placed vertically in these specimens.

Specimens P10 and P11 had door openings with metal door-frames and 2-1/2 inch wide-25 gage metal partition studs. Gypboard was placed vertically in partition specimen P11, whereas it was placed horizontally in speciman P10.

Partition specimen P8 was a partial height partition with an overall size of 8 ft. x 8 ft., with height of gypboard being 6 feet from the base.

Wooden blocking was added at top edge of gypboard, between the studs. Gypboard was placed vertically, and joints were taped. Connection of studs to top runner was by friction only.

Partition specimen P8A (Fig. 11) was similar to P8, except that additional pieces of gypboard were used to fully cover the partition studs. All joints were taped. Screw connection was added between gypboard, studs and top runner.

3.3. Racking Test Method

3.3.1. Testing Frame

The basic description of the test frame was presented in a previous report (14). The loading frame was designed and built for conducting tests of building partitions under in-plane horizontal racking loads. Details of the test frame are given in Figures 1, 2, 40 and 41. The loading test frame has a clear span of 14 feet and is bolted to the 4'-0" thick floor slab in the high-bay laboratory of the School of Architecture.

To simulate the type of horizontal racking experienced by building partitions between adjacent floors, during earthquakes, a pin-connected frame was fabricated. This pinned-frame consists of two horizontal structural steel channels (one at top and the other at base and bolted to floor slab) and two pairs of vertical structural steel tubing (one pair at either end of the horizontal channels). This concept of the use of pinned frame is similar to that first used by Bouwkamp and Meehan (4) to investigate the drift limits imposed by glass in buildings. A modified design of the pinned frame concept was used in the racking tests reported by Freeman, (21), (22), (6), (7). There are 2x4 wood plates bolted to the horizontal channel members of the pinned-frame. Partition metal runners are screw attached to these 2x4 wood plates. Thus the partition test specimens are positioned inside the pinned frame, connected at top and bottom only, with the vertical sides free.

Racking load is applied by means of a hand-pumped, double-acting hydraulic jack, connected at one and to the top channel of the pinned-frame and to the vertical W12x27 of test frame at the other end. The pinned frame is guided to move freely in the horizontal direction by four short-length pieces of structural steel channels, welded to the top channel of pinned frame, with their top flange free to slide on the bottom flange of the W8x28 cross beam spanning between the vertical W12x27 members of the test frame (Fig. 2, Fig. 40 and Fig. 41).

3.3.2. System for Application and Measurement of Loads and Displacements

A block diagram (p. 15) shows the general layout of the racking load application and measurement system. The racking load was applied by means of a hand-pumped, ENERPAC double-acting push-pull type of hydraulic jack (model RD 2510). The racking load was monitored by a BLH universal load-cell (model U3G2) connected to a BLH digital read-out unit. The BLH digital read-out unit consists of BLH digital strain indicator (model 1200) plus a BLH switching and balancing unit (model 1225).

All displacements were monitored by dial gages reading to the nearest 0.001 inch. Initially, it was planned to use LVDT's for displacement measurements but due to lack of operable read-out devices, it was decided to use dial gages instead.

The load application and measurement system was calibrated as recommended by BLH for using the digital read-out unit for measuring the

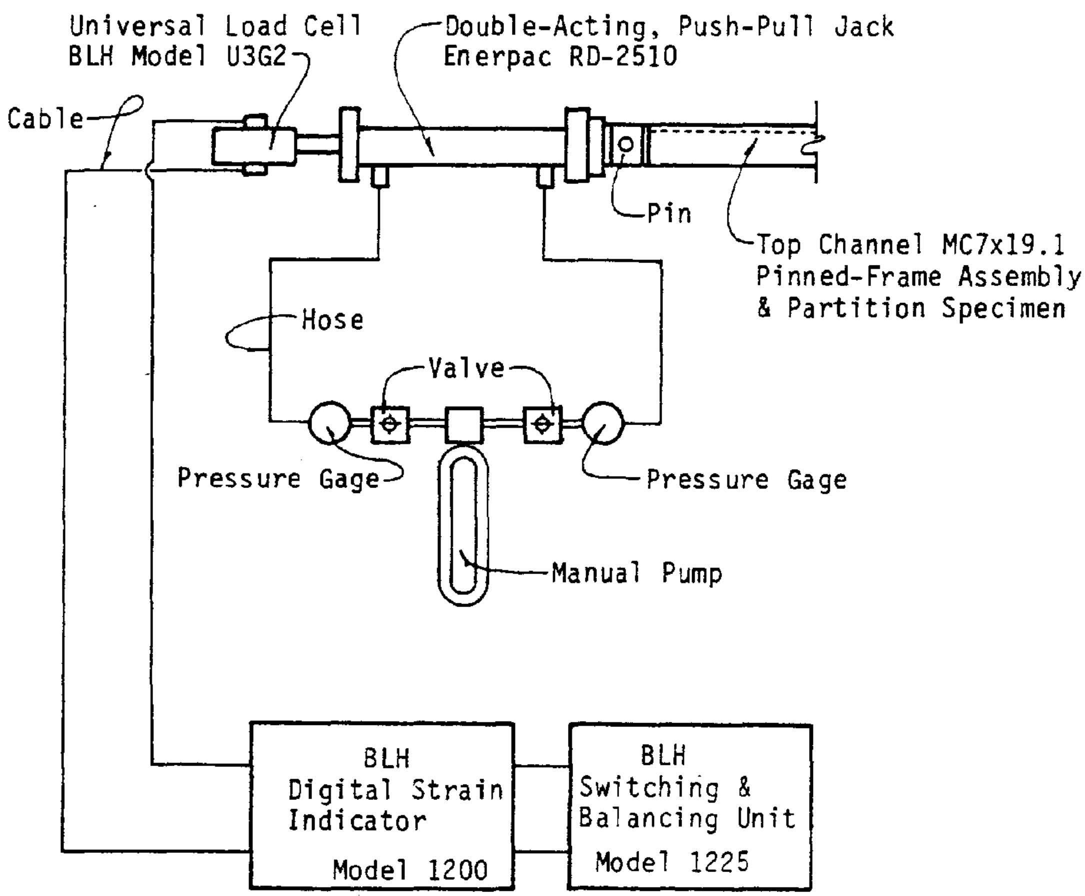

DIAGRAM II

LOAD-APPLICATION & MEASUREMENT
SYSTEM

output of a strain-gage type force transducer (load-cell). A conversion factor for relating the digital read-out to the magnitude of load level at any instant of time, was thus obtained.

3.3.3. Testing Procedure

The racking test procedure was generally similar to that used by Freeman (21). Partition specimens were subjected to two complete cycles of loading for each increasing level of peak horizontal displacement starting with 1/16 inch, 1/8 inch, 1/4 inch, 3/8 inch, 1/2 inch and then loaded to failure.

All the specimens were erected in-place inside the pinned frame of the racking test set-up. Specimens with taped joints were allowed to dry for 24 hours before the start of the test.

At the start of the racking test all the measuring instruments were initialized. The racking test of each specimen began by pushing the specimen in the forward cycle and readings of load vs. deflections taken at suitable intervals until the desired magnitude of peak displacement was reached. The specimen was then racked through the unloading part of the forward cycle, with data being manually recorded. After noting the displacement at zero load the specimen was pulled through the reverse cycle and readings of loads and displacements were recorded until the desired peak displacement was reached in this part of the cycle. The specimen was then taken through the unloading part of the reversal cycle, with data being recorded as before. Upon drop of the load level to zero was defined as one complete cycle of loading with its associated peak level of displacement. For each increasing level of peak horizontal displacement the partition specimen was subjected to two complete cycles of racking, as described above.

During each displacement cycle of the racking tests, observed behaviour of the partition test specimens was recorded. Special attention was directed to record the threshold levels of partition damage, as the test progressed.

Photographs of the partition test specimens were taken during the racking tests and also after the completion of the tests.

4. TEST RESULTS

The results of racking tests of building partitions may be categorized as follows:

Load-Displacement Curves

Upon reduction of the raw test data, load vs. displacement curves were plotted and are presented in Appendix B (Fig. 15 - Fig. 37). For each partition specimen the load vs. displacement curves for each cycle of racking have been manually plotted. The trial specimen P1 was subjected to three cycles of loading with a limiting value of load level, arbitrarily selected as a cut-off point for each cycle (Fig. 15). The data thus obtained provided guidance for the metal-stud partition tests that followed.

Except for specimens P2, P2A, P3 and P8, two graphs of load-displacement curves are presented for each specimen. Starting with specimen P3A, the first graph is a larger scale plot of load-displacement curves for 1/16 inch and 1/8 inch peak-displacement cycles (e.g., Fig. 19). The remaining cycles of loading corresponding to 1/4 inch, 3/8 inch, 1/2 inch ... peak-displacement levels are plotted separately on a second graph of load-displacement curves (e.g., Fig. 20).

For partition specimens P2, P2A, P3 and P8, a single graph showing all the load-displacement curves associated with the various cycles of loading, was plotted for each specimen (Figures 16, 17, 18, 29).

A comparison of the average peak load associated with corresponding peak-displacement of cycle, was made for the partition test specimens P2-P11, and the results are shown in Fig. 39. The average peak load was defined as the average of the peak load in the forward and reversed portions of each cycle.

Energy Absorbed by Partion Test Specimens

An important aspect of the racking test program is to comparatively evaluate the energy absorbed by the partition test specimens during the various cycles of loading.

Energy absorbed by the partition test specimen was defined as the area under the load-displacement curve for each cycle of loading. The areas under the load-displacement curves were determined by using a planimeter, and thus the total amount of energy absorbed during the various peak-displacement cycles of loading was found for each of the partition specimens, P2-P11.

These results are presented in Fig. 38 in the form of graphs of energy absorbed vs. peak-displacement of cycle for the various partition test specimens.

5. DISCUSSION OF TEST RESULTS

The racking tests of building partition specimens were essentially static cyclic tests, since it took at least thirty minutes to rack the specimen through one complete cycle of loading. The reasons for this were that a hand-pumped hydraulic jack was used and the test data of load and displacements (dial gage readings at several locations) had to be recorded manually at preselected load intervals until the peak-displacement of cycle was reached.

The results presented are based on the test of a single specimen of each type of building partition. For this reason these racking tests should be regarded as exploratory only. The consistency of the test results can only be confirmed by testing at least two or three specimens of each type of building partition.

The general pattern of partition behaviour (Fig. 15-Fig. 39) agrees with the test results reported by Freeman (21), in that the load and displacement are zero only at the start of the first cycle of loading, thereafter when the load is dropped to zero the specimen does not return to its original position and it has to be loaded in the reverse direction to bring it to a state of zero displacement. This is due to the fact that the partition specimens do not behave in a perfectly elastic manner. Thus the load-displacement curves of partitions pass through the abscissae and ordinates at points other than the origin during all cycles after the start of the test.

An examination of the load-displacement curves for partition specimens P2 and P3 (Fig. 16, Fig. 18) indicates a lack of consistency between the loops corresponding to the various cycles of loading, as compared to the results obtained for specimens P2A, P3A ... (Fig. 17, Fig. 19 ...). This is influenced by the details of construction used and also due to the fact that during the racking tests of partition specimens P2, P2A and P3, uplift restraint straps had not been installed.

For all specimens P3A-P11, two uplift restraint steel straps were installed at base, one at each end of the partition (see Fig. 2 for details). This seems to have improved the consistency of test results. For all partitions starting with specimen P3A, the comparison of the load-displacement curves (Fig. 19 to Fig. 37) for each of the two cycles of loading for each level of peak-horizontal displacement, shows a general pattern of behaviour. It is believed that a larger number of cycles (3-5) of loading is necessary for each peak-displacement level to establish better consistency of results. The choice of the selected procedure (two cycles of loading per level of peak displacement) was necessitated by the limitations imposed by the hand-pumped jacking system and manual recording of test data.

The partial height partition specimen P8 was subjected to a portion of one complete cycle (Fig. 10). This was due to the flexibility of the upper part of the partition and it took only a load of approximately 230 lbs. to achieve a displacement of 3/8 inch. Furthermore, this partition was built so that connection between gypboard and runner was by friction only. Once the effect of friction was overcome, the specimen would find it difficult to hold the load level. This same type of behaviour was also observed for specimen P2.

The stiffness values of the partition specimens can be found from the load-displacement curves for the various levels of peak-displacement. The partition stiffness may be defined as a tangent-stiffness at selected points of a given cycle and on this basis, a composite average stiffness value may be determined for the cycles with their associated level of peak-displacement.

A study of Fig. 38 shows that for all partition specimens, the energy absorbed during the various cycles of loading increases with the level of the peak horizontal displacement. An evaluation of relative strengths of partition specimens can be obtained from Fig. 39. It is found that for all specimens, the average peak load during the various cycles of loading increases with the level of peak horizontal displacement.

The effect of vertical vs. horizontal placement of gypboard can be studied by comparing the results for specimens P3A and P4. Fig. 38 shows that for peak-displacement levels greater than approximately 3/16 inch, the specimen with horizontally placed gypboard (P4) absorbed greater amount of energy than that absorbed by the specimen with vertically placed gypboard (P3A). Fig. 39 shows that for levels of peak displacement up to approximately 3/8 inch the average peak loads for specimen P4 were higher than those for specimen P3A.

The effect of untaped vs. taped joints between gypboard facing panels can be studied by examining the results for partition specimens P5 and P6 (Fig. 38 and Fig. 39).

A study of the effect of door and window openings on partition behaviour (Fig. 38 and Fig. 39) indicates that, in general, the specimens with openings (specimens P7, P9, P10 and P11) absorbed lesser energy than the other specimens and, furthermore, the average peak loads for the specimens with openings were lower than other specimens, at all levels of peak-displacement.

The comparison of horizontal vs. vertical placement of gypboard in specimens with a metal door frame (Specimens P10 and P11) shows that specimen P10 with horizontally placed gypboard absorbed greater amounts of energy than specimen P11 which had vertically applied gypboard. The average peak loads for specimen P10 were also higher than those for specimen P11 at all levels of peak displacement.

The observations of partition damage were recorded and photographs taken during the progress of the racking tests. All photographs are presented in Appendix C (Fig. 40 to Fig. 91). The only exception is partition P10 for which photographs could not be taken for inclusion in this report.

The highlights of observations of partition performance during these racking tests are presented in Table II.

TABLE II. GENERAL OBSERVATIONS OF PARTITION PERFORMANCE

Partition Specimen (Ref. Table I)	Peak Displacement of Cycles			
	First Creaking Noise @	Louder Creaking Noise/Popping Sounds @	First Indication of Noticeable Damage @	Failure/ Significant Damage @
P2A	1/8"	-	uplift @ left stud @ 3/8"	0.8"
P3	1/32"	1/16"	-	-
P3A	1/16"	1/8"	3/8"	0.6"
P4	1/16"	1/8"	1/4" noticeable horizontal joint-slip	1"
P5	1/16"	1/8" - 1/4"	3/8" - 1/2" noticeable joint slip. Sounds of screws slipping or readjusting.	1" - 1-1/4"
P6	1/16"	1/8" - 1/4"	1/2"	3/4"
P7	-	1/4" - 3/8"	3/8" - 1/2"	1"
P8	-	-	3/8"	-
P8A	-	-	1/4" - 3/8"	1/2" - 0.7"
P9	-	3/8"	3/8" cracks in gypboard @ corners of opening.	1-1/16"
P10	-	-	3/8"	0.7"
P11	-	-	3/8"	0.7"

6. SOURCES OF ERROR

One source of error may be the deflection of the reaction frame. The first trial partition specimen P1 was progressively subjected to a maximum racking load of 1800 pounds. Visually no reaction frame deflection was noticeable. Even though no specific studies were undertaken to investigate the deflection of the reaction frame, it is believed that any possible errors should be within permissable limits.

The uplift restraint straps were installed starting with specimen P3A. Therefore, the lack of uplift restraint straps in the specimens P1, P2, P2A and P3 is a source of error in these specimens.

The hydraulic jacking system and associated controls may really be described as unsophisticated and needing further refinement. There may be errors associated with the lack of accurate controls of loads and displacements during the racking tests.

Another source of error is the difference between the real conditions in the field and attempts to simulate these conditions in the laboratory.

Lastly, human error inherent in recording and interpretation of test data of partition performance, is also a source of error.

7. PRELIMINARY CONCLUSIONS

Based on the exploratory racking tests carried out, the following preliminary conclusions may be drawn:

Thresholds of Partition Damage

Creaking noises/popping sounds, as one indicator of partition distress, occur at peak relative displacement levels between 1/16" and 1/4". These correspond to drift/height ratios of 0.0007-0.0026.

The first noticeable partition damage is found to occur at cycles of loading with a peak relative displacement level of 3/8". This initial damage must be regarded as permanent damage that would still be noticeable even after the specimen is brought back to its original position. The resulting drift/height ratio is 0.0039.

Failure of the partition specimens with accompanying greater damage was found to occur when the peak-relative displacements were greater than 1/2 inch which corresponds to a drift/height ratio of 0.0052.

Partition Stiffness

The partition specimens exhibit non-linear behaviour with the progression of the cycles of loading. The stiffness of building partitions can be obtained from the load-displacement curves, as tangent-stiffnesses at selected control points of a given cycle which may then be used to define a composite average stiffness for the displacement cycle under consideration. Building partition stiffness values, thus obtained, will provide a rational basis to estimate the fundamental time-period of the building partitions, and also to determine the contribution of such building components to the stiffness of the primary lateral force resisting system of a building.

Energy Absorbed by Building Partitions

For all specimens the amount of energy absorbed for all cycles of loading was found to increase with the level of peak-relative displacement. It was discovered that partition assembly and connection details of partition configurations significantly influence the energy absorption characteristics of building partitions. For instance, building partitions with horizontal placement of gypboard absorb greater amounts of energy compared to partitions with gypboard placed vertically, at all levels of relative displacement. The amount of energy absorbed by partitions with openings (e.g., doors, windows) is lower than that absorbed by partitions without openings.

Details of Partition Assembly and Connection Details

The details of partition assembly and connection details significantly influence the behaviour of building partitions under horizontal racking loads. This is evident from a comparative study of the resulting load-displacement curves, and comparison of the amount of energy absorbed by various partition specimens at increasing levels of relative-displacement.

8. PLANS FOR FURTHER RESEARCH

The racking tests of building partitions, reported herein, have been, in fact, static cyclic tests. It is necessary to better simulate the earthquake dynamic environment experienced by building partitions. Therefore, it is planned to conduct a series of dynamic cyclic tests of building partitions, using an electro-hydraulic closed-loop system for applying loads and displacements at controlled rates. When this dynamic testing system is made operational, it should be possible to vary the amplitude and frequency of applied loads and displacements with respect to time. The results of such dynamic racking tests should provide more realistic data needed to improve our understanding of partition behaviour, fundamental characteristics (e.g., stiffness and energy absorption capacity and therefore damping) and thresholds of partition damage. Under this dynamic racking test program, current practices of seismic design and detailing of non-structural building partitions can be evaluated more realistically.

It is planned to evaluate the racking test arrangement used in the current experimental program and make modifications necessary to improve the laboratory simulation of the field conditions at boundaries of building partitions. The racking test programs reported to-date have all used standard 8 ft. x 8 ft. specimens as recommended by ASTM Standards E72 and E564-76.

There is a need to study the dynamic behaviour of building partitions of other geometric configurations (different width-to-height ratios) commonly found in the field and the following parameters:

- o conditions at partition-suspended ceiling interface, and at partition-structure interface
- o intersecting partitions
- o horizontal vs. vertical placement of facing panels
- o single vs. double layers of facing panels
- o door and window openings (wood frame vs. metal frame @ opening)
- o effect of joint-slip between facing panels

Tests reported to-date have all been in-plane racking tests. Thus it is planned to study the out-of-plane behaviour of building partition assemblies under cyclic loading.

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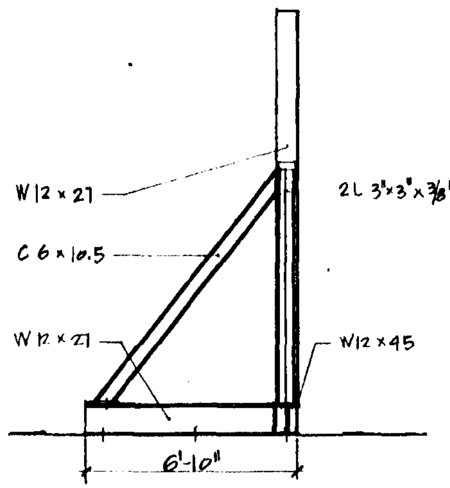
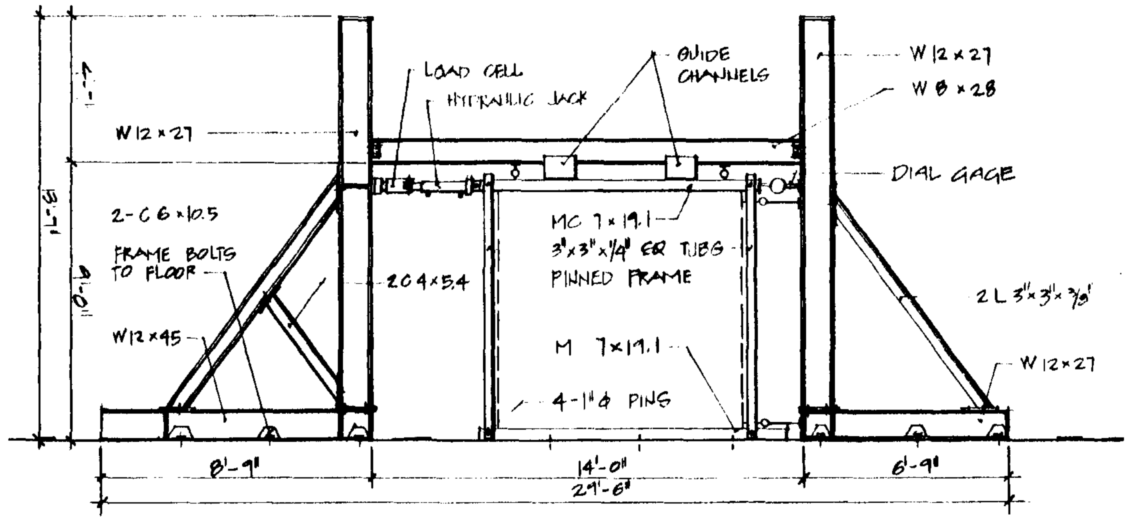
APPENDIX A

DRAWINGS OF TEST FRAME AND PARTITION TEST SPECIMENS



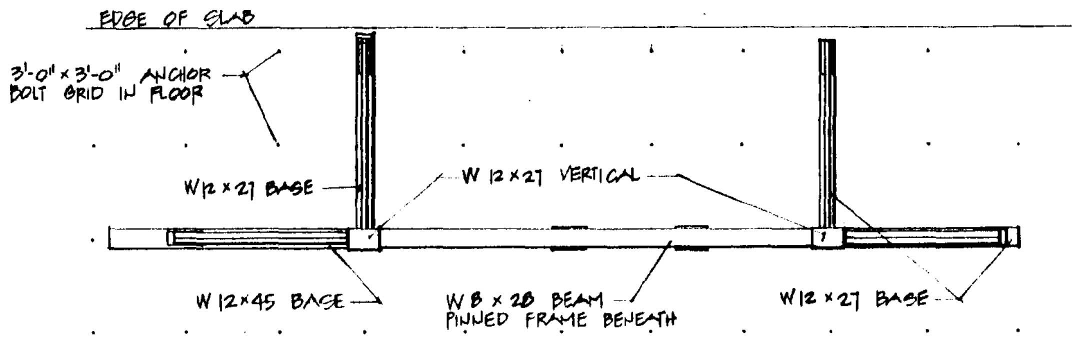
SIDE ELEVATION



FRONT ELEVATION

NOTES

1. EXCEPT AS NOTED DIAGNOLS ARE C 6x10.5 .
2. BEARING PLATES ARE 1/4" STEEL PL MIN.
3. CONNECTIONS MADE W/ 5/8"φ AND 3/4"φ A307 BOLTS.



PLAN

test frame

RACKING LOAD TESTS OF PARTITIONS

FIG. 1

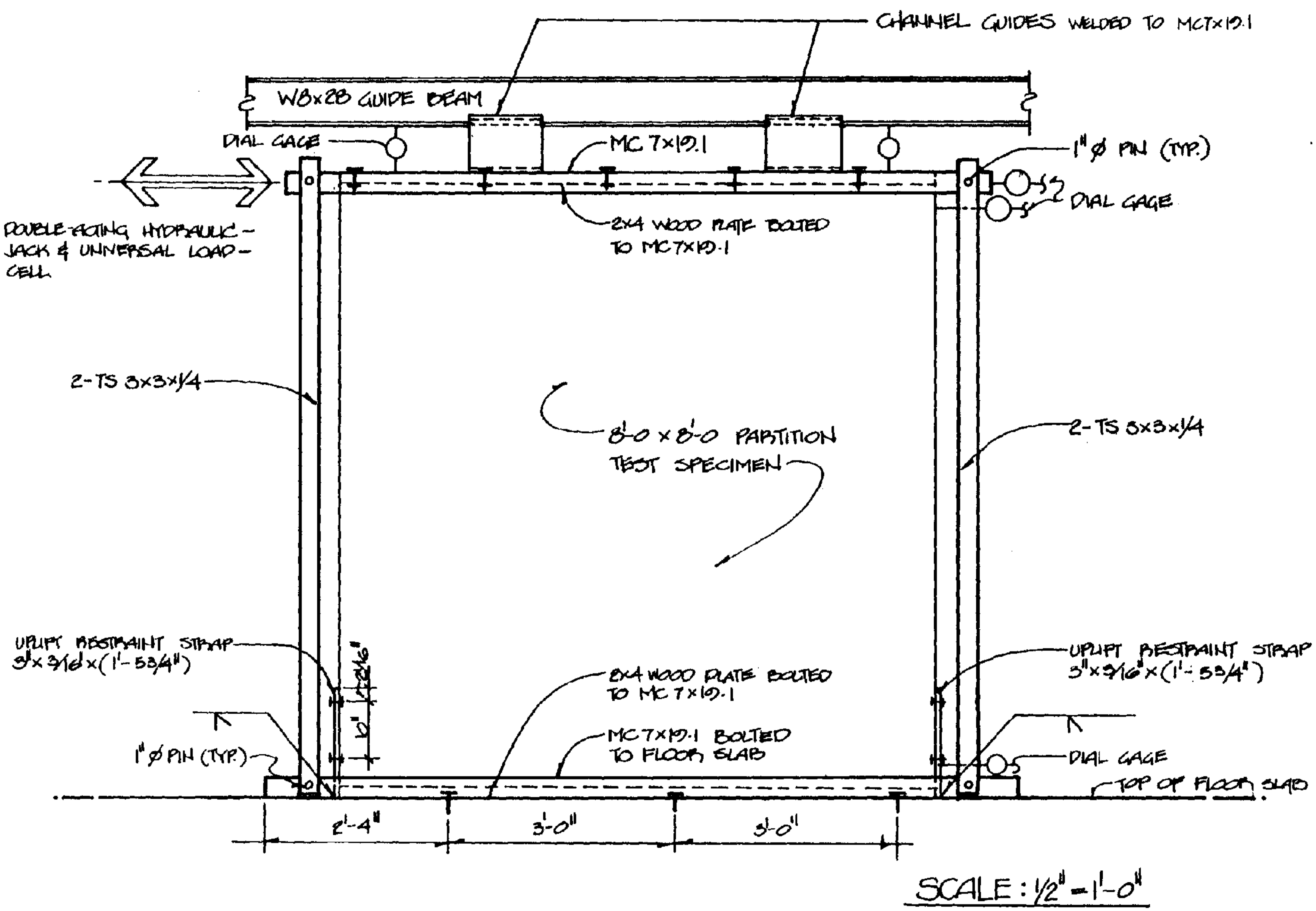


FIG. 2 RACKING TESTS OF PARTITIONS: DETAILS OF TEST SET-UP

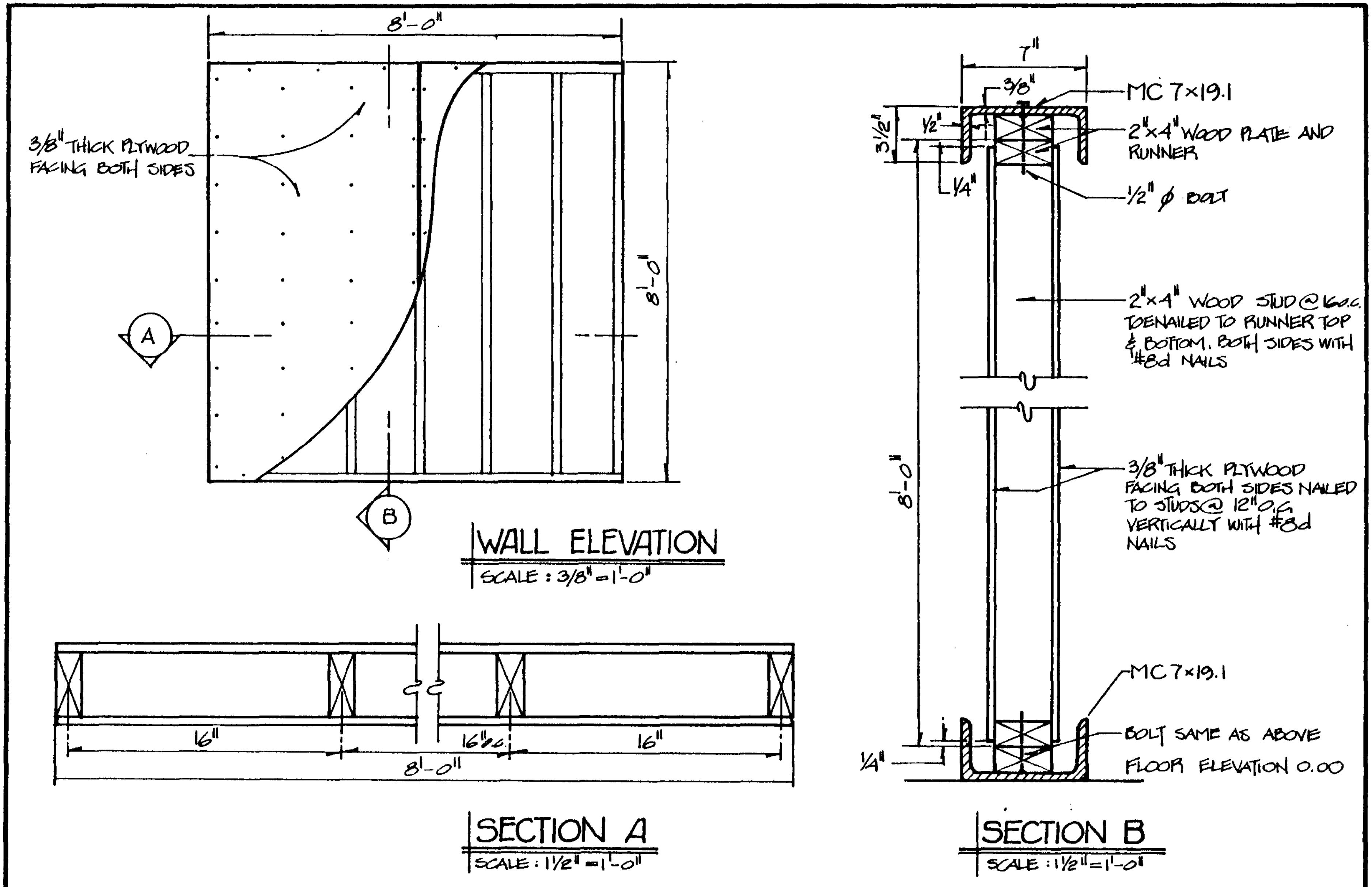


FIG. 3	PARTITION TEST PANEL SPECIMEN P1	3/8" THICK PLYWOOD ON 2"×4" WOOD STUDS

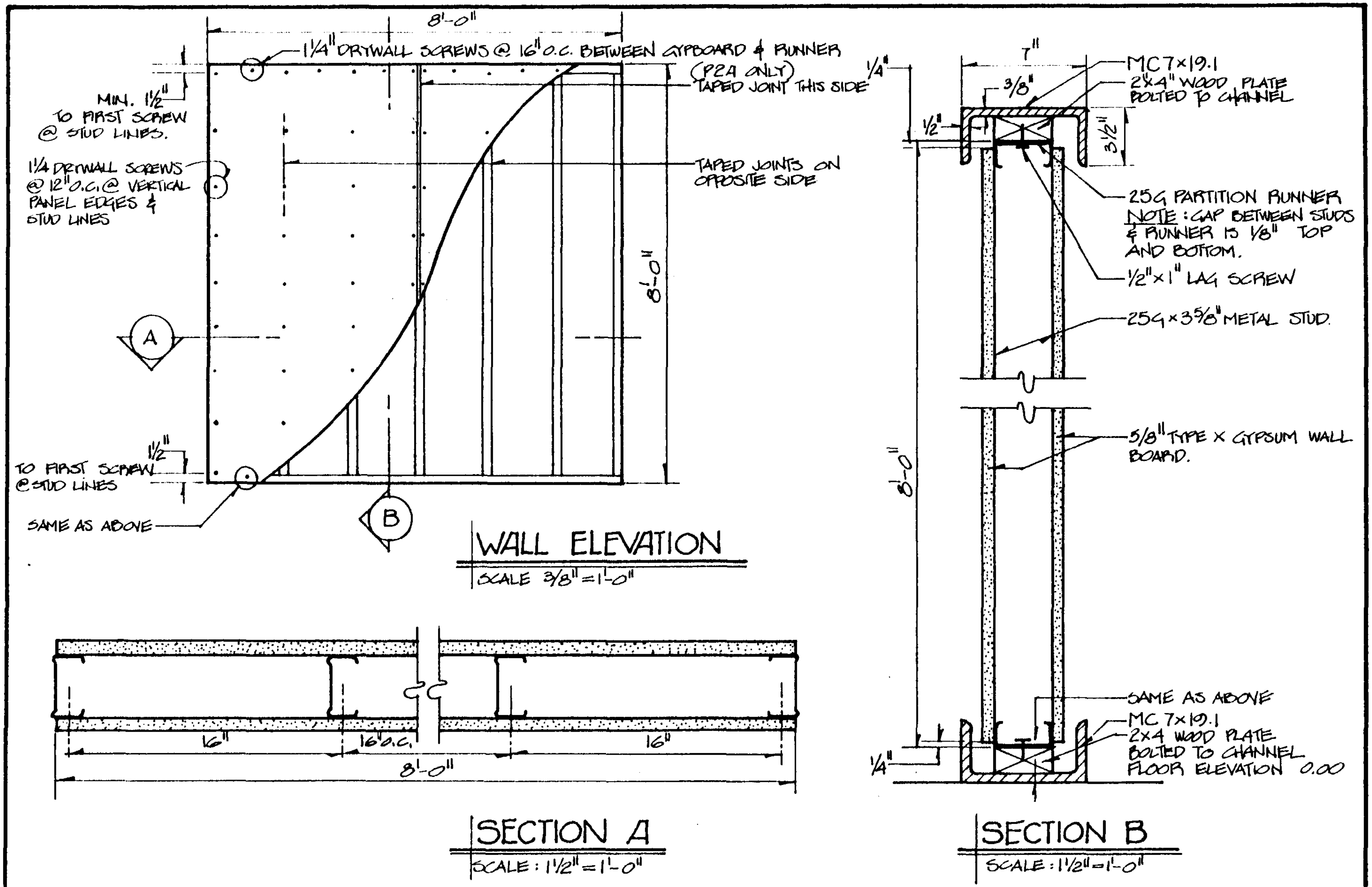


FIG. 4	PARTITION TEST PANEL SPECIMEN P2+P2A	5/8" GYPSUM WALLBOARD ON 3 5/8" METAL STUDS. FACING PANELS PLACED VERTICALLY. P2: CONNECTION OF STUD TO RUNNER @ TOP BY FRICTION ONLY. P2A: SAME AS P2 EXCEPT CONNECTION BETWEEN GYP. BOARD & RUNNER BY 1 1/4" SCREWS @ 16" O.C.

