INVESTIGATION OF THE SEISMIC RESISTANCE OF INTERIOR BUILDING PARTITIONS

PHASE I

R.W. Anderson
Principal Investigator

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February 1981

Prepared under
National Science Foundation Contract No. PFR-8009921

AGBABIAN ASSOCIATES
El Segundo, California

INFORMATION RESOURCES
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ACKNOWLEDGMENTS

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Principal Investigator for this work was R.W. Anderson. Staff members from Agbabian Associates who supported the work included Y-C. Lee and G. Savulian in the analysis phase of the work, B. Barclay and G. Lee in the testing of the wall panel assemblies, and J. Athey (ed.).

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SECTION 1

INTRODUCTION

A program to evaluate the contributions of partitions to the lateral load resistance of an unreinforced masonry building undergoing earthquake ground motions is of great importance to owners and tenants of apartments, hotels, and other high-occupancy buildings, as well as to government agencies and the construction industry. This introductory section provides background information on the role of partitions as shear walls and their participation in the ultimate resistance capacity of a structure to seismic loading, and then summarizes the activity and results of the current research program to explore these effects and provide recommendations. The organization of the report is outlined at the end of the section.

1.1 STATEMENT OF THE PROBLEM

Concern for safety in unreinforced masonry load-bearing construction in seismically active regions has increased throughout the country. Public agencies and the private sector are more conscious of the potential hazards associated with these structures when subjected to earthquake shaking and of the potential liability in the event of injury or loss of life. Other significant economic and social implications include property damage and resulting disruption and dislocation of services.

For example, the city of Los Angeles has adopted an earthquake hazard-reduction ordinance (LAMC, 1981) that establishes minimum earthquake standards for all pre-1934 unreinforced masonry load-bearing wall buildings except for detached residential buildings containing less than five dwelling units. Building owners are required to hire a licensed engineer or architect to determine the building's earthquake deficiencies and to structurally alter these deficiencies, if any, to meet established standards. Time schedules for compliance with the ordinance are based on priority classifications relating to essential and high occupancy buildings. Earthquake performance standards are outlined in the ordinance, as well as allowable design values for existing construction materials. Unsafe buildings not brought into compliance with the new ordinance within the allotted time schedules will have to be demolished. This ordinance is reprinted in Appendix A.

It is important to note that provisions of the Los Angeles ordinance establish standards for structural resistance required to minimize loss of life rather than minimize property damage. These provisions are less strict than current building codes. The intent of the ordinance is to minimize the cost of strengthening unsafe pre-1934 unreinforced masonry buildings in order that owners will be encouraged to repair their buildings rather than demolish them. This is especially important in the case of old apartment houses and hotels, because these potentially hazardous structures provide low income housing. It is imperative that the costs of rehabilitating unsafe buildings of this occupancy will not be so severe as to force demolition of the structures or result in rent increases that tenants will not be able to afford.

The primary targets of seismic hazard reduction measures are unreinforced masonry buildings that normally have a high occupancy load, such as apartment houses, hotels, nursing homes, and office buildings. A common characteristic of these facilities is the extensive use of floor-to-ceiling interior walls required to partition off floor space. The contribution of these partitions to the lateral load resistance of a building may be more significant than presently allowed by building officials. Research that justified increased allowable stresses for interior shear walls would be a significant factor in reducing the costs of strengthening when increased seismic resistance is required.

1.2 PURPOSE AND SCOPE OF RESEARCH PROGRAM

The purpose of this Phase I study is to investigate the in-plane shear resistance of interior partitions and their influence on the safety of unreinforced masonry buildings. Wood-stud partition framing is stressed because (1) it is the type normally found in the older buildings that are especially susceptible to earthquake damage and (2) research directly applicable to this type of partition construction is very limited.

The study combines analysis and testing to investigate the in-plane shear load resistance characteristics of various combinations of lath and plaster materials commonly utilized for interior partition wall construction in older one-, two-, or three-story unreinforced masonry apartment houses and hotels. Wood lath and plaster, gypsum lath and plaster, and gypsum wall board partitions were tested to determine strength and rigidity to in-plane lateral forces, ultimate strength, and failure mode characteristics. Analytical predictions were made of load/deflection relationships and correlated with test results, and reiterated, if necessary, to obtain realistic strength and stiffness characteristics. Test results were compared with building codes, including the new Los Angeles earthquake safety ordinance, and with other available test data.

Phase I is essentially an exploratory program. Results from this phase will be used to develop a Phase II analytical and experimental program that will extend the Phase I work into a comprehensive evaluation of the effectiveness of interior partitions on the lateral load resistance of buildings and will establish guidelines for the assessment and strengthening of existing buildings in which interior partitions may be proved significant in the mitigation of life-safety hazards.

1.3 SUMMARY OF RESULTS

During Phase I, the research effort has been primarily directed toward determining whether the wood-framed interior partitions of the type normally found in the older masonry apartment/hotel buildings are effective in resisting lateral seismic loading and whether these partitions may be significant in the mitigation of life-safety hazards. Since research applicable to wood stud and plaster construction is limited, static load/deflection tests were first conducted on 8 ft x 8 ft specimens constructed of four different facing materials, including wood lath and plaster, gypsum lath and plaster, and gypsum wallboard with joints between sheets placed either horizontal or vertical. The wood lath and plaster construction was found to be significantly stronger and stiffer than the other three specimens and, further, allowable shear wall values currently permitted by building codes for wood lath and plaster materials appear to be too conservative.

The test panels were then analyzed using finite element methods to predict the static resistance characteristics of the panels. The predictions were correlated with test results and reiterated, when necessary, to obtain realistic material properties and strength and stiffness characteristics for panel specimens based on linear elastic behavior. It was found that the facing material acts as the primary shear resisting structural element, while the wood studs only carry a small portion of the load, especially in the case of wood lath and plaster construction.

The effectiveness of shear wall partitions in resisting the lateral loads imposed on a two- and three-story masonry apartment/hotel building was assessed using a partition layout typical of buildings where extensive use has been made of floor-to-ceiling interior walls to partition off floor space. Maximum shear values in transverse partitions were developed based on tributary area assumptions using lateral seismic forces specified in the new Los Angeles ordinance for a medium-risk building. Based on the test performed on the wood lath and plaster specimen, it was observed that wood stud partitions constructed with wood lath and plaster appear to have the shear capacity required to resist the seismic loading associated with the two- to three-story masonry apartment houses considered in this study, depending on desired factor of safety. This observation may be premature since it is based on the results of only one test, but it can be concluded that wood lath and plaster partitions have the potential for contributing significantly to the lateral load resistance of masonry buildings and that additional research is justified to further evaluate and extend the findings of Phase I.

Suggested subsequent steps for Phase II are (1) conducting an experimental program on wood lath and plaster shear wall panels that includes static cyclic loading to investigate strength and stiffness characteristics under load reversal, (2) investigating effectiveness of partition connections to floors, ceilings, and cross-walls for transferring lateral loads to shear walls, (3) developing methods of strengthening in-plane shear resistance of existing partitions and their attachments to the structural system, (4) performing finite element analyses of typical buildings to study the contribution of existing and/or strengthened partitions to the resistance of the structure to lateral seismic loading, (5) evaluating the results of the experimental and analytical program as to the effectiveness of interior partitions on the lateral load resistance of buildings, and (6) establishing guidelines for the assessment and strengthening of existing buildings in which interior partitions may be significant in the mitigation of life-safety hazards.

1.4 REPORT ORGANIZATION

This report is organized into seven sections. Section 2 indicates research needs for determining in-plane shear resistance of interior partitions and describes prior investigations relating to the performance of interior building partitions during earthquakes. Section 3 describes the test specimens, testing method and procedures, test results, and general observations concerning the behavior of partition test panels under in-plane shear loading. Test panels were analyzed in Section 4 using finite element methods to predict the static resistance characteristics of the panels and predictions correlated with test results. The effectiveness of shear wall partitions in resisting the lateral loads imposed on two- or three-story masonry buildings were assessed in Section 5. Conclusions reached from the Phase I study and recommendations for a Phase II study are given in Section 6. References are listed in Section 7.

SECTION 2

BACKGROUND

2.1 RESEARCH NEEDS FOR DETERMINING IN-PLANE SHEAR RESISTANCE OF INTERIOR PARTITIONS

The influence of interior partitions on the safety of masonry buildings depends on their contribution to the (1) strength and stiffness of the building, (2) increase in overall energy absorption capacity of the building due to stiffness and damping characteristics, and (3) alteration in the distribution of lateral loads due to shear-resistance provided by the partitions. An investigation of these items must consider the following problems:

- Unknown material properties of the composite wood-stud and plaster construction
- Connections of partitions to other elements of the building system
- Strength and rigidity of the partition walls to in-plane lateral forces, including effects of fixity at partition boundaries
- Brittle response characteristics of the partitions due to in-plane shear stresses and deformations
- Stiffness degradation characteristics as the partition cracks and yields under in-plane deformations

Because information regarding these items is very limited, research to investigate these effects is needed.

2.2 INVESTIGATIONS OF PARTITIONS

Investigations into the performance of interior building partitions during an earthquake and their interaction with the response of structural framing systems must deal with a variety of topics. One long-term research program on racking tests of wall panels has been conducted by URS/John A. Blume & Associates of San Francisco (URS/Blume, 1966, 1968; Freeman, 1971, 1974). Nonbearing partitions need the capacity to conform to story drift racking without presenting a life safety hazard. Also, since plaster is a brittle material, partitions are vulnerable to cracking from out-of-plane bending when a building is subjected to earthquake motions. Normally, it is assumed that building partitions contribute only to the dead load of the building; so their contribution, if any, to the strength, stiffness, damping, and other properties of the primary structural system, is neglected. Few recent programs have addressed the matter of interior partitions subjected to story drift racking and their influences on the dynamic response of the building.

A research program at the California Polytechnic State University conducted experiments on the behavior of nonstructural building partitions under horizontal racking loads (Rihal, 1980). The purpose of the program was to describe fundamental partition characteristics that are important in assessing the effect of nonstructural building partitions on the seismic response behavior of buildings. The tests were designed to investigate stiffness and energy-absorbing characteristics of partitions as determined by cyclic racking tests of wall panels simulating lateral interstory displacements in high-rise buildings. Partition test panels were 8 ft by 8 ft, constructed of metal studs with 5/8-in. gypsum wallboard facing material on each side. The research program was concerned primarily with (1) load vs. displacement characteristics of the partition test panels under several cycles of reverse racking and (2) an evaluation of the energy absorbed by the panels. The test specimens were racked back and forth as displacements were increased incrementally, and peak cycle displacements were noted at points of first noticeable damage and at failure, defined as significant damage. It was noted that the general pattern of partition behavior agreed with the test results reported by Freeman (1977) on racking tests of high-rise building partitions.

Prior investigations of partitions, especially wood-framed partitions, to determine their effectiveness as shear walls and their contribution to the ultimate resistance capacity of a building to seismic loading are scarce. General research on the in-plane shear resistance of interior partitions and their participation in the dynamic response of structures to earthquake motions should be expanded to include structural as well as non-structural considerations regarding the functions of partitions in buildings.

SECTION 3

PARTITION TEST SPECIMENS

3.1 INTRODUCTION

This section describes the test specimens, testing method and procedures, test results, and general observations and conclusions concerning the behavior of the partition test panels under in-plane shear stresses. Figures of these test specimens appear at the end of the section.

3.2 TYPES OF CONSTRUCTION

Four types of partition construction were tested to determine their load/deflection characteristics and mode of failure. Test panels were 4 ft high by 8 ft long constructed of vertical 2 x 4 Douglas Fir studs (construction grade) spaced at 16 in. on center. See Figure 3-1 for details of panel construction. Two test panels were prepared for each partition type and bolted together (as shown in Fig. 3-2) prior to applying facing material to the studs. The assembly was then tested as a double panel as described in Section 3.3.

The panel types tested included the following facing materials:

Specimen A:	Wood Studs with Gypsum Wallboard (Horizontal Joints)
Specimen B:	Wood Studs with Gypsum Wallboard (Vertical Joints)
Specimen C:	Wood Studs with Gypsum Lath and Plaster
Specimen D:	Wood Studs with Wood Lath and Plaster

See Figures 3-3 through 3-6 for details on the application of the facing materials.

Specimens A and B utilized 5/8-in. gypsum wallboard nailed to the wood framing members with 6d cooler nails at a maximum spacing of 8 in. on center. Specimen A simulates a partition wall where the joint between wallboard sections is horizontal; Specimen B has the joint vertical. The research conducted by Rihal (1980) indicated that the orientation of joints between wallboard sections made a difference in the load/deflection and energy absorption characteristics of the test panels. Therefore, it was appropriate to include two joint orientations in this series of tests in order to compare data with another research program on partition wall behavior under in-plane shear loading.

Specimens C and D incorporated plaster over gypsum lath and wood lath, respectively. This type of construction is more representative of the materials used in the older masonry buildings and very pertinent to this study.

3.3 TEST METHOD

The objective of the tests was to investigate the in-plane shear load resistance of the four types of partition construction described in Section 3.2. Two panels of the same facing material were bolted together and tested as a simple beam, as shown in Figure 3-7, with the load applied at the top of the assemblage between panels. This procedure is simple to perform and appropriate for an exploratory test program. The purpose of the test is to assess the possible contribution of interior partitions to the lateral load resistance of unreinforced masonry buildings subjected to seismic ground motions. Previous researchers have found that this test method results in almost pure shear loading in each panel (Young and Medearis, 1962). The panels were tested in a horizontal position resting on pavement and supported on blocking. Three steel weldments were assembled and buried in the ground to act as abutments, one at each end of the assemblage for support and one at the center of the opposite side to jack against. Loading was applied by a hand-pumped hydraulic jack with load measured by a pressure gage. Care was exercised to ensure that load was transmitted to the wood framing members directly and not to the facing material (see Fig. 3-8). For testing validity it was necessary to assure that loads were transferred to the facing material through the nailing provided; this is discussed in Section 3.6. Deflections were measured at the center of the panel and at quarter points by use of a carpenter's square, reading to 1/32 of an inch.

3.4 TEST PROCEDURE

Loads were applied in fixed increments, measuring deflections after applying each load increment. The loading at first cracking was noted and the crack(s) were highlighted by a black felt marking pen. The progress of the crack(s) was recorded and marked as the loading was increased, and new cracks were marked and noted as they occurred. Loading was increased in increments until the panels failed completely and loading could not be sustained by the assemblage.

Photographs were taken of the partition specimens during the tests when appropriate and at the completion of the tests to show cracking patterns and degree of damage. The panels were then turned over and cracks on the backside of the panel were highlighted in black ink and photographed.

3.5 TEST RESULTS

Load vs. displacement curves at center and quarter point locations were plotted for each type of construction and are shown in Figures 3-9 to 3-12. Test results are summarized in Table 3-1. Photographs showing panels before and after testing, including crack patterns, are shown as Figures 3-13 through 3-29.

Table 3-2 summarizes the shear per linear foot for each test panel assemblage as measured at first cracking, at effective yield point (or noticeable break in load/deflection curve), and at failure where loading could not be maintained. These shears have been compared to the allowable shear wall values as specified in Division 68 of the Los Angeles Municipal Code (LAMC, 1981) for existing lath and plaster construction (Specimens C and D) and to the Uniform Building Code (1979) for gypsum wallboard construction (Specimens A and B). Existing gypsum wallboard partitions are not covered by Division 68 of the new LAMC. Comparing test shear values with code allowables provides the factors of safety given in Table 3-2.

3.6 LATERAL STRENGTH OF WOOD LATH NAILING

Seismic forces transmitted through the shear wall partitions must be transferred to the wood lath and plaster facing material through nails that attach the lath to the wood framing. Tests were conducted on sections cut from the wood lath and plaster panels to determine the lateral resistance of these nails.

A static test was performed on a section of panel containing six wood lath nailed to each side of two studs spaced at 16 in. on center (see Fig. 3-30). A hydraulic jack was placed within the test specimens with blocking at each end to distribute the jacking load to the twelve lath. Specimens with and without plaster were tested. Load/deflection curves are shown in Figure 3-31, where the dual purpose is to plot deflection vs. total jacking load and deflection vs. loading per nail (assuming twelve nails to resist the load).

TABLE 3-1. SUMMARY OF TEST RESULTS

Specimen	First Cracking		Effective Yield		Ultimate	
	Load, lb	Deflection, in.	Load, lb	Deflection, in.	Load, lb	Deflection, in.
A	1,800	0.27	2,300	0.5	3,800	1.8
B	2,250	0.20	4,000	0.4	6,300	1.1
C	4,050	0.12	6,000	0.25	9,225	1.1
D	8,300	0.19	10,000	0.25	14,900	0.65

TABLE 3-2. SHEAR WALL VALUES PER FOOT

Specimen	Test Results			Code Allowables	Factor of Safety		
	1st Crack	Yield	Ultimate		1st Crack	Yield	Ultimate
A	112	144	238	--	--	--	--
B	140	250	400	--	--	--	--
C	253	375	575	200	1.3	1.9	2.9
D	518	625	930	100	5.2	6.3	9.3

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The ultimate shear strength of the wood lath and plaster panel was 930 lb per ft. There are approximately seven lath (and nails) per foot of wall and the average shear per nail required to transfer this shear will be approximately 66 lb. From an inspection of Figure 3-31, it can be concluded that the lateral resistance of the nails is adequate to transfer shear loads between stud and wood lath.

3.7 OBSERVATIONS AND CONCLUSIONS

1. Test results indicated that the gypsum wallboard specimen with horizontal joints (Specimen A) behaved as a shear beam, i.e., the displacement measurements at the quarter points were about one-half of those measured at the center point. Significant slippage at the joint between wallboard sections occurred, nails were deformed and loosened in the plaster, and panel stiffness rapidly deteriorated after first cracking as the loading was increased. Eventual failure was the result of the separation of nails from the wallboard. The panel is more ductile and able to absorb more energy than the other types of construction tested as indicted by its performance.

2. The gypsum wallboard specimen with vertical joints (Specimen B) has a similar load-displacement pattern to that observed for the horizontal joint orientation (Specimen A), except that it is stiffer and failed at a load more than 60% greater. Failure was caused by the separation of nails from the wallboard as occurred in Specimen A and the panel behaved as a shear beam.

3. The gypsum lath and plaster specimen (Specimen C) behaved more like a deep beam than a shear panel.

Displacements measured at the quarter point were more than one-half of those measured at the center. Tension cracks at the center of the panel assemblage, as well as diagonal tension cracks, propagated under increasing load. The panel failed at a much higher load than those observed for the gypsum wallboard specimens, but ultimate loads are similar for gypsum lath and plaster and gypsum wallboard with vertical joints if the actual thickness of the facing material is considered. The combined thickness of the gypsum lath and plaster is 7/8 of an inch vs. 5/8 of an inch for the gypsum wallboard. The ultimate load for the gypsum lath and plaster was 9225 lb compared with 6300 lb for the gypsum wallboard; indicating the increase in ultimate load was directly proportional to the difference in thickness.

4. The wood lath and plaster specimen proved to be the strongest of the four types of interior partition construction tested. It was much stronger and stiffer than anticipated. Performance was nearly elastic up to approximately 10,000 lb, which relates to a shear of 625 lb per ft in the panel. Since an allowable shear of 100 lb per ft is all that is permitted by the new Los Angeles ordinance (LAMC, 1981), a significant increase in the current shear wall allowable for wood lath and plaster may be justified based on the large factors of safety shown in Table 3-2 for Specimen D. Further testing and analysis of this type of construction to investigate the influence of the wood lath in strengthening the plaster against diagonal tension cracking will be necessary to better understand this phenomenon and to confirm the exploratory test conducted in this study. The plaster is well keyed to the wood

lath by the plaster that has squeezed into the space between the lath (see Fig. 3-24). The nails attaching the lath to the studs did not seem to be stressed or loosened during the test. The tests conducted to determine the lateral strength of the nailing between wood lath and stud indicated that the lateral resistance of the nails is adequate to transfer the measured shear loads between the partition framing and wood lath and plaster facing material. It was observed that the major crack that eventually led to failure was induced by flexural tension stresses rather than shear, and occurred and propagated parallel with and in the space between lath near the center of the assemblage (see Fig. 3-27). Diagonal tension cracks also appeared in the facing material late in the test but they were not the major cause of panel failure. Judging from the crack pattern, the panel behaved much like a beam, with the wood lath apparently providing resistance against diagonal tension and preventing the panel from failing in a shear cracking pattern. Flexural type of failure may not be indicative of how a shear wall would actually respond and further testing is required to confirm the significance of tension failures.