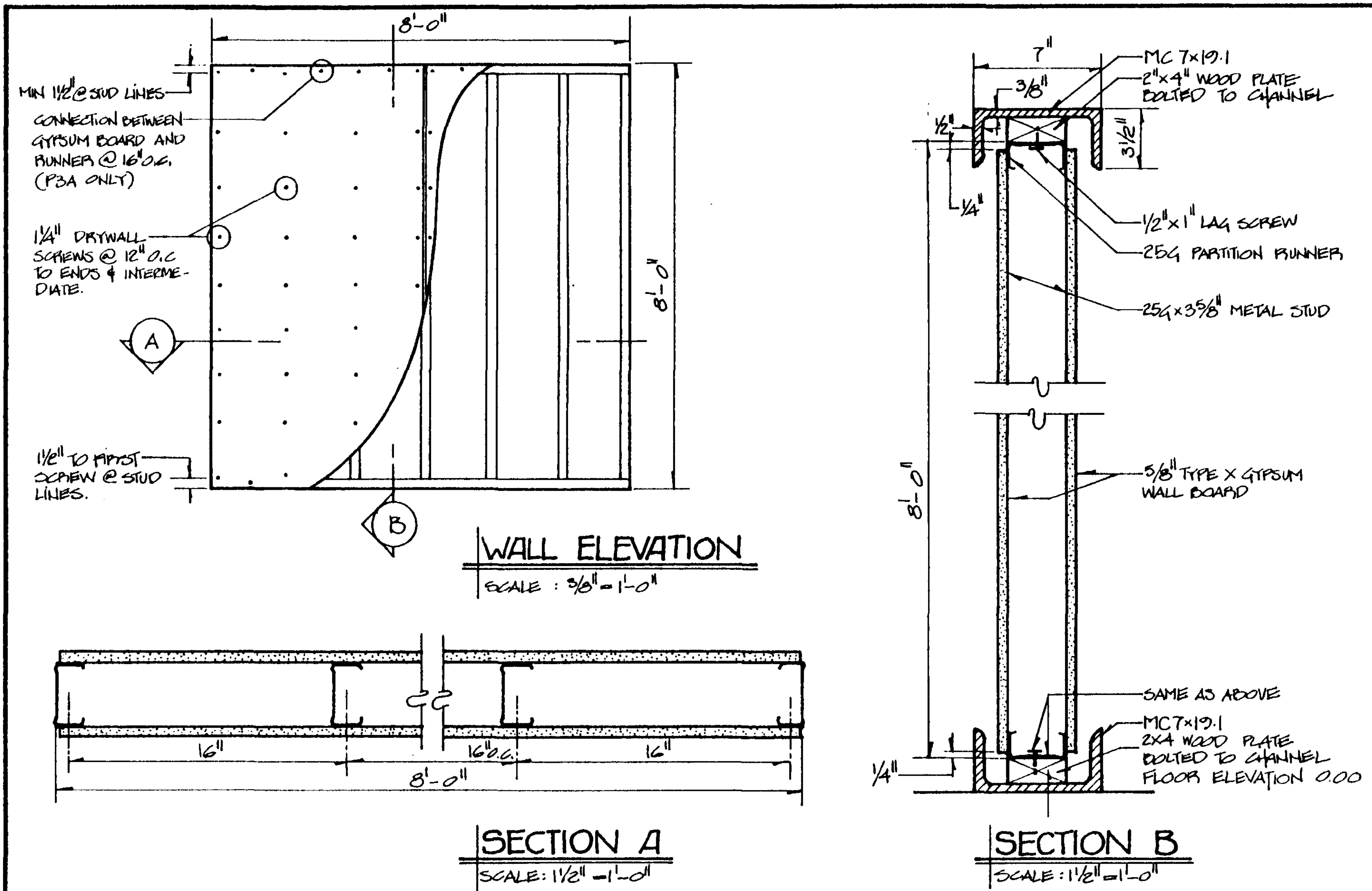


FIG. 5.	PARTITION TEST PANEL SPECIMEN P3+P3A	5/8" GYPSUM WALLBOARD ON 3⅝" METAL STUDS. P3. : SAME AS P2 EXCEPT NO GAP BETWEEN STUDS & RUNNER & JOINTS NOT TAPED. P3A : SAME AS P2A EXCEPT NO GAP BETWEEN STUDS & RUNNER & JOINTS NOT TAPED.

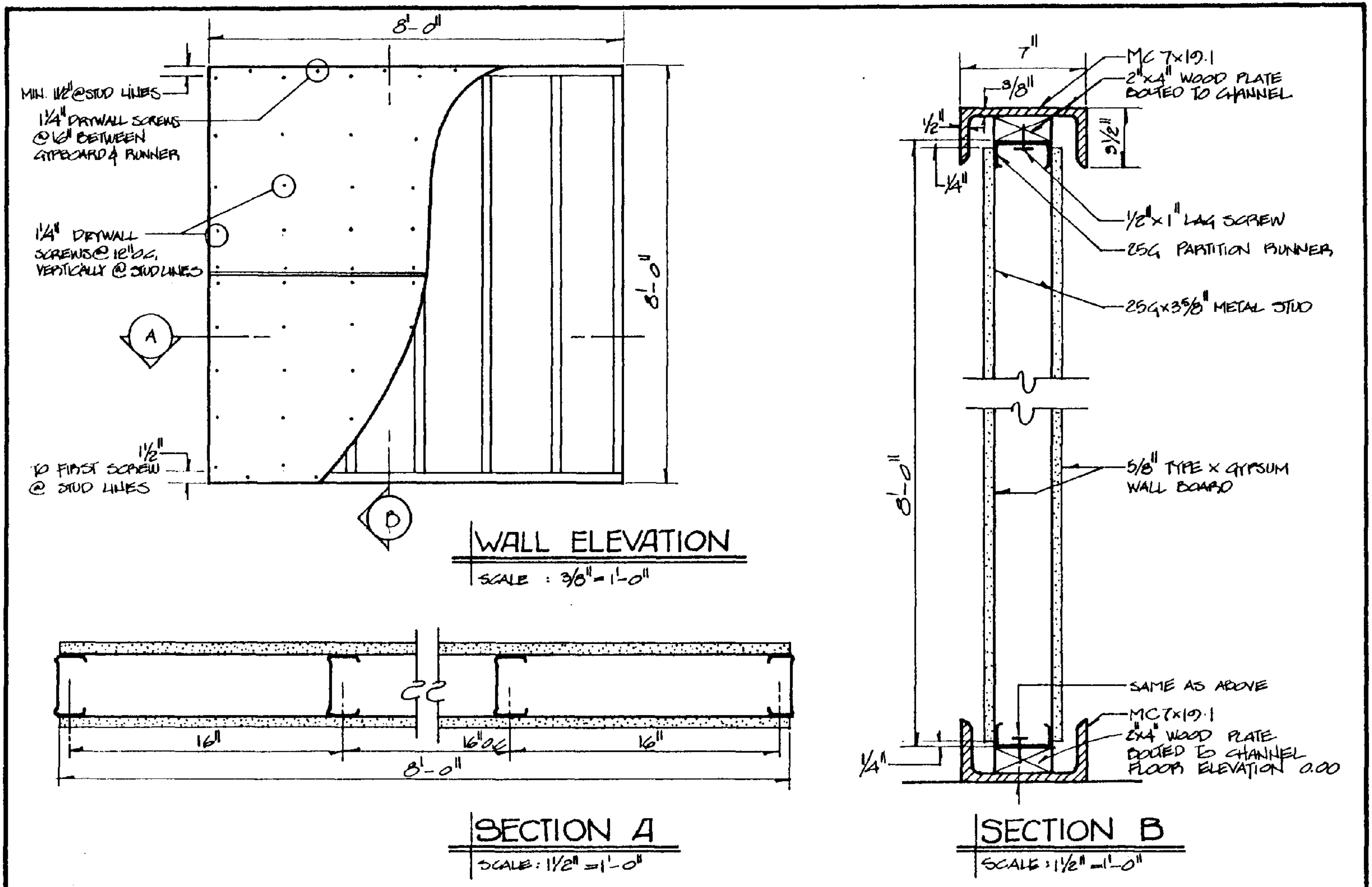


FIG. 6	PARTITION TEST PANEL SPECIMEN P4	5/8" GYPSUM WALLBOARD ON 3 5/8" METAL STUDS. FACING PANELS PLACED HORIZONTALLY UNTAPED JOINTS.

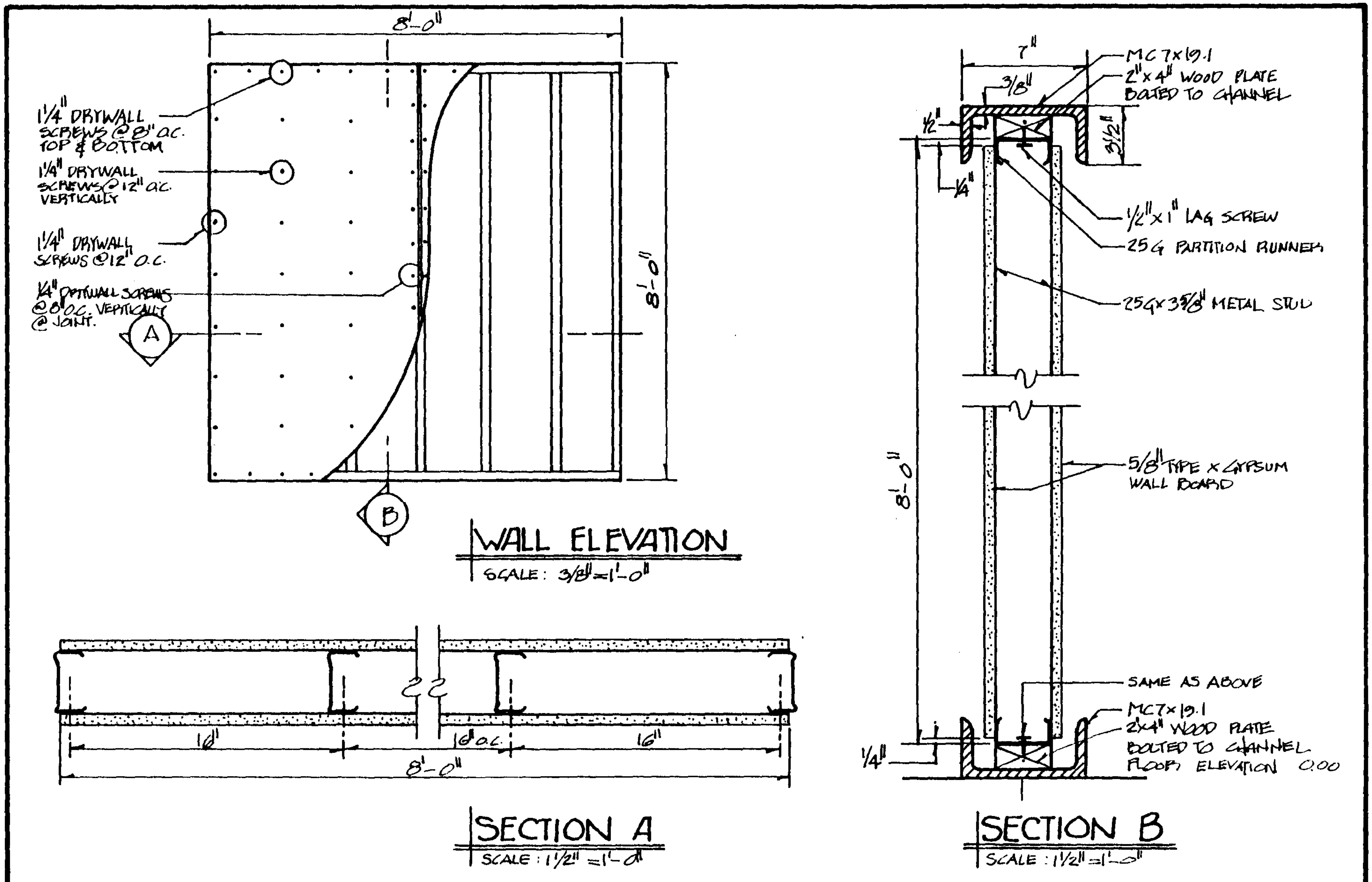
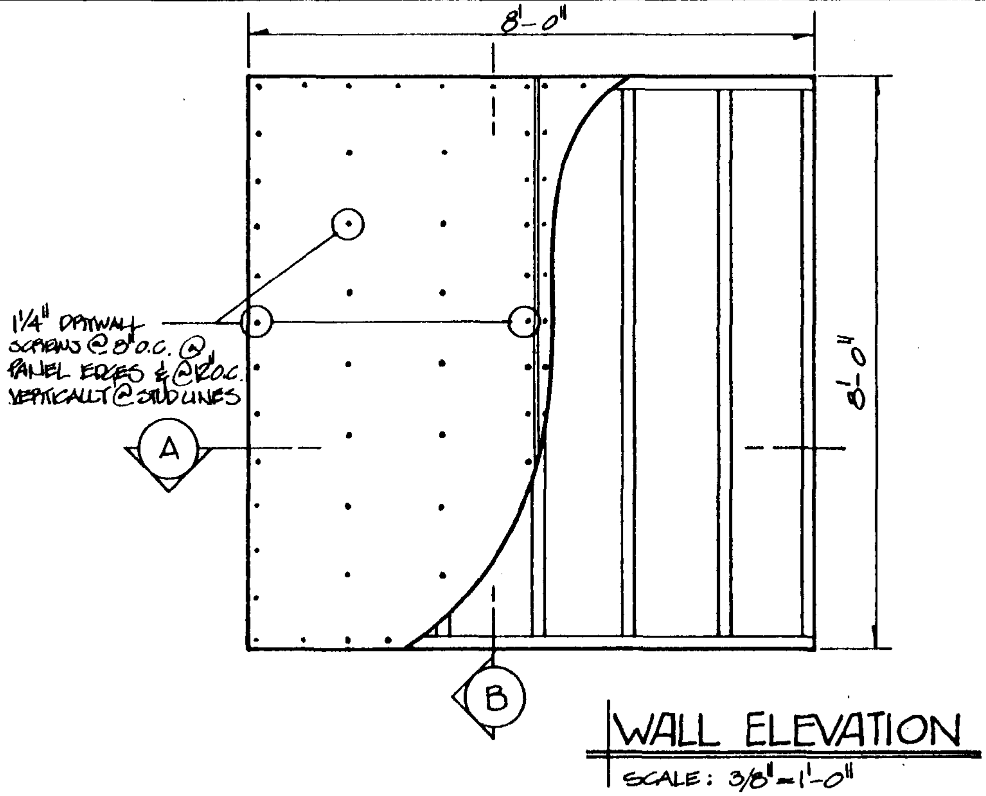
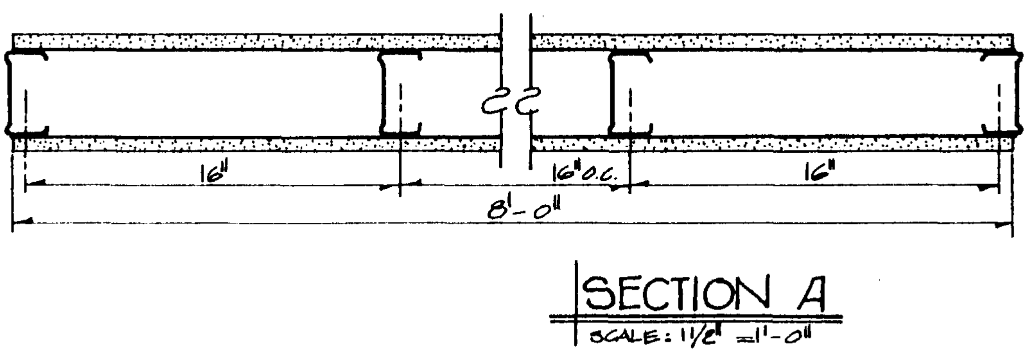


FIG. 7	PARTITION TEST PANEL SPECIMEN P5	5/8" GYPSUM ON 3 5/8" METAL STUDS. FACING PANELS PLACED VERTICALLY GYP. BD., STUD & RUNNER CONNECTED ALONG STUD LINES. JOINTS NOT TAPED.





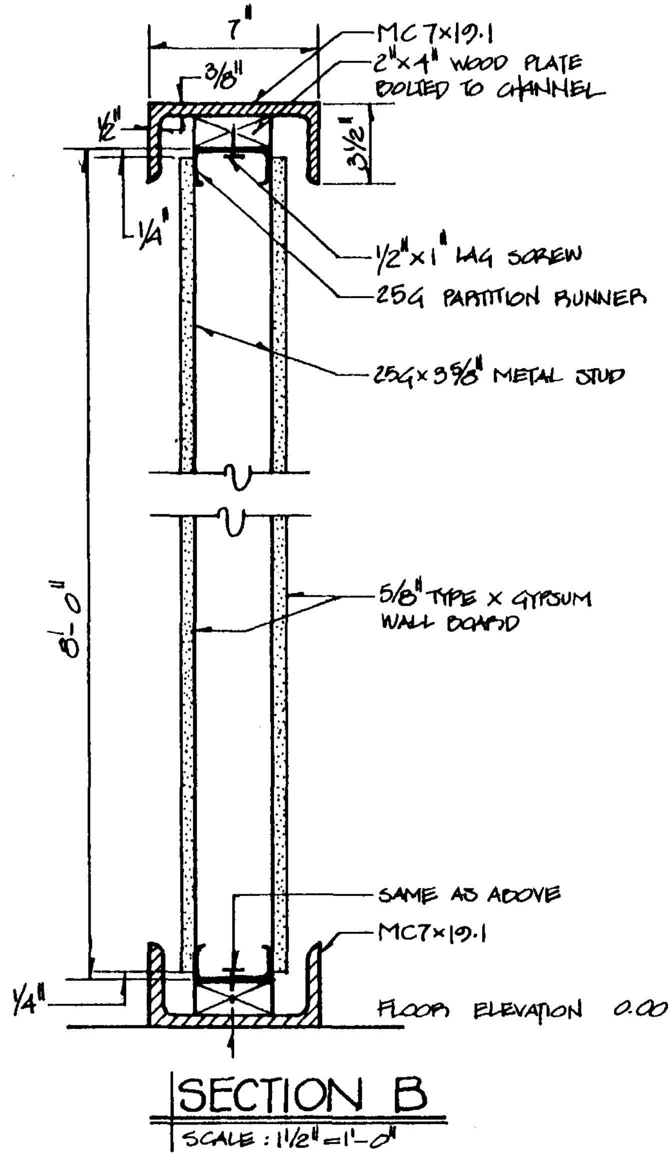


FIG. 8 — PARTITION TEST PANEL SPECIMEN P6

SAME AS P5 EXCEPT SCREW SPACING IS 8" AROUND ALL EDGES AND AT JOINTS; AND JOINTS ARE TAPED.

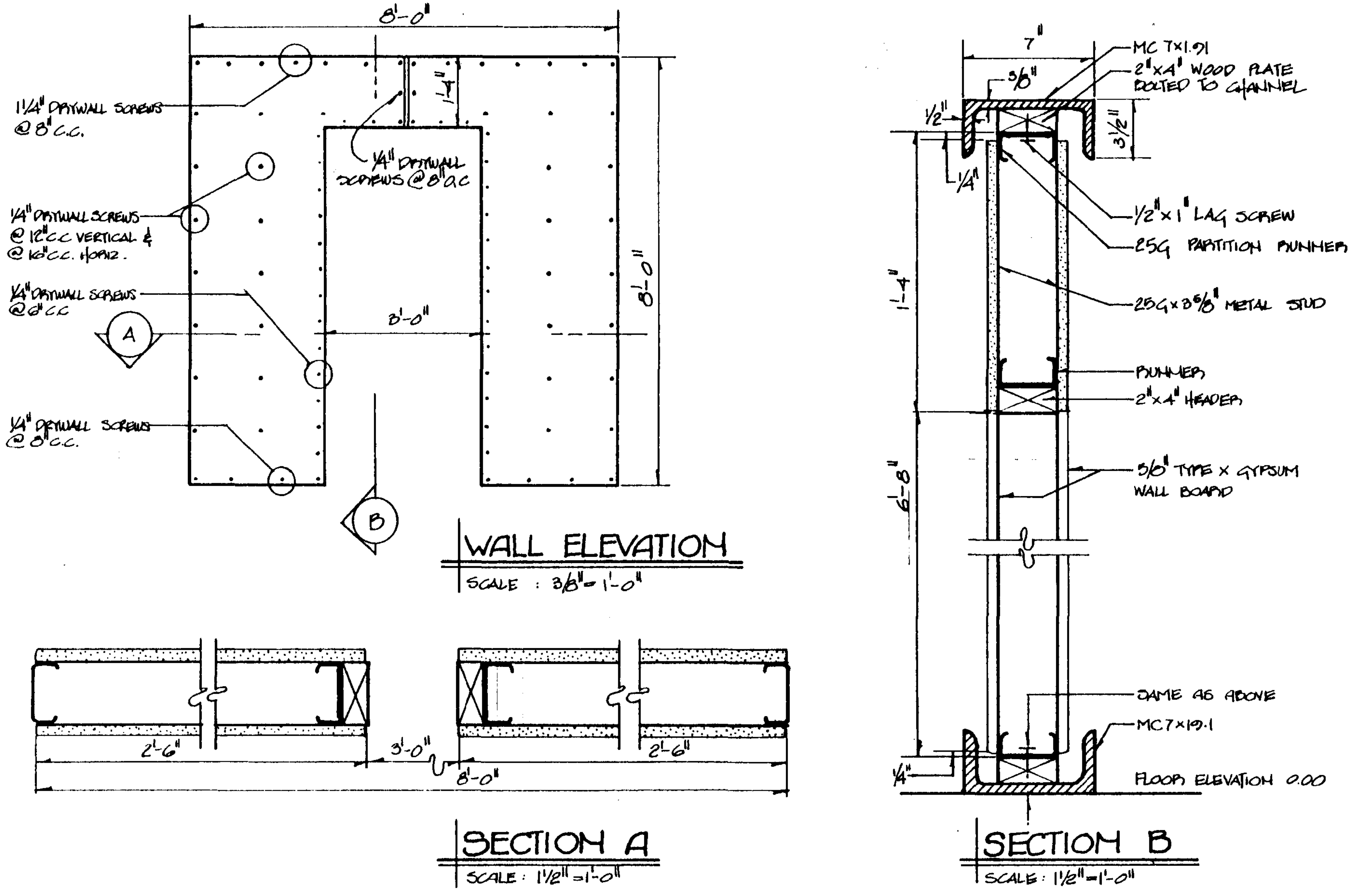


FIG. 9	PARTITION TEST PANEL SPECIMEN P7	5/8" GYPSUM WALLBOARD ON 3 5/8" METAL STUDS WITH 3'-0" x 6'-8" DOOR OPENING (WOODEN DOOR FRAME)

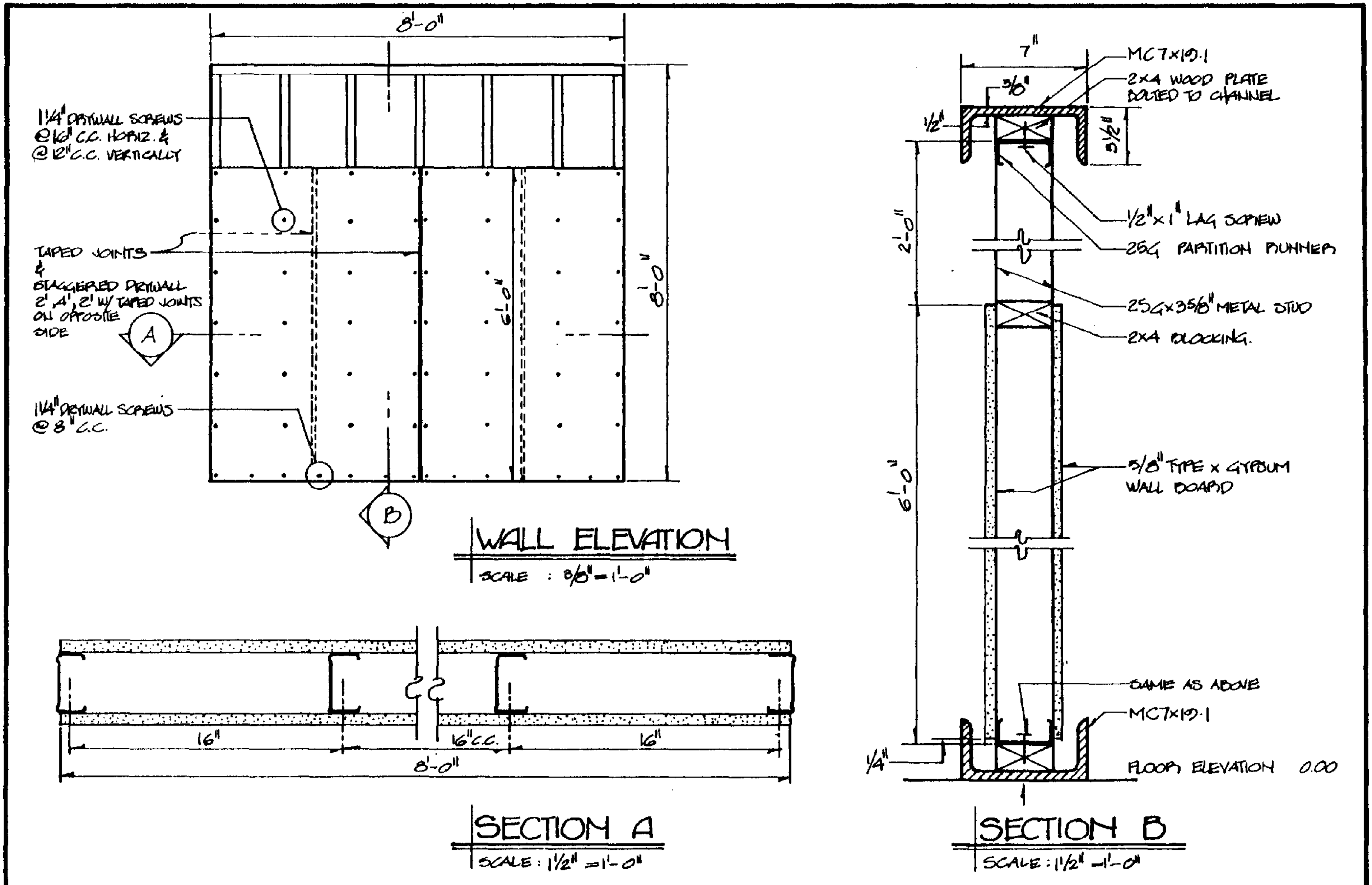


FIG. 10	PARTITION TEST PANEL SPECIMEN P8	PARTIAL HEIGHT PARTITION : 5/8" GYPSUM WALLBOARD ON 3 5/8" METAL STUDS. HEIGHT OF GYPBOARD IS 6'-0".

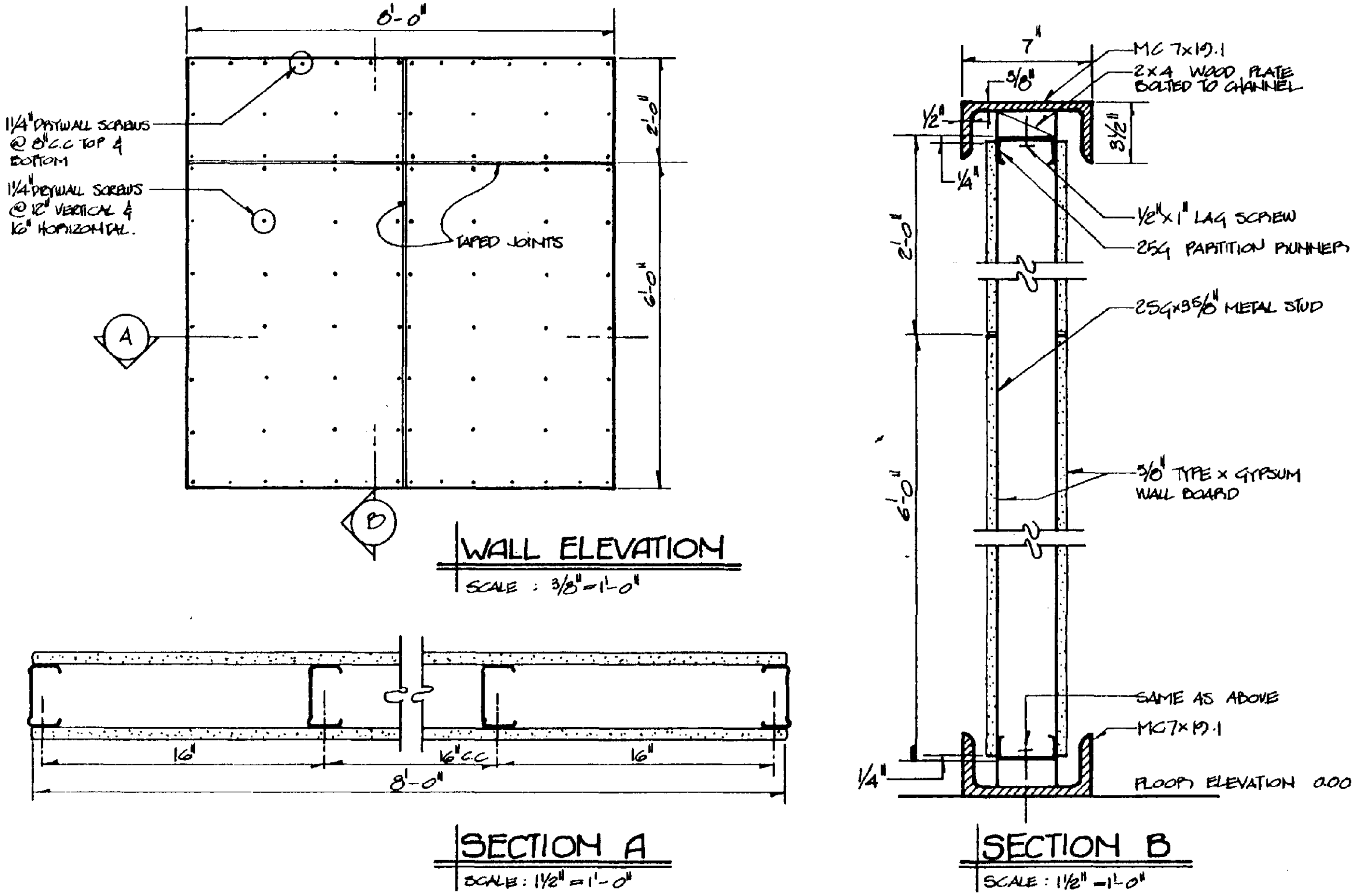
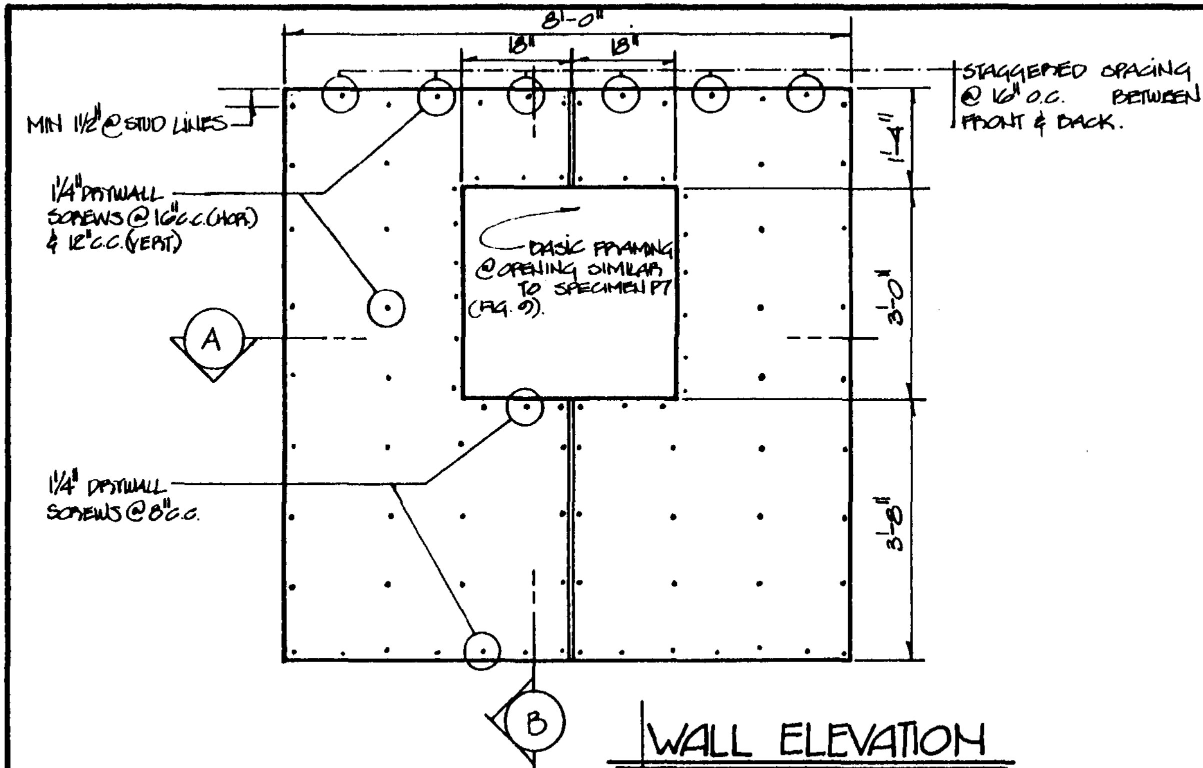
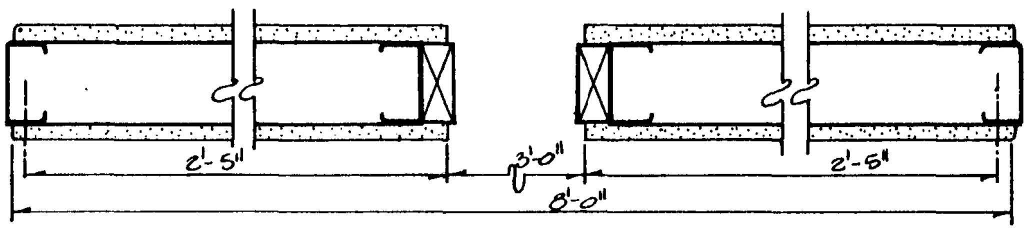