5. An anomaly was noted in the damage patterns when the test specimens were turned over after completion of the tests. Cracking in the underside facing material was not as extensive as on the top surface, and in some instances there was no damage. This was consistent for all test panels. Care was exercised in aligning the hydraulic jack during the test setup so as to distribute the load as symmetrically as possible to each panel and to each panel face, but it appears that the top surface

was under more stress than the bottom surface. One possible explanation could relate to the alignment of the jack relative to the plane of the panel assemblage. As the abutment was loaded by the jack, rotation of the abutment due to compression of the soil could have induced bending stresses in the panel assemblage, placing the top surface in tension and the bottom side in compression.

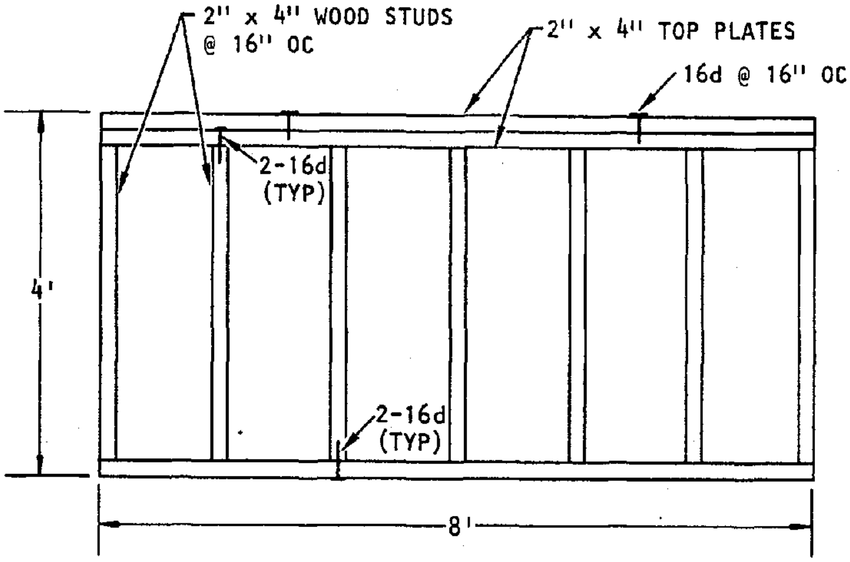


FIGURE 3-1. TYPICAL TEST PANEL FRAMING

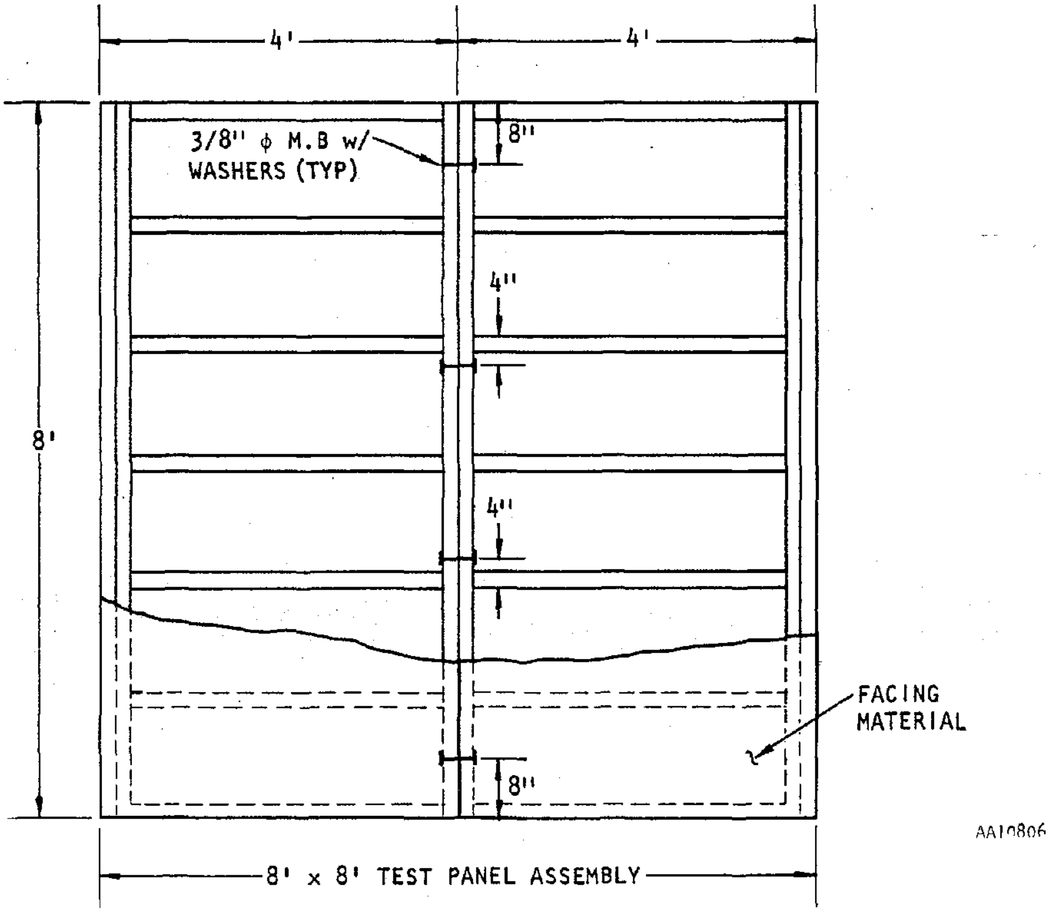


FIGURE 3-2. TYPICAL TEST PANEL ASSEMBLY

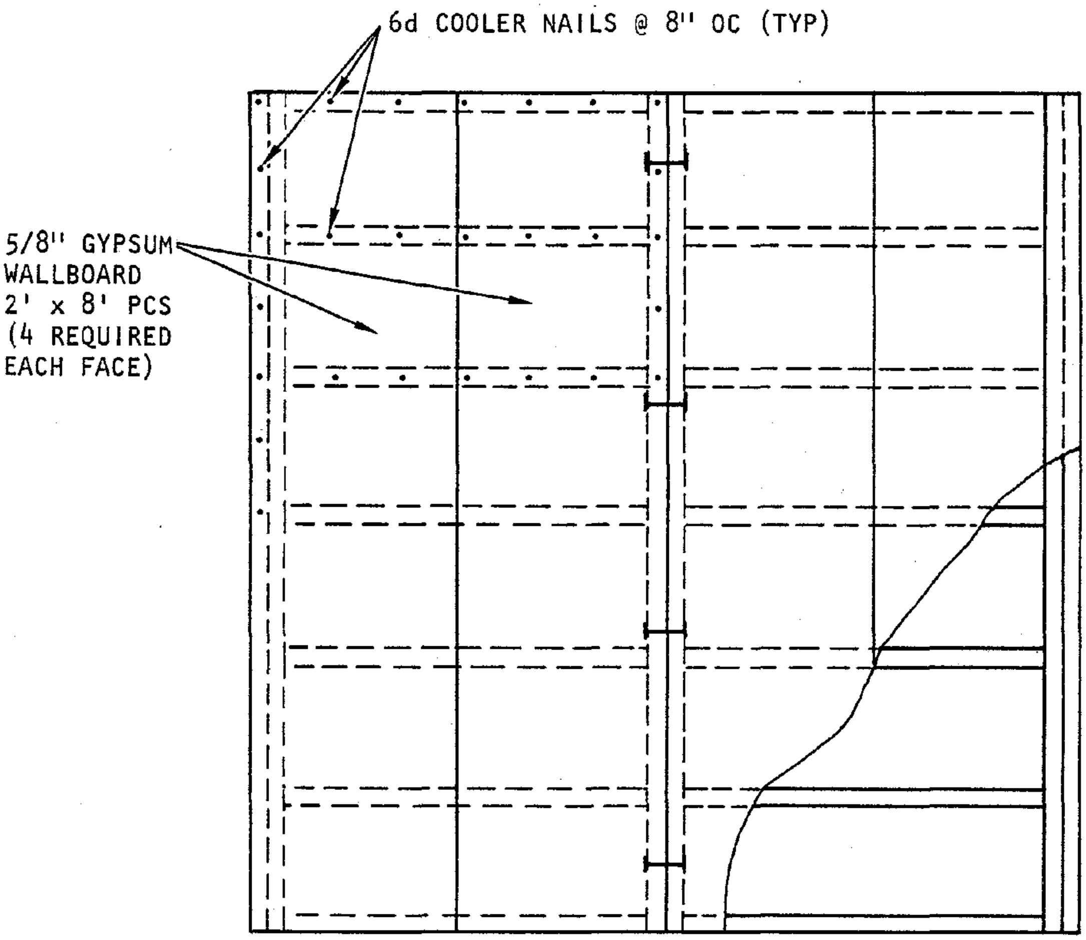


FIGURE 3-3. SPECIMEN A — GYPSUM WALLBOARD (HORIZONTAL JOINT)

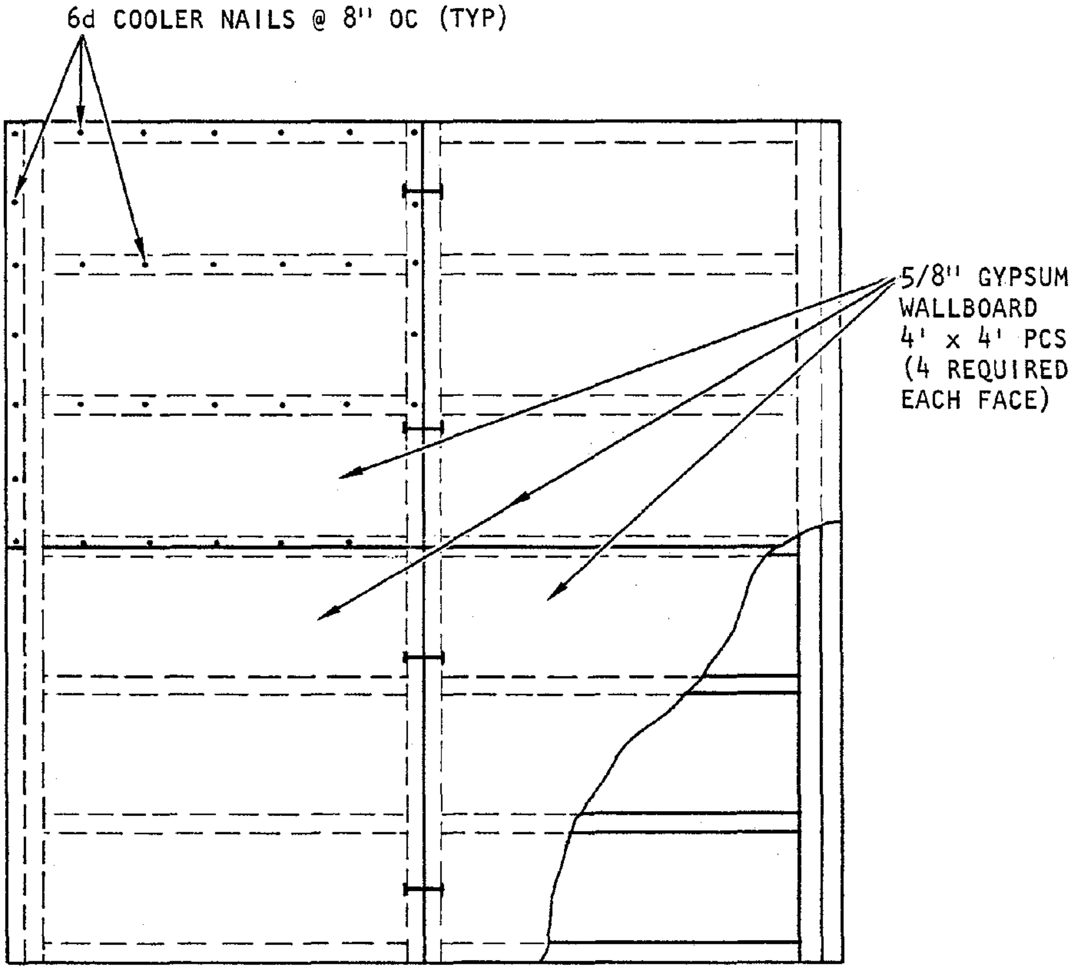


FIGURE 3-4. SPECIMEN B – GYPSUM HARD BOARD (VERTICAL JOINT)

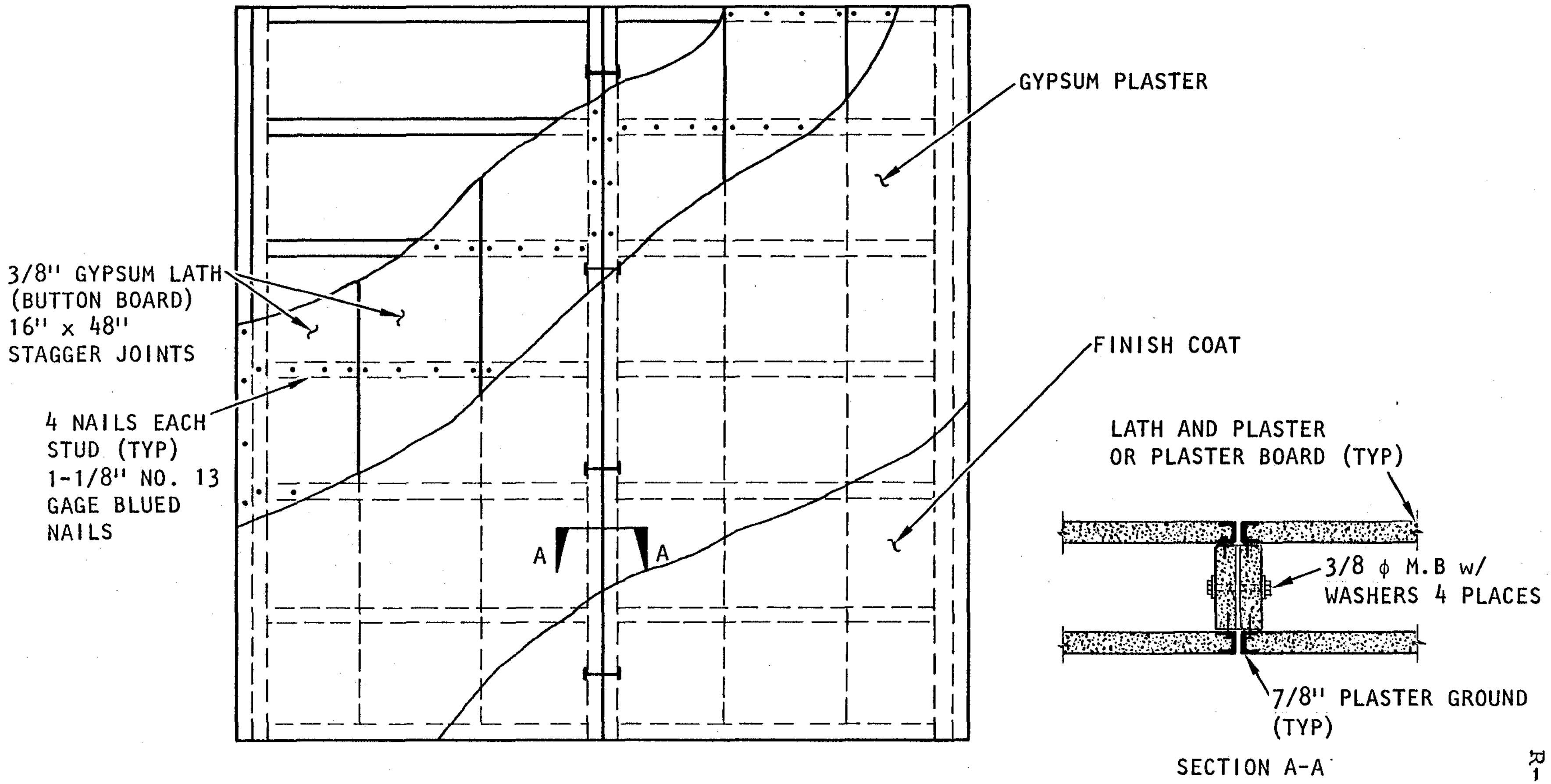


FIGURE 3-5. SPECIMEN C – GYPSUM LATH AND PLASTER

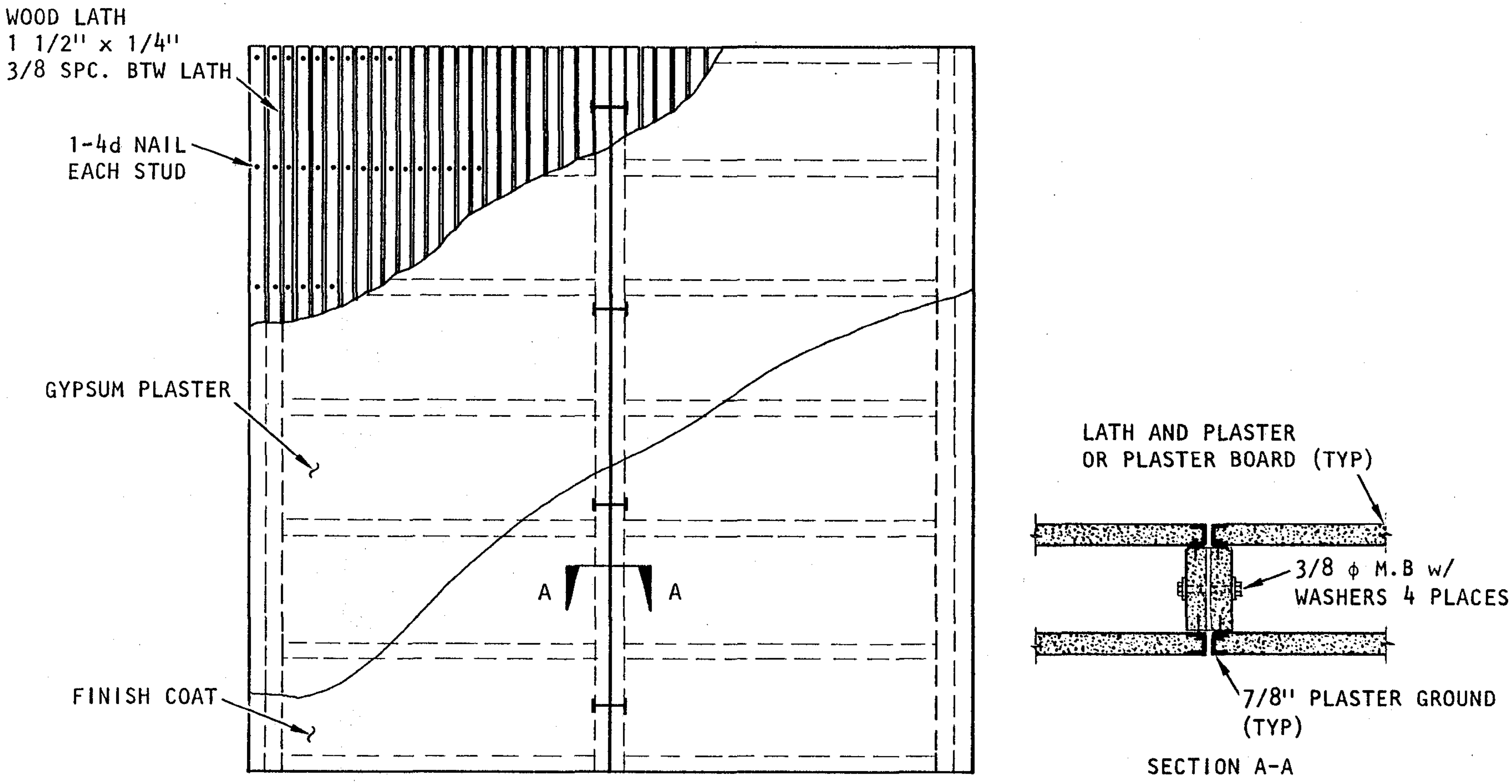
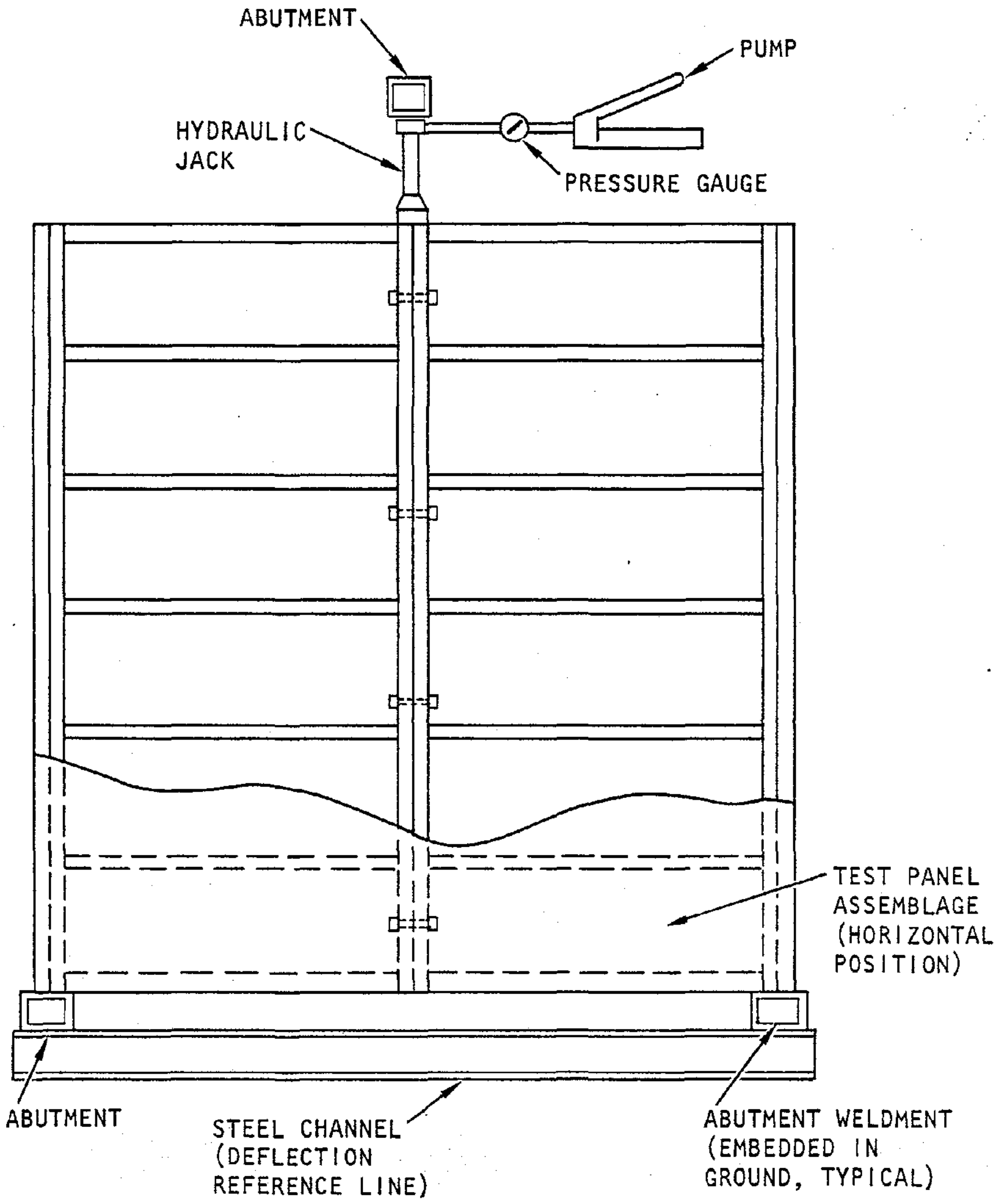