FIG. 11.	PARTITION TEST PANEL SPECIMEN P8A	5/8" GYPSUM WALLBOARD ON 3 5/8" METAL STUDS. CONDITION SIMILAR TO P8 EXCEPT STUDS FULLY COVERED



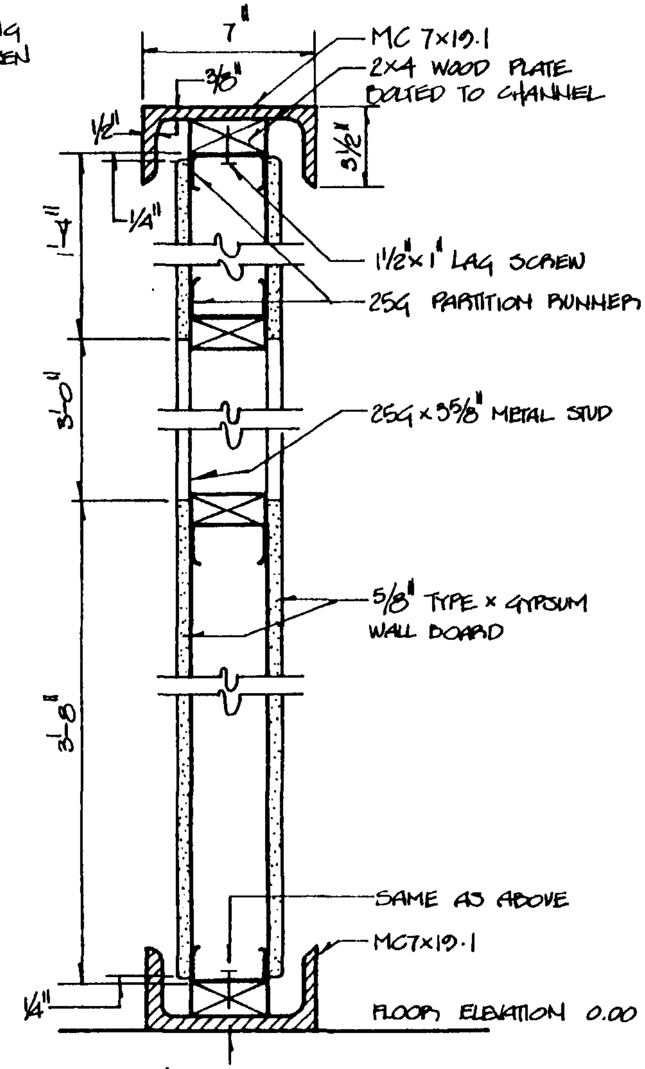
WALL ELEVATION

SCALE : 3/8" = 1'-0"



SECTION A

SCALE : 1½" = 1'-0"



SECTION B

SCALE : 1½" = 1'-0"

FIG. 12	PARTITION TEST PANEL SPECIMEN P9	5/8" GYPSUM WALLBOARD ON 3⅝" METAL STUDS WITH 3'×3' WINDOW OPENING (WOODEN WINDOW FRAME)

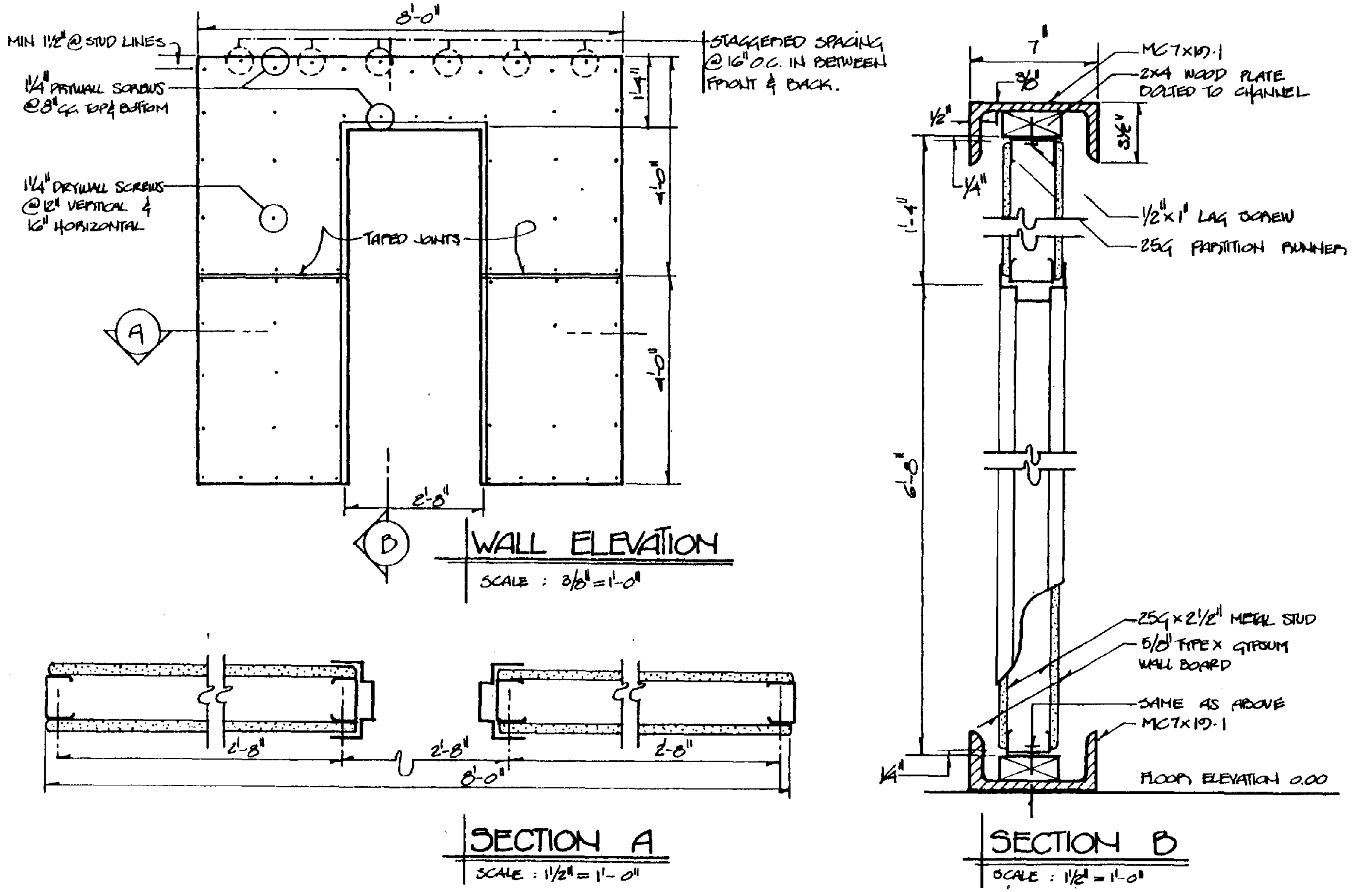


FIG. 13.	PARTITION TEST PANEL SPECIMEN P10.	SAME AS P11 EXCEPT GYPBOARD IS PLACED HORIZONTALLY (SEE FIG. 14)

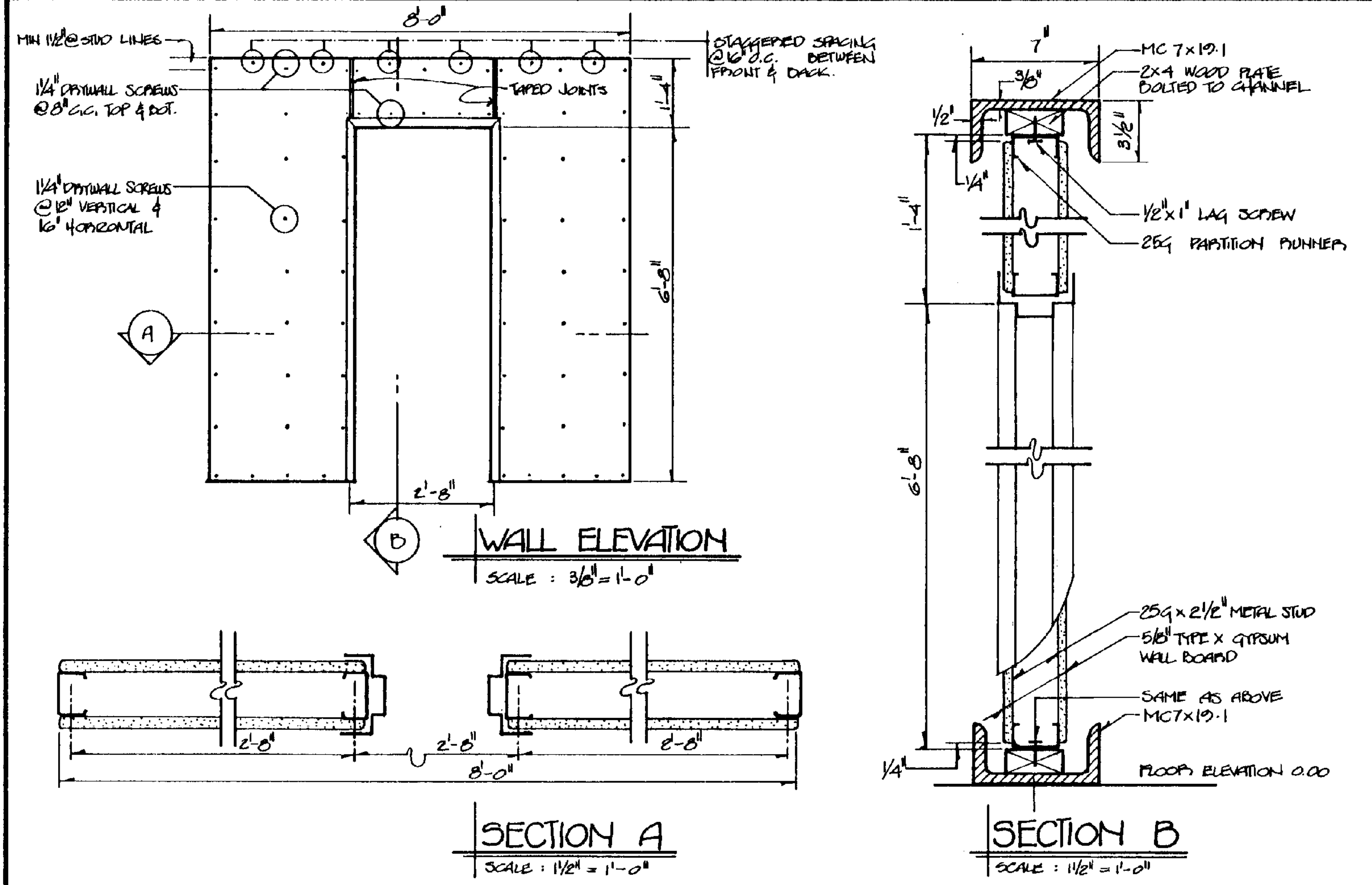
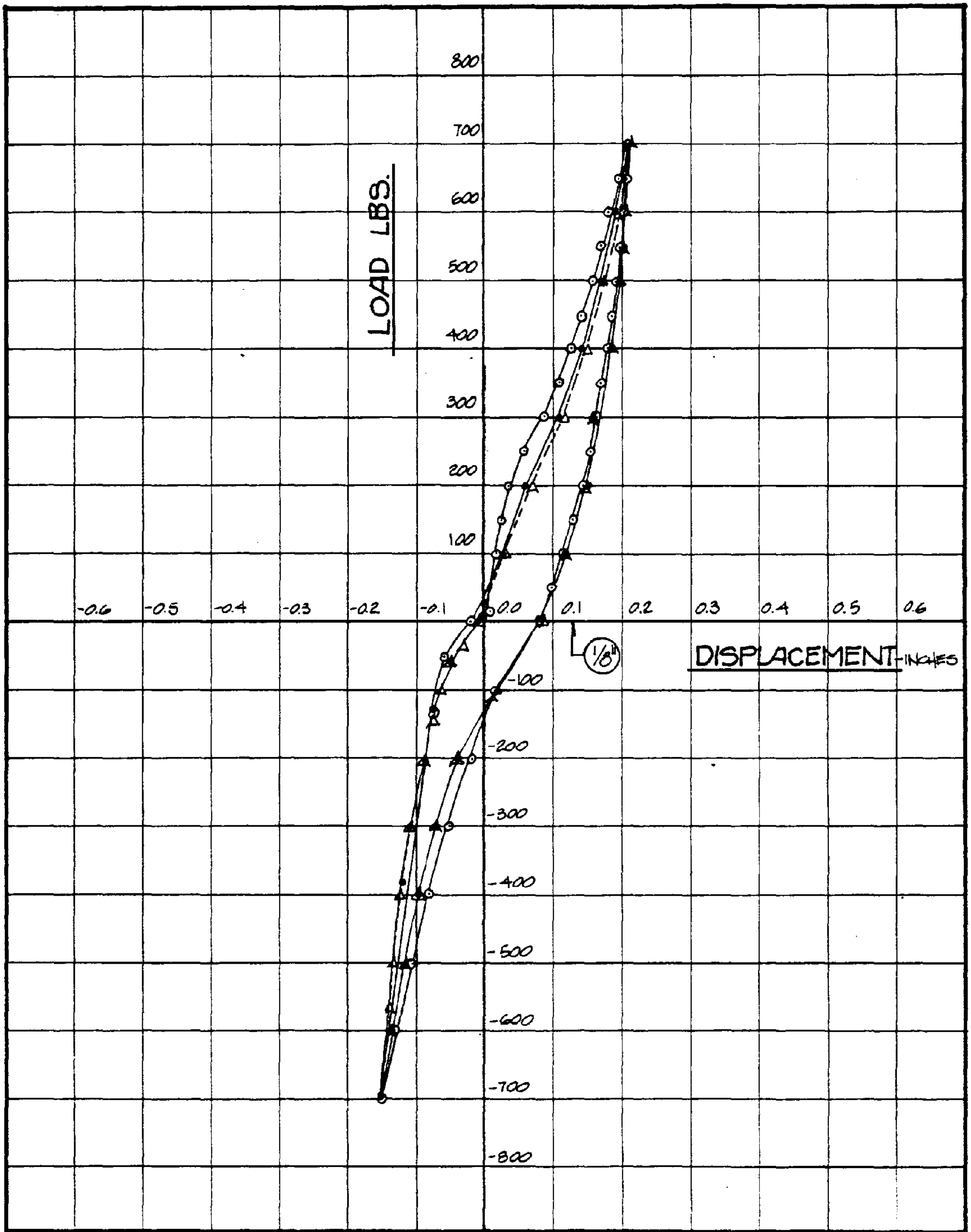


FIG. 14	PARTITION TEST PANEL SPECIMEN P11	5/8" GYPSUM WALLBOARD ON 2 1/2" METAL STUDS WITH 2'-8" x 6'-8" DOOR OPENING (METAL DOOR FRAME)

APPENDIX B

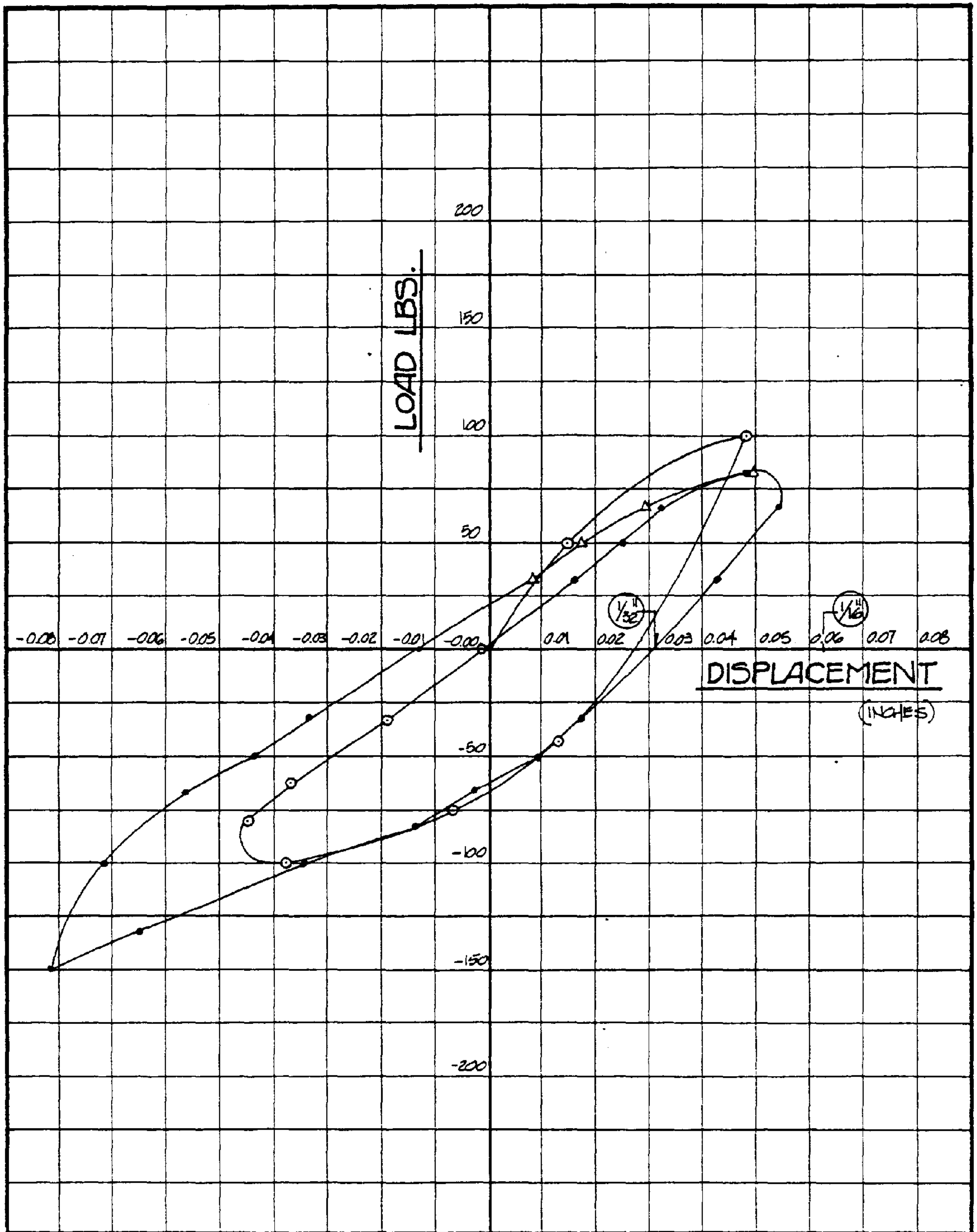
RESULTS OF RACKING TESTS



SPECIMEN P1
LOAD-DISPLACEMENT CURVES

⊙ — CYCLE No. 1
• — CYCLE No. 2
▵ — CYCLE No. 3

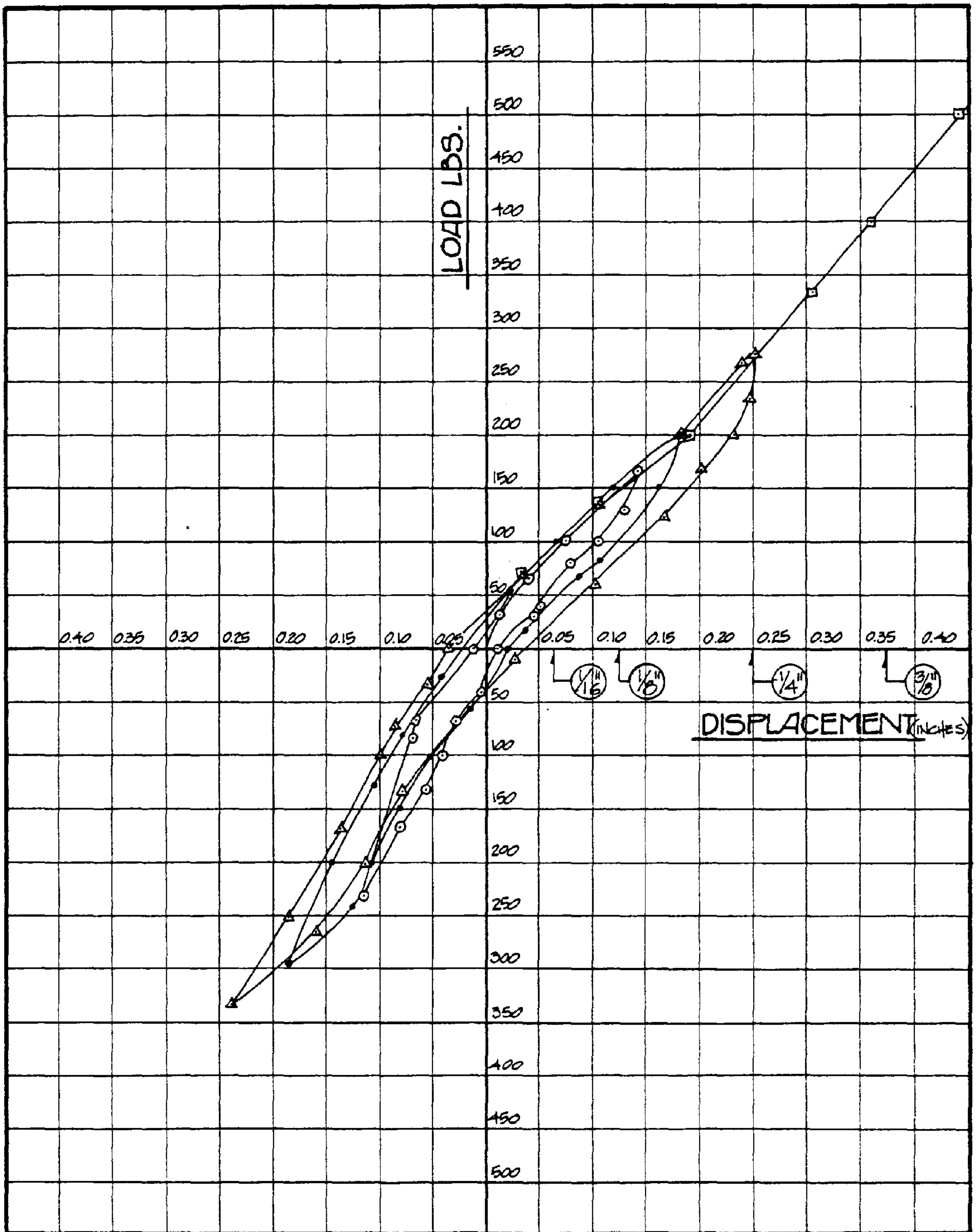
FIG. 15



SPECIMEN P2
LOAD-DISPLACEMENT CURVES

⊙ — CYCLE No. 1
• — CYCLE No. 2
△ — CYCLE No. 3

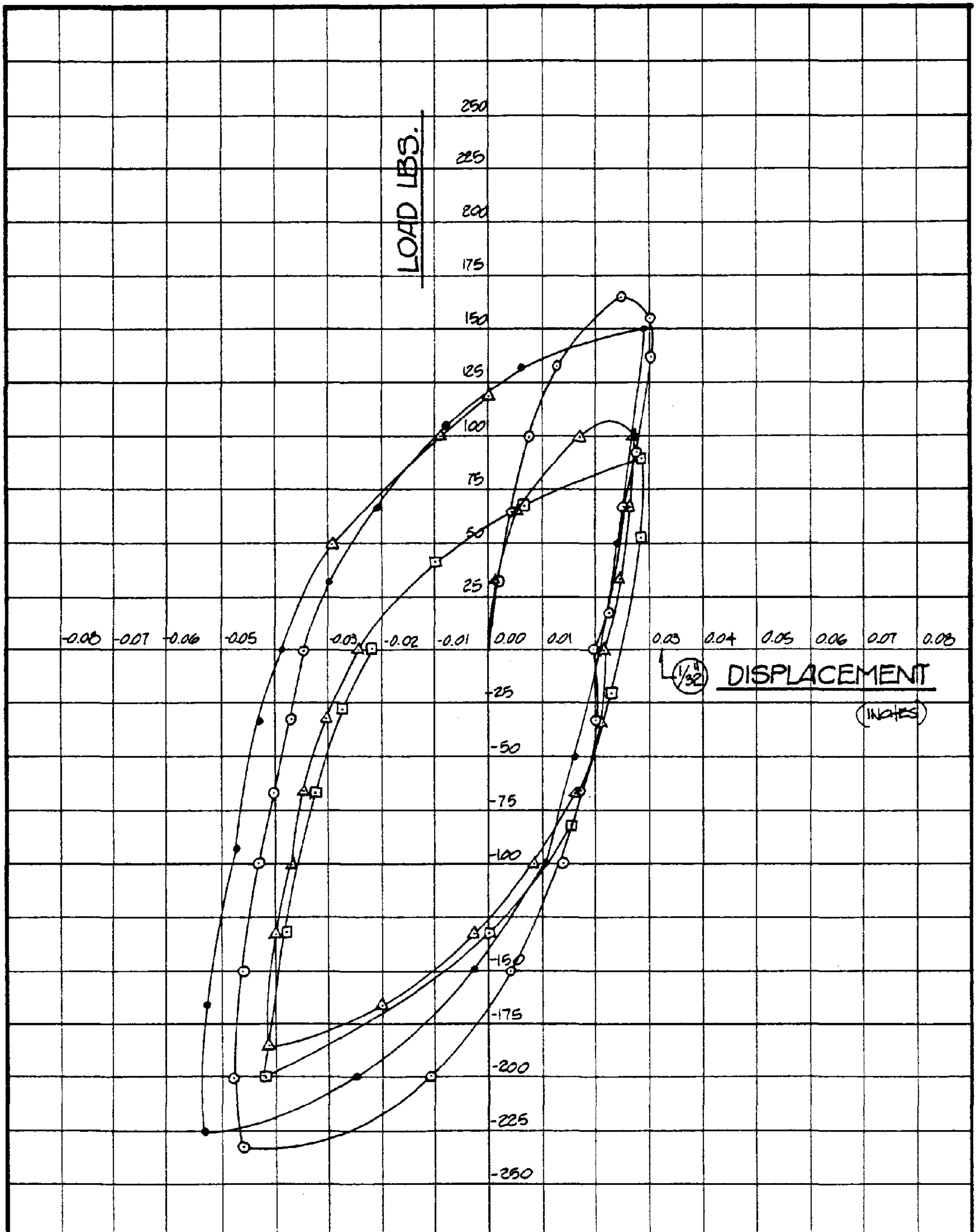
FIG. 16



SPECIMEN P2A
LOAD-DISPLACEMENT CURVES

⊙ — CYCLE No. 1
• — CYCLE No. 2
△ — CYCLE No. 3
□ — CYCLE No. 4

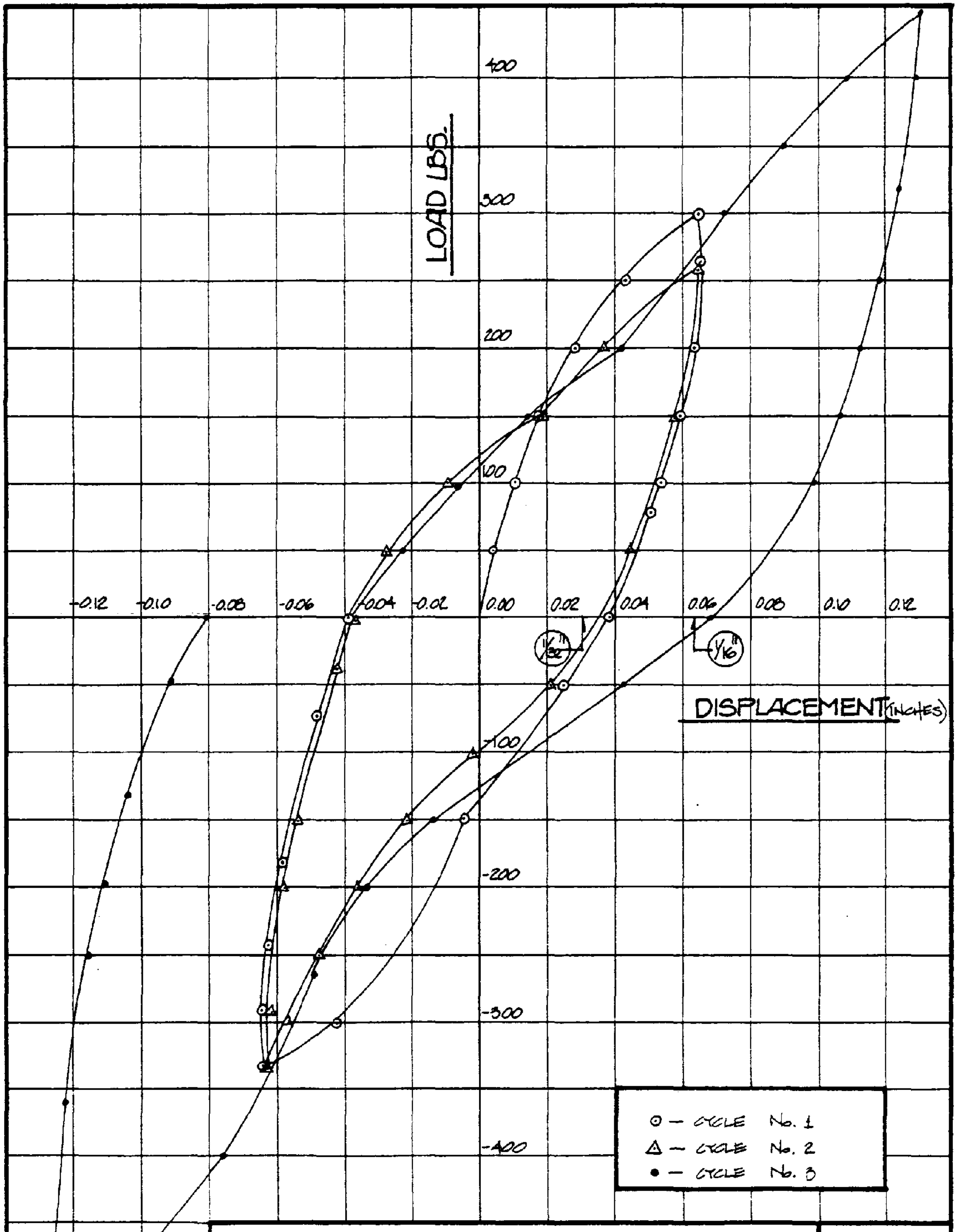
FIG. 17



SPECIMEN P3
LOAD-DISPLACEMENT CURVES

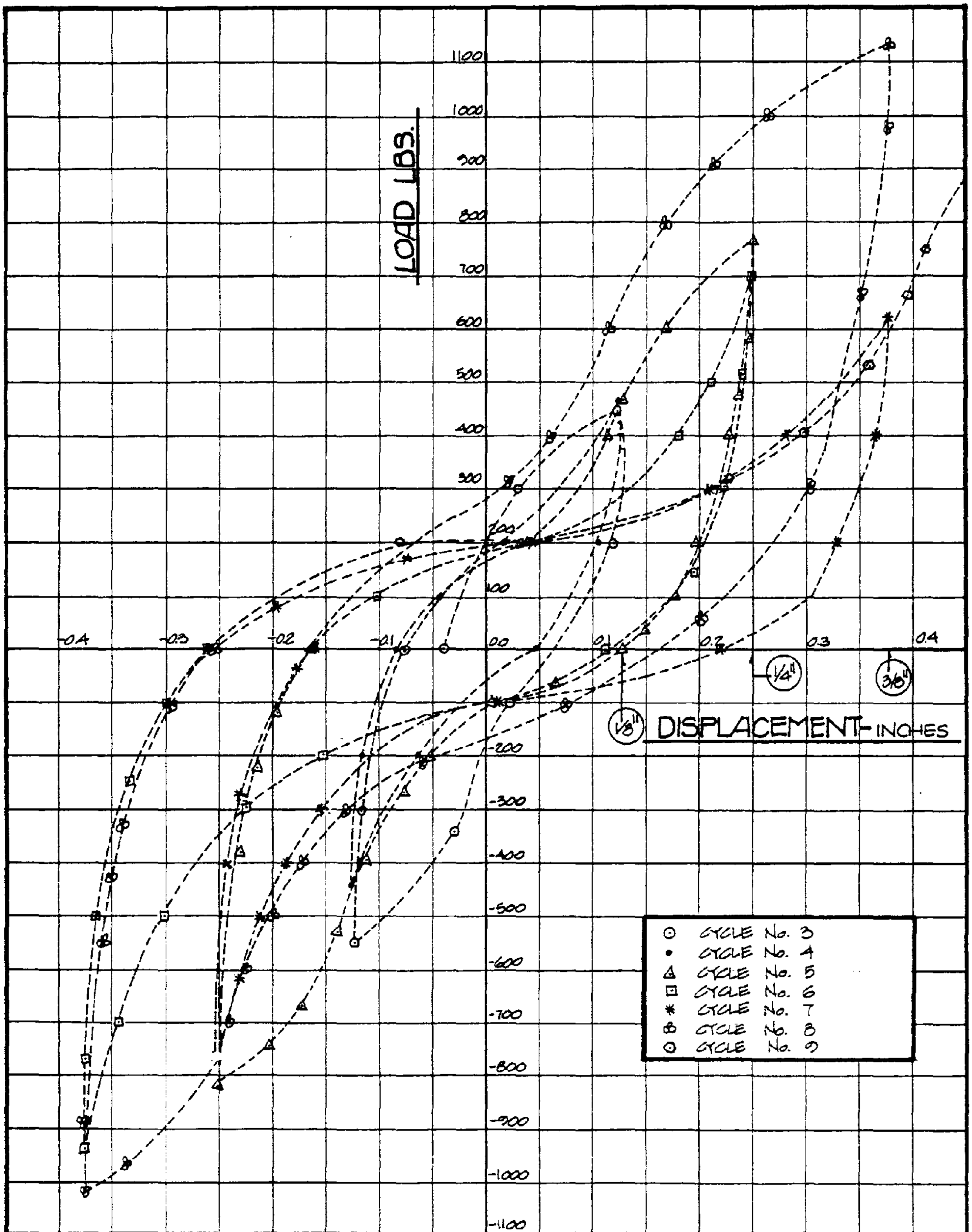
⊙ – CYCLE No. 1
• – CYCLE No. 2
△ – CYCLE No. 3
⊡ – CYCLE No. 4