FIGURE 3-6. SPECIMEN D – WOOD LATH AND PLASTER



PLAN VIEW

FIGURE 3-7. TEST SET-UP

FIGURE 3-8. TRANSFER OF LOAD AT JACK TO WOOD FRAMING MEMBERS

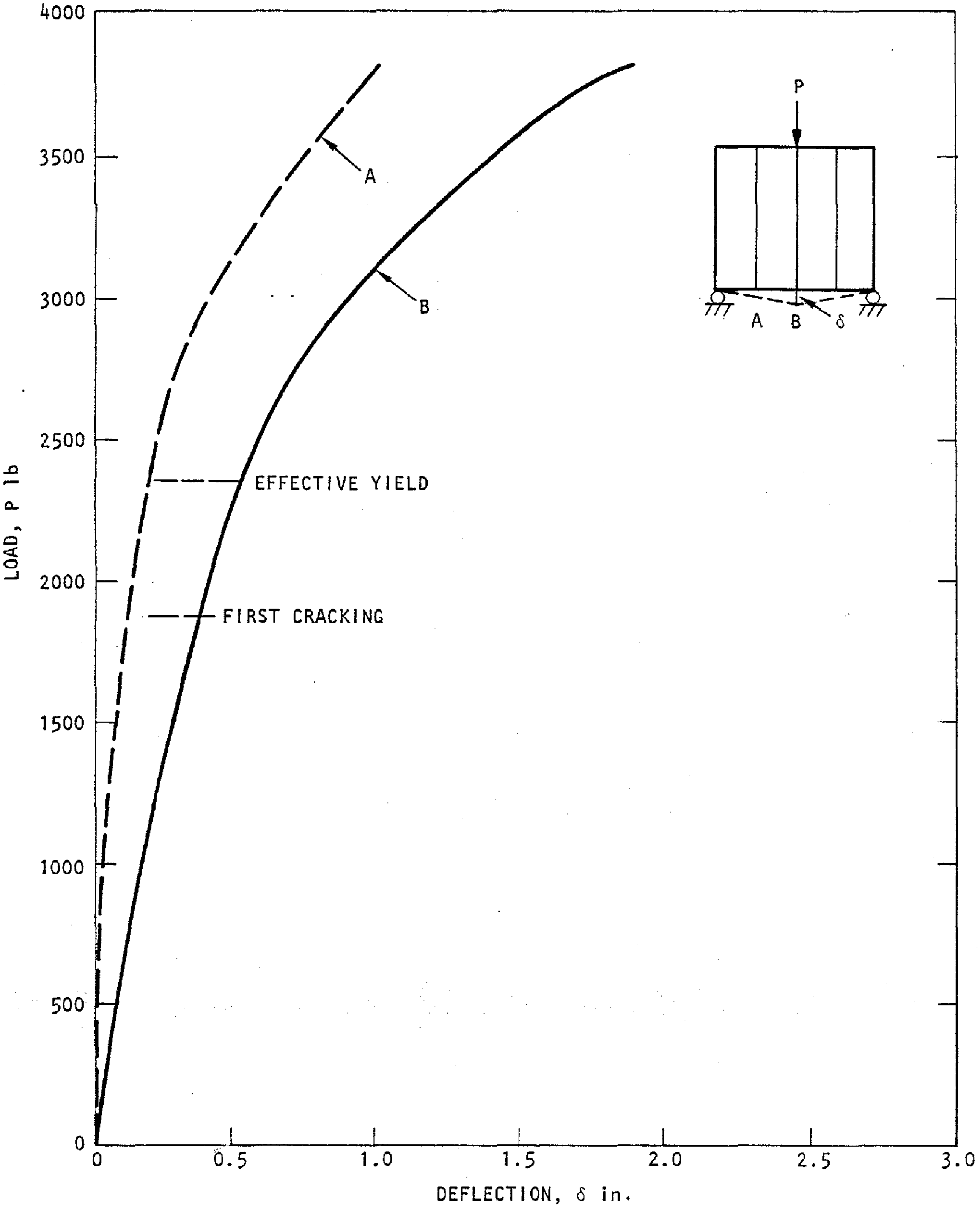


FIGURE 3-9. SPECIMEN A – TEST RESULTS 5/8" GYPSUM WALLBOARD (HORIZONTAL JOINTS)

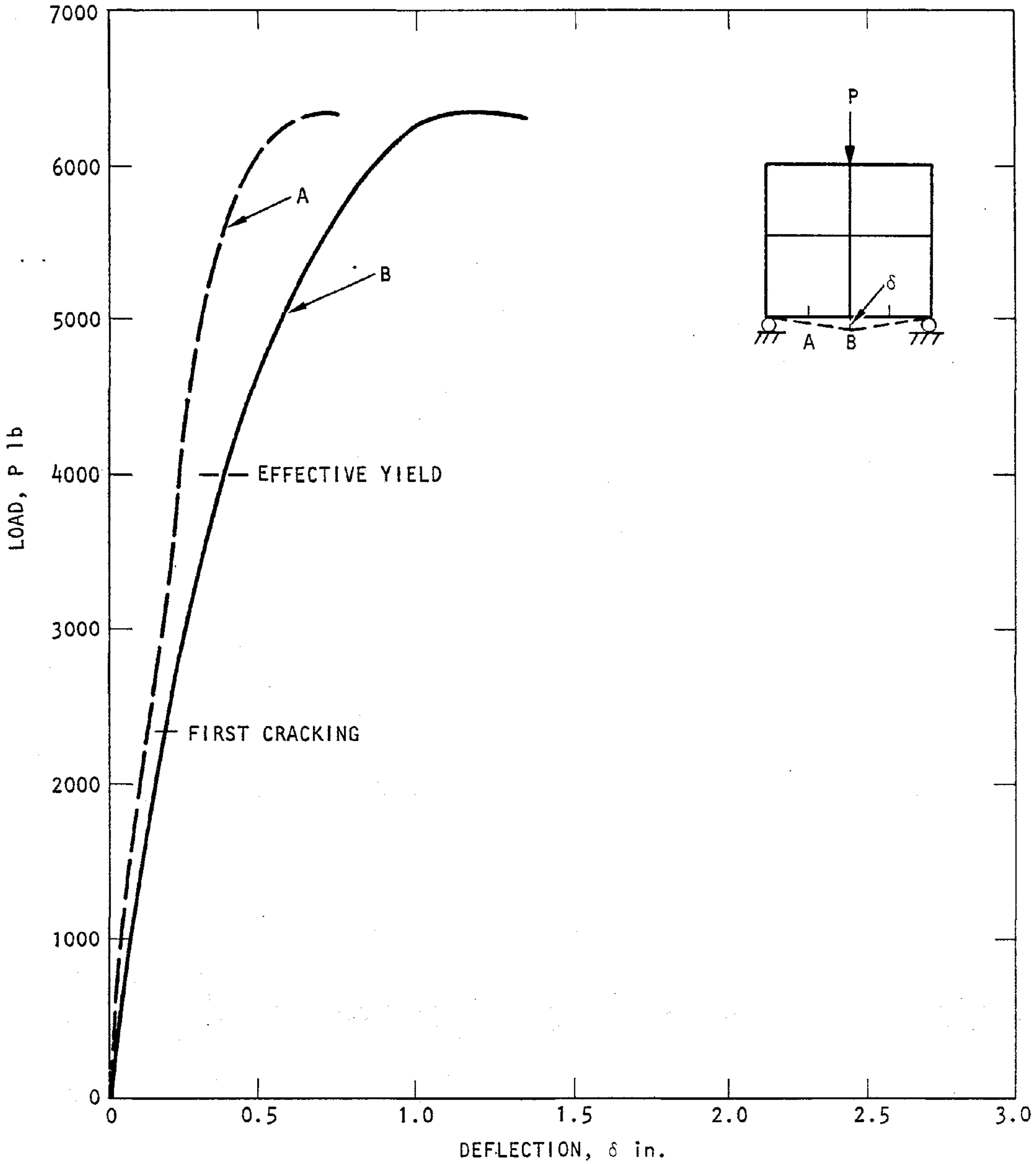


FIGURE 3-10. SPECIMEN B — TEST RESULTS 5/8" GYPSUM WALLBOARD (VERTICAL JOINTS)

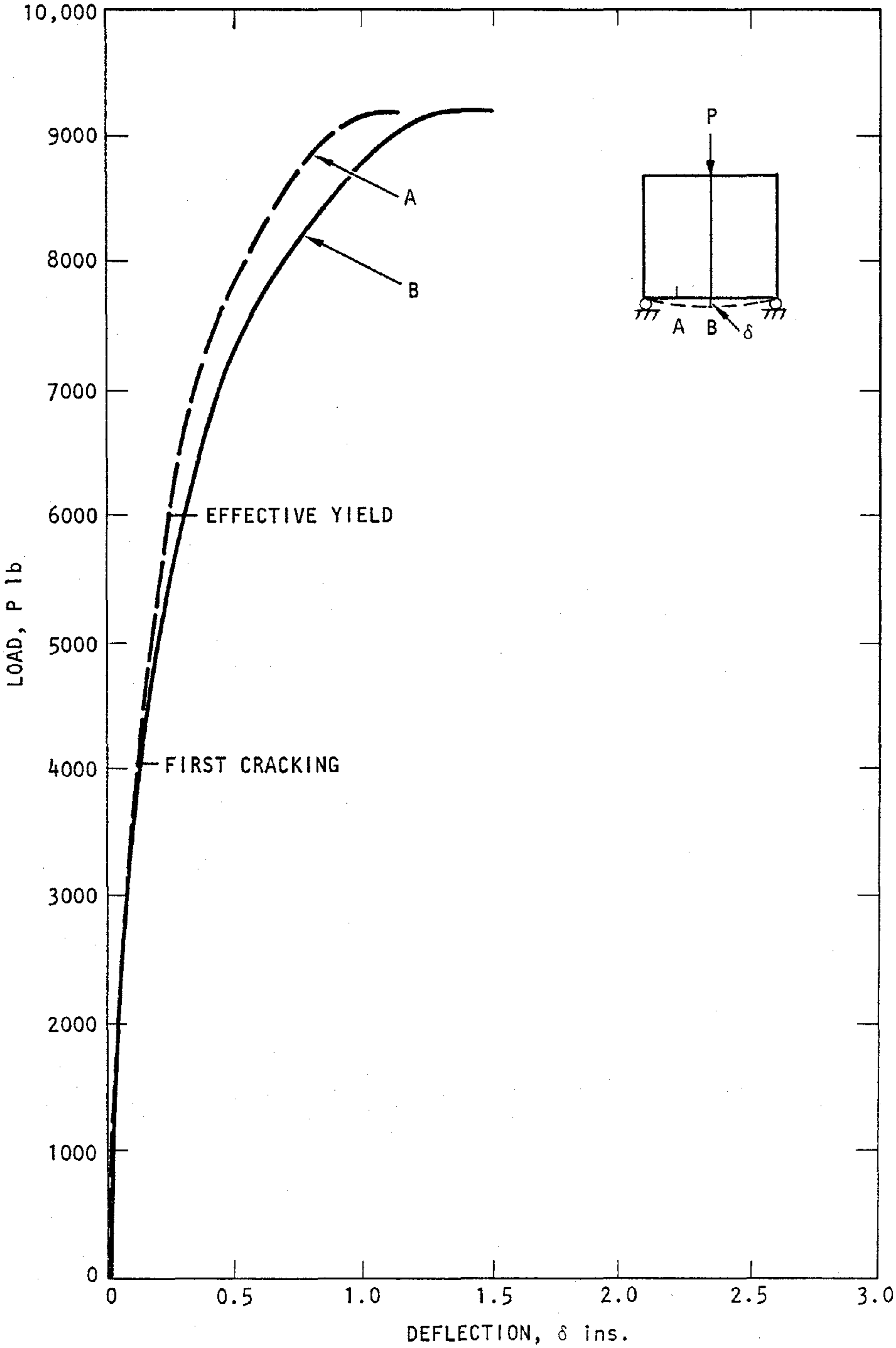


FIGURE 3-11. SPECIMEN C — TEST RESULTS GYPSUM LATH AND PLASTER

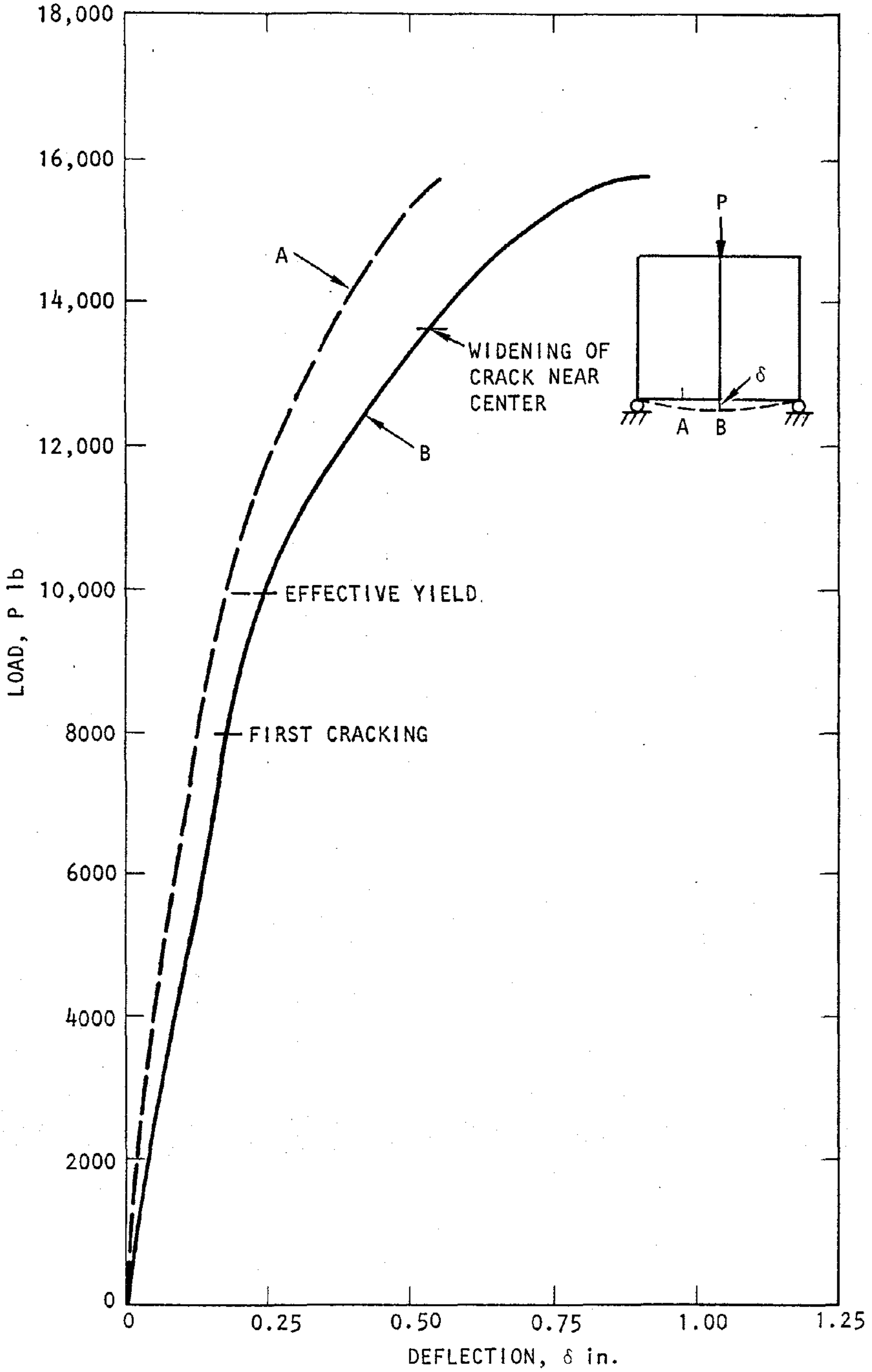
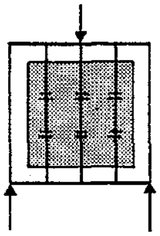