FIG. 18



PARTITION SPECIMEN P3A
LOAD-DISPLACEMENT CURVES

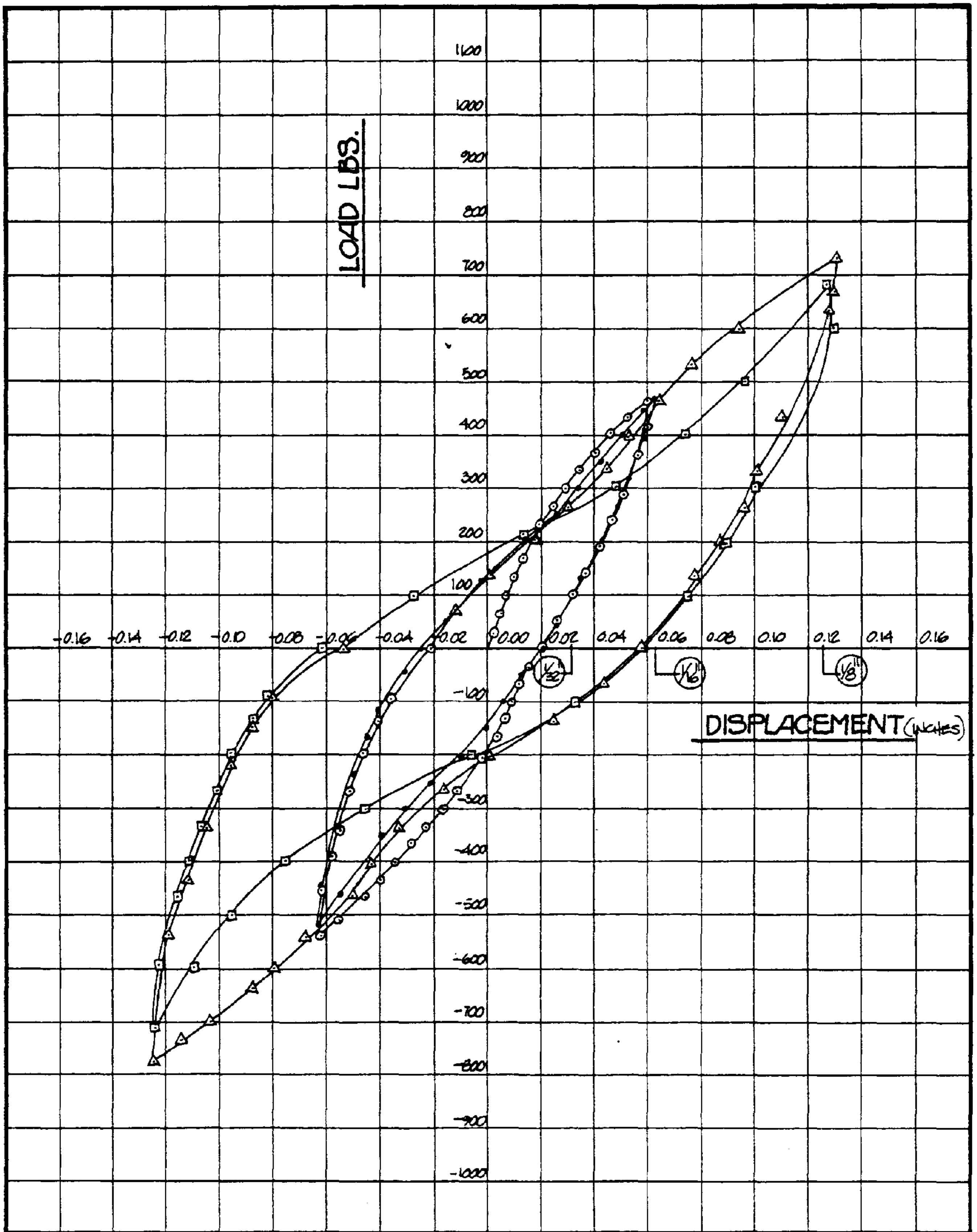
FIG. 19



PARTITION SPECIMEN P3A
LOAD-DISPLACEMENT CURVES

1/8" - 3/8" CYCLES

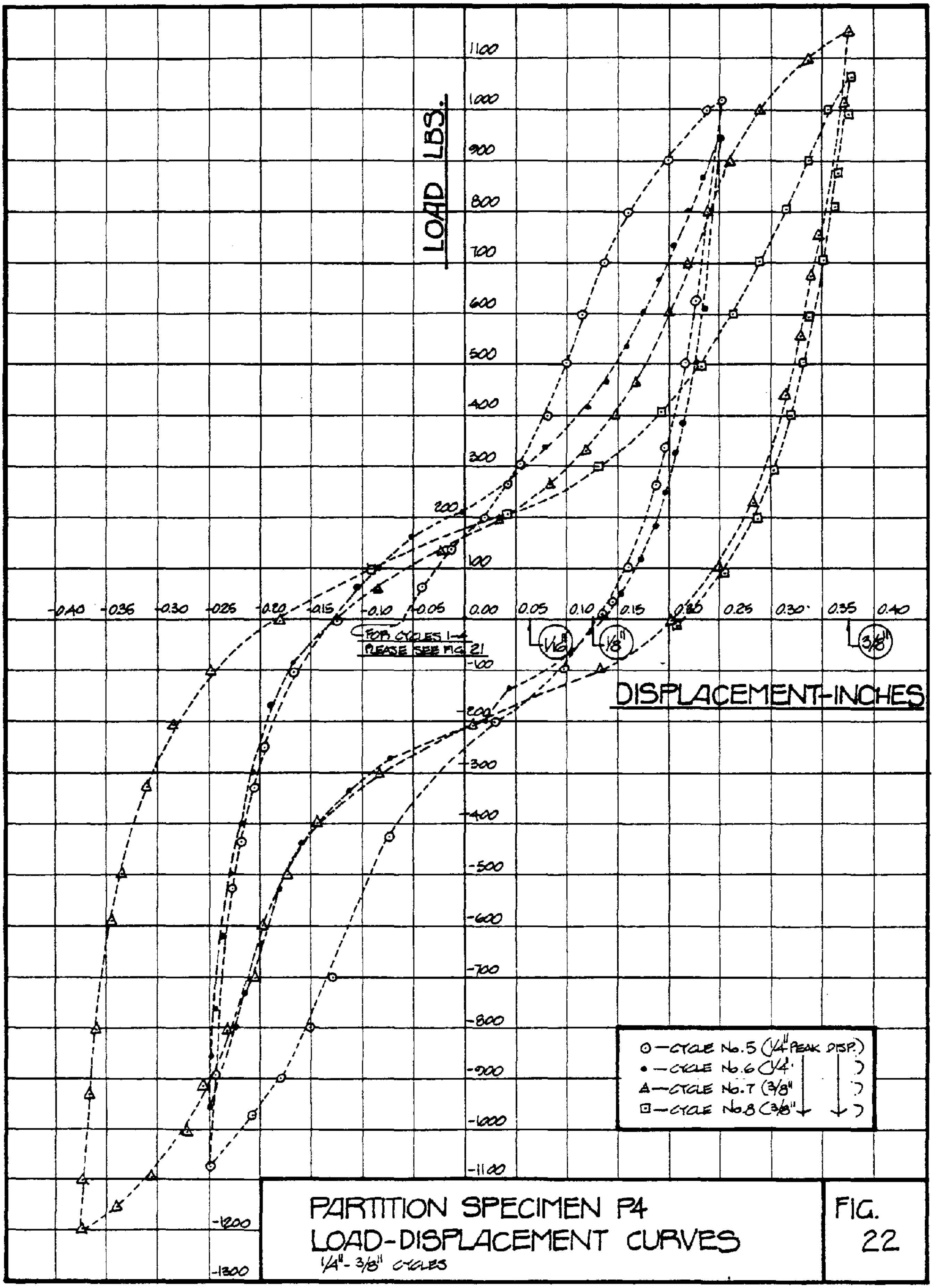
FIG. 20



PARTITION SPECIMEN P4
LOAD-DISPLACEMENT CURVES
1/16" - 1/8" CYCLES

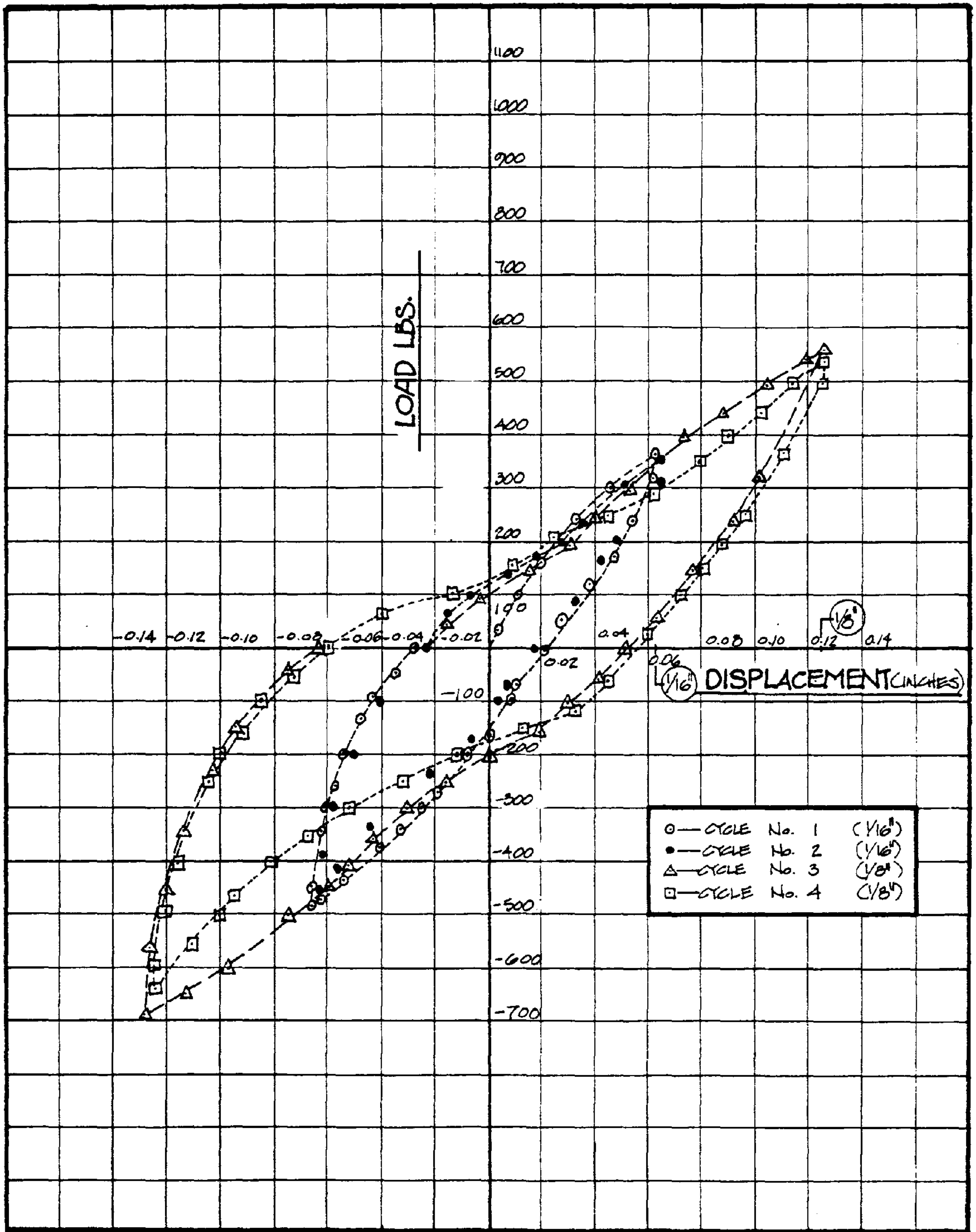
⊙ — CYCLE No. 1 (1/16" PEAK)
• — CYCLE No. 2 (1/16" ")
△ — CYCLE No. 3 (1/8" ")
⊡ — CYCLE No. 4 (1/8" ")

FIG. 21

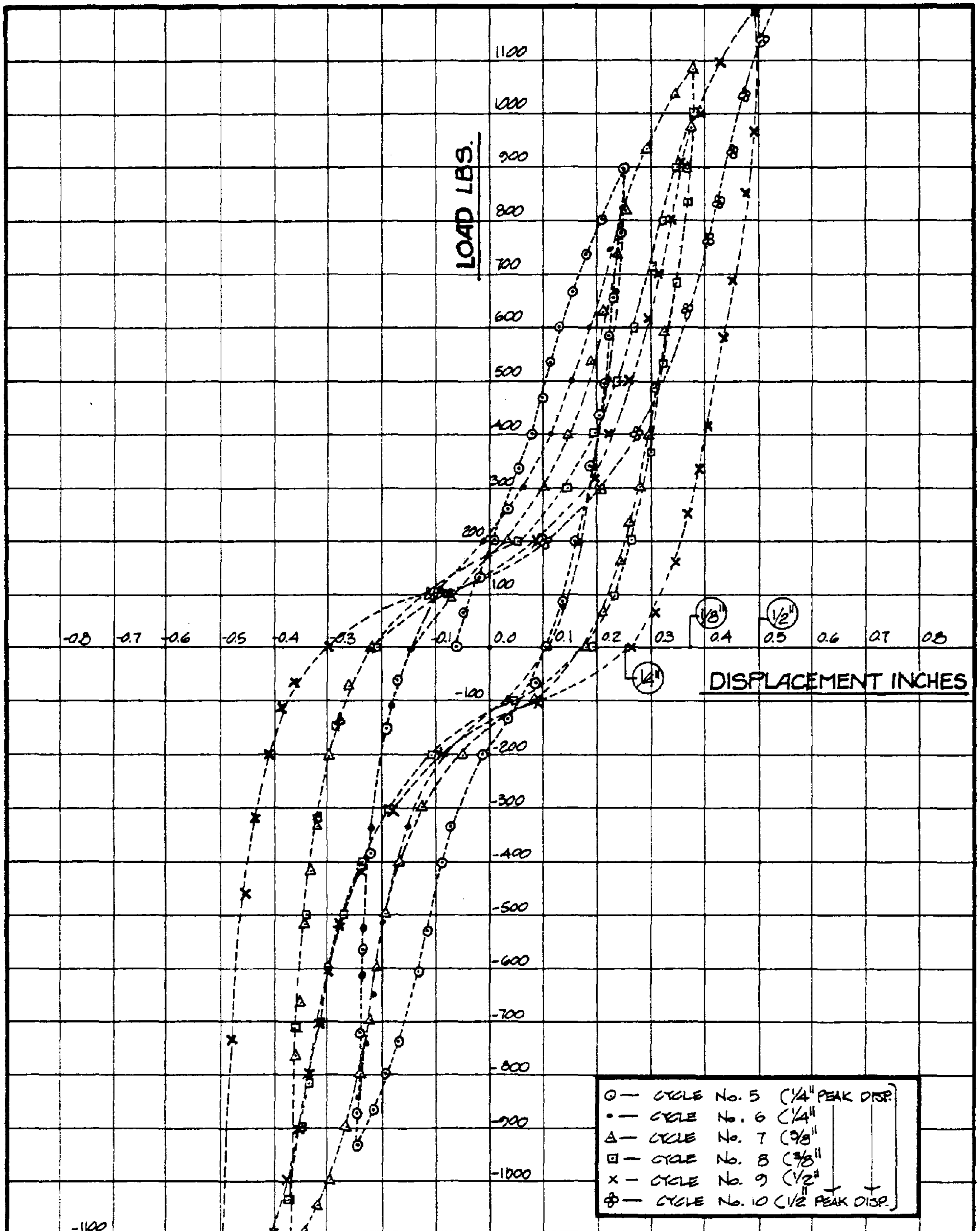


PARTITION SPECIMEN P4
LOAD-DISPLACEMENT CURVES
1/4"-3/8" CYCLES

FIG. 22

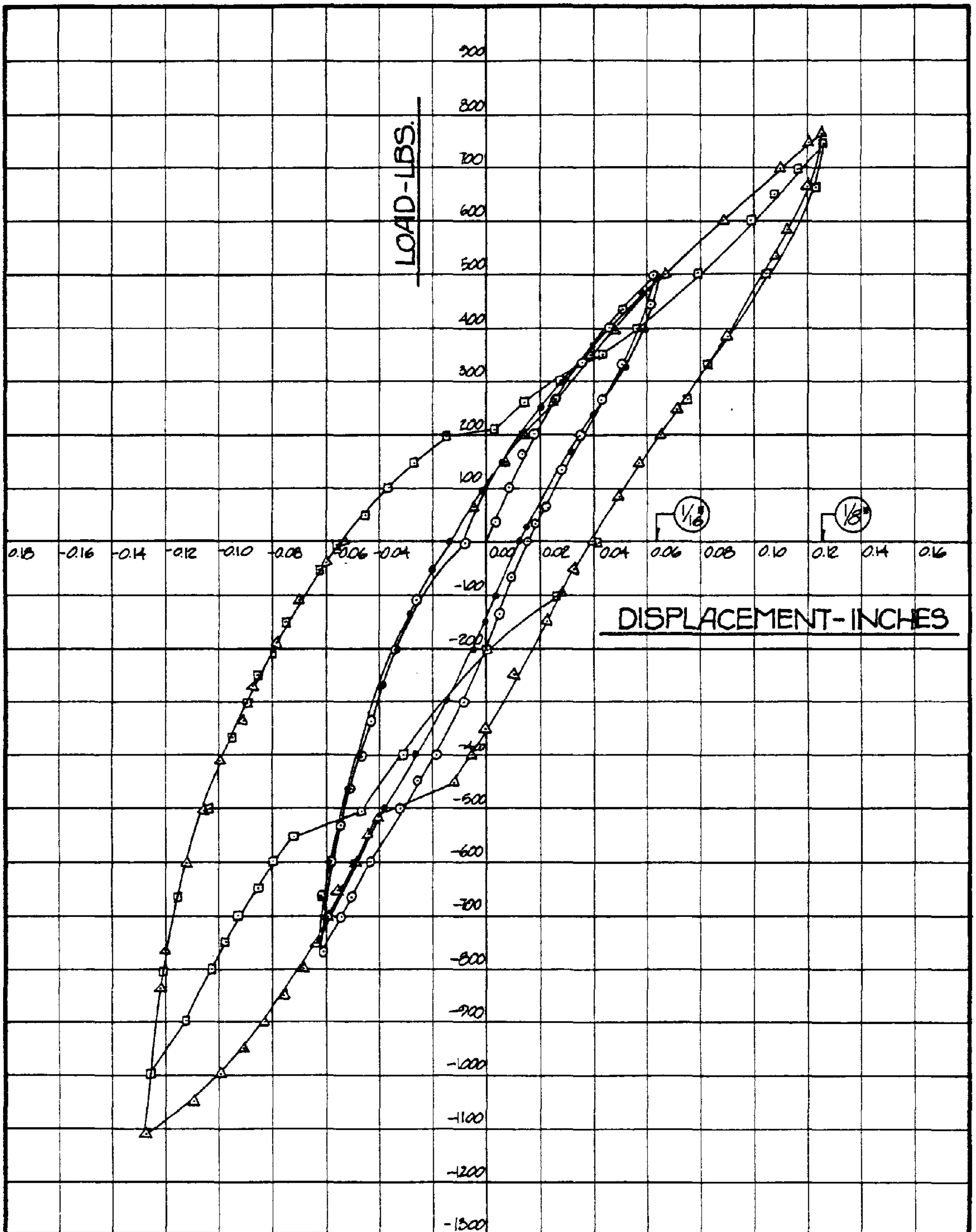


PARTITION SPECIMEN P5 LOAD-DISPLACEMENT CURVES 1/16"-1/8" CYCLES	FIG. 23



PARTITION SPECIMEN P5
LOAD-DISPLACEMENT CURVES
1/4" – 3/8" CYCLES

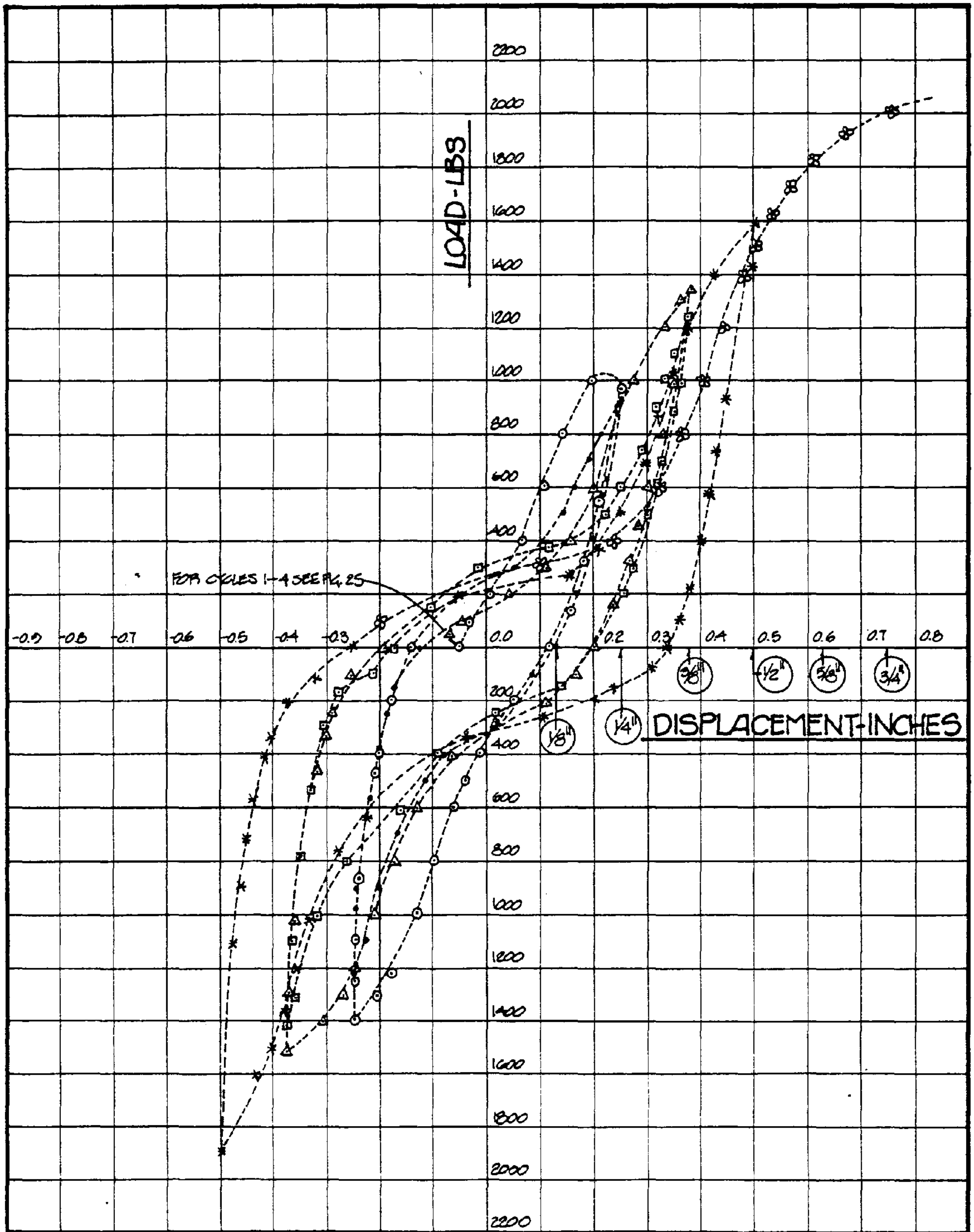
FIG. 24



PARTITION SPECIMEN P6
LOAD-DISPLACENT CURVES 1/16"-1/8" CYCLES

○—CYCLE No. 1 (1/16" PEAK DIS)
•—CYCLE No. 2 (1/16")
△—CYCLE No. 3 (1/8")
⊡—CYCLE No. 4 (1/8" + +)

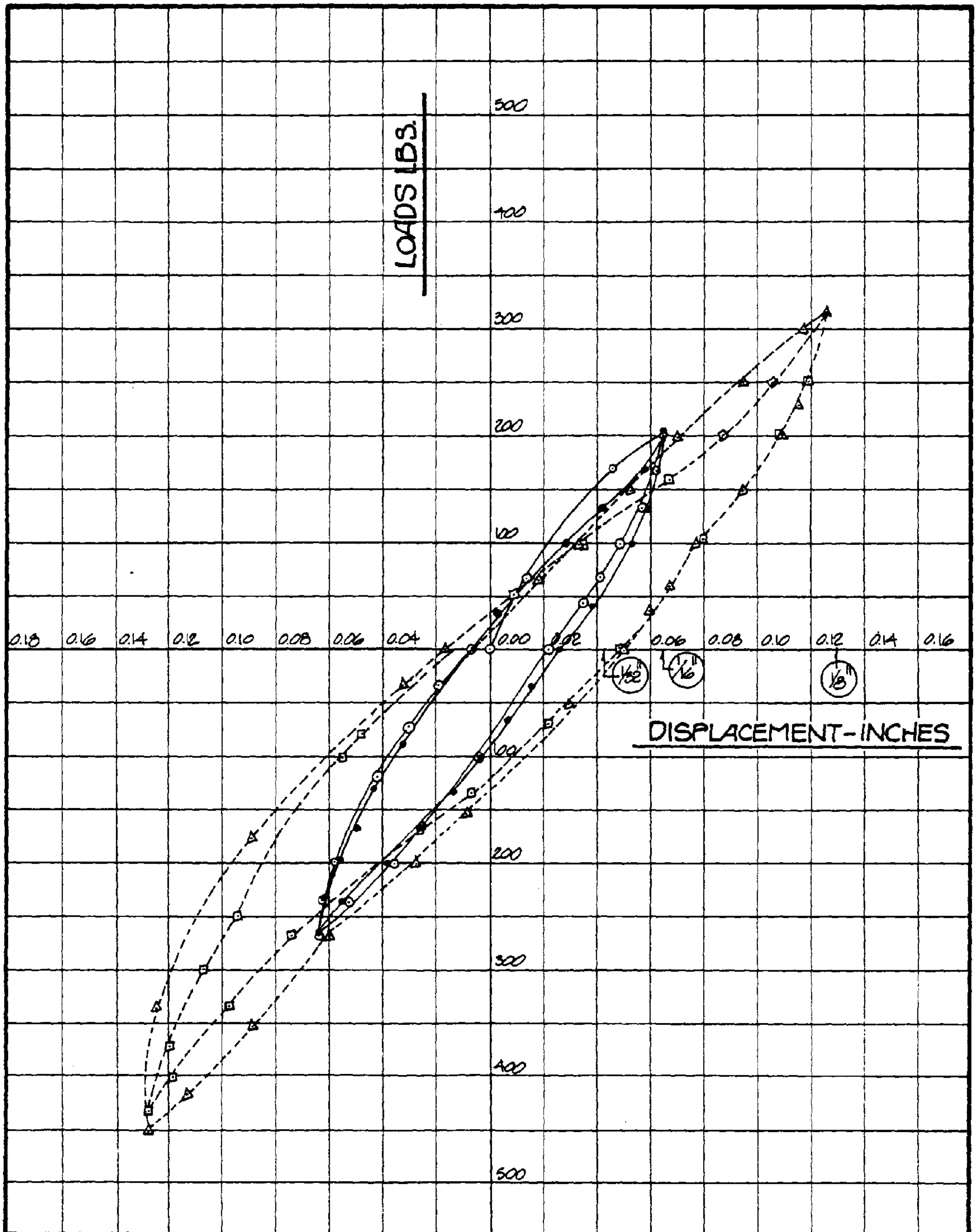
FIG. 25



PARTITION SPECIMEN P6
LOAD-DISPLACEMENT CURVES 1/4"-3/8" CYCLES

Symbol	Cycle No.	Peak Disp.
⊙	5	1/4"
•	6	1/4"
△	7	3/8"
□	8	3/8"
*	9	1/2"
✤	10	FINAL

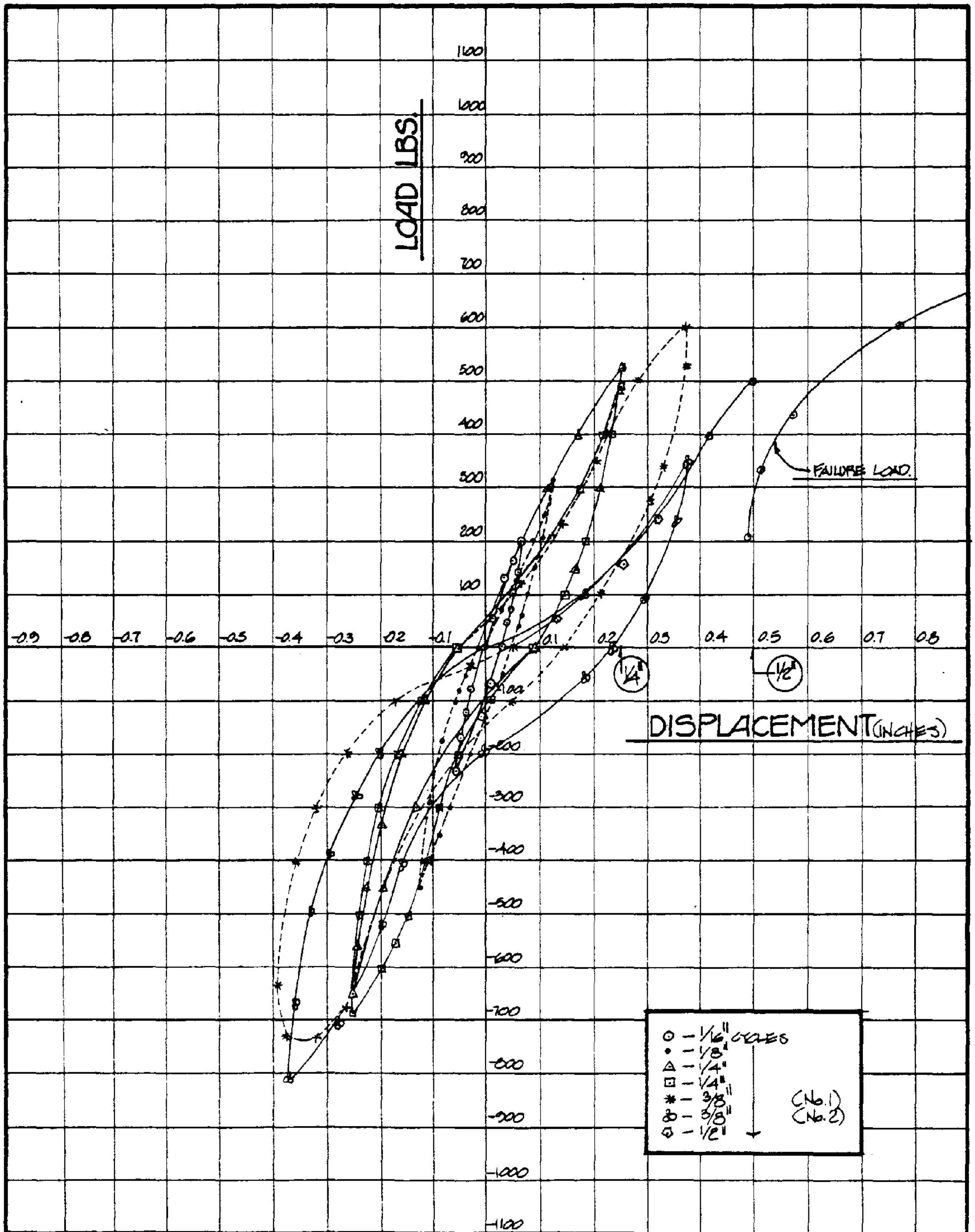
FIG. 26



PARTITION SPECIMEN P7 CYCLES 1/16"-1/8"
LOAD-DISPLACEMENT CURVES

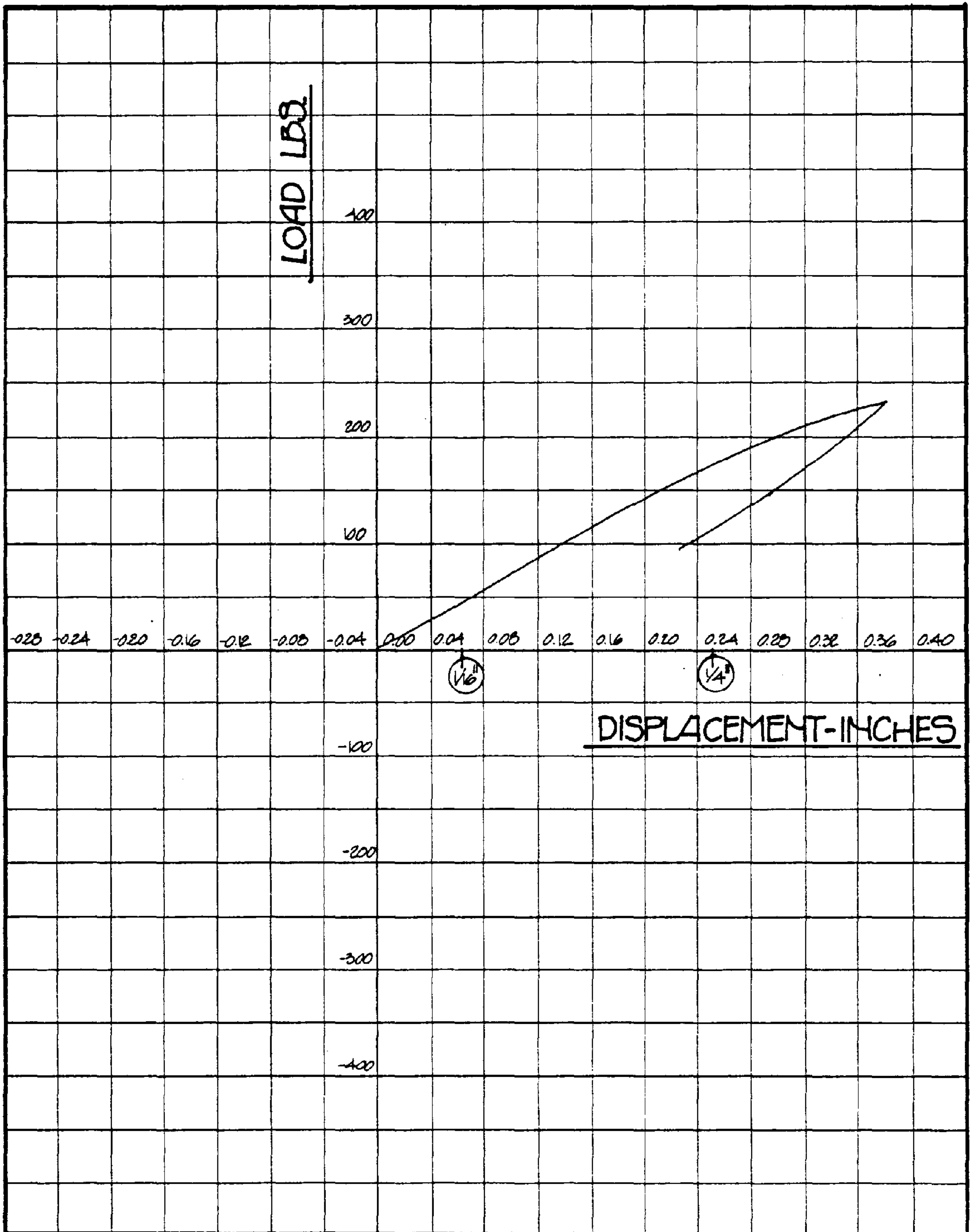
⊙—CYCLE No1 @ 1/16"
•—CYCLE No2 @ 1/16"
△—CYCLE No1 @ 1/8"
⊡—CYCLE No2 @ 1/8"