FIGURE 3-12. SPECIMEN D — TEST RESULTS WOOD LATH AND PLASTER



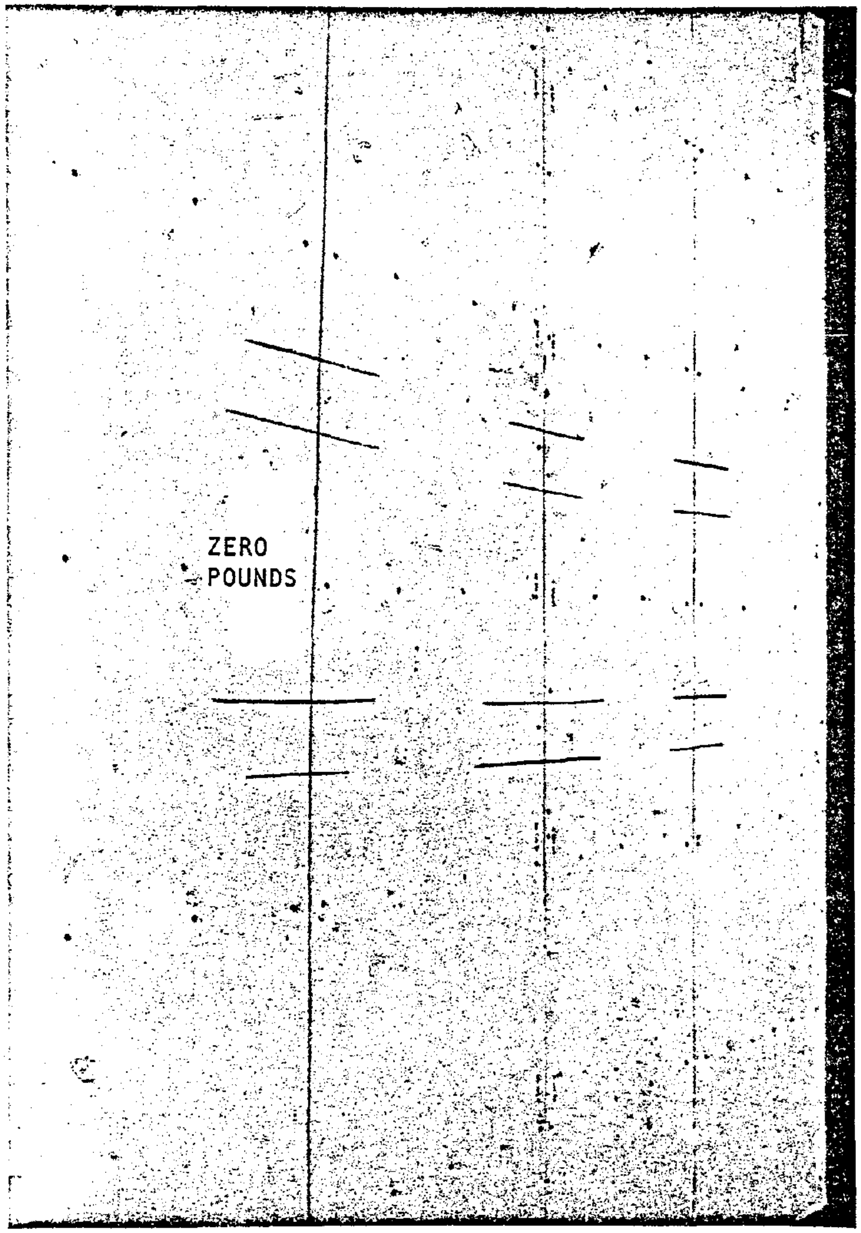
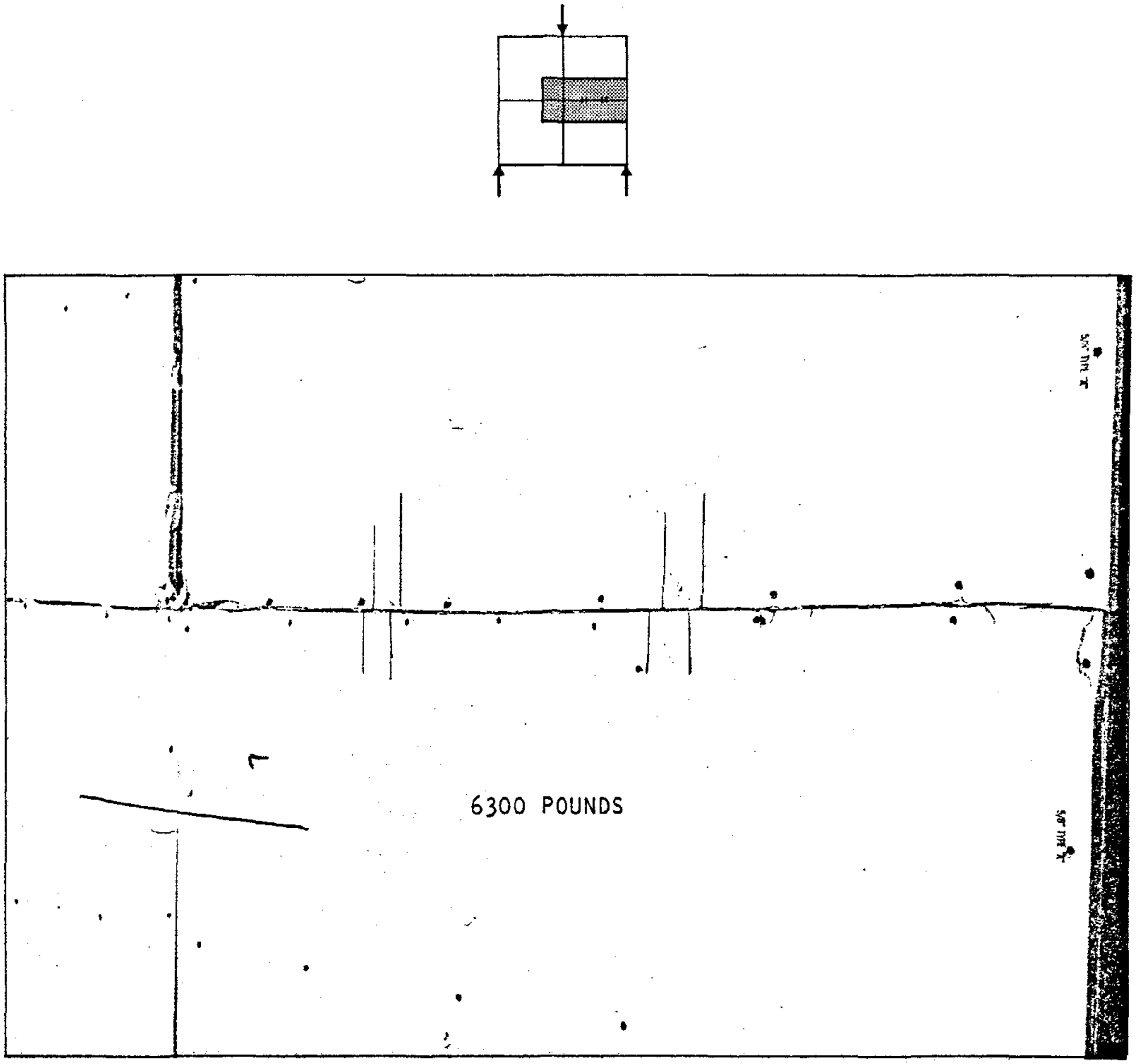
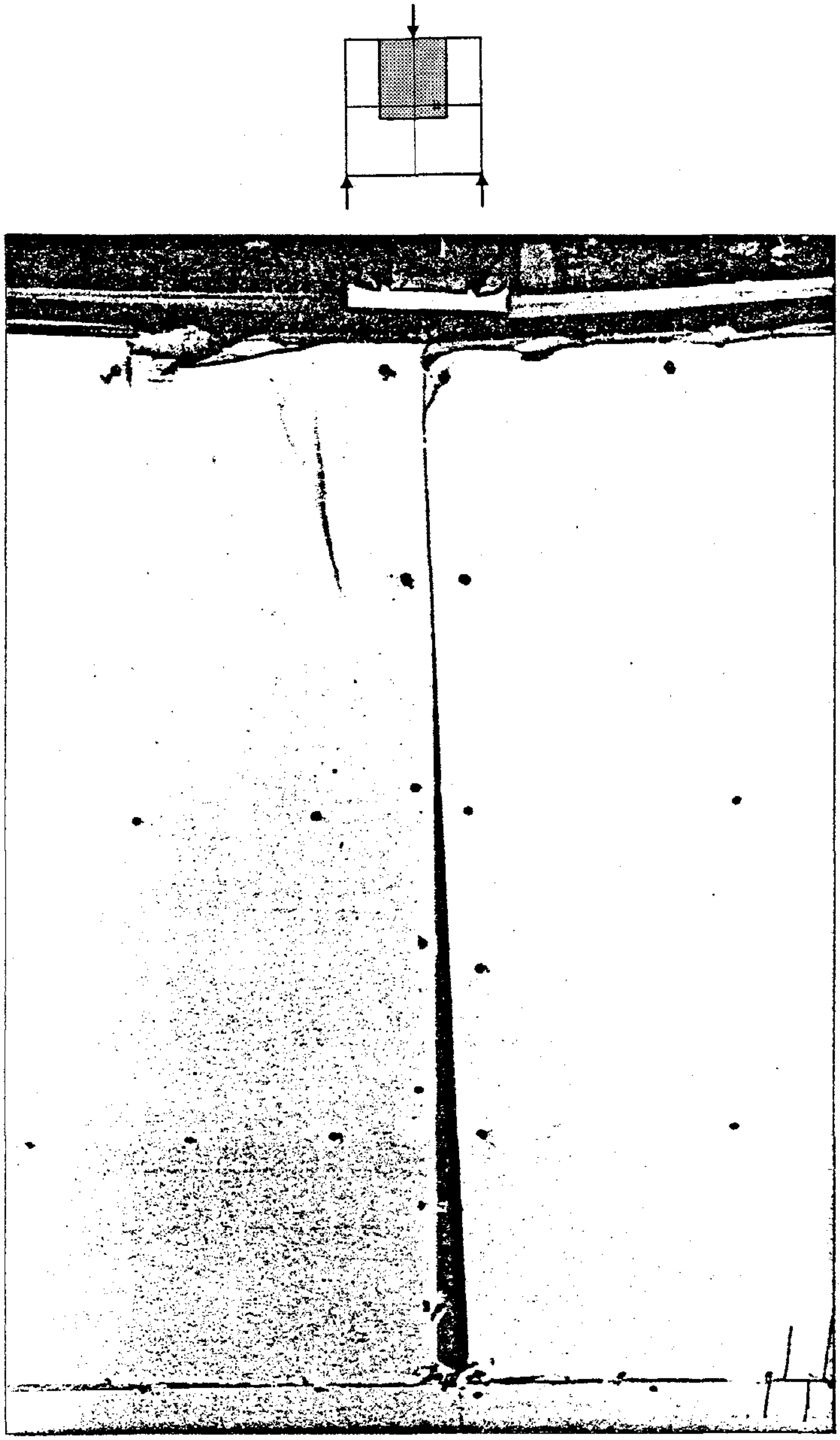


FIGURE 3-13. SPECIMEN A, GYPSUM WALLBOARD PRIOR TO LOADING



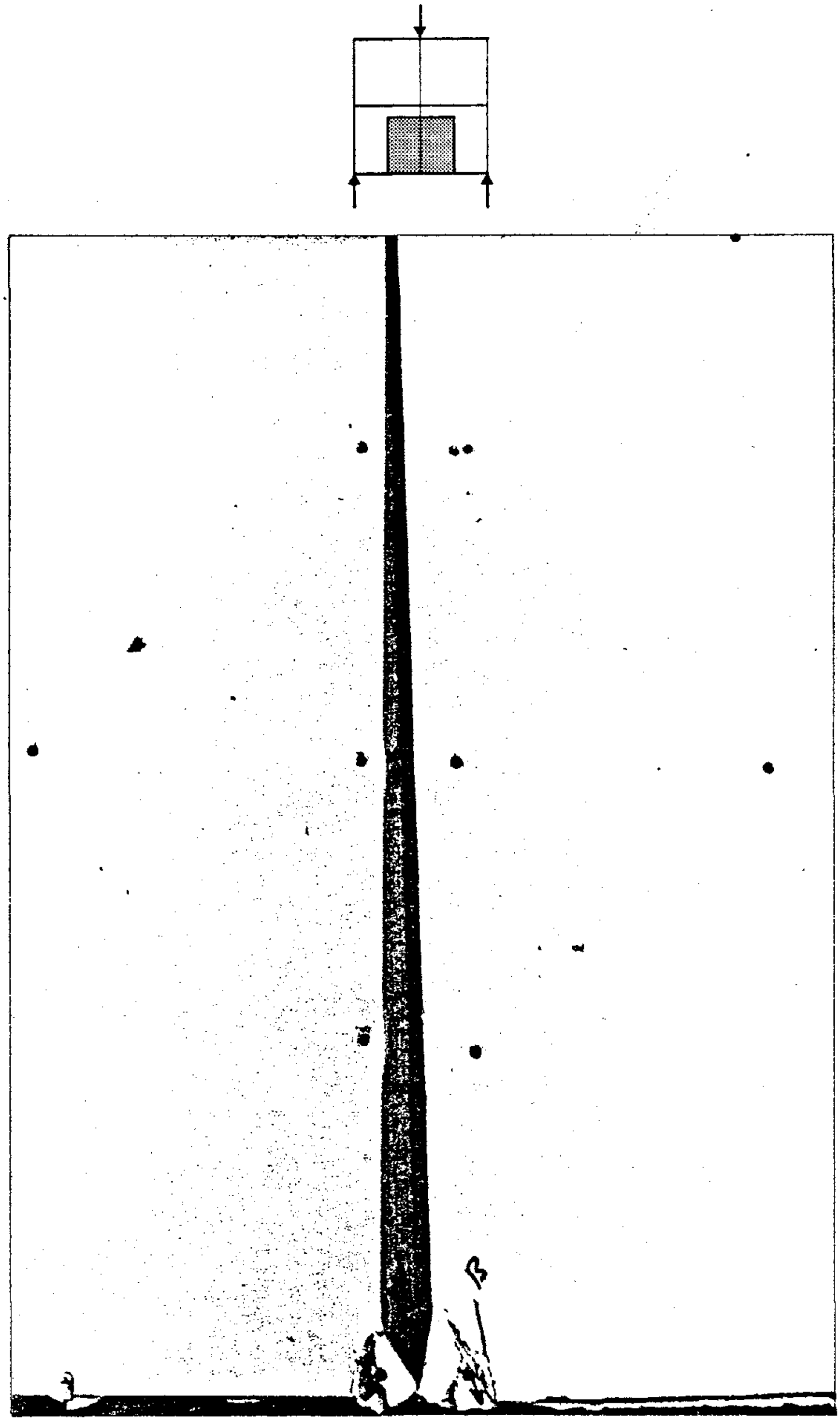
ULTIMATE LOAD, 6300 lb

FIGURE 3-14. SPECIMEN B — GYPSUM WALLBOARD, TYPICAL SLIPPAGE AT VERTICAL JOINTS IN WALLBOARD SECTIONS



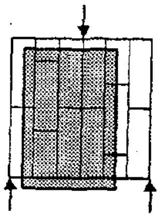
ULTIMATE LOAD, 6300 lb

FIGURE 3-15. SPECIMEN B – GYPSUM WALLBOARD, TYPICAL SLIPPAGE AND SEPARATION OF WALLBOARD BETWEEN PANEL SECTIONS



ULTIMATE LOAD, 6300 lb

FIGURE 3-16. SPECIMEN B – GYPSUM WALLBOARD, TYPICAL SEPARATION OF WALLBOARD BETWEEN PANEL SECTIONS



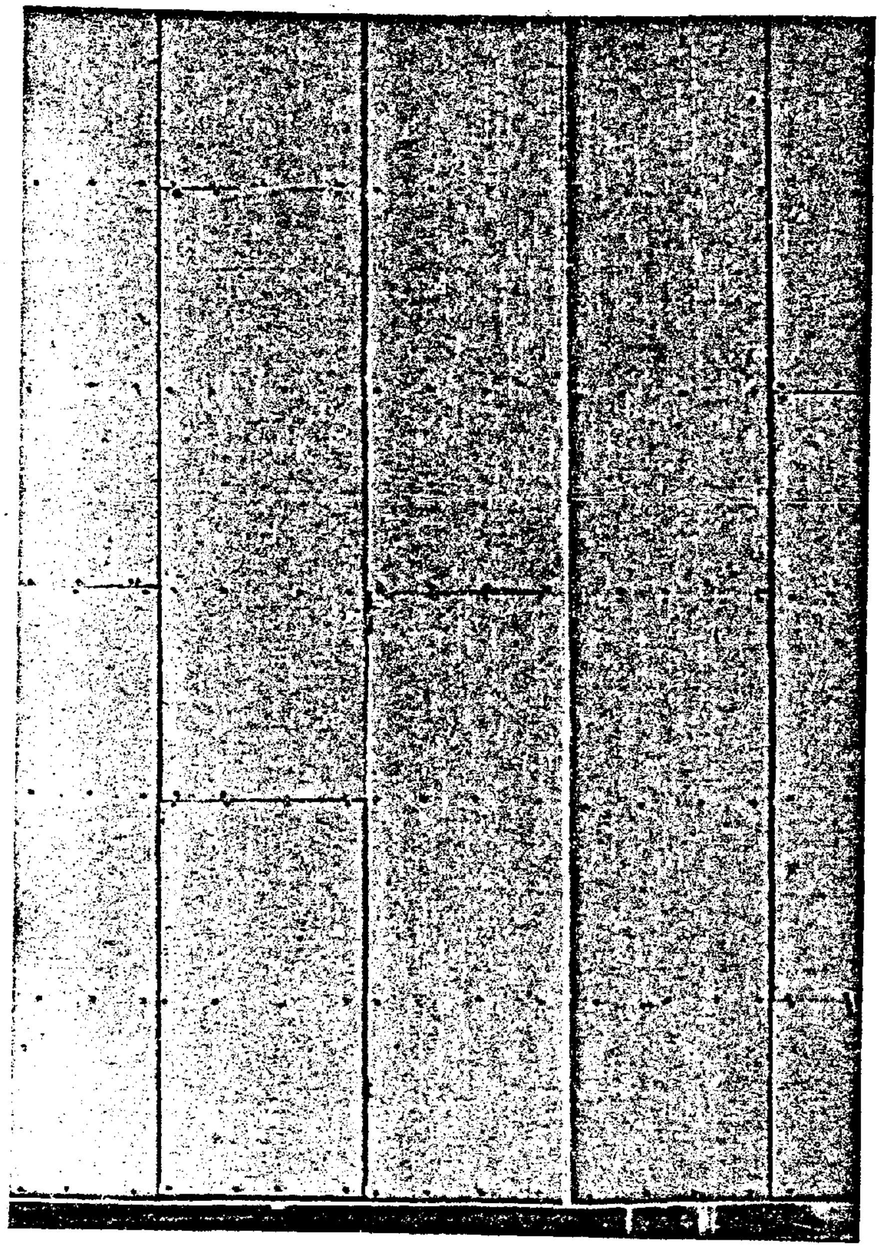
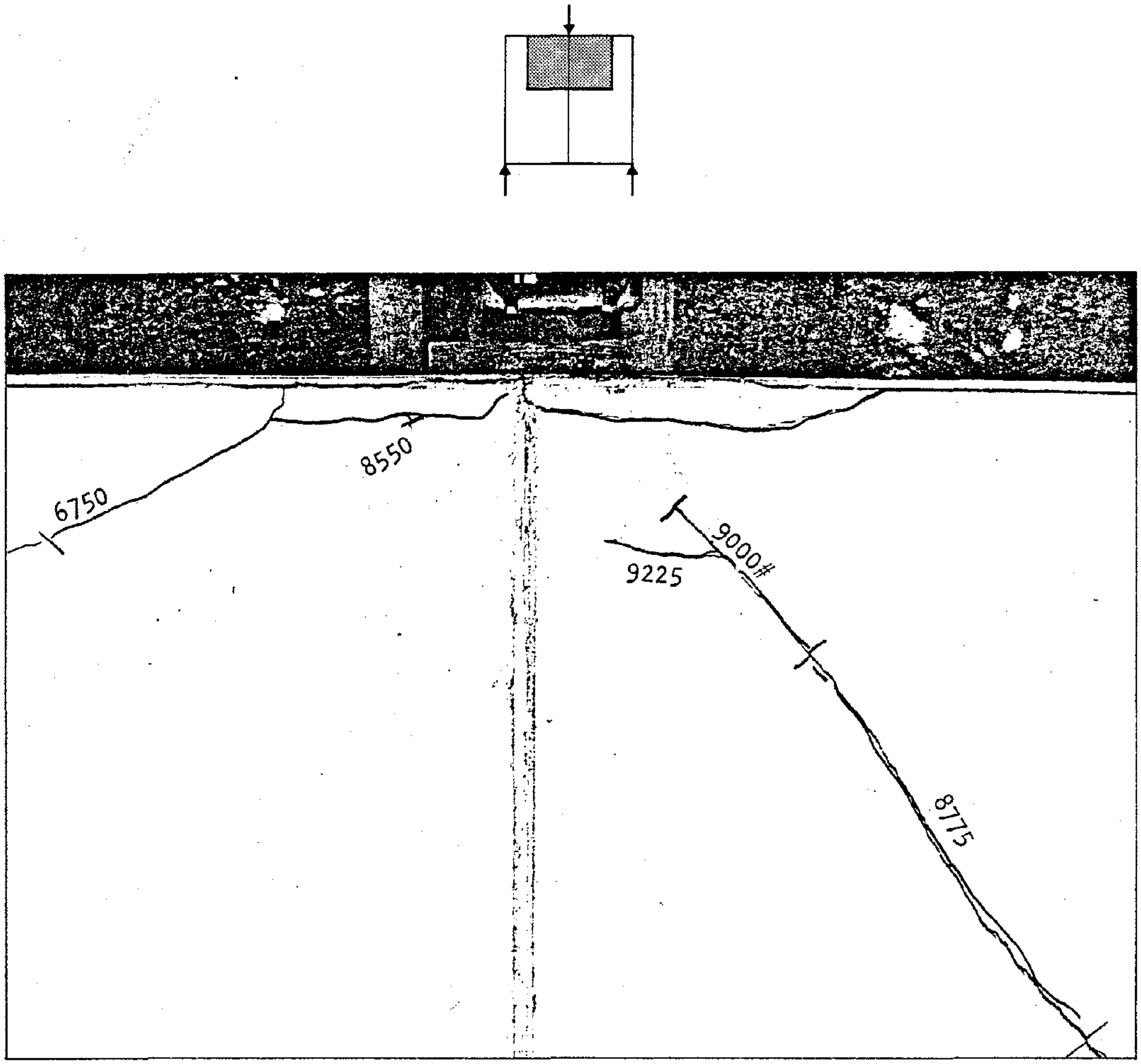