FIG. 27



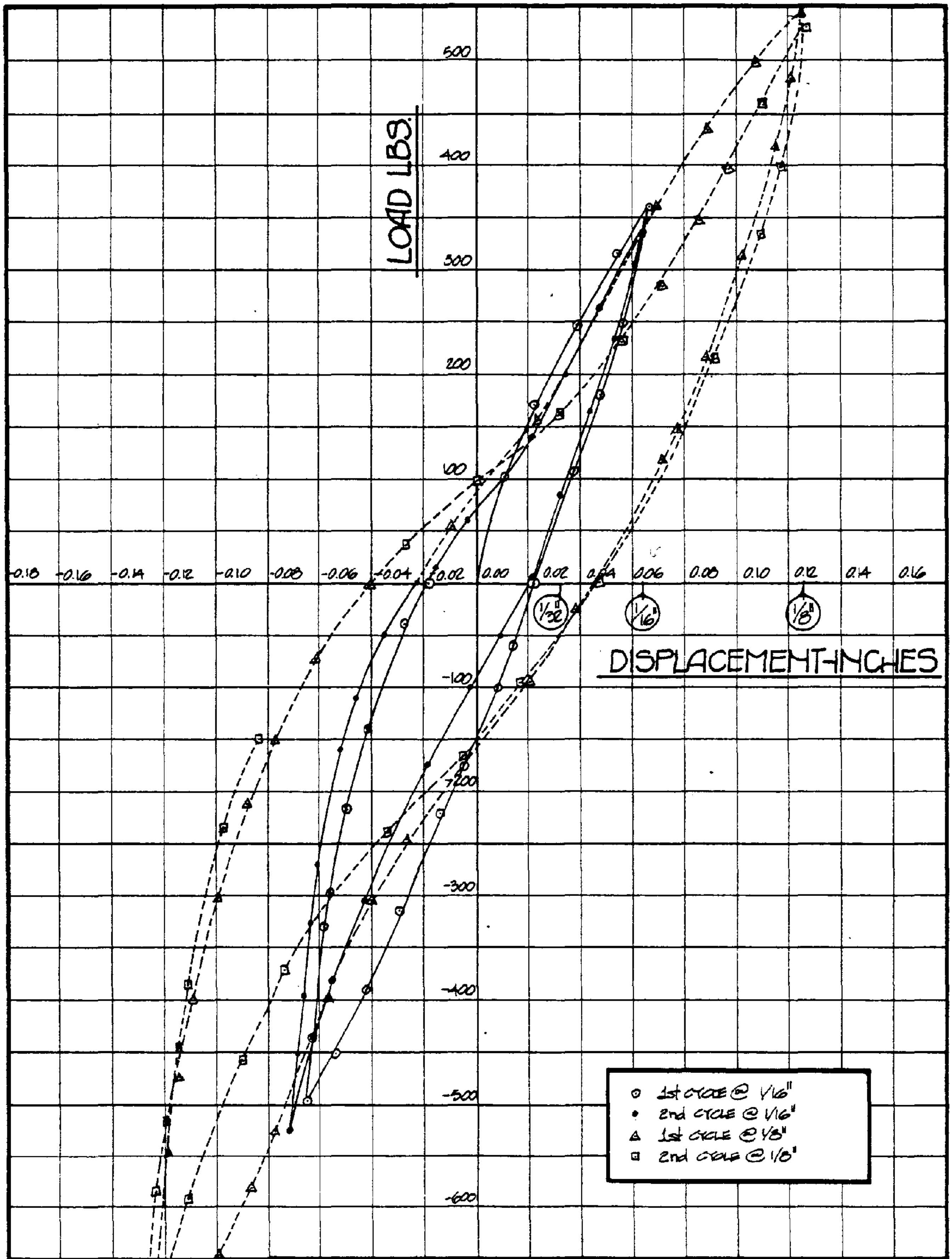
PARTITION SPECIMEN P7
LOAD-DISPLACEMENT CURVES

FIG. 28



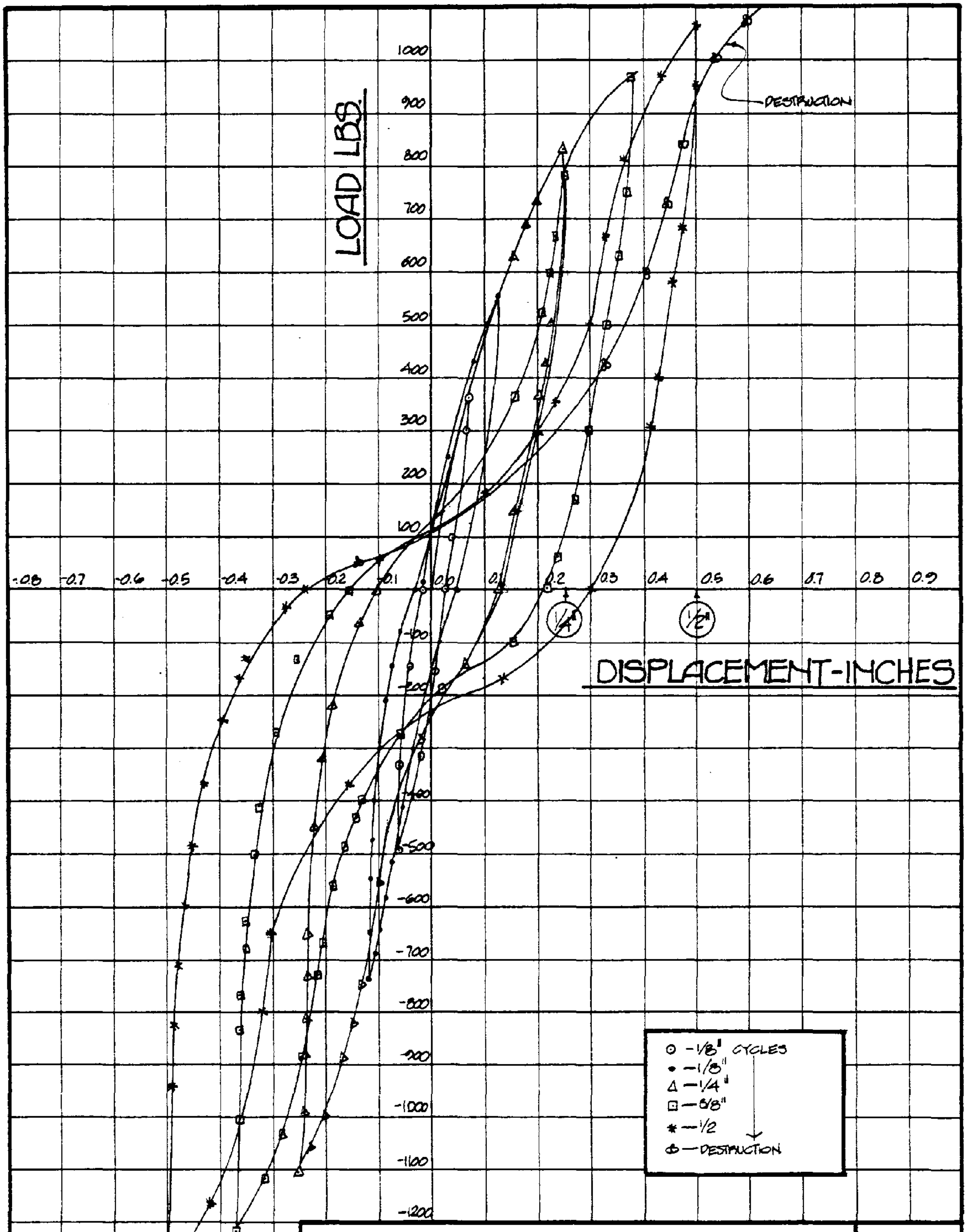
PARTITION SPECIMEN P8
LOAD-DISPLACEMENT CURVE

FIG. 29



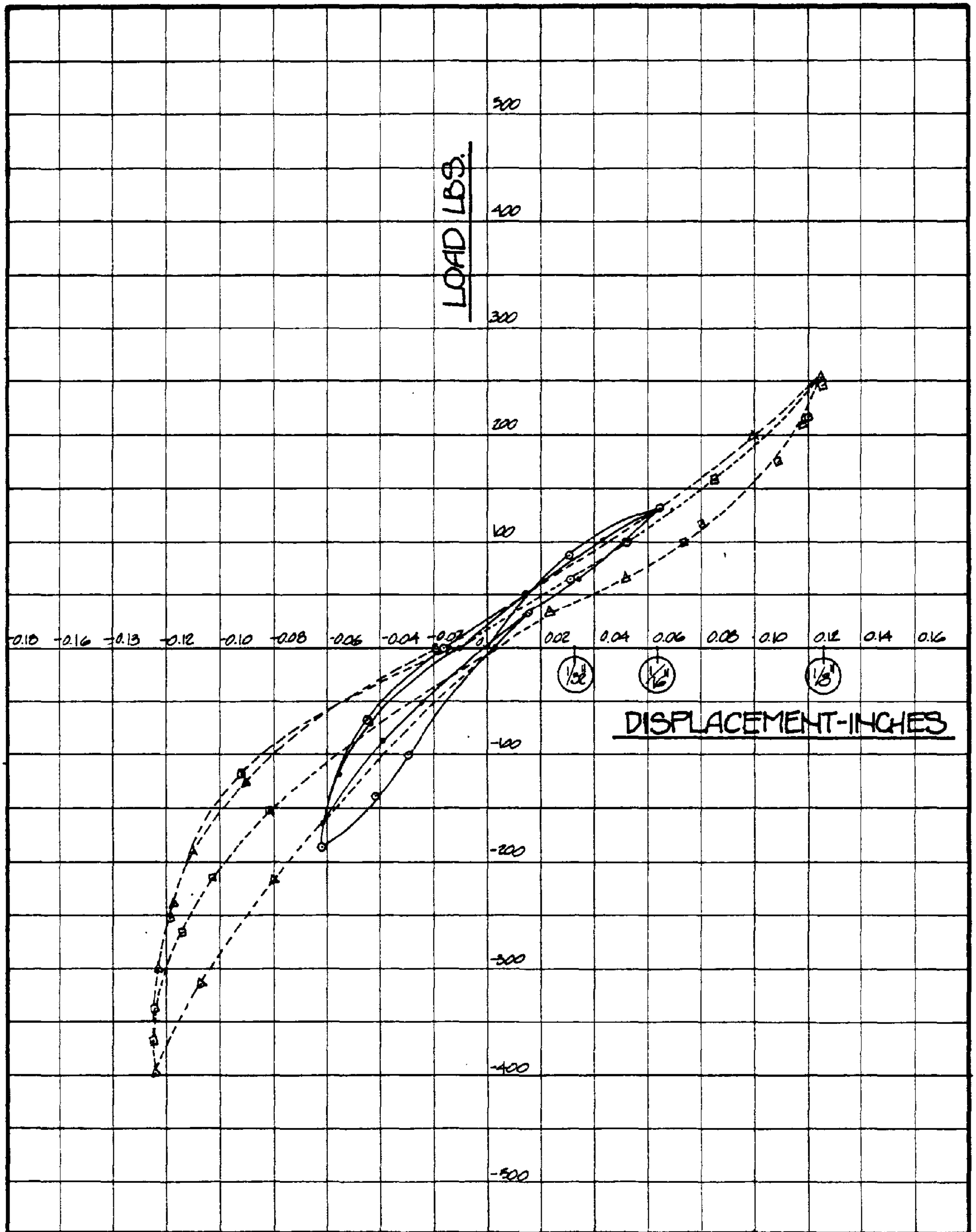
PARTITION SPECIMEN P8A
LOAD-DISPLACEMENT CURVES

FIG. 30

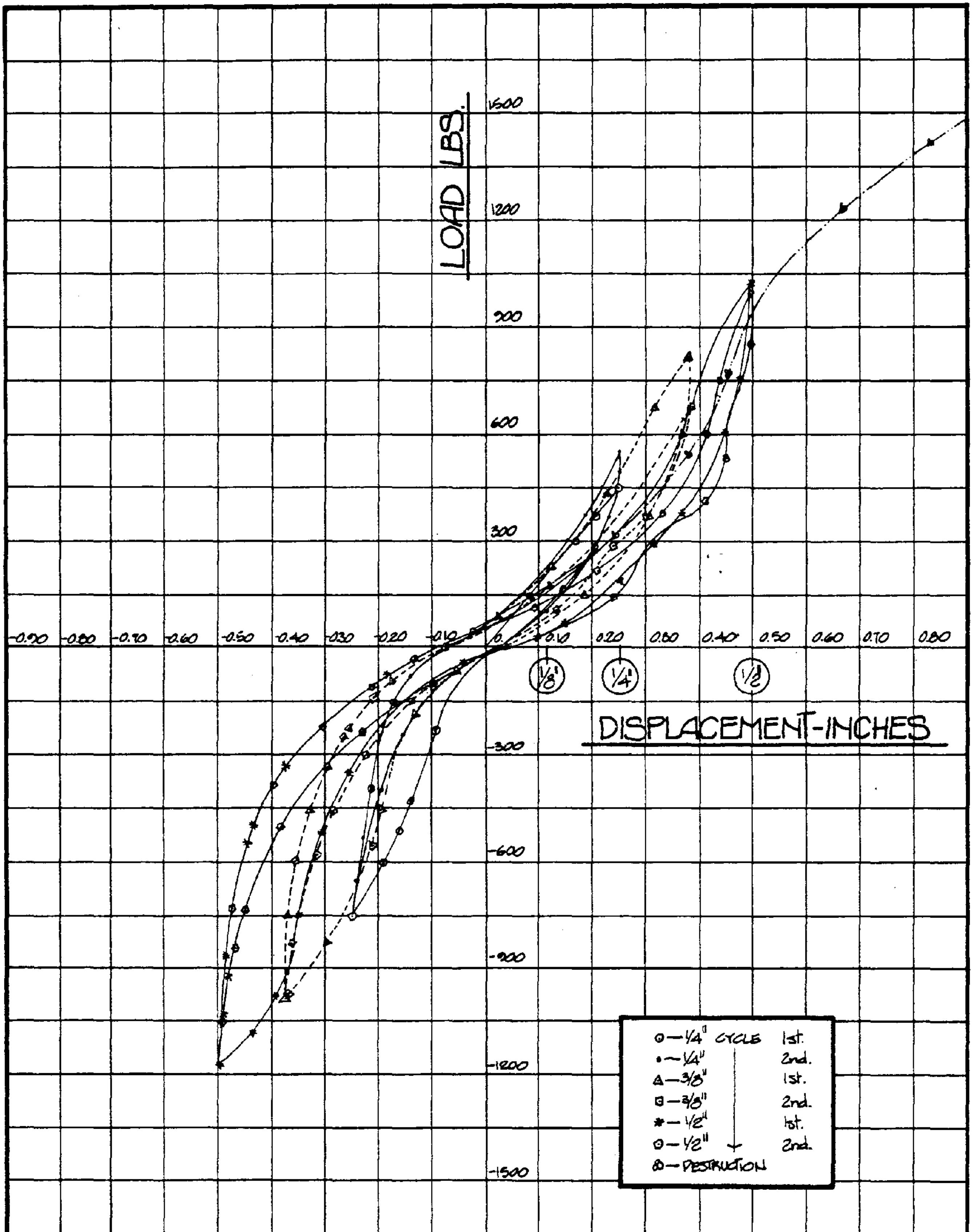


PARTITION SPECIMEN P8A
LOAD-DISPLACEMENT CURVES.

FIG. 31

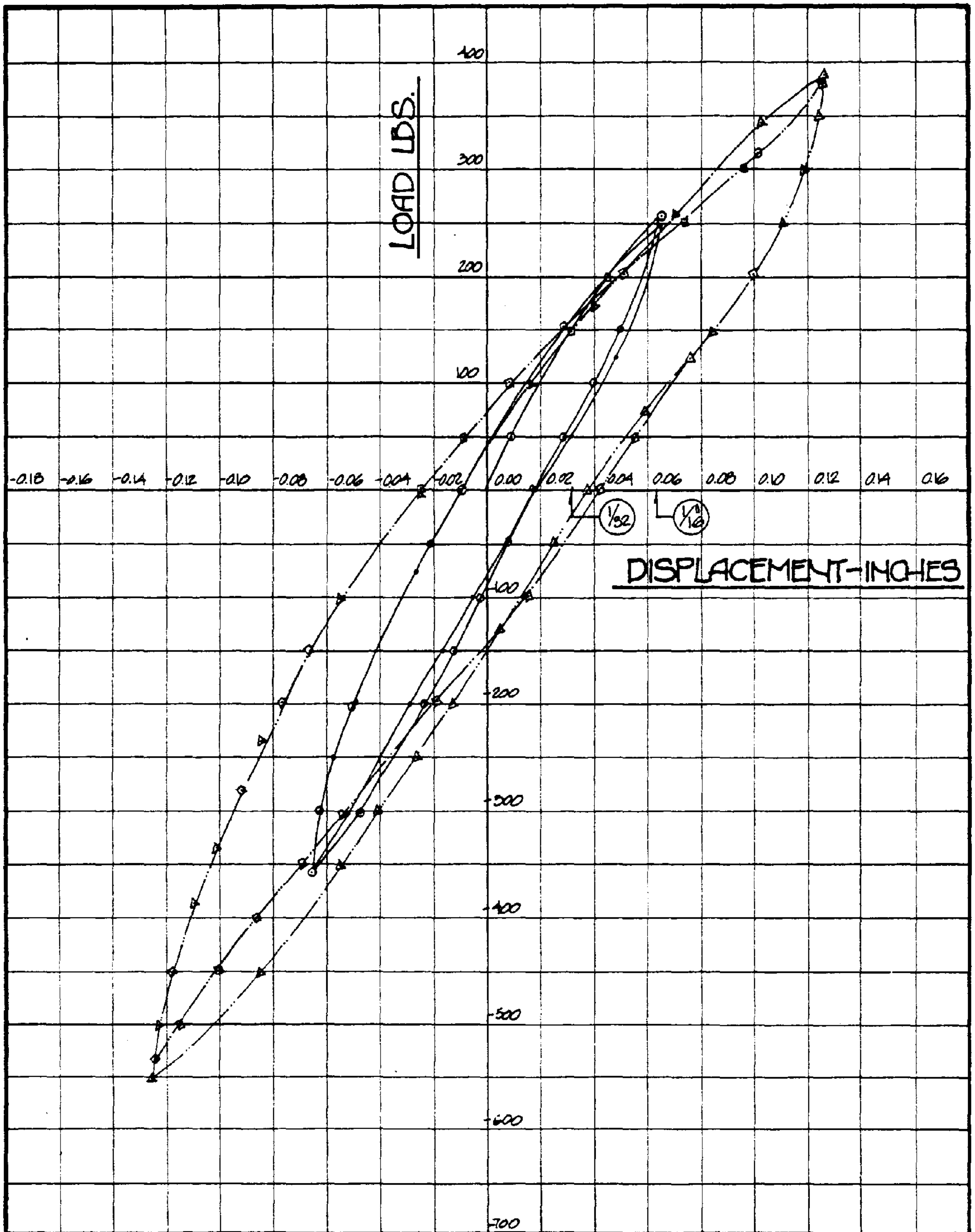


PARTITION SPECIMEN P9 LOAD-DISPLACEMENT CURVES	○ – 1ST CYCLE @ 1/16" • – 2ND " @ 1/16" △ – 1ST " @ 1/8" □ – 2ND " @ 1/8"	FIG. 32