FIGURE 3-17. SPECIMEN C — GYPSUM LATH WITHOUT PLASTER

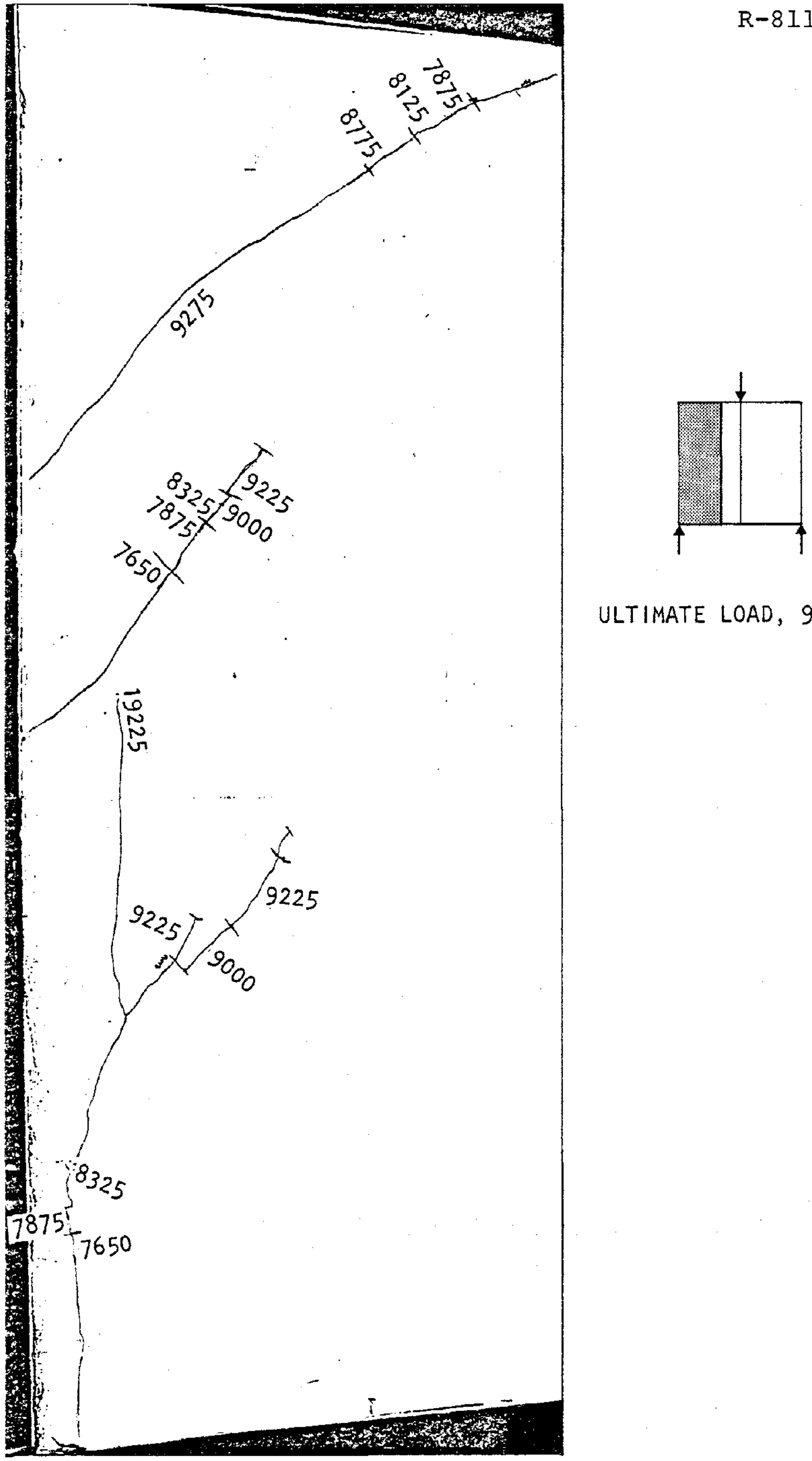


CRACK PATTERN CONTINUED IN FIGURE 3-19

CRACK PATTERN CONTINUED IN FIGURE 3-20

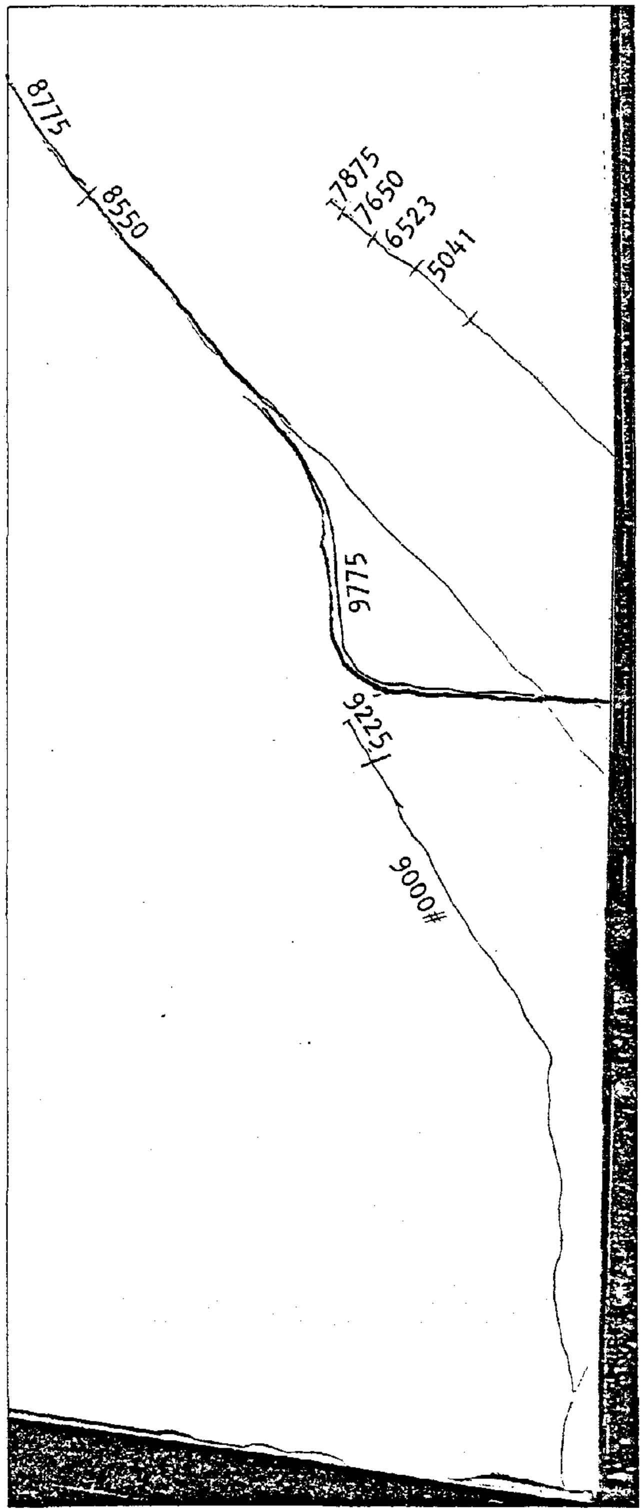
ULTIMATE LOAD, 9225 lb

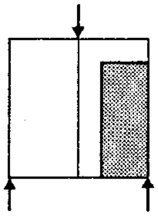
FIGURE 3-18. SPECIMEN C — GYPSUM LATH AND PLASTER, CRACK PATTERNS AT FAILURE



ULTIMATE LOAD, 9225 lb

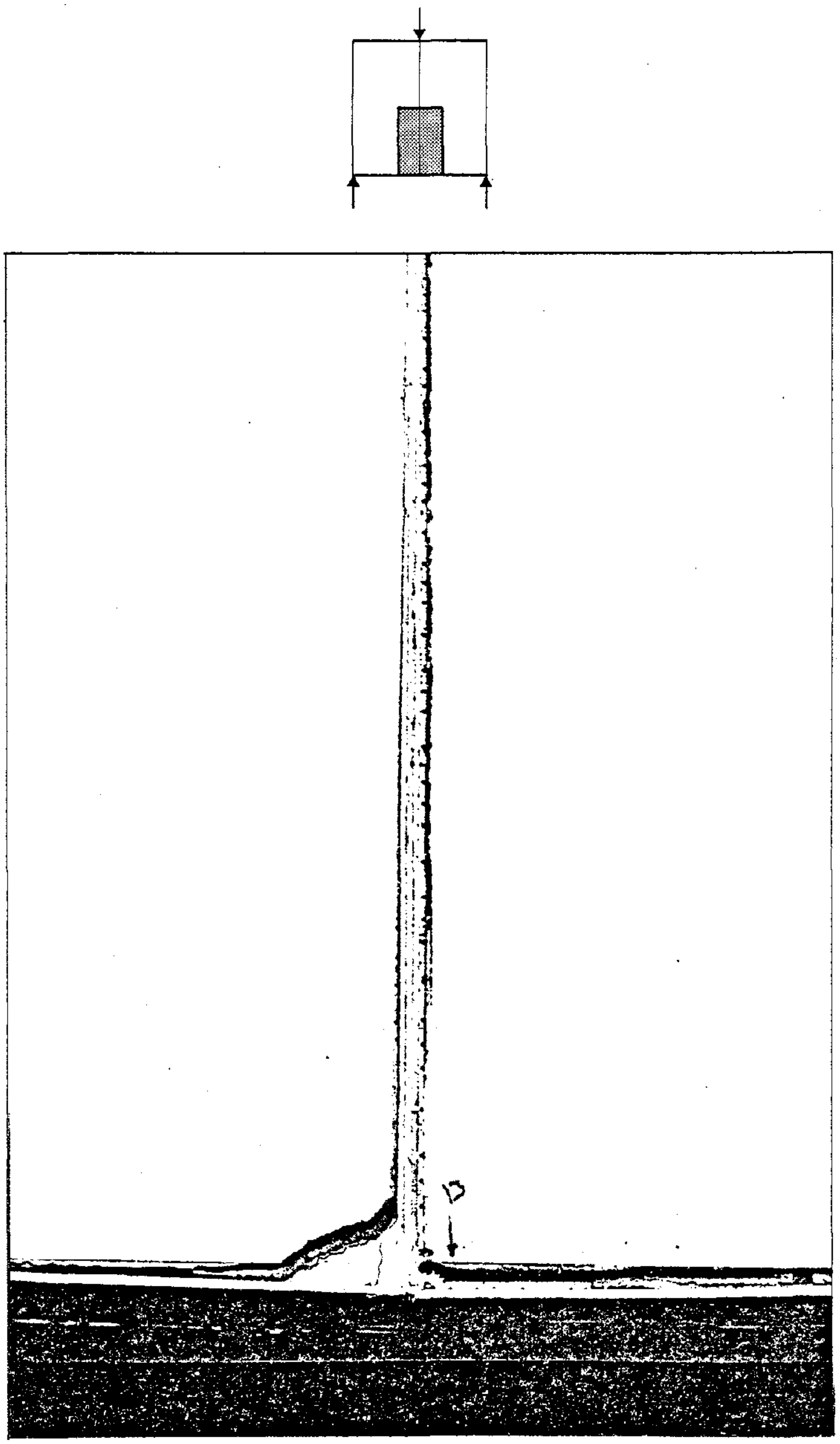
FIGURE 3-19. SPECIMEN C — GYPSUM LATH AND PLASTER, CRACK PATTERNS AT FAILURE





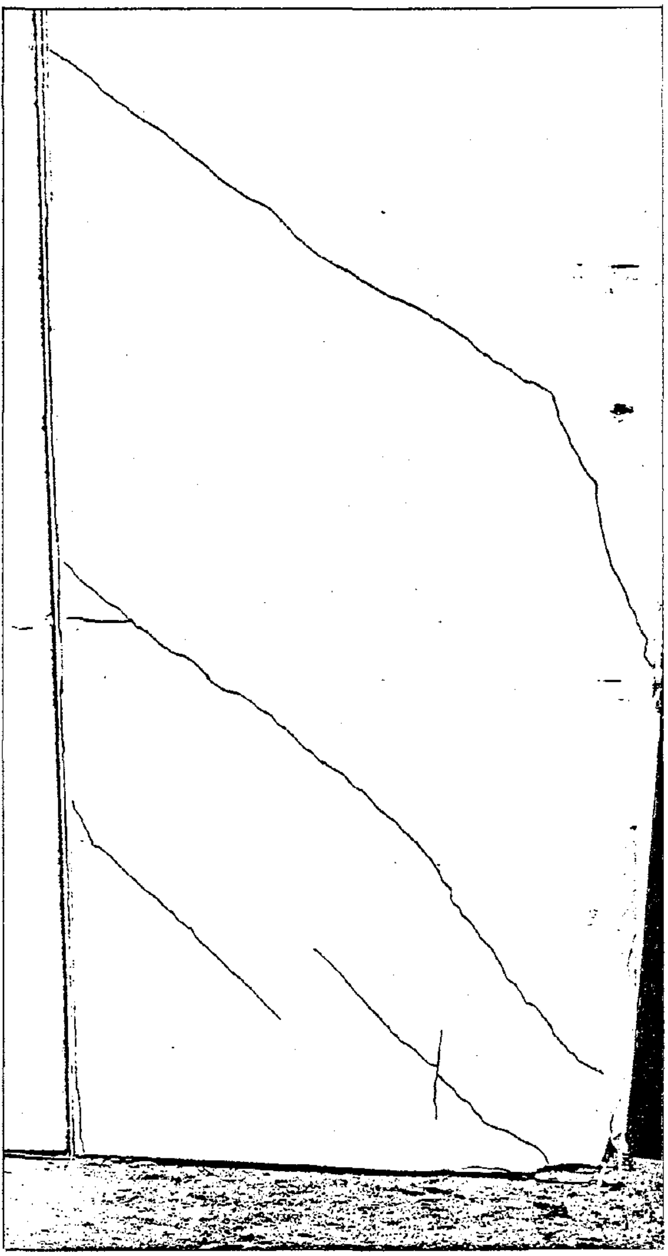
ULTIMATE LOAD, 9225 lb

FIGURE 3-20. SPECIMEN C — GYPSUM LATH AND PLASTER, CRACK PATTERNS AT FAILURE



ULTIMATE LOAD, 9225 lb

FIGURE 3-21. SPECIMEN C — GYPSUM LATH AND PLASTER, CRACK PATTERNS AT FAILURE



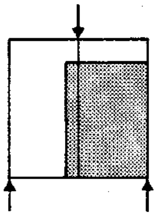
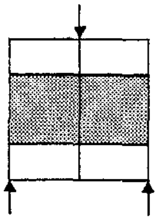