PARTITION SPECIMEN P9
LOAD-DISPLACEMENT CURVES

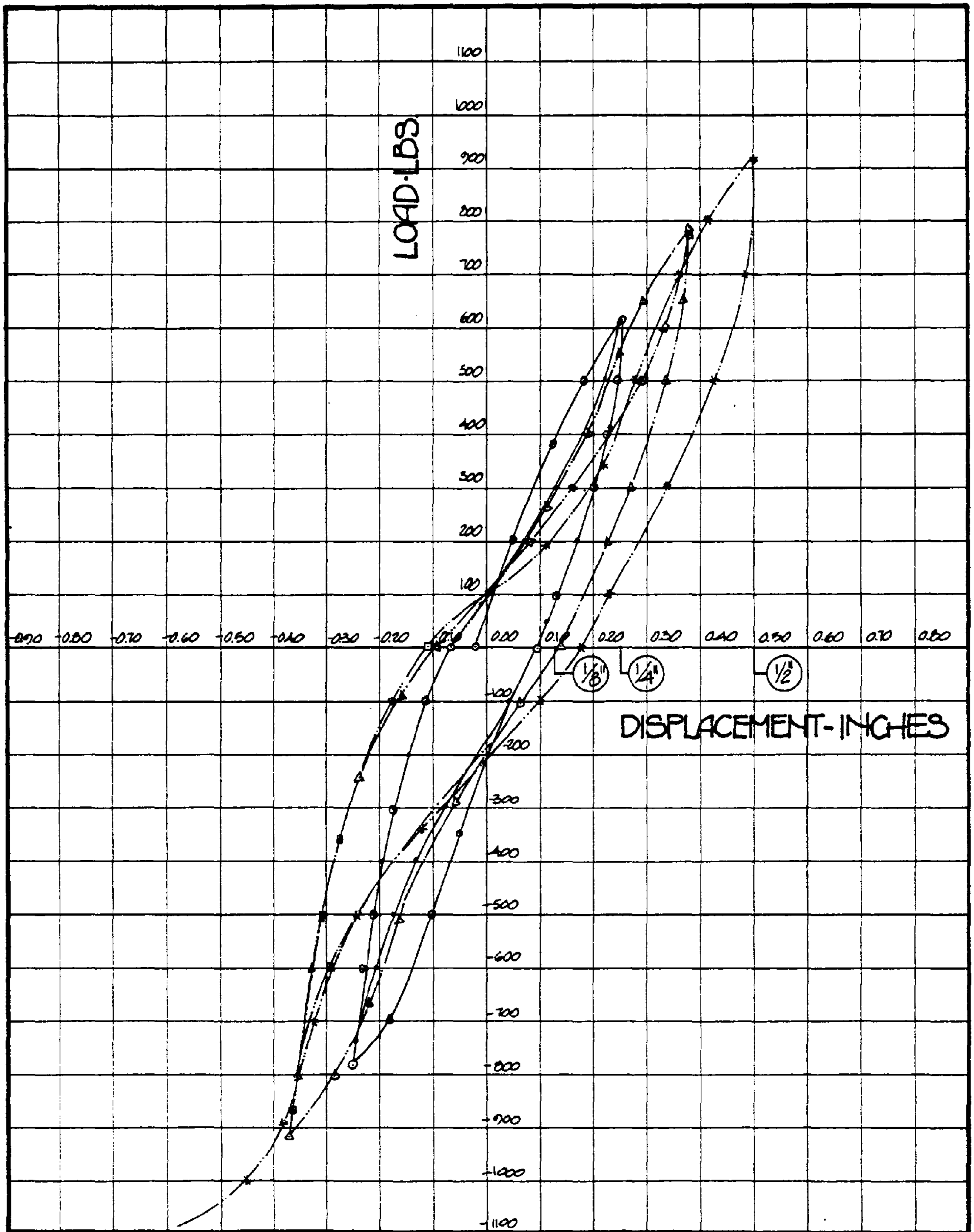
FIG. 33



PARTITION SPECIMEN P10
LOAD-DISPLACEMENT CURVES

Symbol	Cycle	
⊙	1/16"	1ST
•	1/16"	2ND
▲	1/8"	1ST
⊡	1/8"	2ND

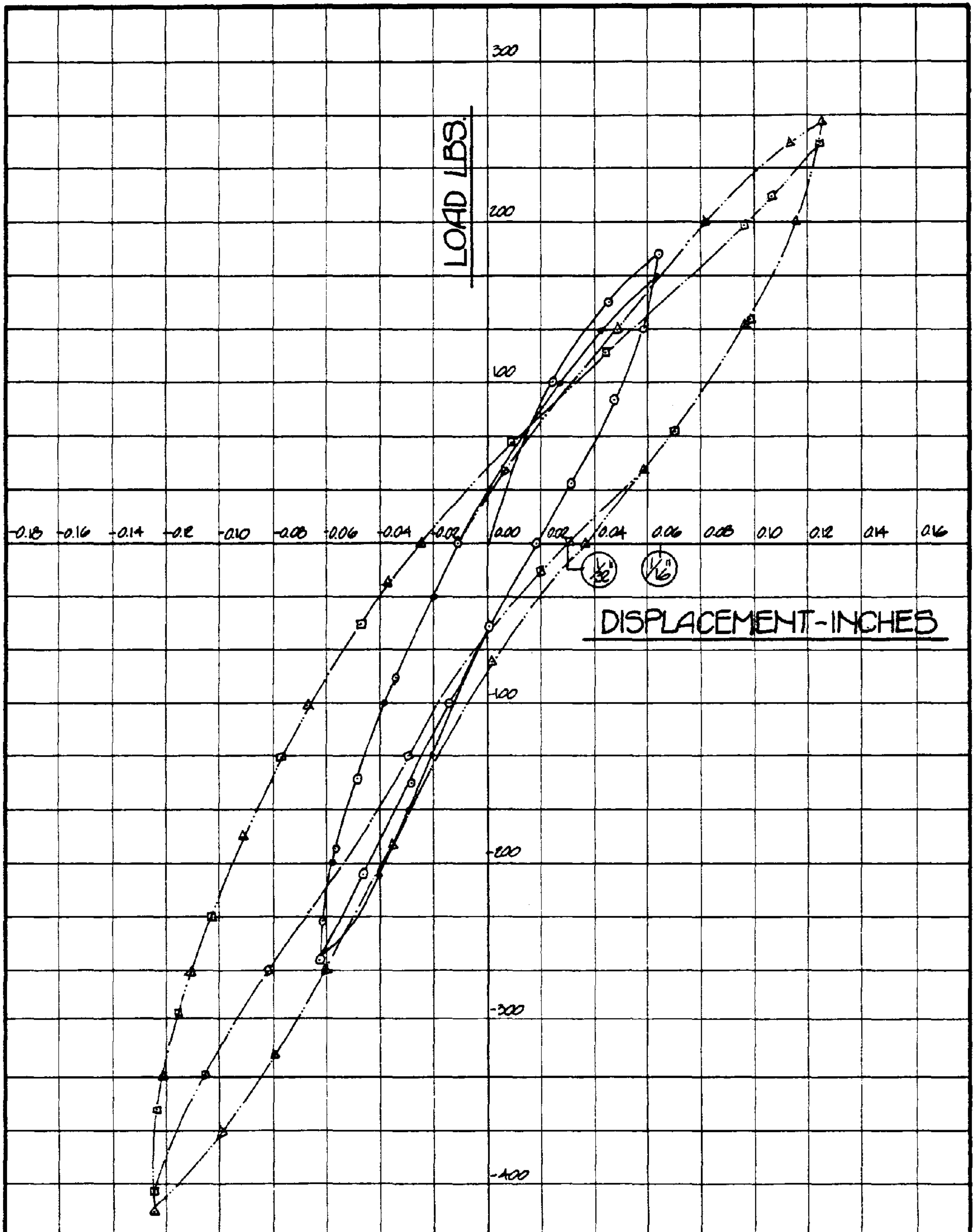
FIG. 34



PARTITION SPECIMEN P10
LOAD-DISPLACEMENT CURVES

○	1/4" CYCLES	1ST
•	1/4"	2ND
△	3/8"	1ST
□	3/8"	2ND
*	1/2" CYCLES	

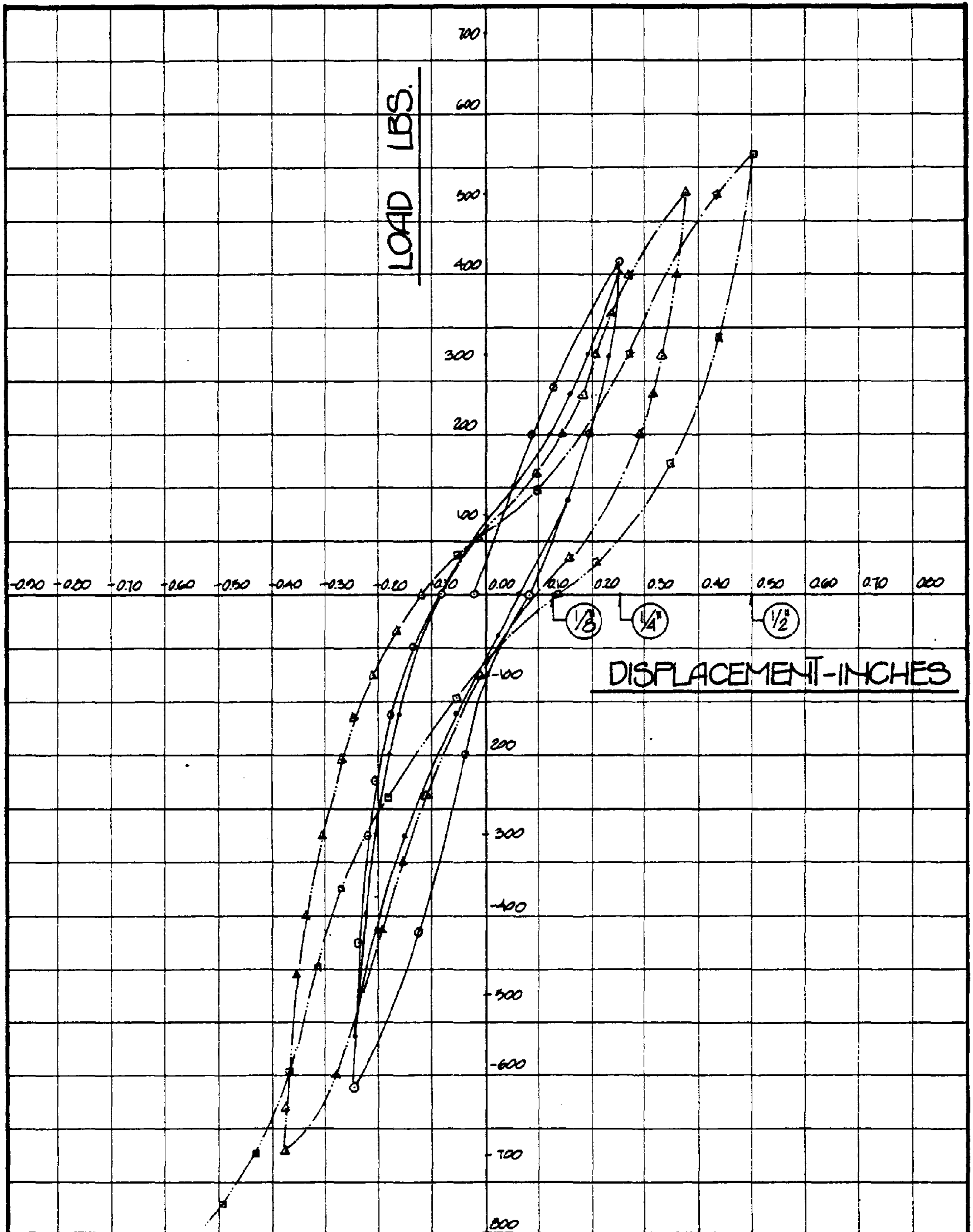
FIG. 35



PARTITION SPECIMEN P11
LOAD-DISPLACEMT CURVES

⊙ – 1/16" CYCLE 1ST
• – 1/16" 2ND
△ – 1/8" 1ST
⊡ – 1/8" 2ND

FIG. 36



PARTITION SPECIMEN P11 LOAD-DISPLACENT CURVES	⊙ 1/4" CYCLE 1ST • 1/4" 2ND △ 3/8" □ 1/2"	FIG. 37

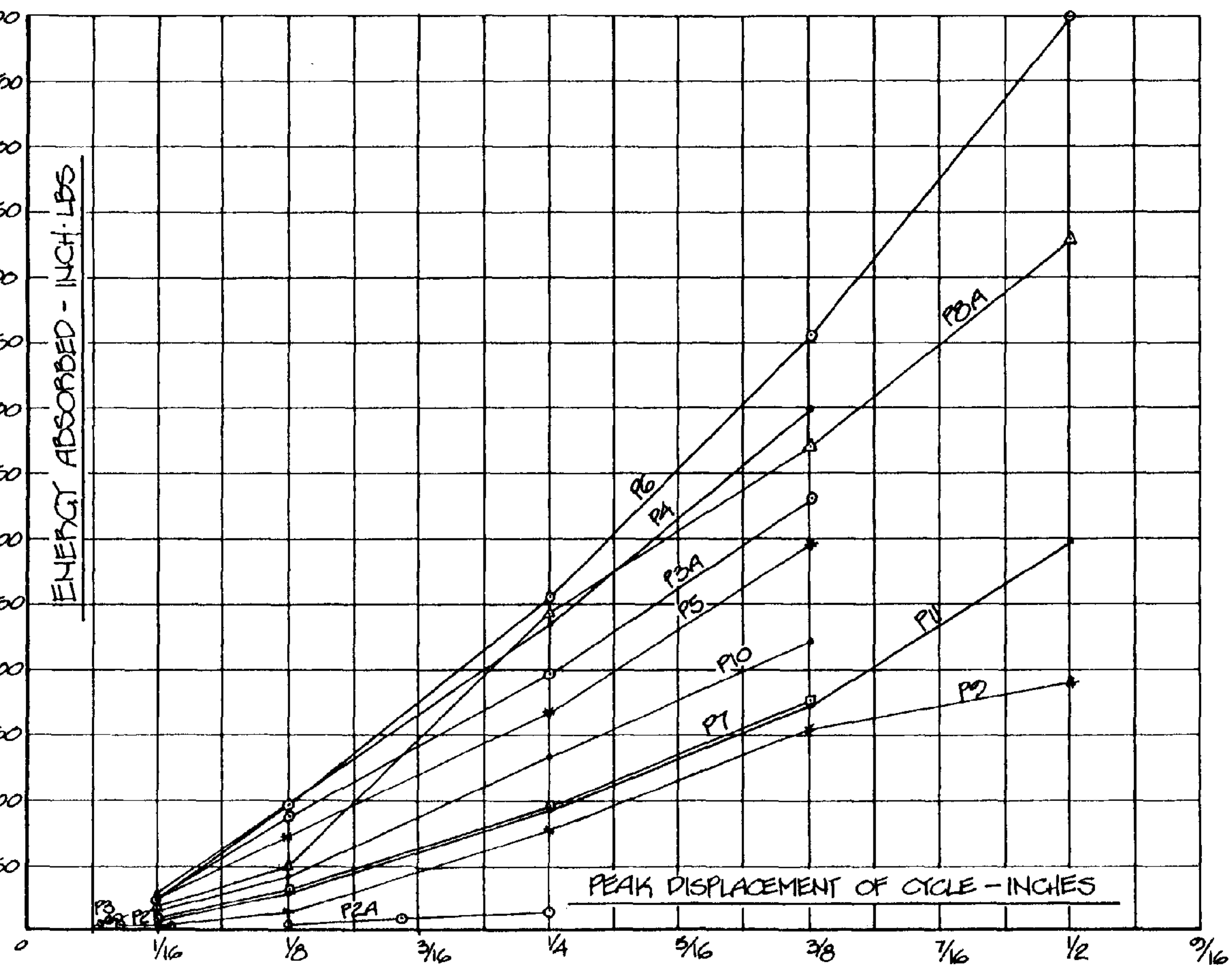
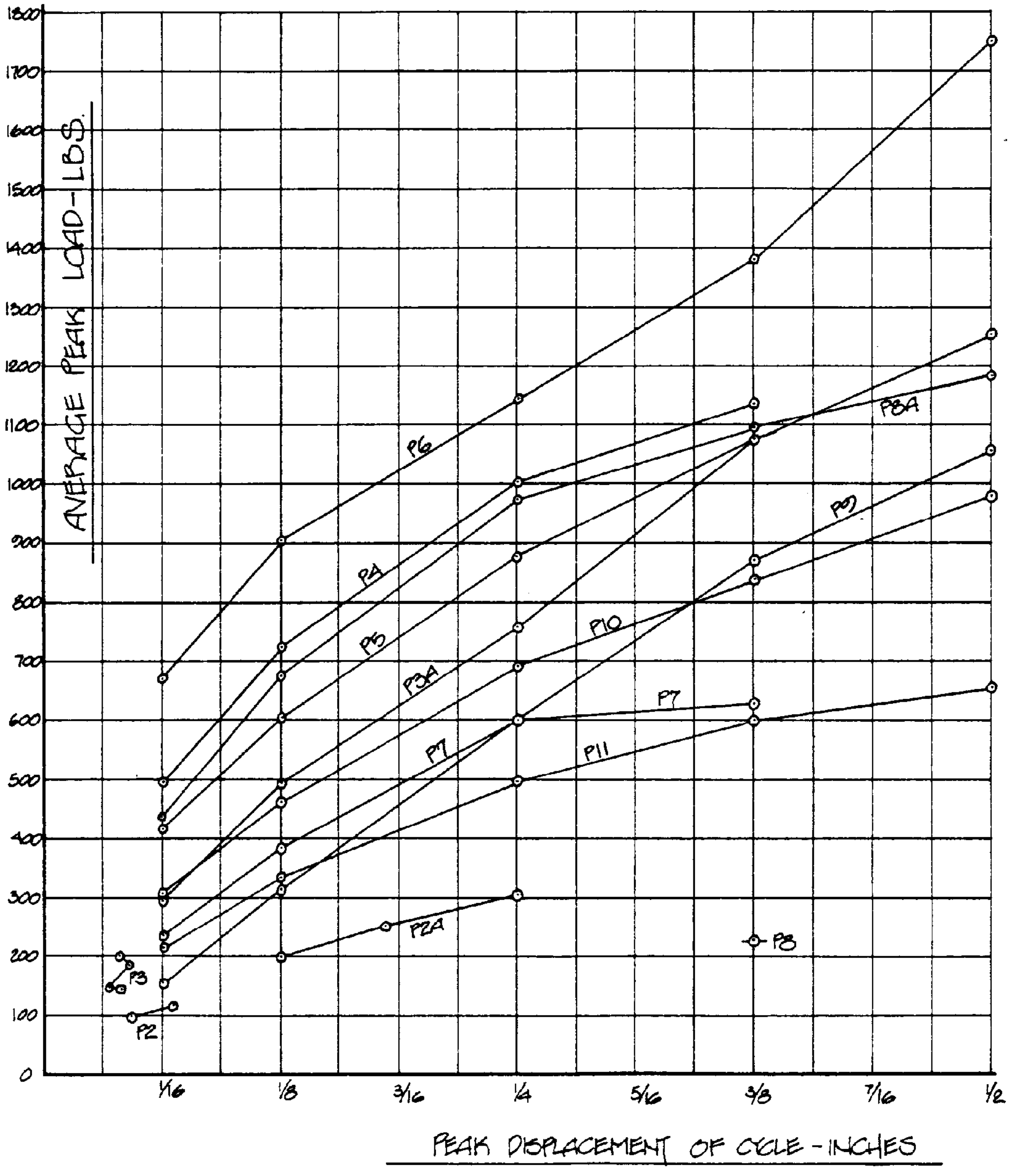


FIG. 38. ENERGY ABSORBED vs. PEAK DISPLACEMENT OF CYCLES PARTITION SPECIMENS P2-P11



AVERAGE PEAK LOAD vs. PEAK DISPLACEMENT OF CYCLE: PARTITION SPECIMENS P2-P11	FIG. 39.

APPENDIX C

PHOTOGRAPHS

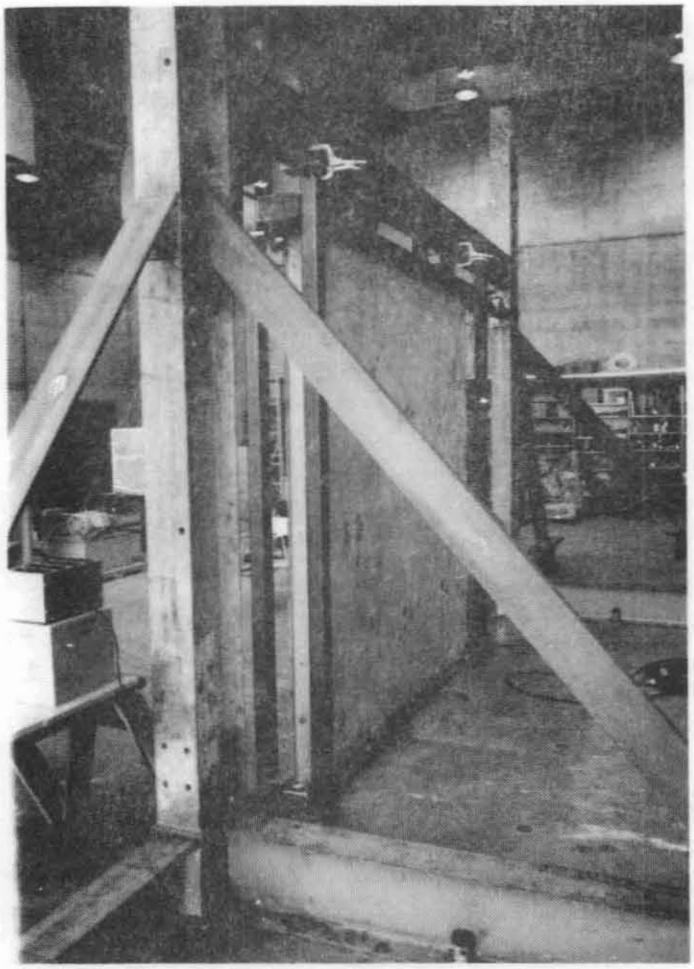


Fig. 40: Partition Racking Test Set-up--Rear View

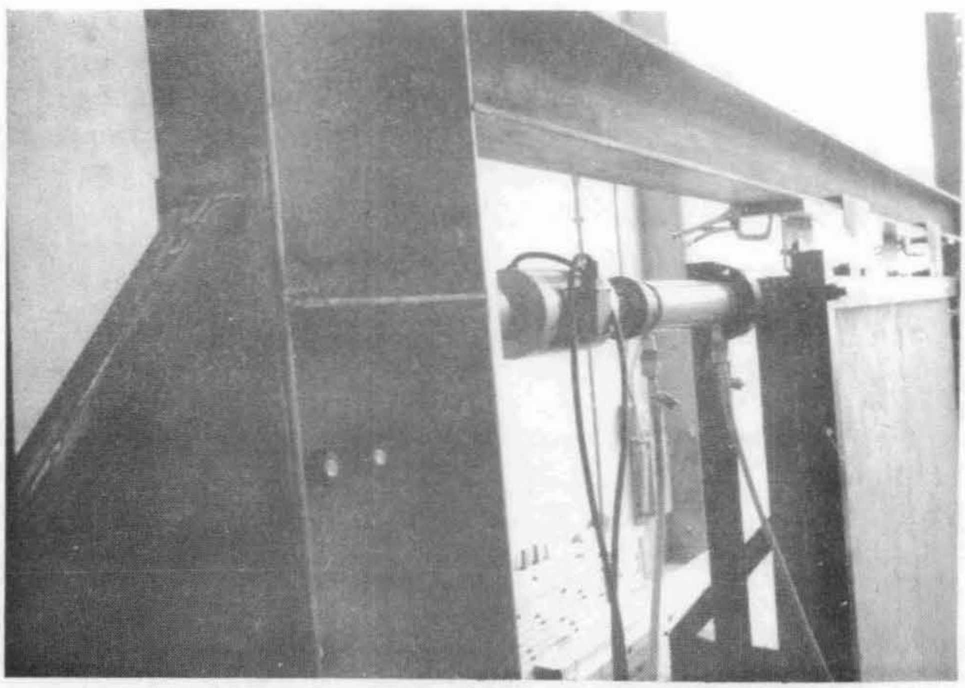


Fig. 41: Partition Racking Test Set-up: Channel Guides and Loading System

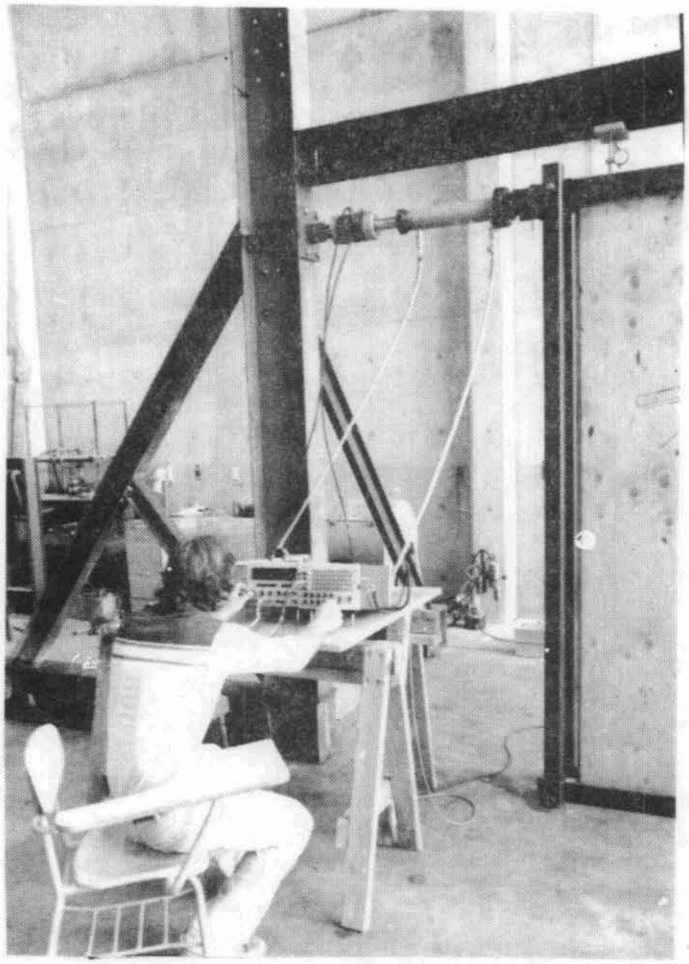


Fig. 42: Racking Test Set-up: Details of Pinned Frame & Load Application and Measurement

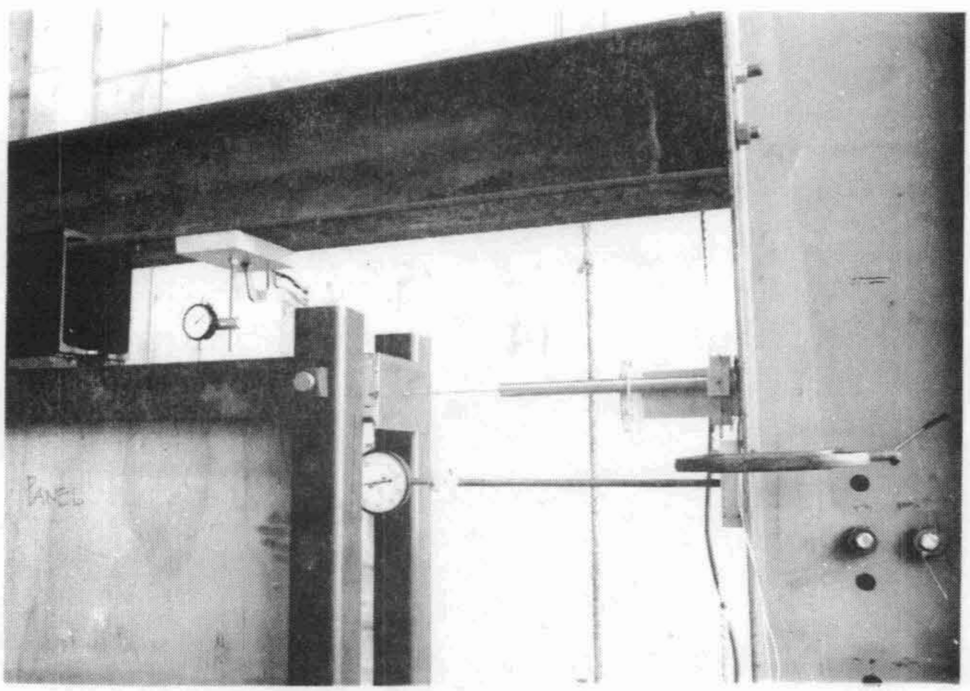


Fig. 43: Racking Test Set-up: Displacement Measurement Instruments

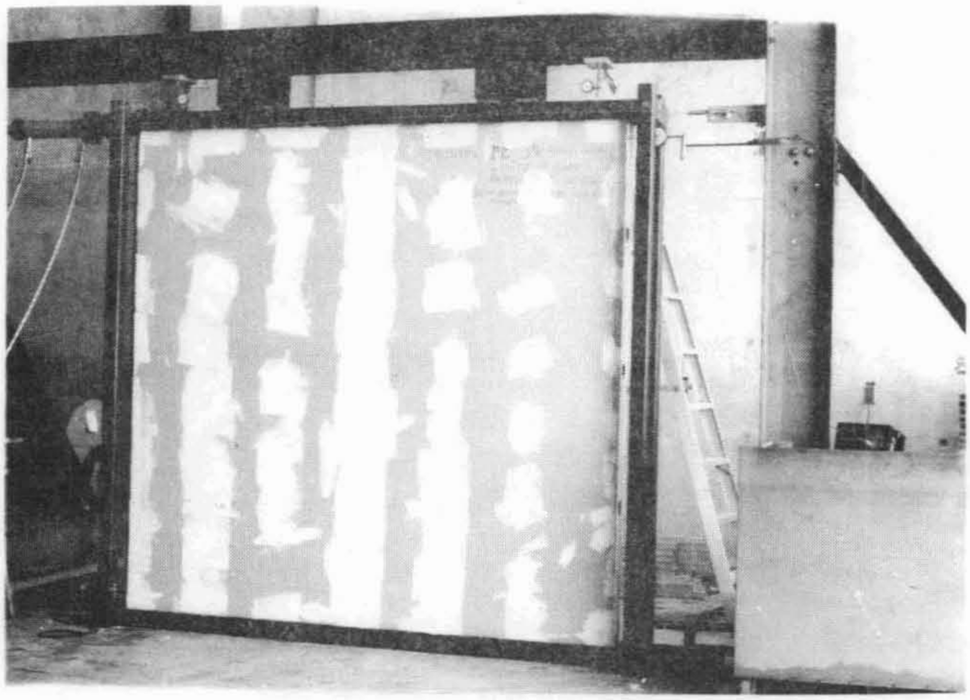


Fig. 44: Partition Test Specimen P2

Fig. 45: Partition Test Specimen P2: Slippage @ Top Runner

Fig. 46: Partition Test Specimen P2: Failure @ Loading End Stud @ Bottom Runner

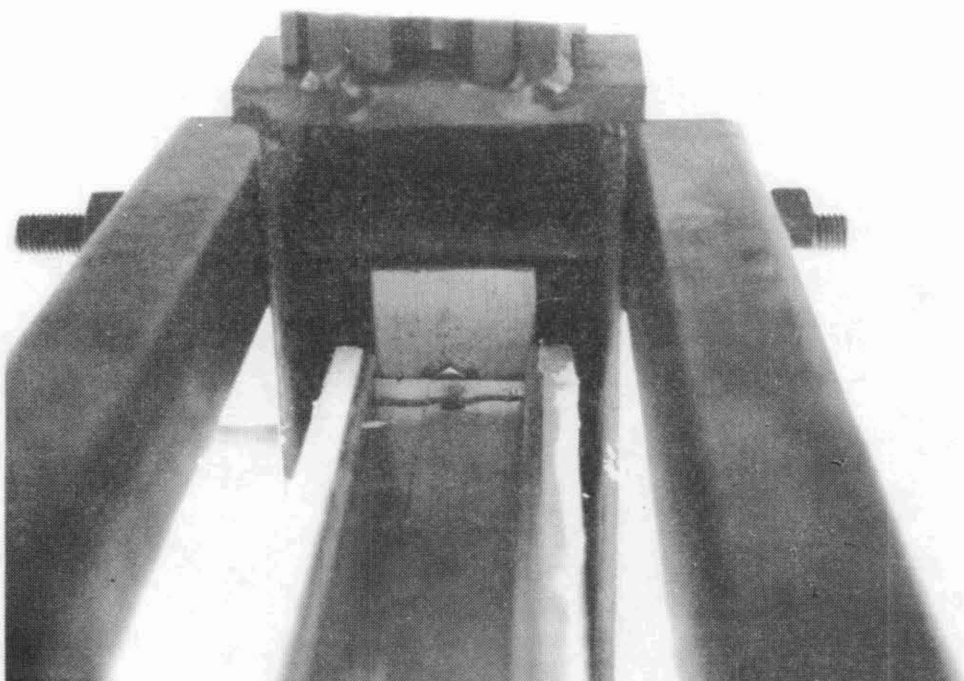


Fig. 47: Partition Test Specimen P2: Typical Slippage @ Top Runner

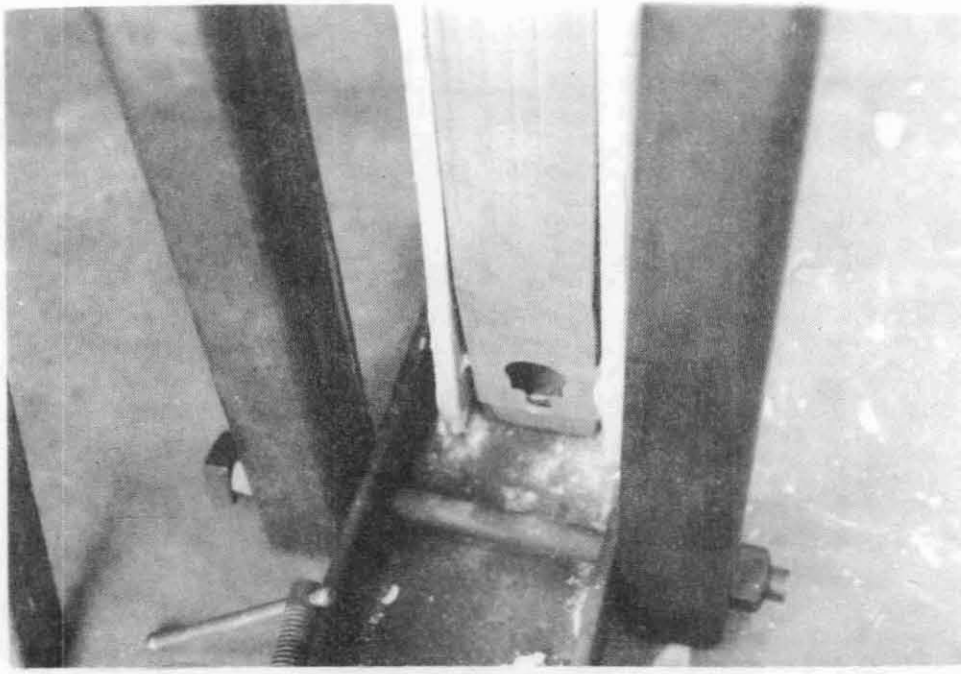


Fig. 48: Partition Test Specimen P2A: Typical Failure at End Stud

Fig. 49: Partition Test Specimen P2A: Typical Stud Failure

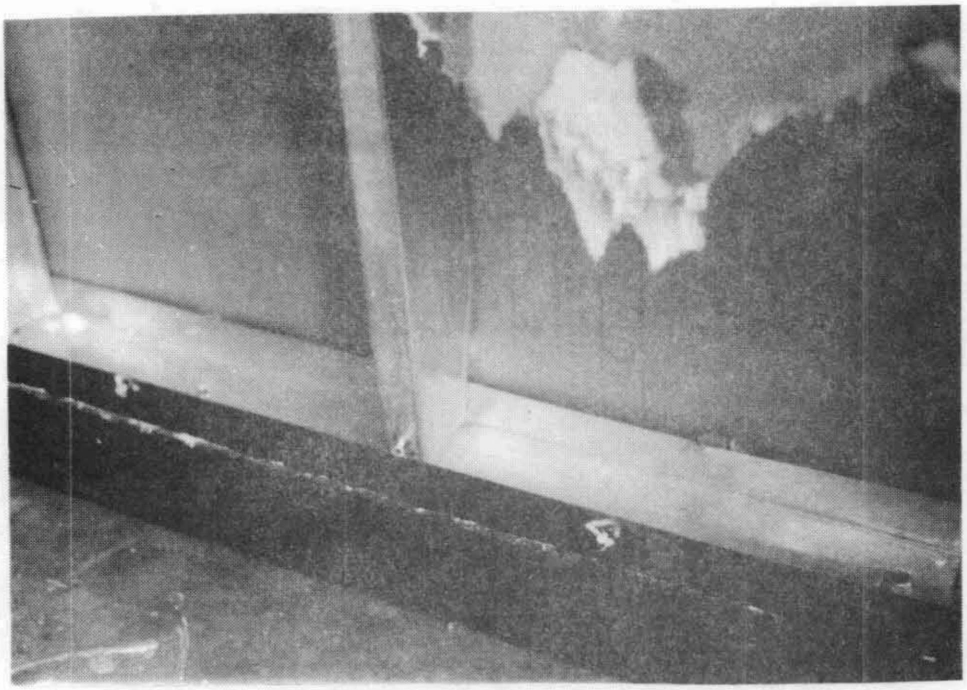


Fig. 50: Partition Test Specimen P2A: Typical Interior Stud Failure

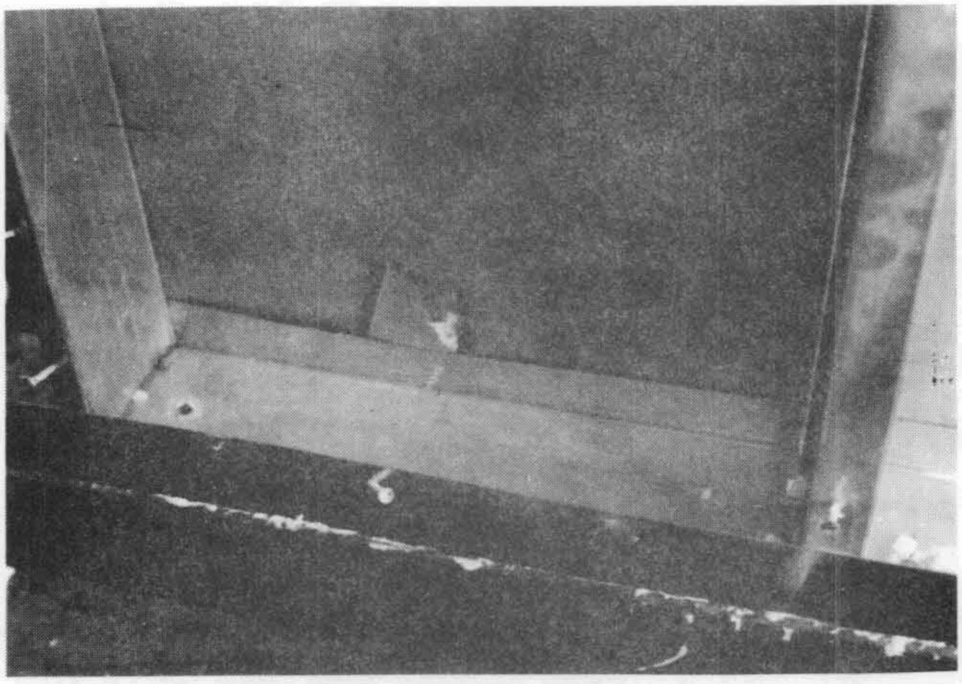


Fig. 51: Partition Test Specimen P2A: Gypboard Failure @ Interior Face

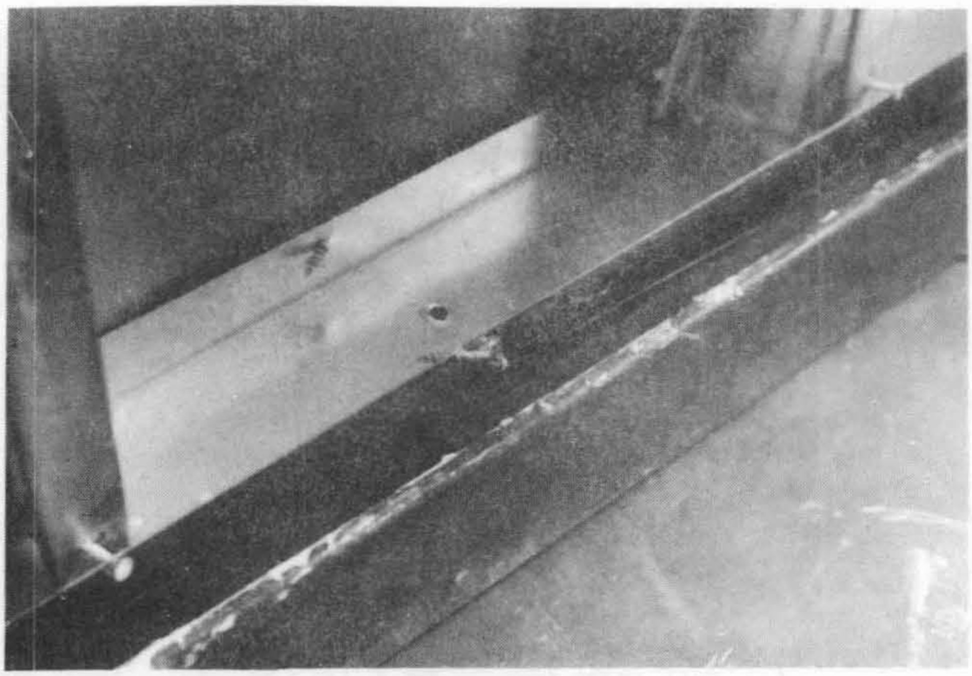


Fig. 52: Partition Test Specimen P2A: Typical Screw Deformation @ End of Test

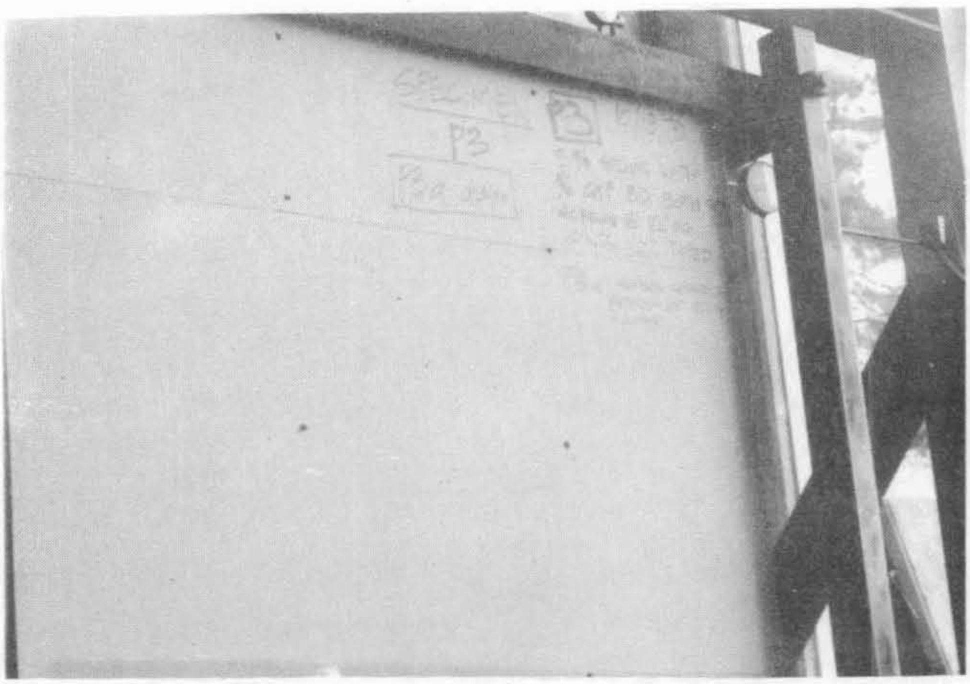


Fig. 53: Partition Test Specimens P3 and P3A

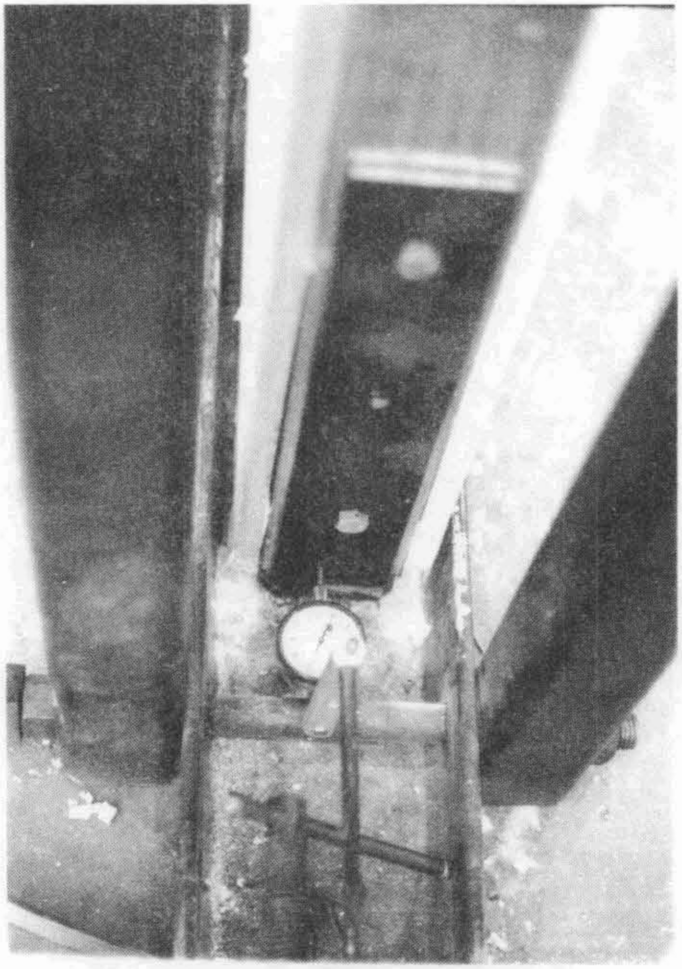


Fig. 54: Typical Uplift Restraint Strap
Partition Test Specimen P3A

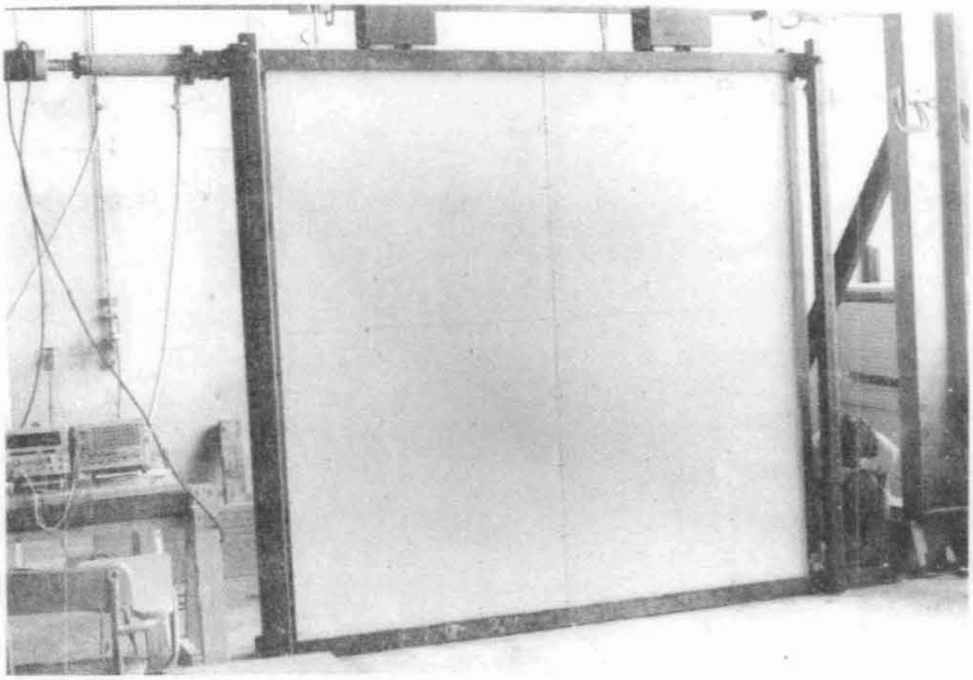


Fig. 55: Partition Test Specimen P3

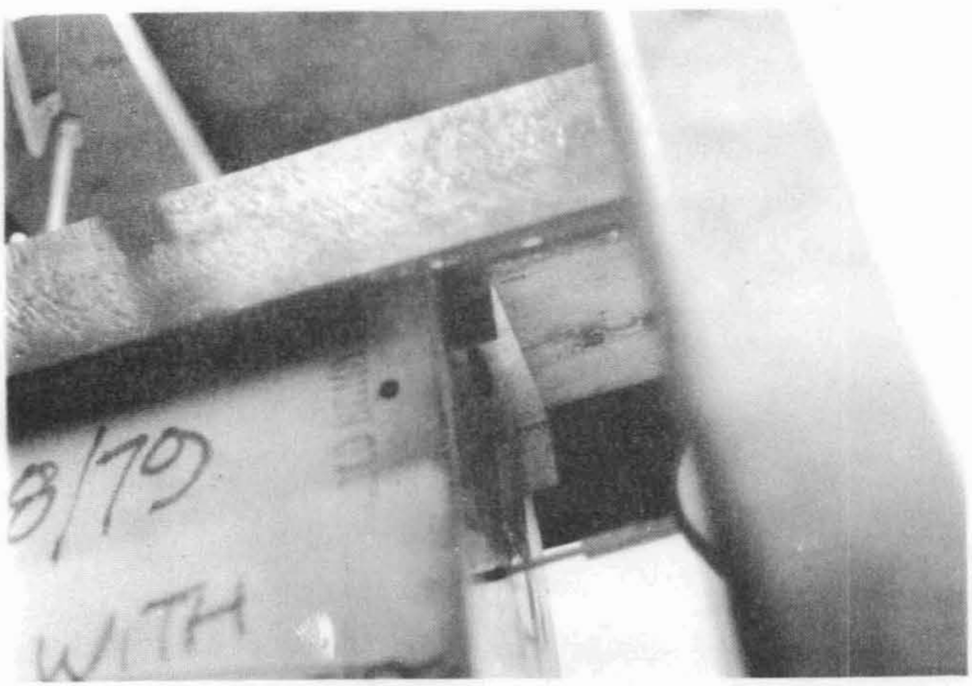


Fig. 56: Partition Test Specimen P3: Typical Failure @ Top Runner

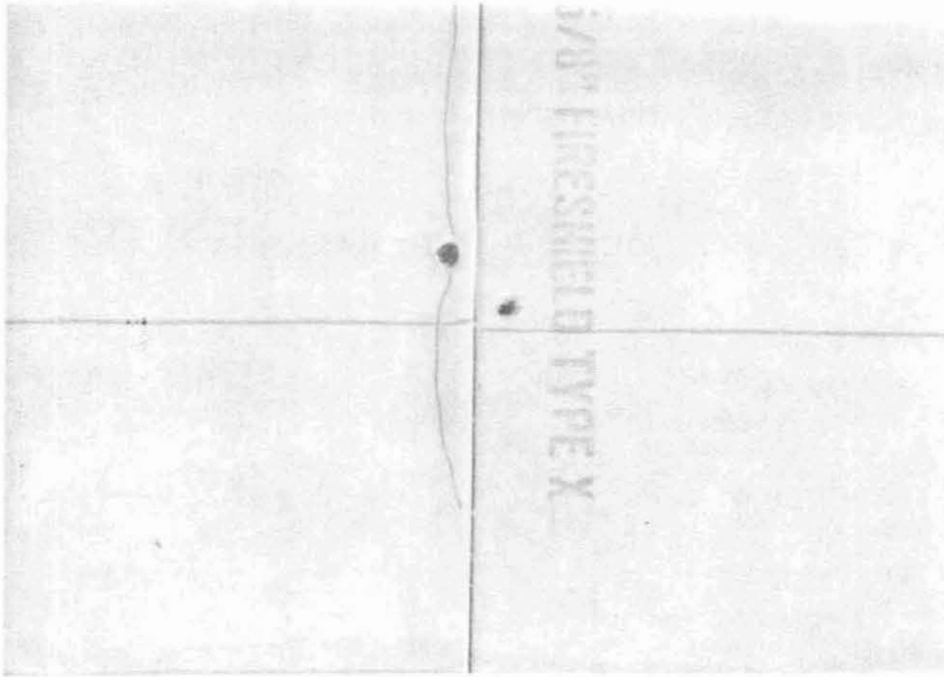


Fig. 57: Partition Test Specimen P3A: Typical Slippage @ Vertical Joint and Wrinkling of Gypboard @ Failure

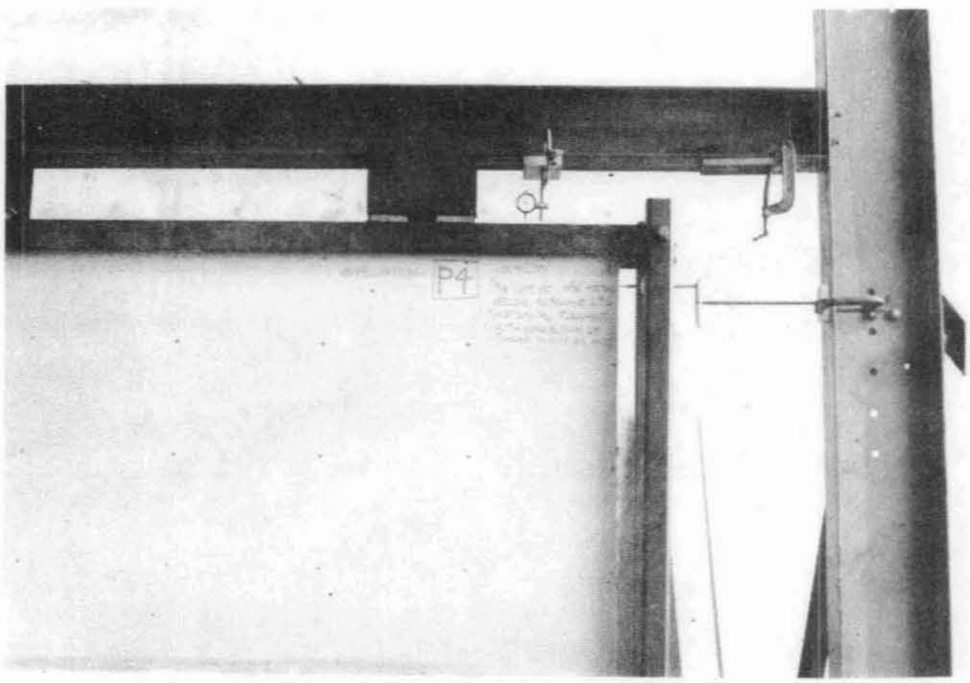


Fig. 58: Partition Test Specimen P4

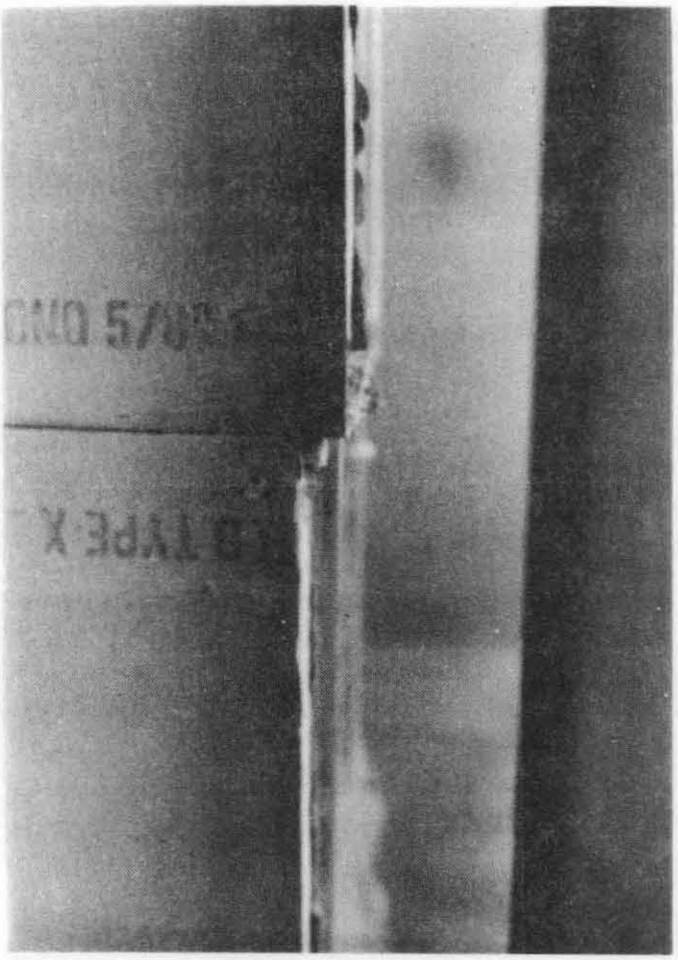


Fig. 59: Partition Specimen P4: Typical Slippage Failure @ Horizontal Joint

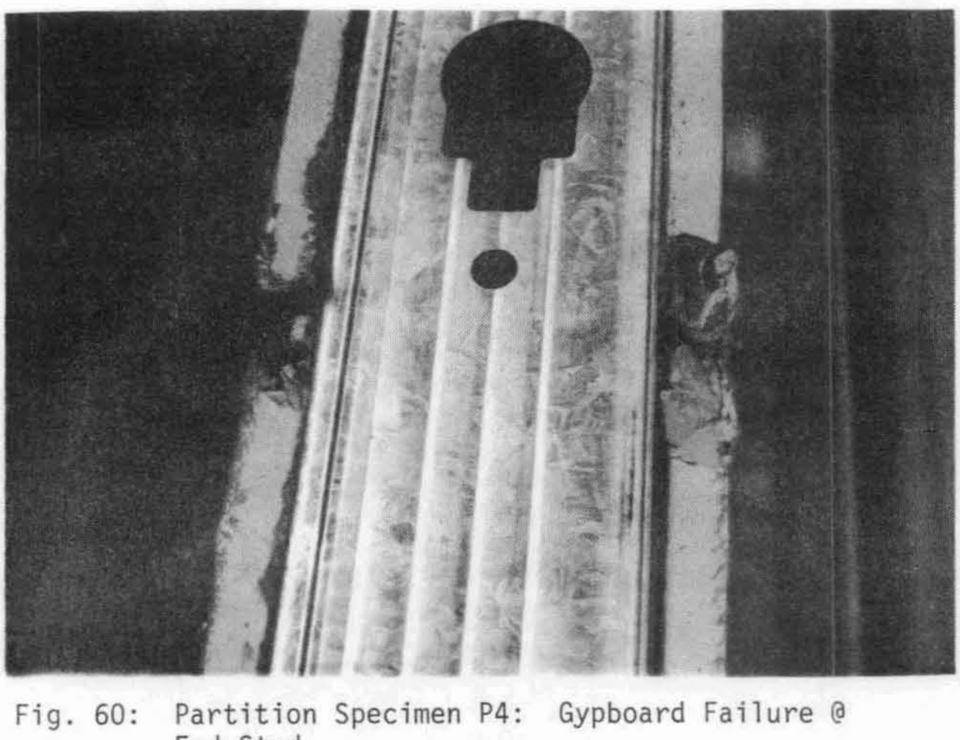


Fig. 60: Partition Specimen P4: Gypboard Failure @ End Stud

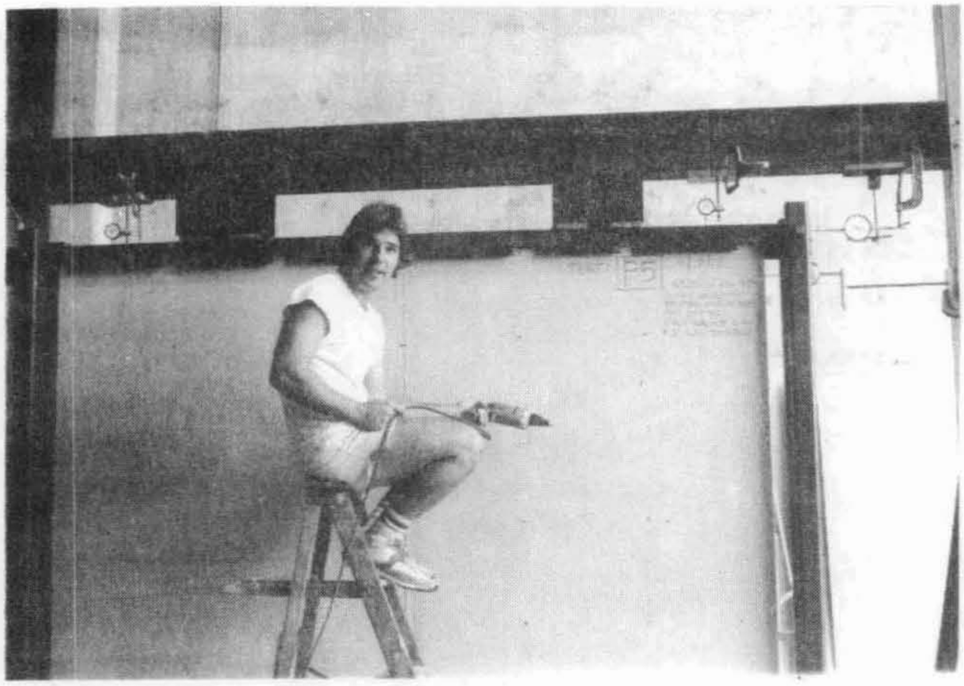


Fig. 61: Partition Test Specimen P5

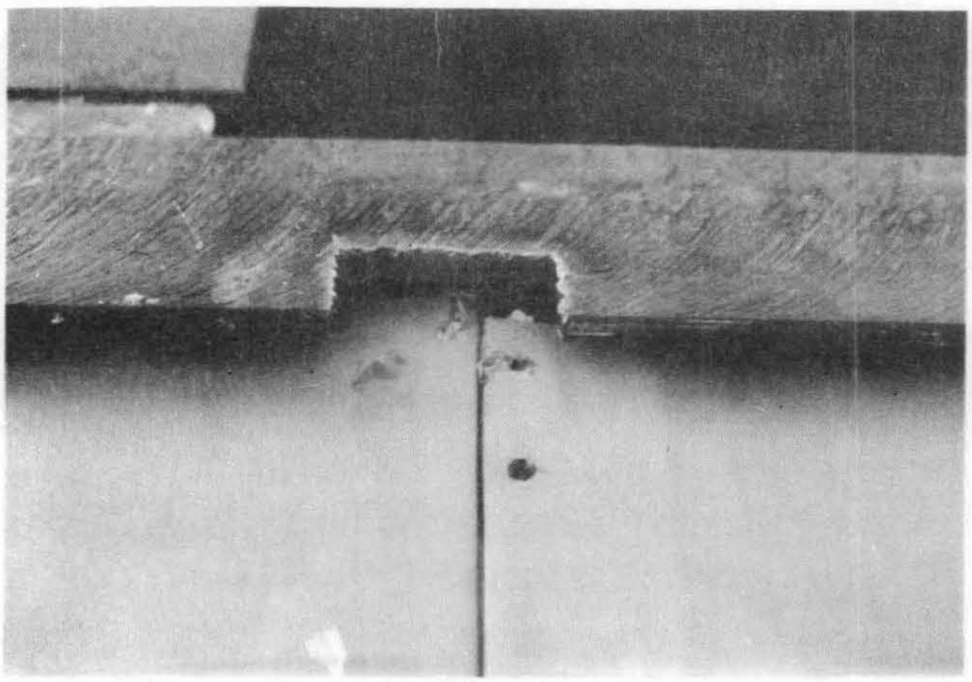


Fig. 62: Partition Test Specimen P5: Typical Slippage Failure @ Vertical Joint

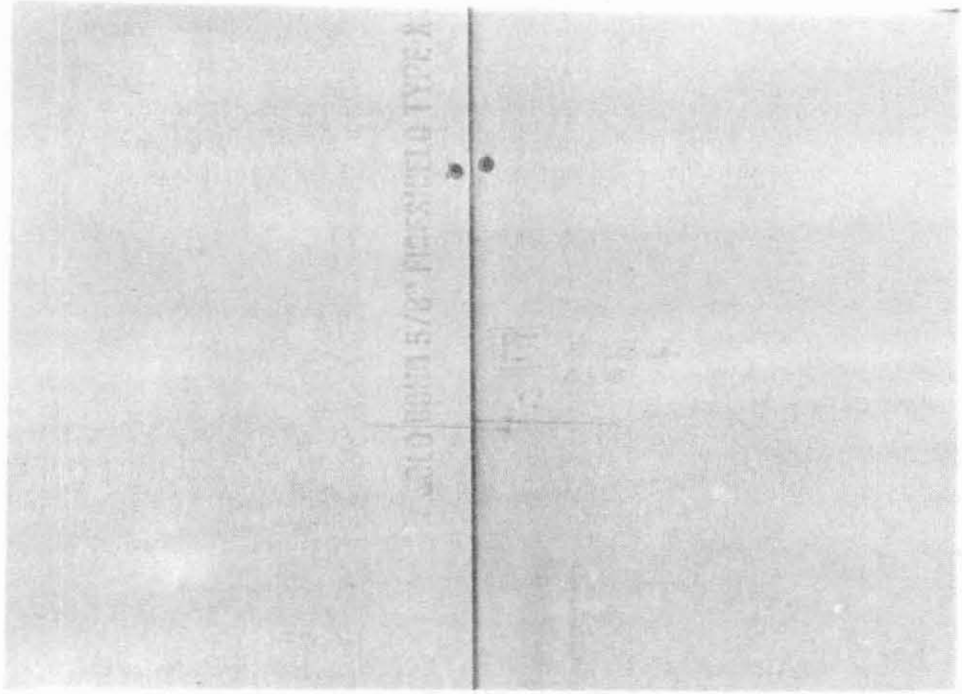


Fig. 63: Partition Test Specimen P5: Typical Slippage @ Vertical Joint

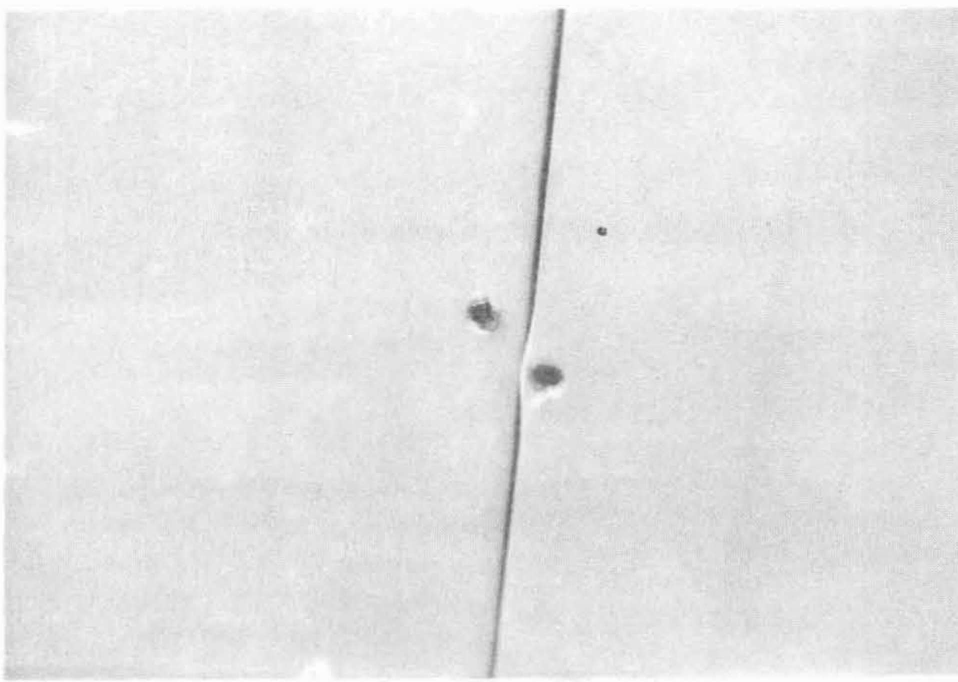


Fig. 64: Partition Test Specimen P5: Typical Damage @ Screw Location @ Vertical Joint

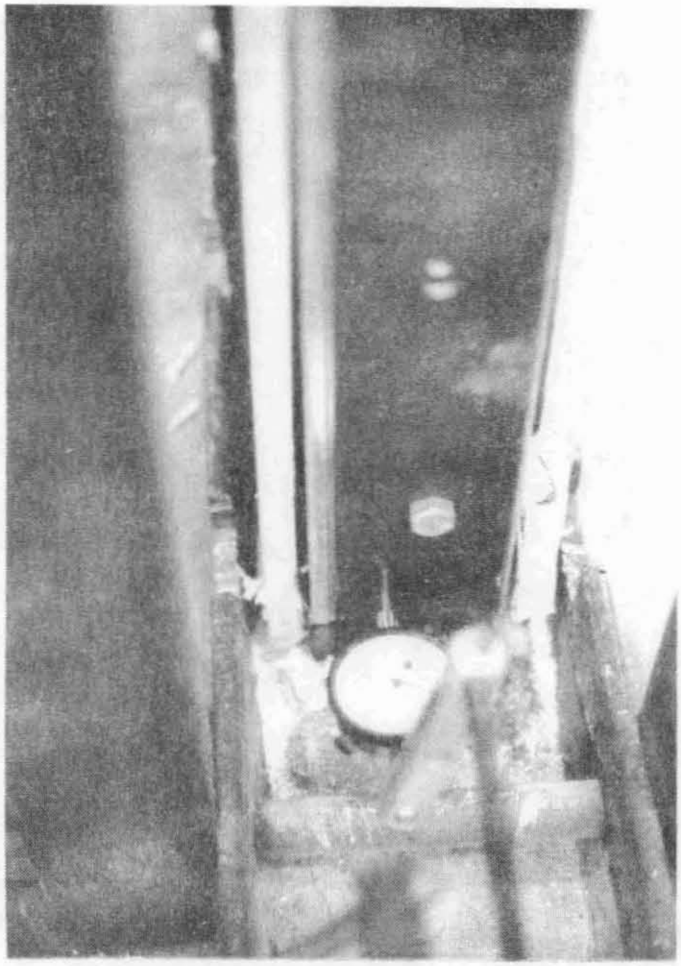


Fig. 65: Partition Test Specimen P5:
Uplift Restraint Strap

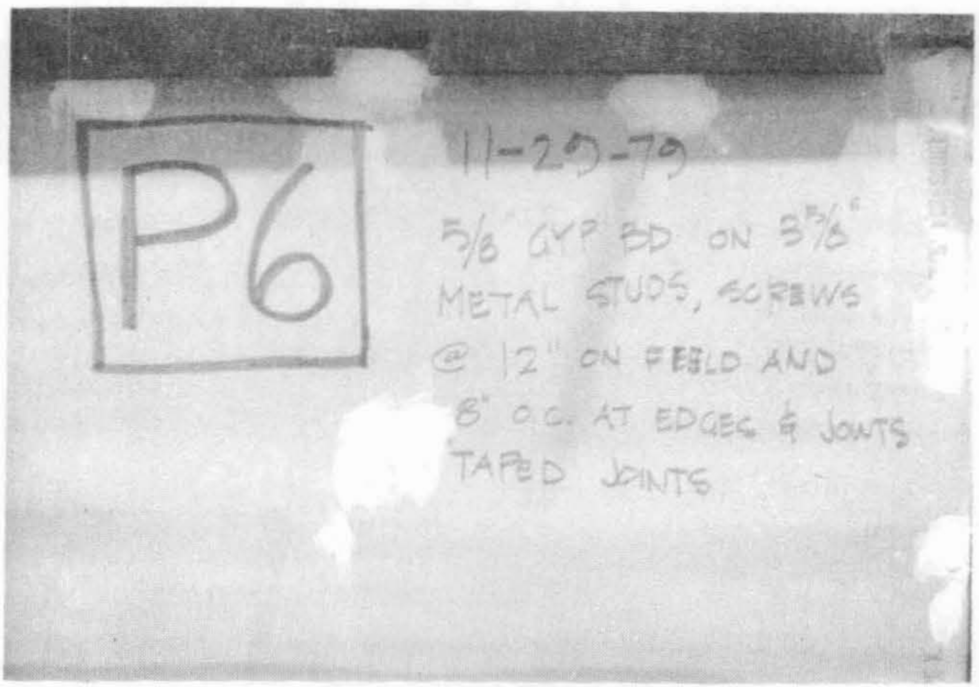


Fig. 66: Partition Test Specimen P6

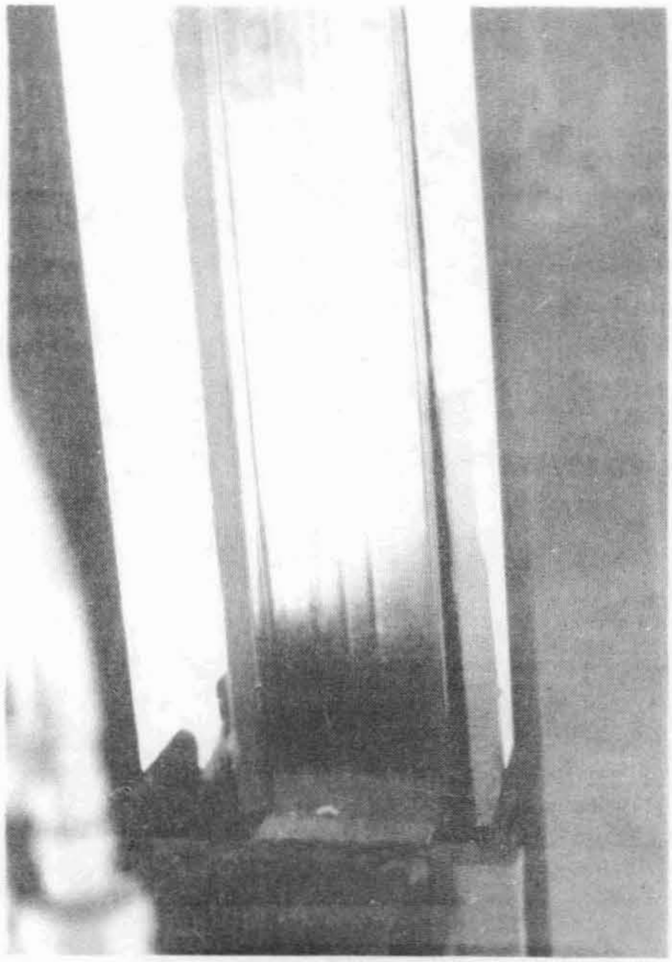


Fig. 67: Partition Test Specimen P6: Separation of Gypboard & End Stud @ Failure

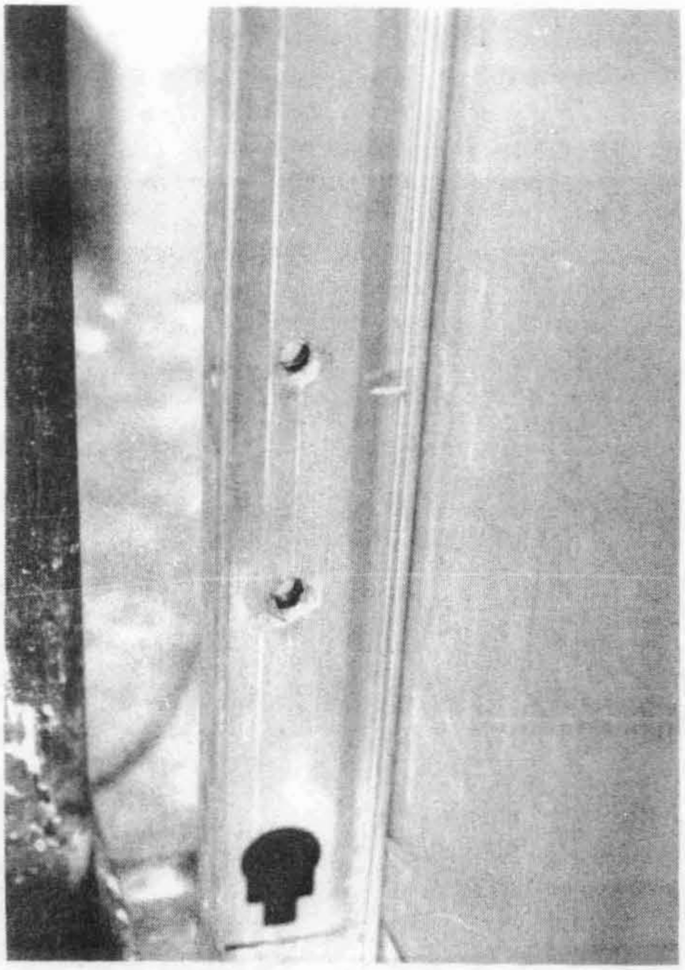


Fig. 68: Partition Test Specimens P5 & P6: Typical Bolt Hole Deformations @ Uplift Restraint Strap