FIGURE 3-22. SPECIMEN C — GYPSUM LATH AND PLASTER, CRACK PATTERNS AT FAILURE ON UNDERSIDE OF TEST PANEL ASSEMBLAGE



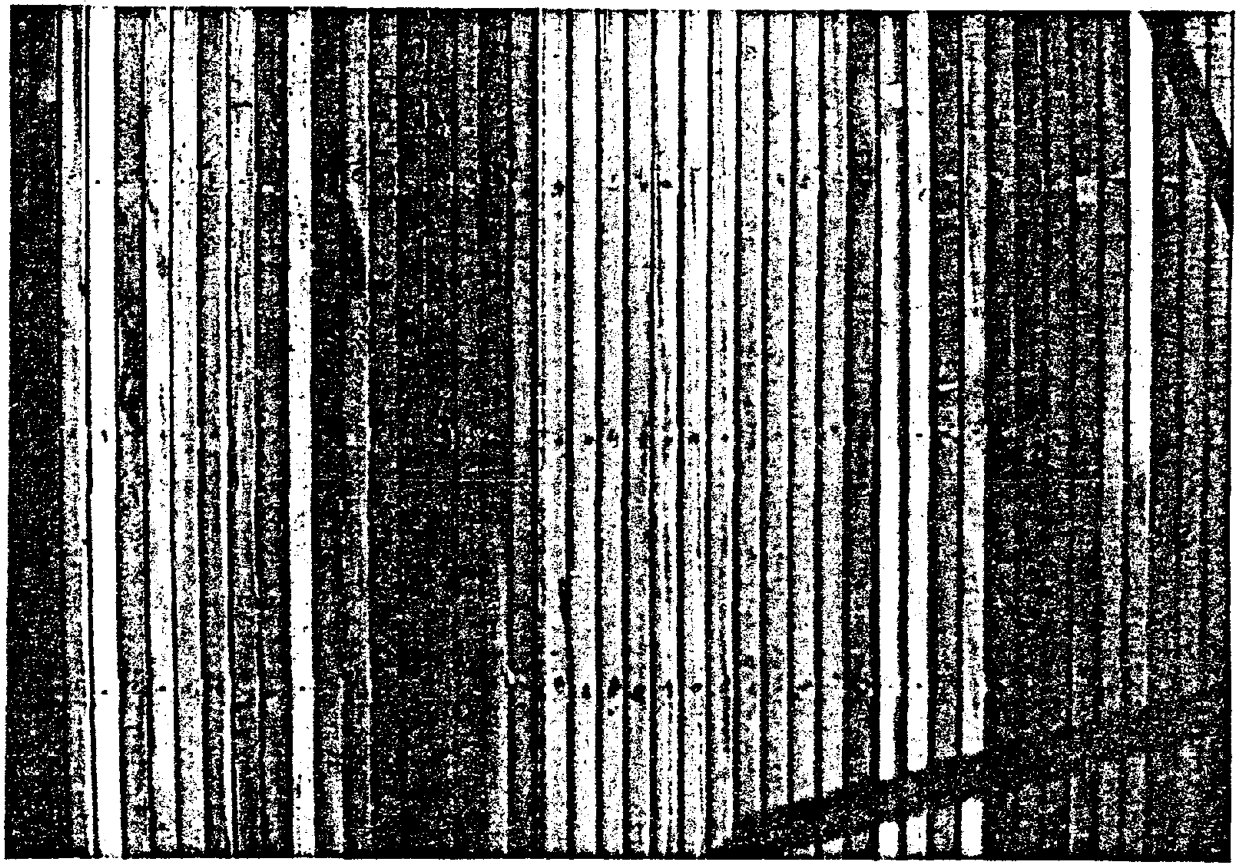


FIGURE 3-23. SPECIMEN D — WOOD LATH WITHOUT PLASTER

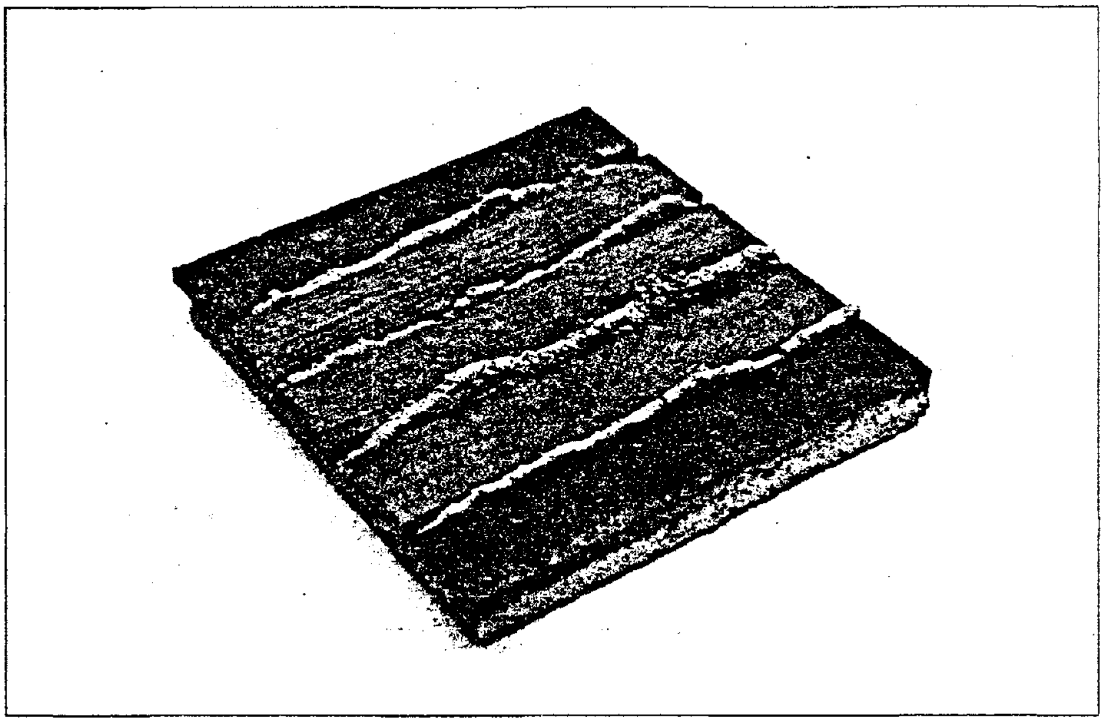
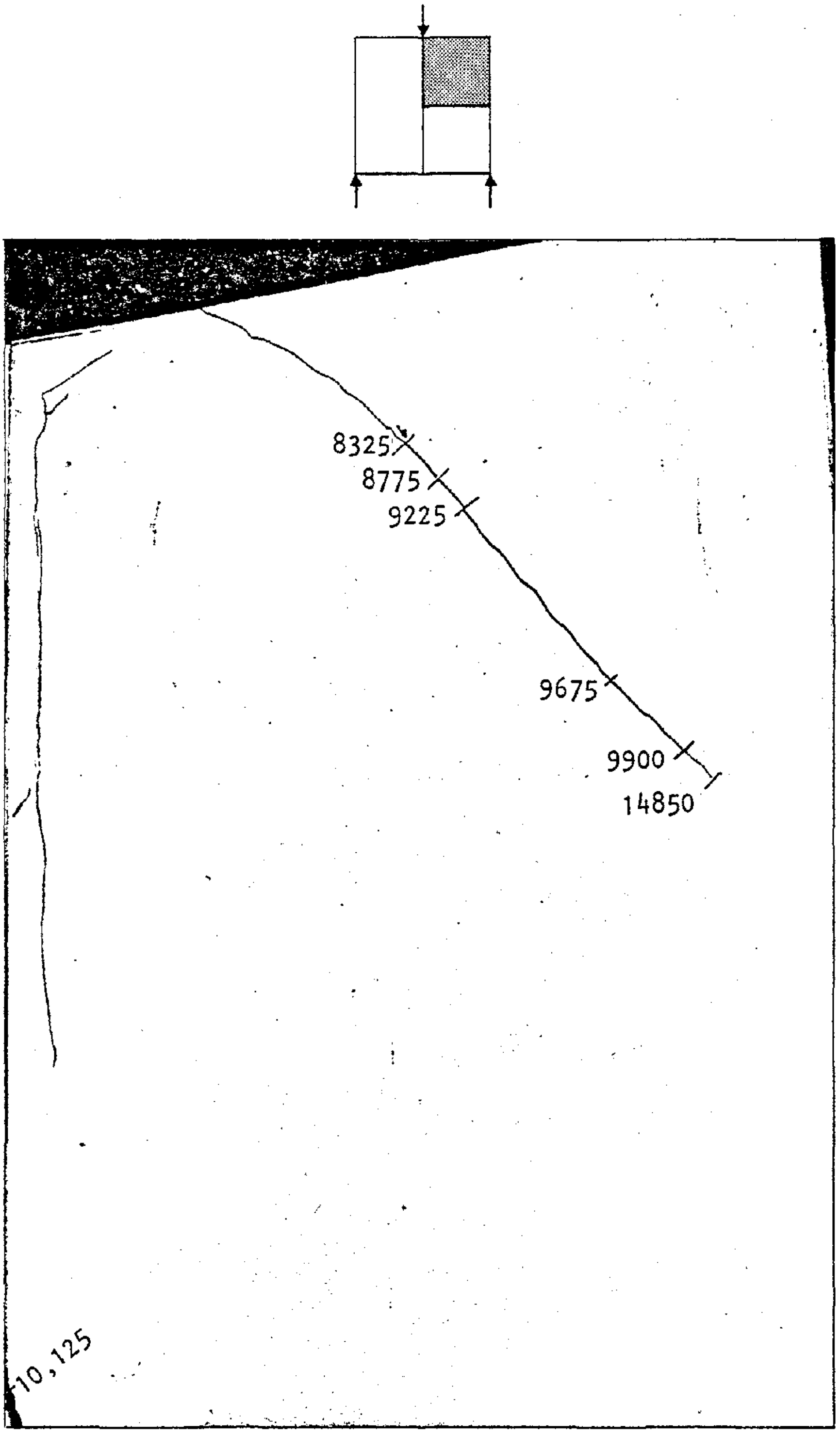
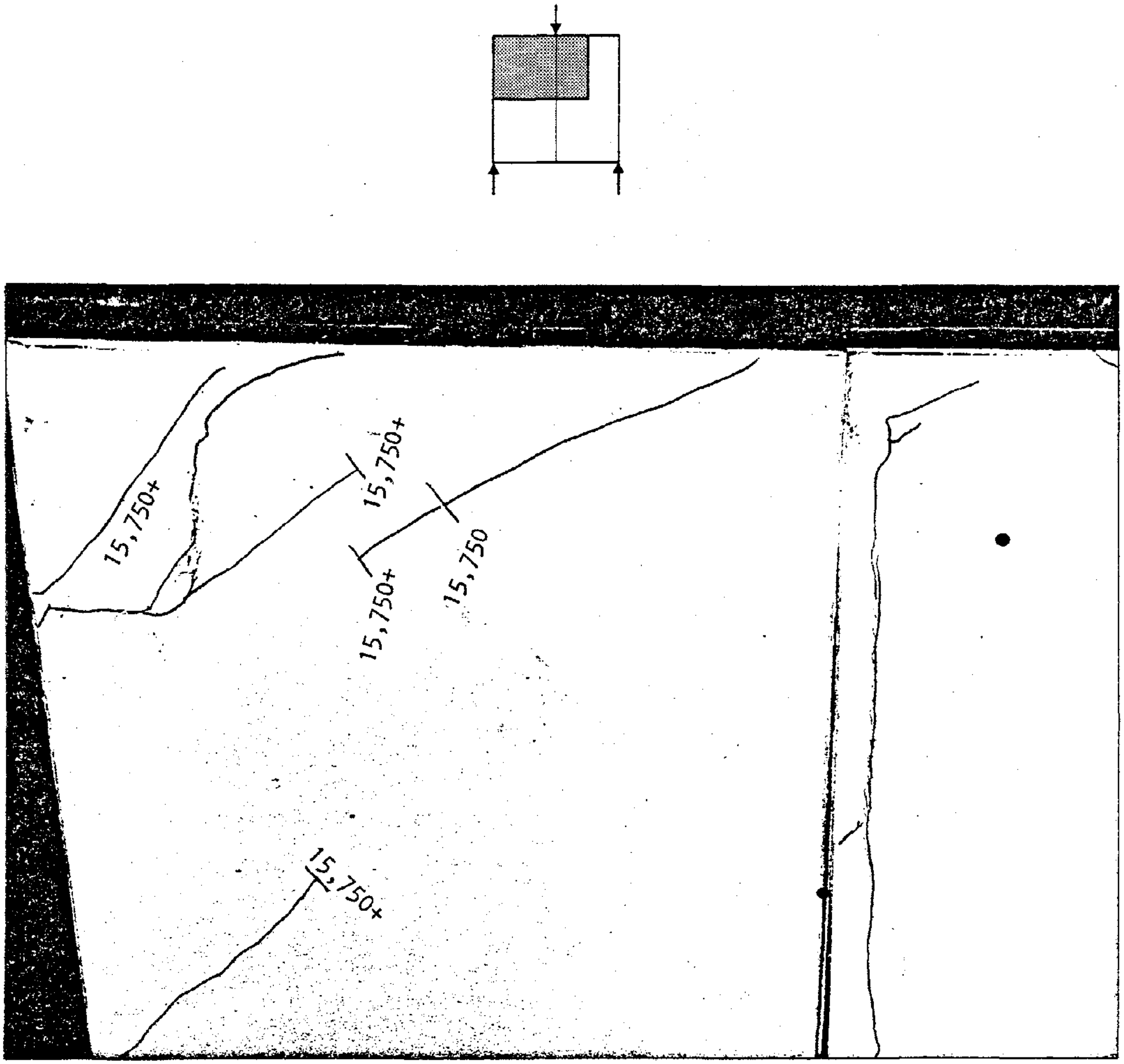


FIGURE 3-24. SPECIMEN D – SAMPLE OF WOOD LATH AND PLASTER CUT FROM PANEL AFTER TEST



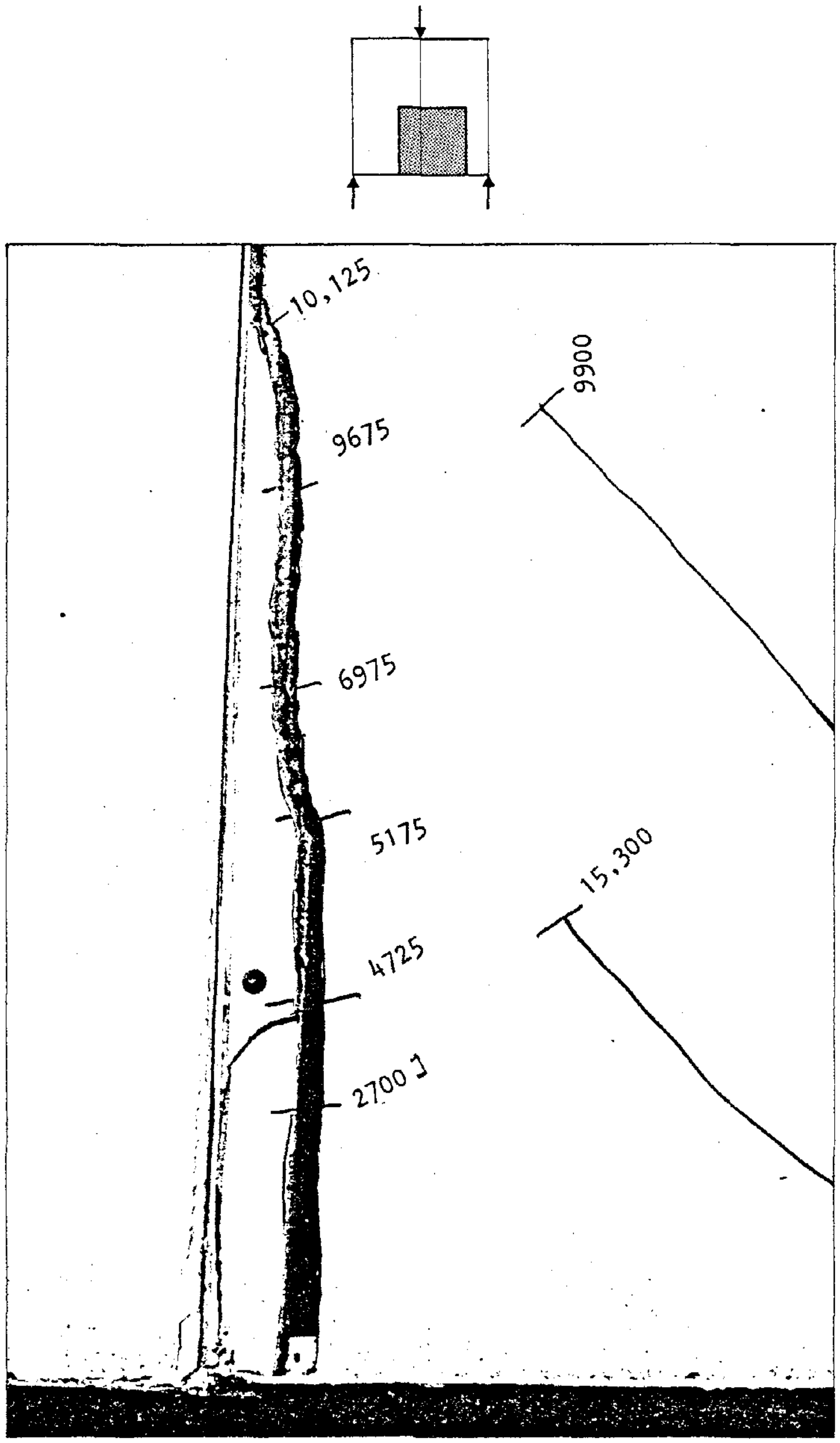
ULTIMATE LOAD, 14,900 lb

FIGURE 3-25. SPECIMEN D — WOOD LATH AND PLASTER, CRACK PATTERNS AT FAILURE



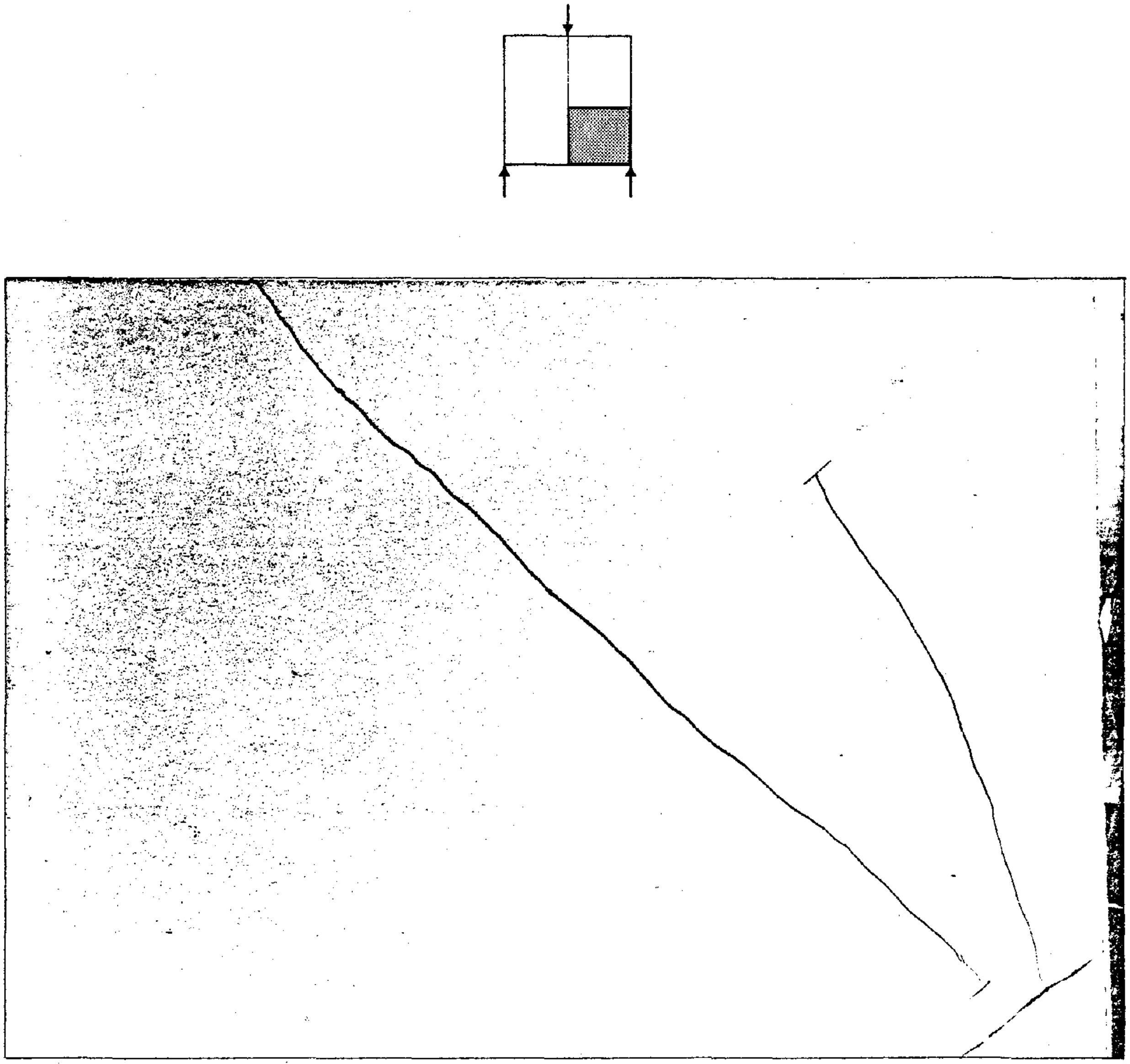
ULTIMATE LOAD, 14,900 lb

FIGURE 3-26. SPECIMEN D — WOOD LATH AND PLASTER, CRACK PATTERNS AT FAILURE



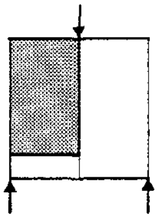
ULTIMATE LOAD, 14,900 lb

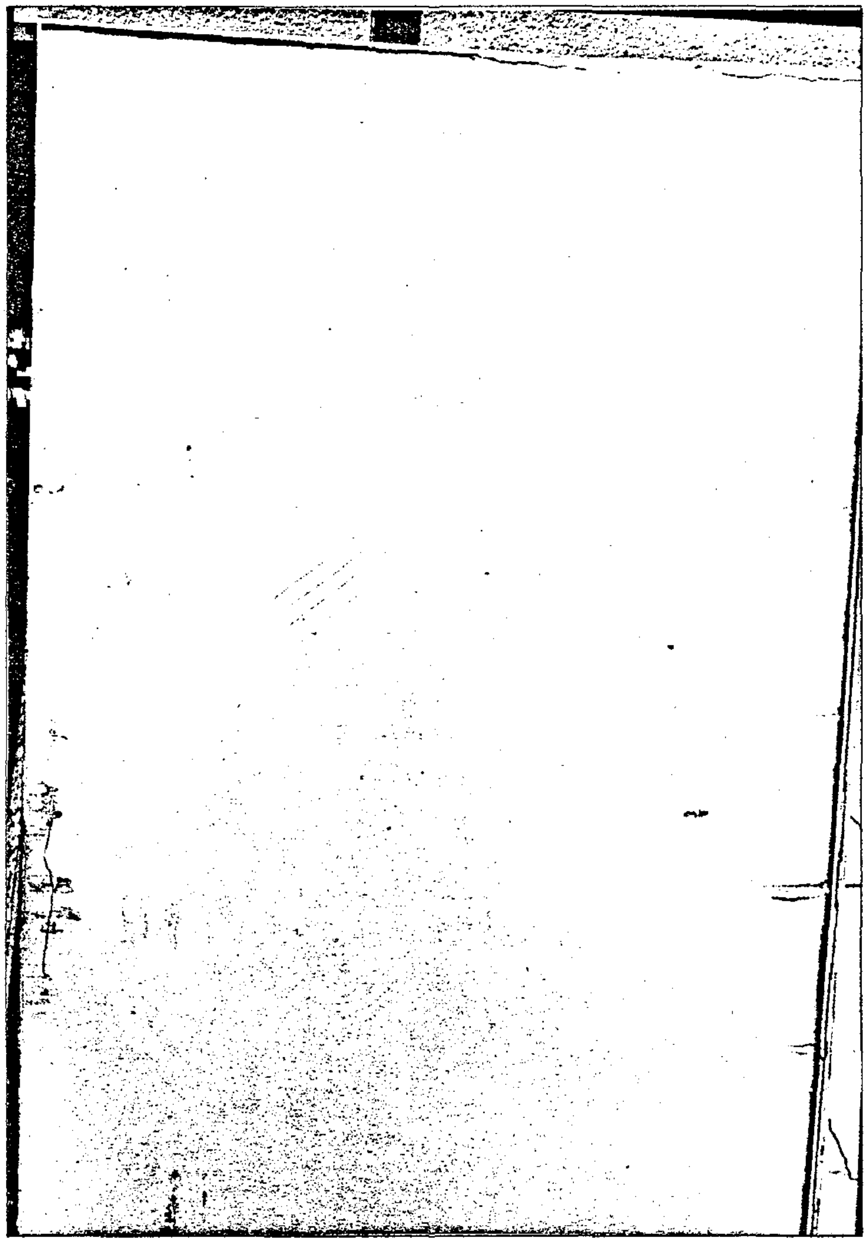
FIGURE 3-27. SPECIMEN D — WOOD LATH AND PLASTER, CRACK PATTERNS AT FAILURE



ULTIMATE LOAD, 14,900 lb

FIGURE 3-28. SPECIMEN D — WOOD LATH AND PLASTER, CRACK PATTERN AT FAILURE ON UNDERSIDE OF PANEL ASSEMBLAGE





ULTIMATE LOAD, 14,900 lb

FIGURE 3-29. SPECIMEN D – WOOD LATH AND PLASTER, UNDAMAGED UNDERSIDE OF PANEL ASSEMBLAGE

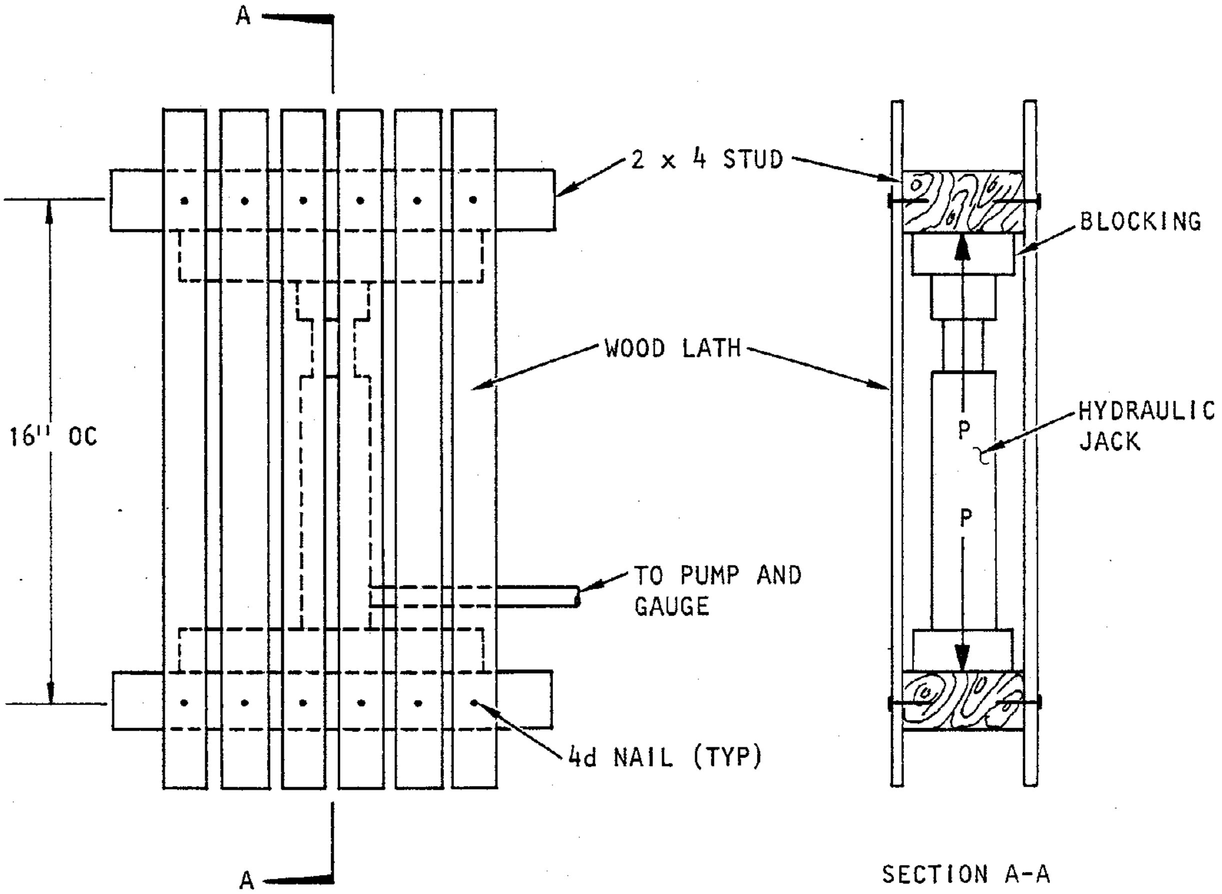
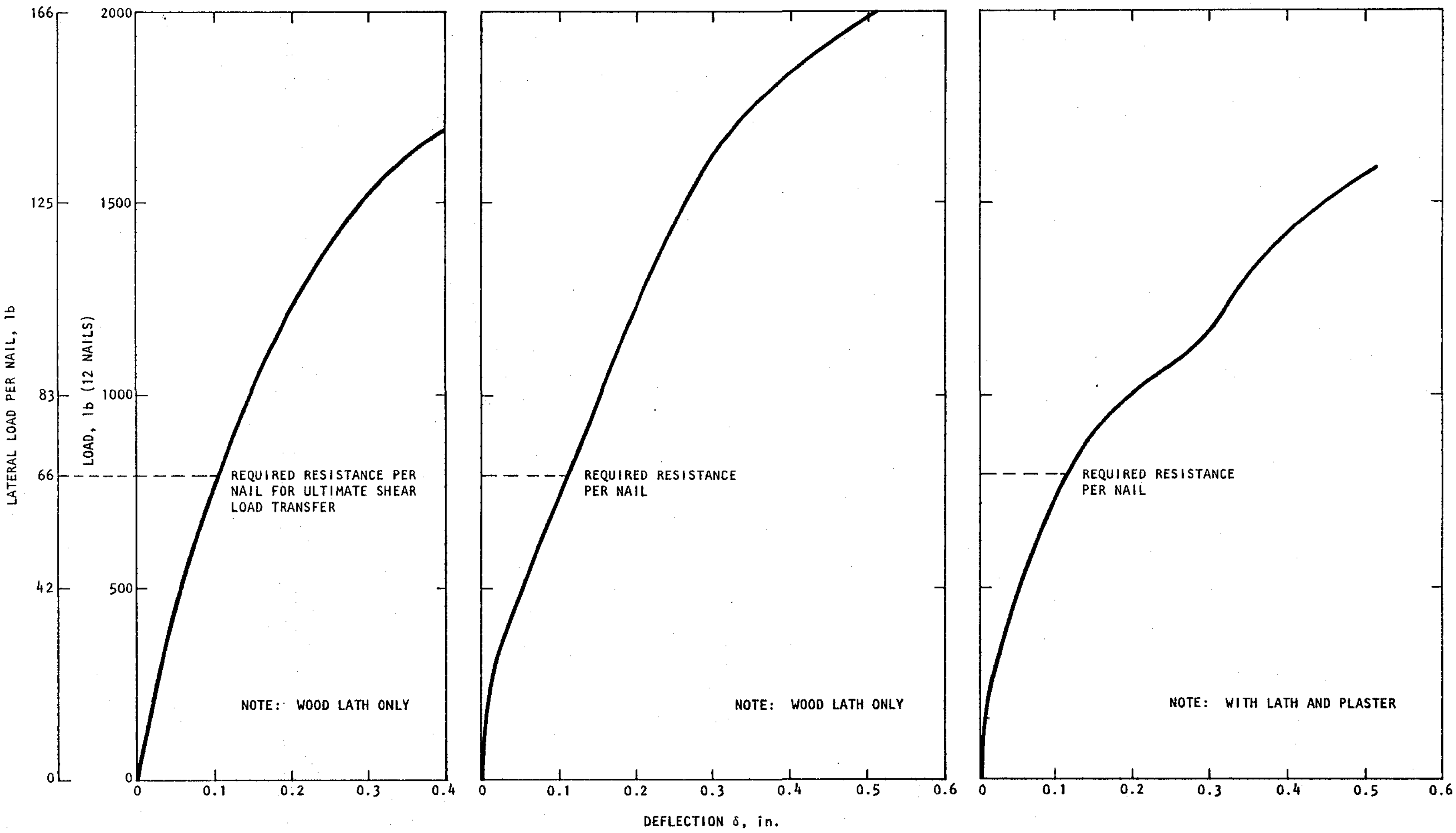


FIGURE 3-30. LATERAL RESISTANCE OF NAILS TEST SET-UP



(a) First test specimen (b) Second test specimen (c) Third test specimen

FIGURE 3-31. LATERAL NAIL RESISTANCE, LOAD/DEFLECTION TEST BASED ON RESISTANCE OF 12 NAILS

SECTION 4

ANALYTICAL PROGRAM

4.1 INTRODUCTION

To supplement the test program conducted in Section 3, the test panels were analyzed using finite element methods to predict the static resistance characteristics of the panels. The predictions were correlated with test results and reiterated, when necessary, to obtain realistic material properties and strength and stiffness characteristics for the panel specimens, based on linear elastic behavior. The scope of this study precluded the development and verification of nonlinear models that would predict a more realistic shape of the actual load/deflection curves for use in a nonlinear finite element program.

4.2 ANALYSIS METHOD

The test panel assemblages were analyzed utilizing the finite element model shown in Figure 4-1. The finite element model uses beam elements for studs and plane stress elements for wall facing materials. Studs are represented in the model by 32 beam elements; 12 plane stress elements were used to represent wall facing material on the two sides of the panel. The model assumes that the assemblage is pinned at Nodes 1 and 15 and that the load is applied at Node 14.

Material properties finally selected to represent each type of material in the finite element model are indicated in Table 4-1 based on correlating analyses with test results.

4.3 CALCULATED LOAD/DEFLECTION CURVES

Elastic load/deflection relationships were calculated for each of the four types of partition construction. These curves are plotted in Figures 4-2 through 4-5 and compared with the measured load/deflection curves.

4.4 CONCLUSIONS

It is seen that the elastic stiffness of interior panels can be simulated by finite element models representing the wood stud and facing material system. Such finite element models may be considered appropriate in determining natural frequencies of interior panels and in dynamic analyses of the response of building/interior partition systems to seismic input motions.

The static finite element analyses showed that the facing material acts as the primary shear-resisting structural element, while studs carry only a small portion of the load, especially for wood lath and plaster construction. Since the shear load is introduced through the wood framing system, it is important that nails connecting the facing material to the wood studs have sufficient strength to transfer the lateral loading to the wallboard or plaster elements.

In the case of wood lath and plaster construction where the lath run in one direction, it is also important that the nails connecting the studs to the runners have ample strength to transmit shear loading across the joints.

TABLE 4-1. MATERIAL PROPERTIES FOR FINITE ELEMENT MODEL

Material	Modulus of Elasticity E, psi	Shear Modulus G, psi	Poisson's Ratio, γ
Wood Stud	1.6 x 10^6		0.4
Gypsum Wallboard (Horizontal Joint)	2,400	1000	0.2
*Gypsum Wallboard (Vertical Joint)	4,800	2000	0.2
*Gypsum Lath and Plaster	12,500	5200	0.2
*Wood Lath and Plaster	17,000	7100	0.2

*Combined Moduli

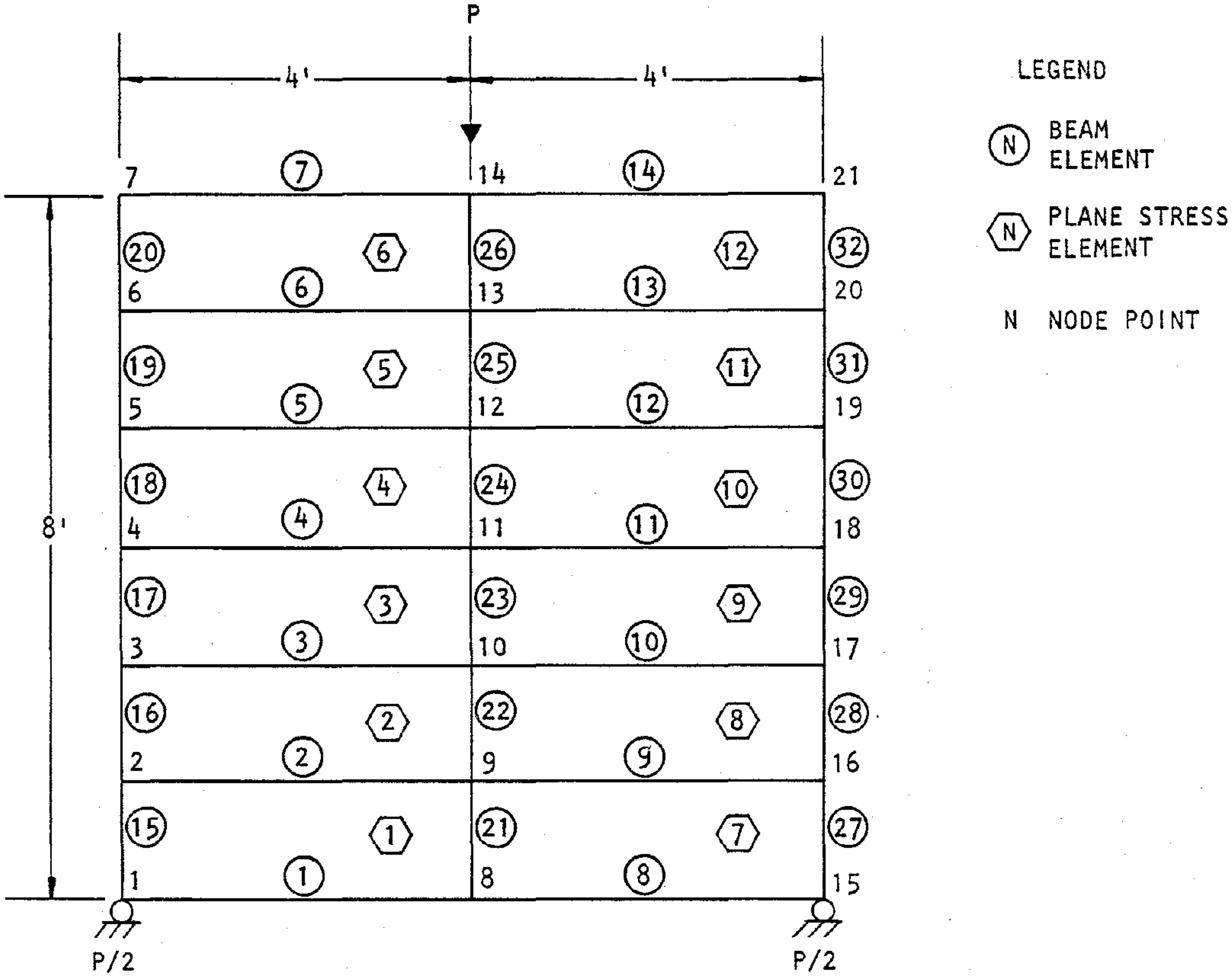


FIGURE 4-1. FINITE ELEMENT MODEL FOR WALL PANEL TEST ASSEMBLAGE

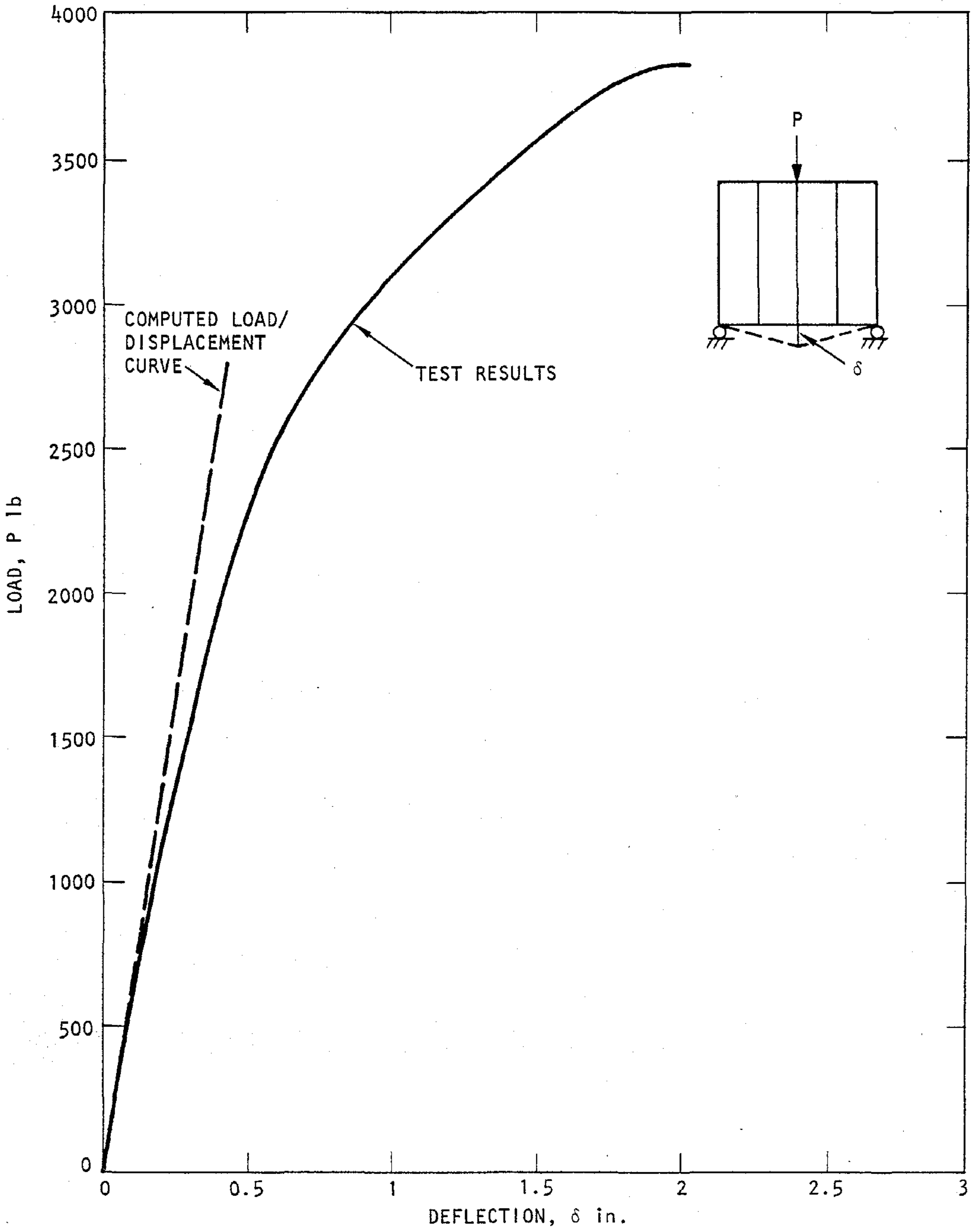


FIGURE 4-2. COMPARISON OF COMPUTED LOAD/DEFLECTION CURVE WITH TEST RESULTS — SPECIMEN A GYPSUM WALLBOARD (HORIZONTAL JOINTS)