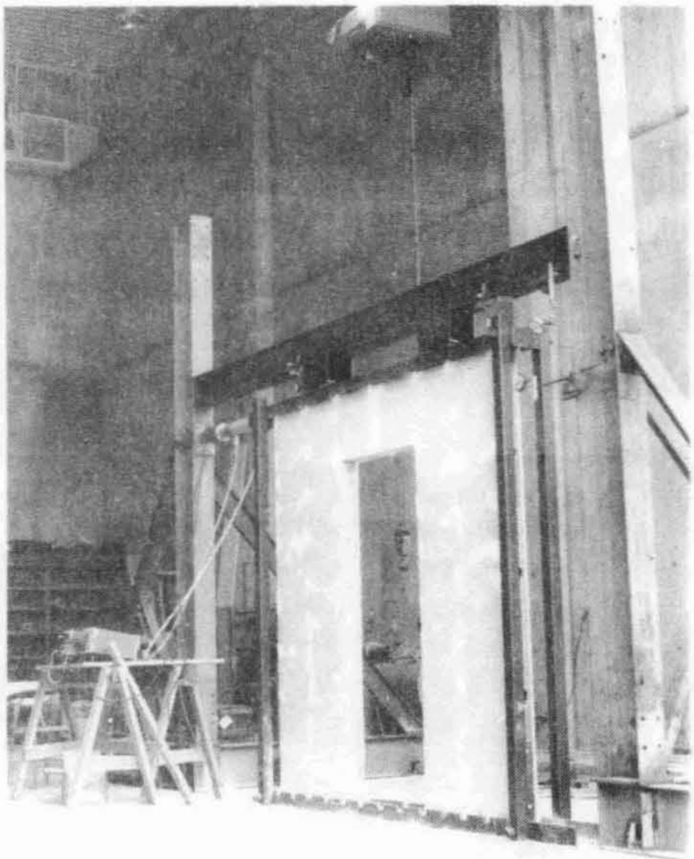


Fig. 69: Partition Test Specimen P7

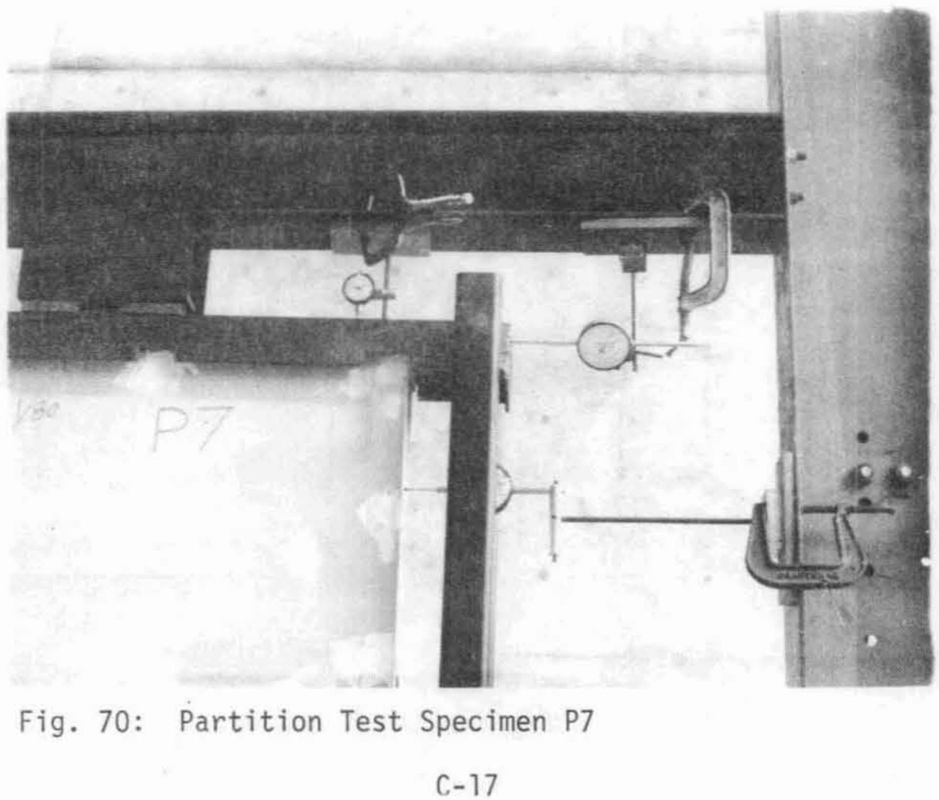


Fig. 70: Partition Test Specimen P7

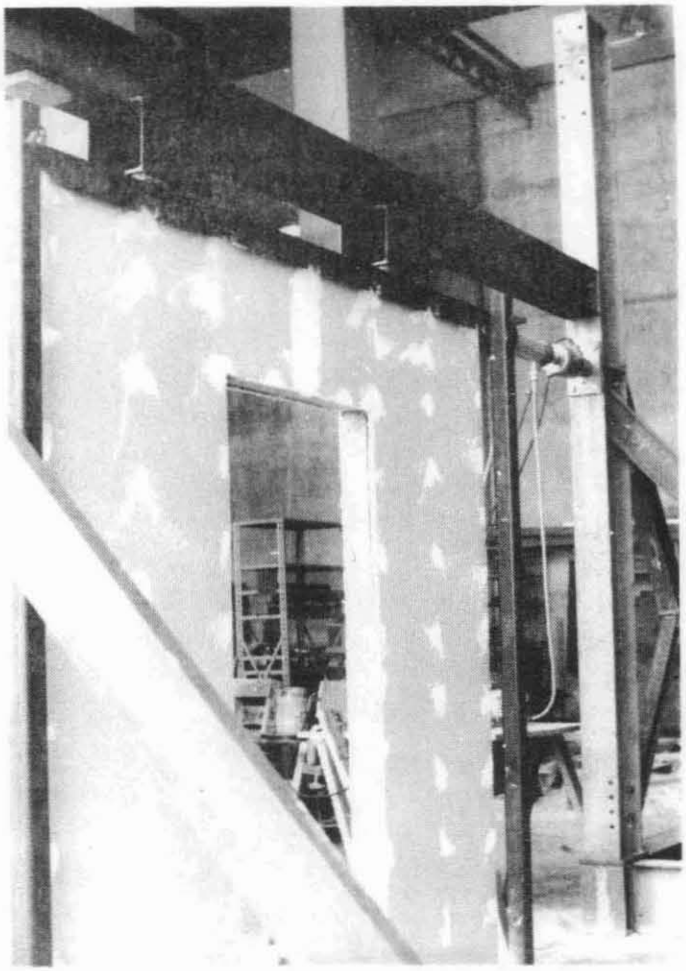


Fig. 71: Partition Test Specimen P7

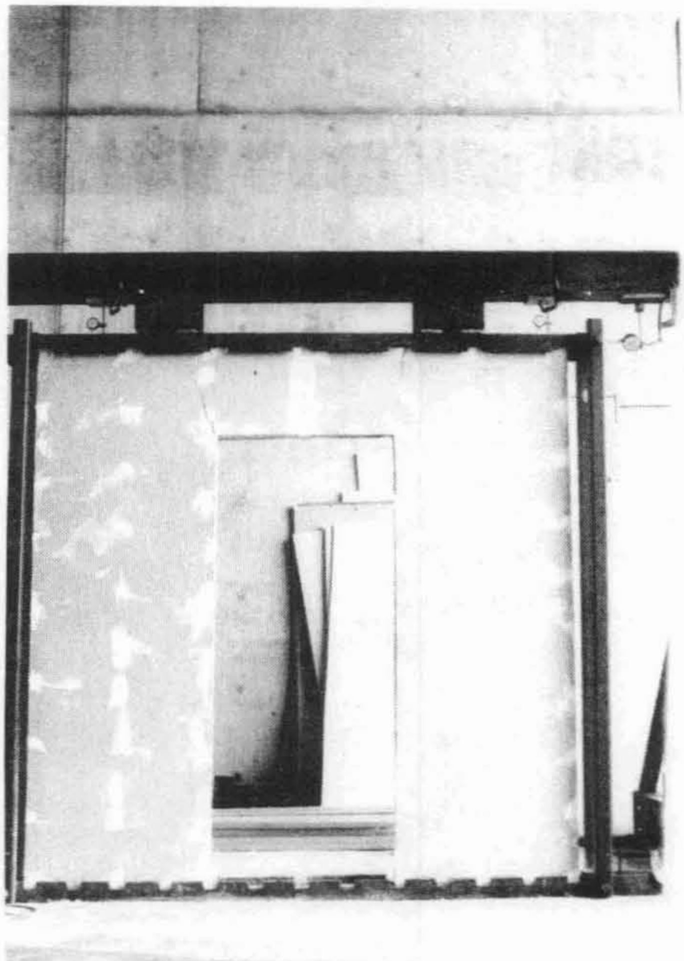


Fig. 72: Partition Test Specimen P7:
Typical Failure Above Door Opening

Fig. 73: Partition Test Specimen P7:
Uplift Restraint Strap

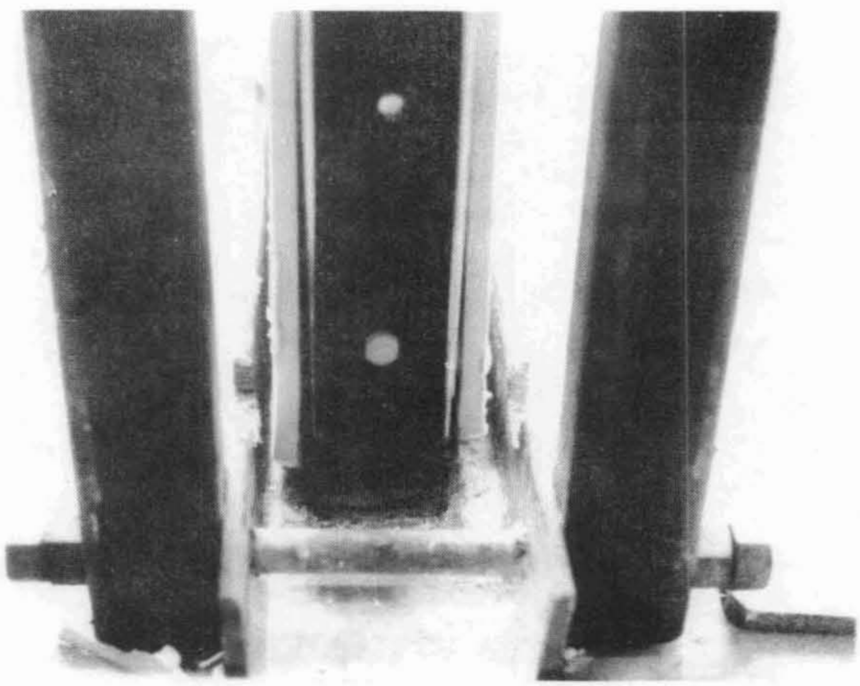


Fig. 74: Partition Test Specimen P7: Typical Separation
Between Gypboard & End Stud @ Base

Fig. 75: Partition Test Specimen P7:
Detail at Uplift Restraint Strap

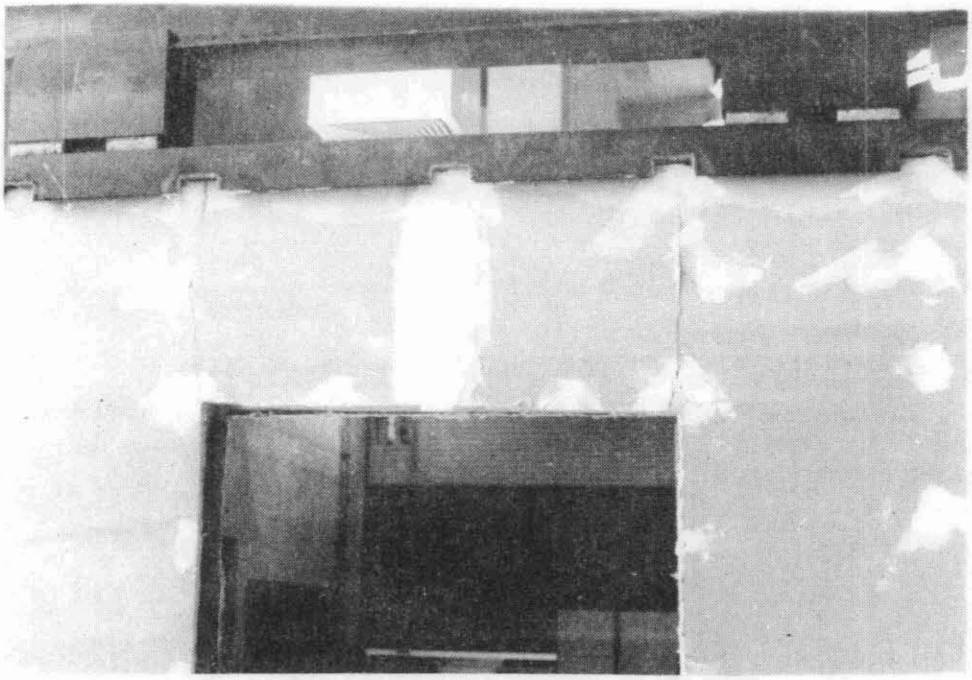


Fig. 76: Partition Test Specimen P7: Typical Failure Above Door Opening (Rear View)

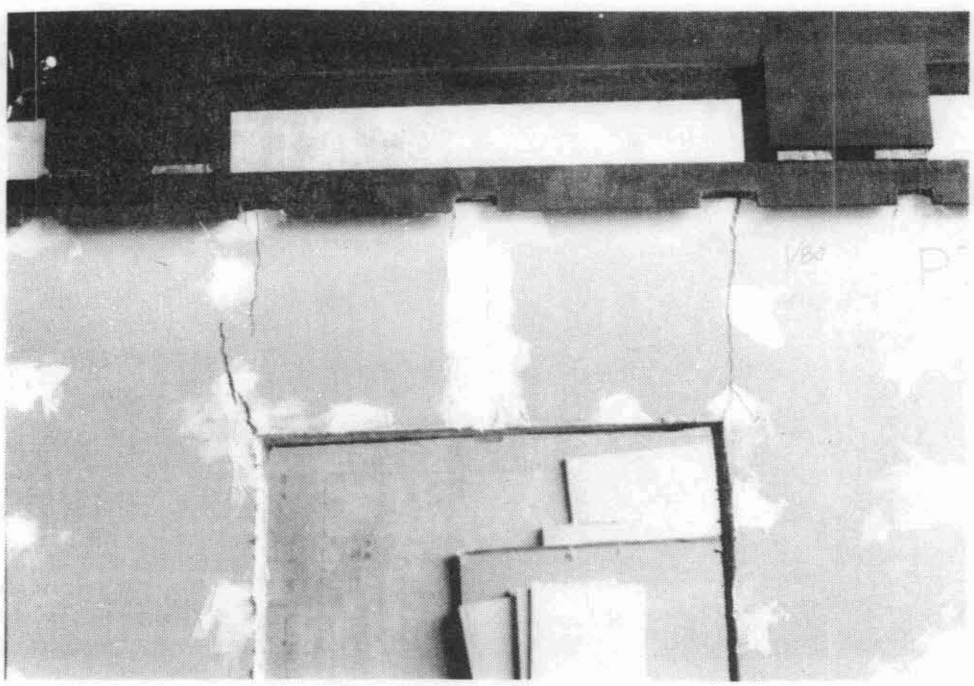


Fig. 77: Partition Test Specimen P7: Typical Failure Above Door Opening (Front View)

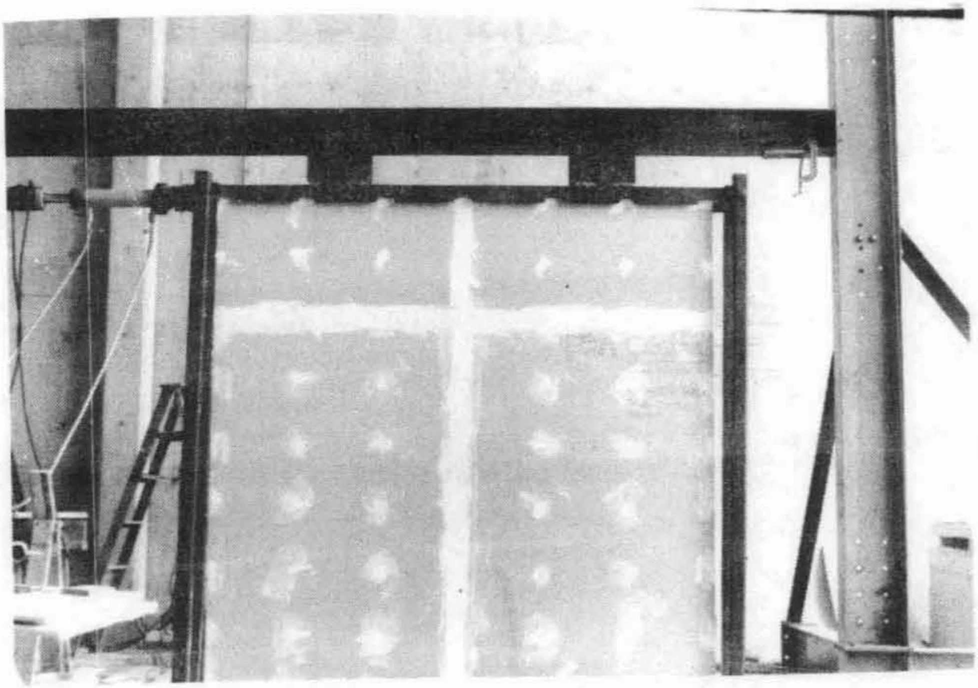


Fig. 78: Partition Test Specimens P8 & P8A

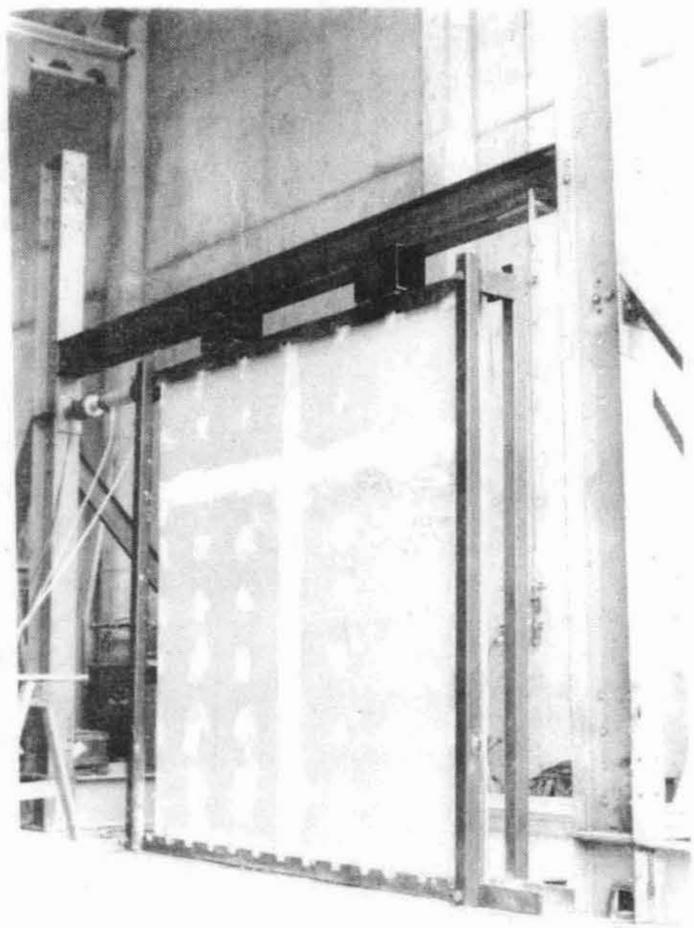


Fig. 79: Partition Test Specimens P8 & P8A

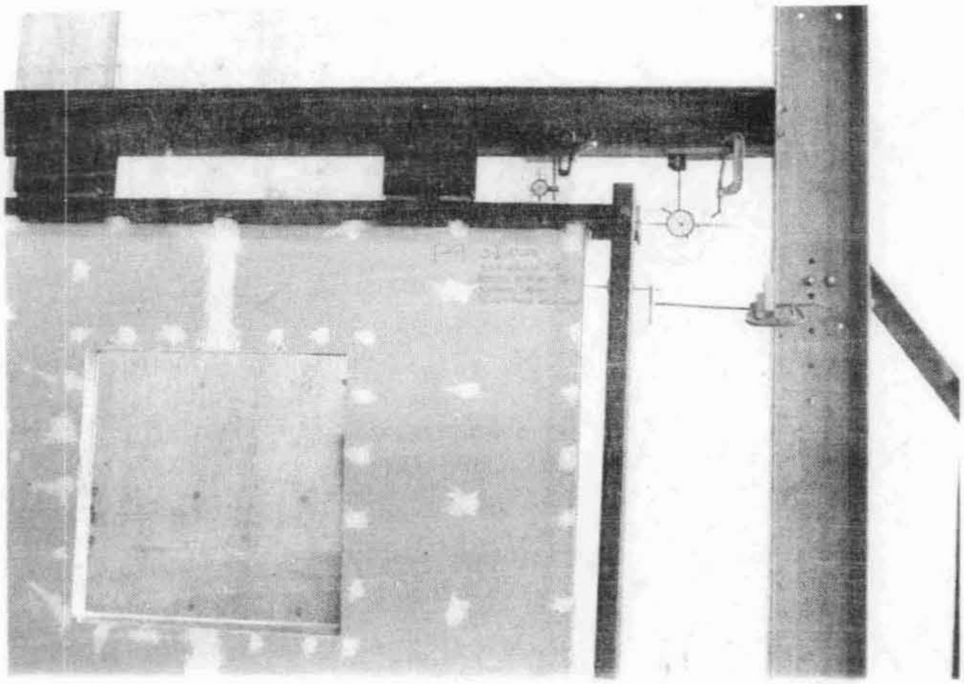


Fig. 80: Partition Test Specimen P9

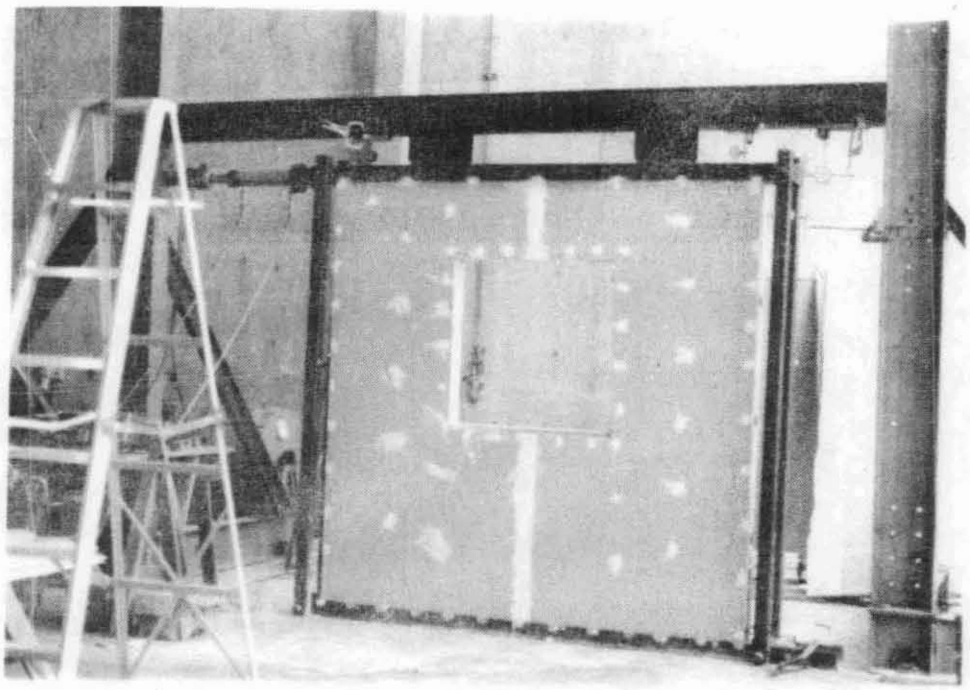


Fig. 81: Partition Test Specimen P9

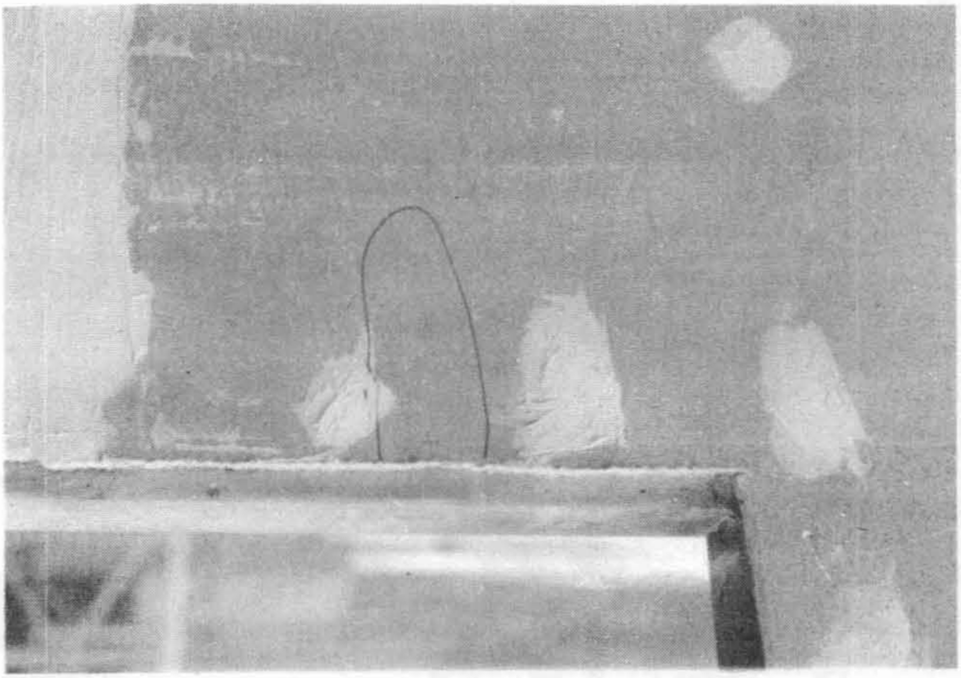


Fig. 82: Partition Test Specimen P9: Failure Above Window Opening

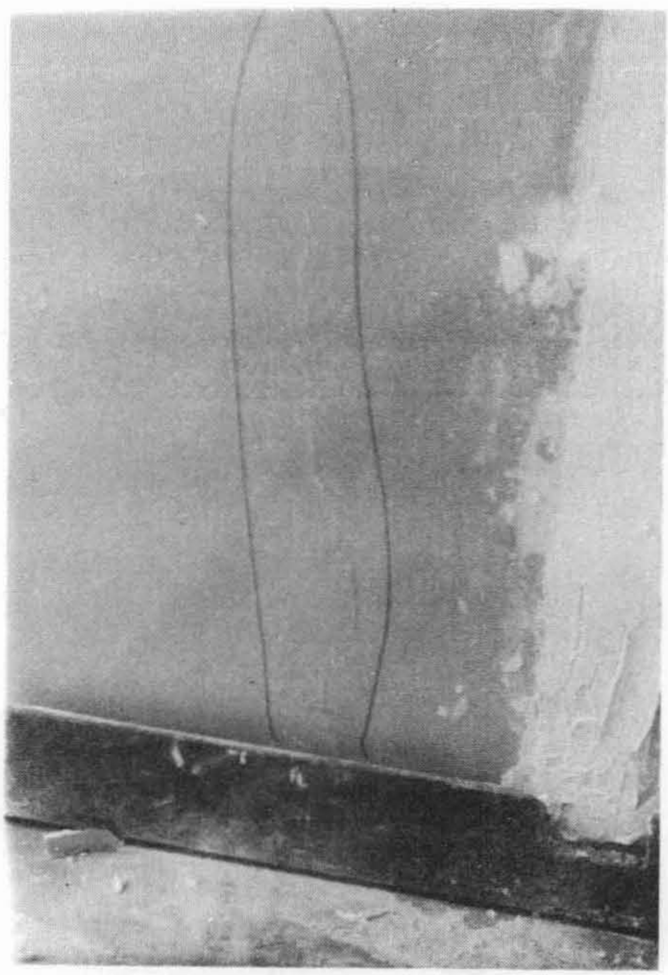


Fig. 83: Partition Test Specimen P9: Cracking in Gypboard @ Failure

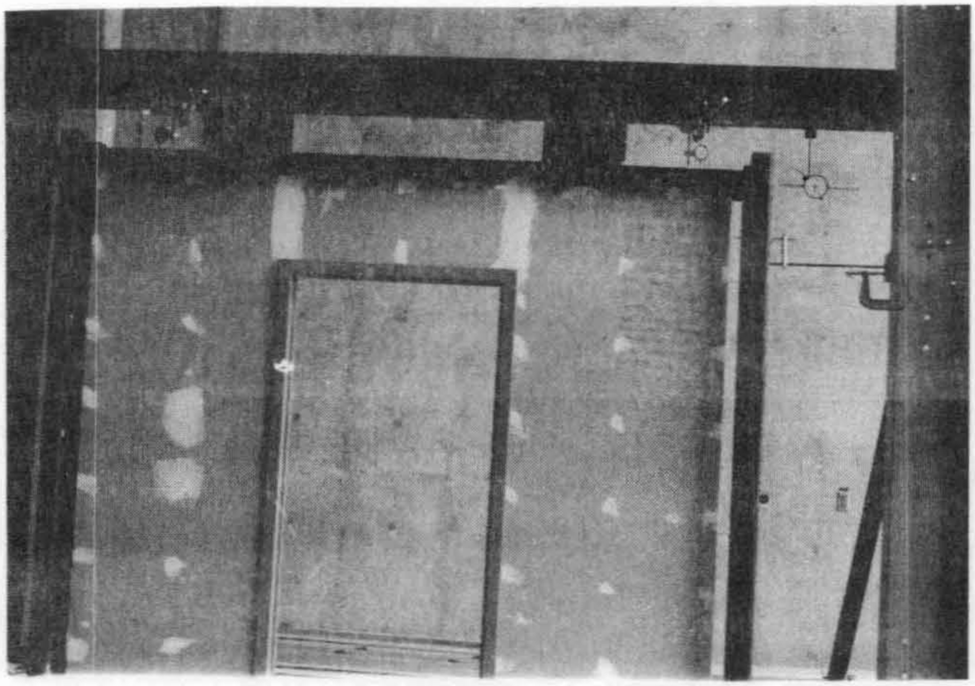


Fig. 84: Partition Test Specimen P11

Fig. 85: Partition Test Specimen P11: Failure Above Metal Door Frame Opening

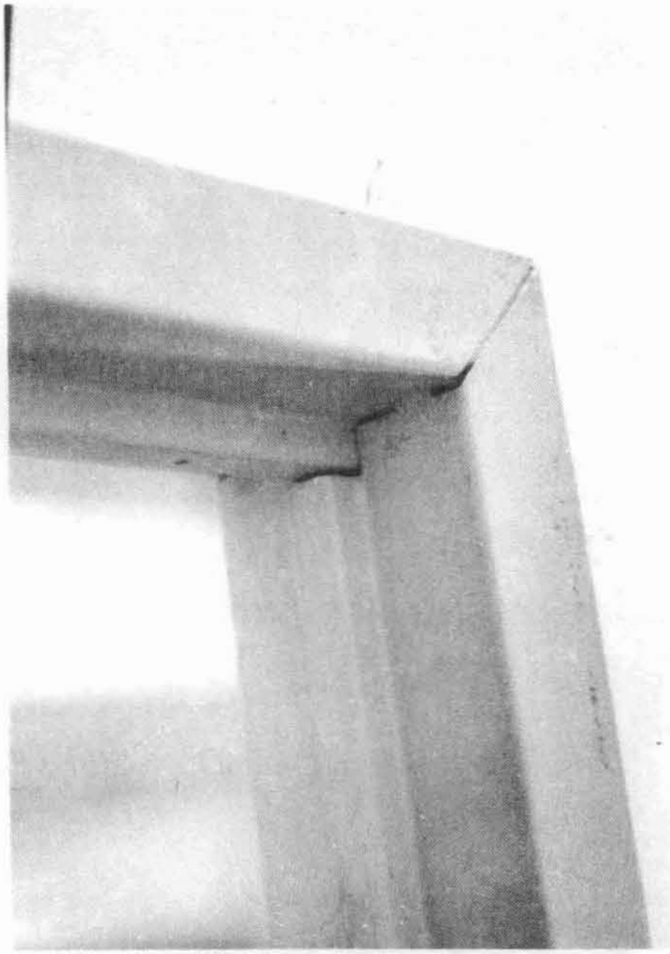


Fig. 86: Partition Test Specimen P11: Detail @ Metal Door Frame

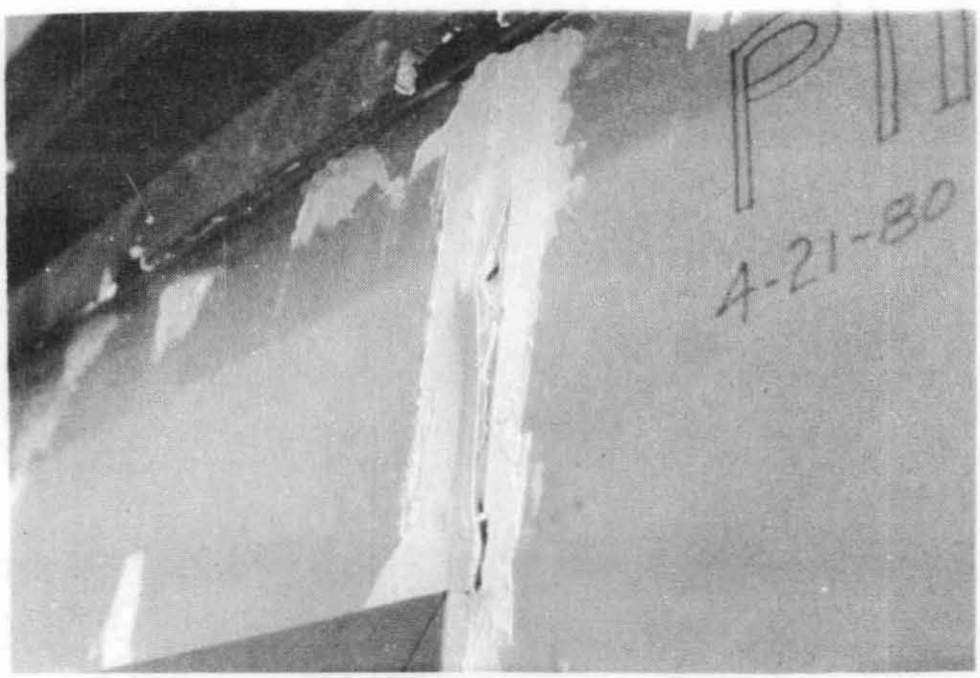


Fig. 87: Partition Test Specimen P11: Failure Above Door Opening

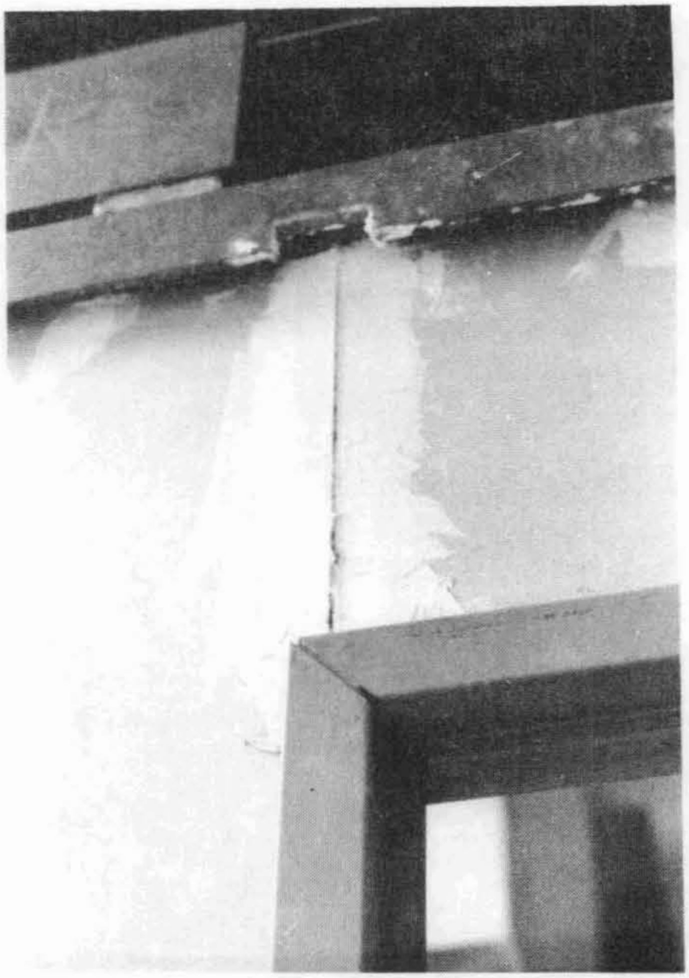


Fig. 88: Partition Test Specimen P11: Failure Above Door Opening

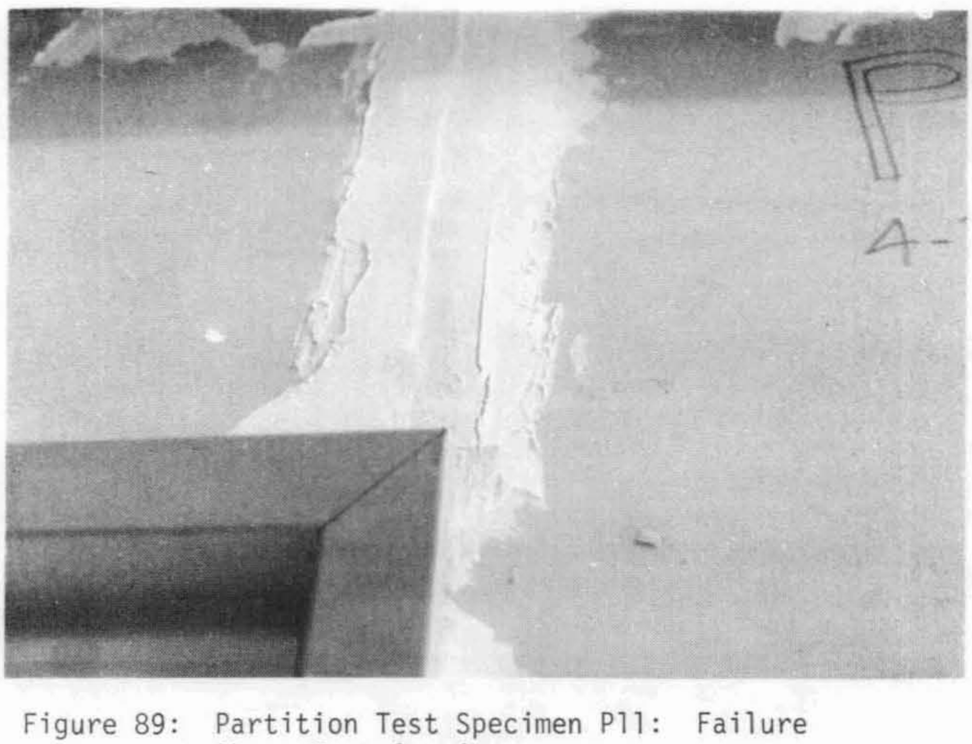


Figure 89: Partition Test Specimen P11: Failure Above Door Opening

Fig. 90: Partition Test Specimen P11: Failure Above Door Opening

Fig. 91: Partition Test Specimen P11: Failure Above Door Opening