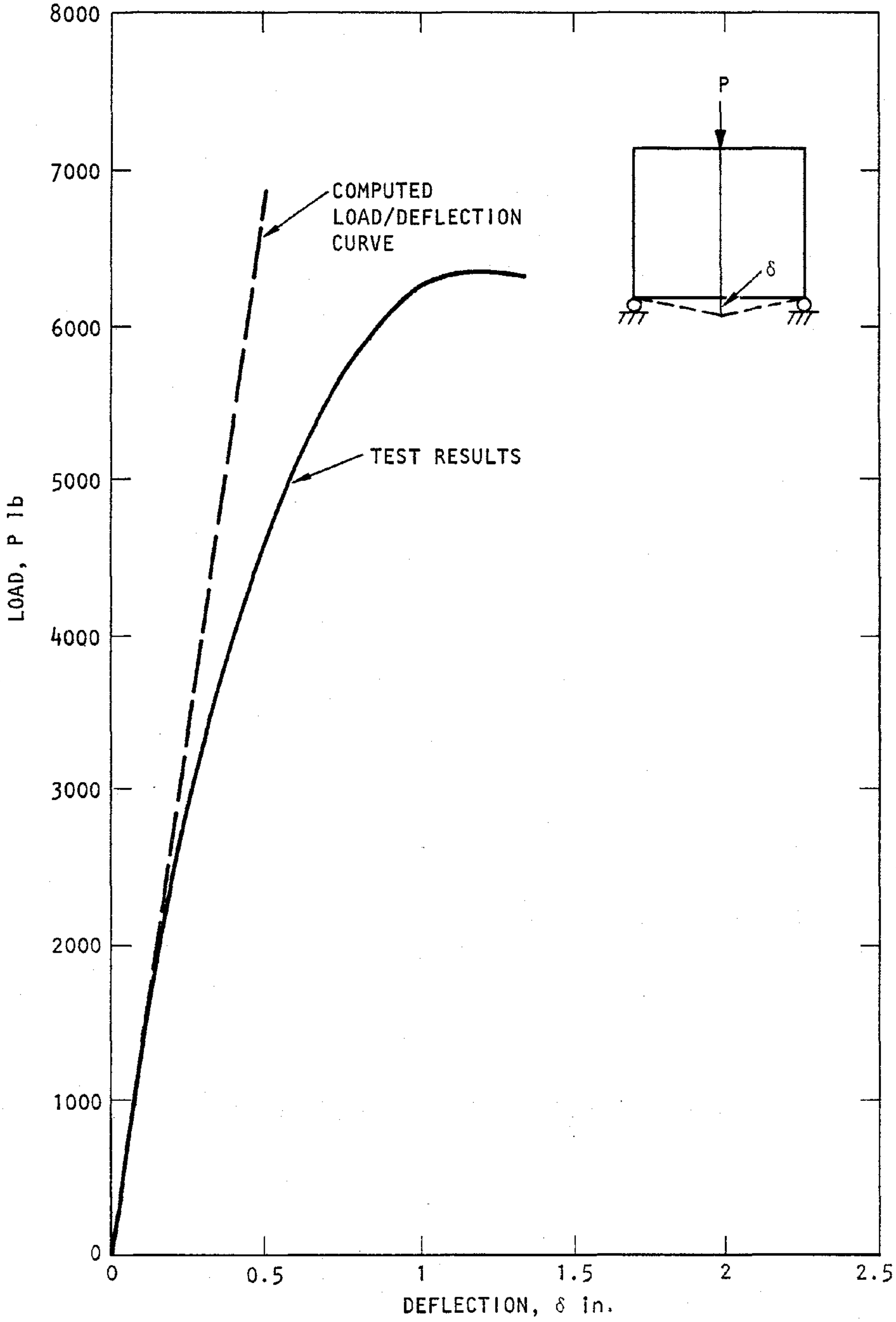


FIGURE 4-3. COMPARISON OF COMPUTED LOAD/DEFLECTION CURVE WITH TEST RESULTS — SPECIMEN B GYPSUM WALLBOARD (VERTICAL JOINTS)

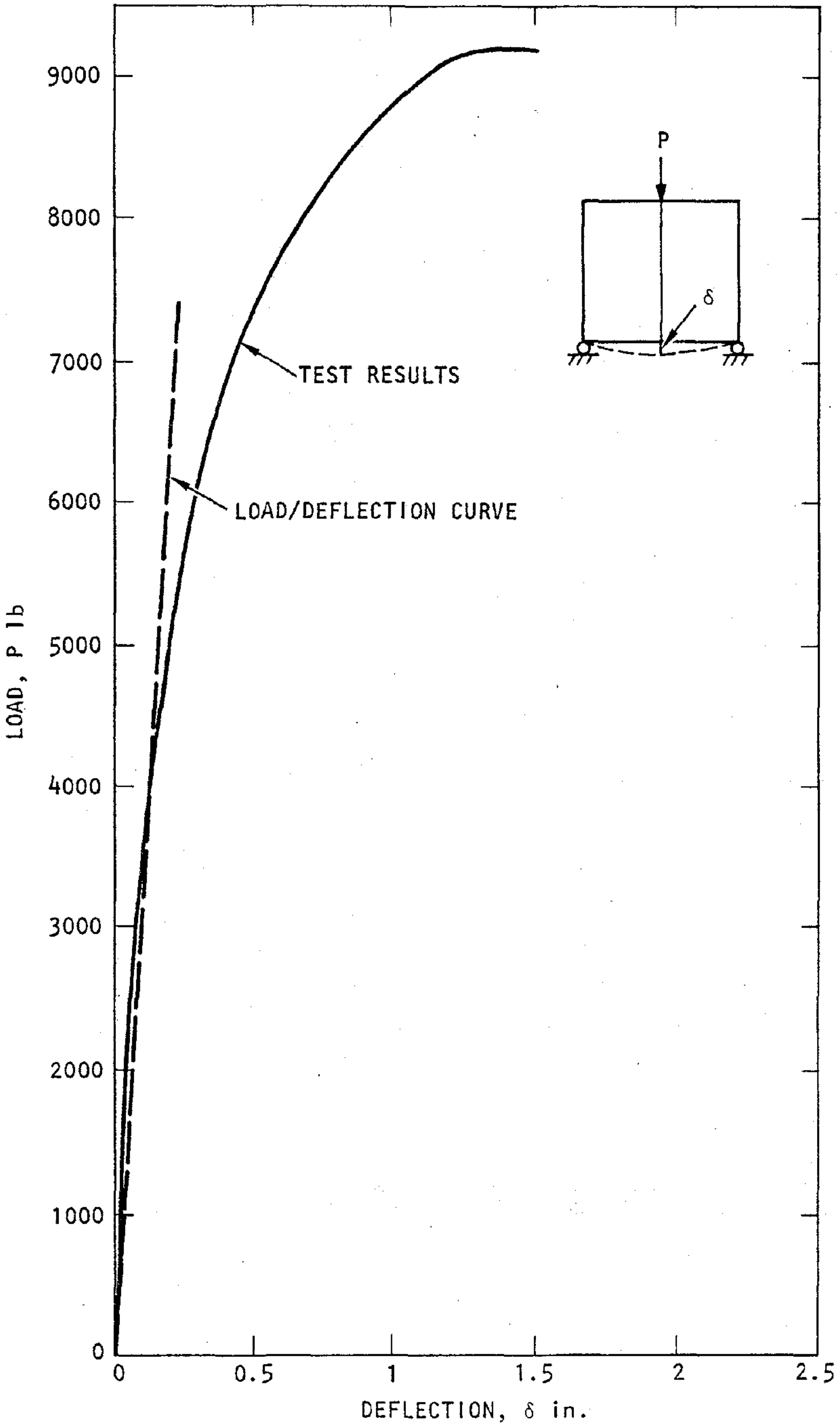


FIGURE 4-4. COMPARISON OF COMPUTED LOAD/DEFLECTION CURVE WITH TEST RESULTS – SPECIMEN C GYPSUM LATH AND PLASTER

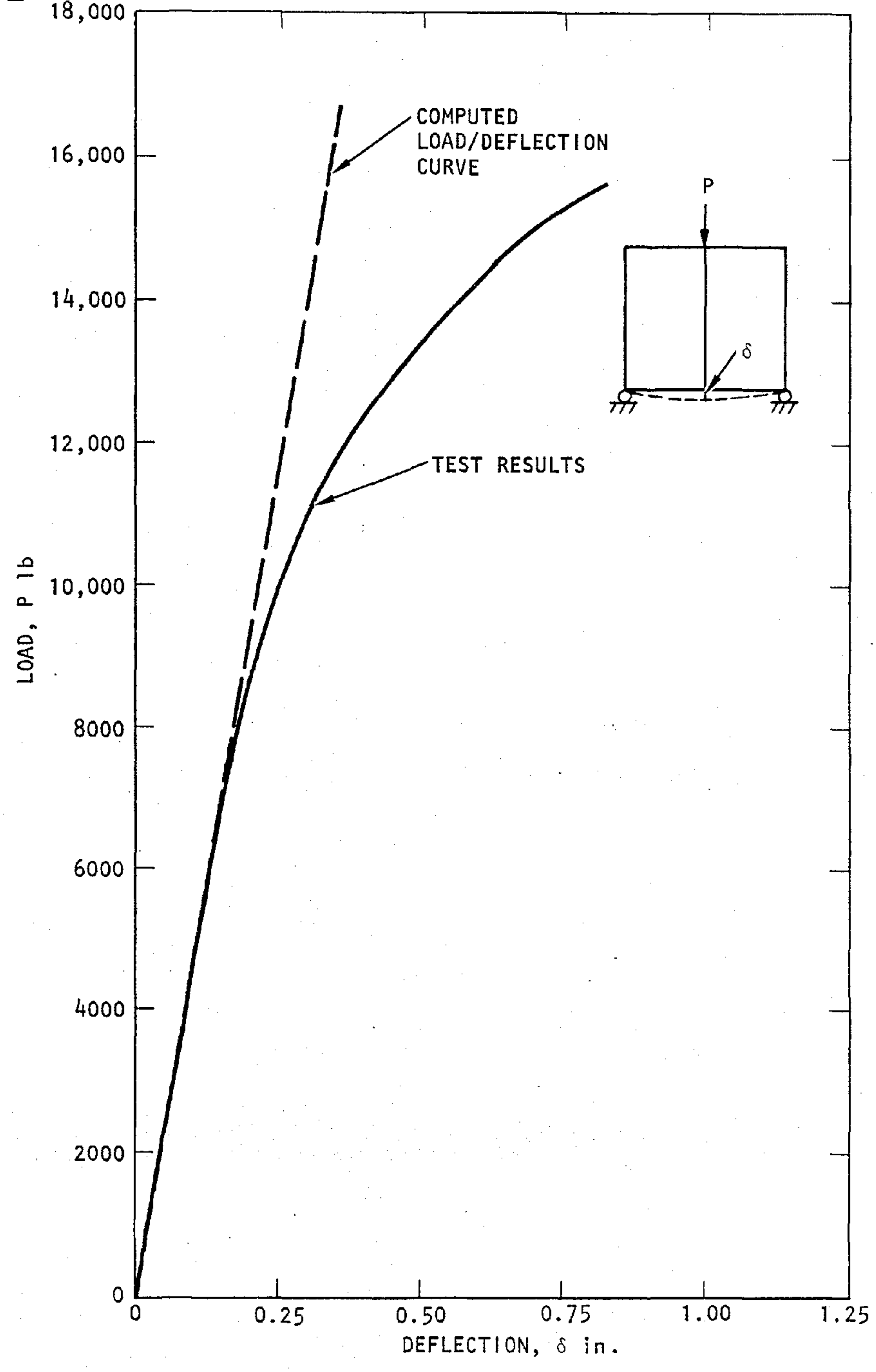


FIGURE 4-5. COMPARISON OF COMPUTED LOAD/DEFLECTION CURVE WITH TEST RESULTS — SPECIMEN D WOOD LATH AND PLASTER

SECTION 5

EFFECTIVENESS OF SHEAR WALL PARTITIONS

5.1 INTRODUCTION

This section assesses the effectiveness of shear wall partitions in resisting the lateral loads imposed on two- or three-story masonry apartment/hotel buildings where extensive use has been made of floor-to-ceiling interior walls to partition off floor space. These structures normally use wood joists and sheathing for the floor and roof systems.

5.2 BASIS FOR THE ASSESSMENT

The building used to assess the effectiveness of shear wall partitions is a three-story apartment building of unreinforced masonry wall construction. The layout of apartments and arrangement of partitions are shown in Figure 5-1a for a typical floor. The building elevation and floor heights are shown in Figure 5-1b. Extensive testing was conducted on the masonry walls of this building prior to demolition in 1978 for street realignment near the Los Angeles downtown area (Schmid et al., 1978). Testing was undertaken to verify some of the design values listed in the new Los Angeles ordinance (LAMC, 1981).

The interior construction of the apartment building was typical 2 x 4's at 16 in. on center. Diagonal sheathing was used as the subfloor over floor joists at 16 in. on center and overlaid by finished wood flooring.

It was assumed for the purpose of this assessment that the exterior masonry walls and interior partitions are adequately connected to floor and roof diaphragms so that lateral seismic forces can be transferred from diaphragms into the shear walls and down to the foundation.

5.3 COMPARISON OF RELATIVE WALL STIFFNESSES

With regard to Figure 5-1, it is usually assumed that the effective stiffness of the two exterior masonry end walls is several magnitudes higher than the combined stiffness of the transverse interior wood lath and plaster partitions. To check this premise based on the wood lath and plaster test data and on the linear feet of transverse partitions associated with apartment occupancy, the following comparisons were made for rigid and semirigid diaphragm assumptions based on building layout and dimensions obtained from Figure 5-1.

5.3.1 RIGID DIAPHRAGM ASSUMPTION

a. Stiffness of Masonry End Walls

Total effective length, L_e = 66 ft
Shear modulus, G = 1×10^6 psi
Thickness, t = 17 in.
Height (one story), h = 10 ft
Wall area, $A = L_e t$ = 13,464 sq in.

$$K = \frac{AG}{h} = 112 \times 10^6 \text{ lb/in.}$$

b. Stiffness of Transverse Interior Partitions

Total effective length, L_i = 516 ft
Stiffness based on test data
Panel height = 4 ft
Panel length = 8 ft
For a load P of 5000 lb, deflection, δ
= 0.25 in. per 8 ft length
Adjust deflection for actual shear wall dimension based on height of 9 ft and length of 516 ft

$$\text{Effective } \Delta = \frac{\delta}{P}\left(\frac{8}{516}\right)\left(\frac{9}{4}\right) = 1.74 \times 10^6$$

$$K = \frac{1}{\Delta} = 0.57 \times 10^6 \text{ lb/in.}$$

c. Summary

Based on the assumption of a rigid diaphragm, the exterior masonry walls will resist 99% of the total lateral load.

5.3.2 SEMIRIGID DIAPHRAGM

If the diaphragm is flexible instead of rigid, lateral loading will be distributed to the interior partitions. If they do not possess sufficient strength to resist the lateral loads, they will fail and the lateral load must then be transmitted through the diaphragm to the exterior end walls. However, diaphragms can normally be considered as semirigid and will participate in the distribution of lateral loads to all shear-resisting elements in the structural system based on the stiffness characteristics of the shear elements and the diaphragm. Semirigid diaphragms are analyzed in this section to determine the distribution of load to partitions when their stiffness is considered, as well as that of the diaphragm.

a. Mathematical Model

Figure 5-2 indicates a simplified structural model of a semirigid diaphragm with interior partitions lumped at the one-third points. The diaphragm is modeled as three square shear panels as shown. The mathematical model used to represent one-half of the structural model is indicated in Figure 5-3, where $k_i = 0.29 \times 10^6$ lb/in. and $k_e = 56 \times 10^6$ lb/in., corresponding to one-half the values defined in Section 5.3.1.

b. Definition of Diaphragm Stiffness

The National Science Foundation is currently funding a study to develop a methodology for mitigaton of seismic hazards in existing unreinforced masonry buildings. As part of this work, a series of test were performed on 20 ft by 60 ft diaphragms typical of those found in existing structures (Ewing et al., 1980). These tests involved both static in-plane load/displacement tests and dynamic, in-plane shaking tests to obtain diaphragm stiffness and dynamic response characteristics. This data was utilized to define the stiffness, k_d, of wood diaphragms.

Three diaphragm systems were analyzed:

1. 1" x 6" straight sheathing with 5/16" plywood overlay (designated Type H).
2. 1" x 6" diagonal sheathing with 1" x 6" straight sheathing overlay (designated Type K)
3. 3/4" plywood with 3/4" plywood overlay (designated Type P)

The first system (H) represents lower-bound and the second and third systems (K and P) represent upper-bound stiffnesses for wood diaphragms. Force/deflection envelopes for the three diaphragms are shown in Figure 5-4. Based on a linear elastic force/deflection relationship, the following stiffness values, k_d, are derived from Figure 5-4.

1. Type H Diaphragm

   $P = 12{,}000$ lb; $\delta = 1"$
   $k_d = 12{,}000$ lb/in.

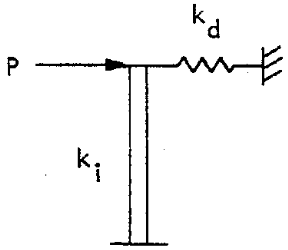
2. Types K and P Diaphragms

   $P = 30{,}000$; $\delta = 1"$
   $k_d = 30{,}000$ lb/in.

Although these stiffnesses are associated with 20 ft by 20 ft shear panels, they can be applied to any square shear panel of the same construction.

c. Simplification of Mathematical Model

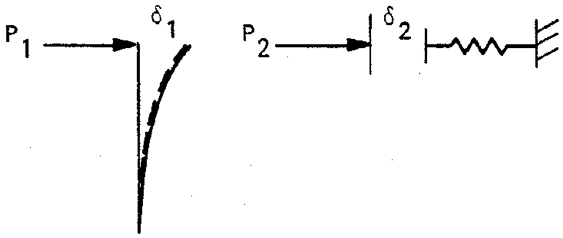
Since k_e/k_i is approximately 196, it can be assumed that k_e equals infinity as compared to k_i, and a simplified math model results as shown below



Therefore: $P = P_1 + P_2$

where P_1 = Force on interior partition
P_2 = Force on masonry wall

Further:



or $P_1 = k_i \delta_1$
$P_2 = k_d \delta_2$

Since $\delta_1 = \delta_2$, it follows that

$$\frac{P_1}{k_i} = \frac{P_2}{k_d} \quad \text{or} \quad \frac{P_1}{P_2} = \frac{k_i}{k_d}$$

1. For the 1" x 6" straight sheathing with 5/16" plywood overlay:

$$\frac{P_1}{P_2} = \frac{0.29 \times 10^6 \text{ lb/in.}}{12{,}000 \text{ lb/in.}} = 24 \text{ , or force}$$

in partitions is 24 times force going to masonry wall.

2. For the 3/4" plywood with 3/4" plywood overlay and 1" x 6" diagonal sheathing with 1" x 6" straight sheathing overlay:

$$\frac{P_1}{P_2} = \frac{0.29 \times 10^6 \text{ lb/in.}}{30 \times 10^3 \text{ lb/in.}} = 10 \text{ , or force}$$

in partitions is 10 times force going to masonry wall.

d. Summary

Although the stiffer diaphragms (Types P and K) might transfer about 10% of the total lateral load to the end masonry walls, a reduction in the lateral seismic loading that must be resisted by the partitions is probably not justified. The reduction for diaphragms constructed of straight sheathing would be less than 5%. It is therefore concluded that the lateral loading in the transverse direction be distributed to shear wall partitions based on tributary area.

5.4 SHEAR LOAD IN PARTITIONS

The maximum shear in transverse partitions is developed in this section for typical masonry two-story and three-story apartment buildings based on tributary area assumptions. The shear loads are then compared with the shear wall values determined by tests of wood lath and plaster construction. See Specimen D, Table 3-1.

Based on the general layout and dimensions of the building depicted in Figures 5-1 and 5-2, the following lateral seismic forces were calculated based on a rating classification of III, defined in Table No. 68-A of LAMC (1981) as a medium risk building. For this classification, the minimum total lateral seismic force is defined as V = 0.1 W.

5.4.1 CALCULATION OF LATERAL SEISMIC LOADING

A representative portion of the floor plan shown in Figure 5-1 was selected that is typical of repetitive partition layouts in the building. This area is identified in Figure 5-5. The seismic forces associated with the weight of building components tributary to this portion of the building were calculated for both a two- and three-story structure.

a. Unit Weights (based on assumed construction)

Roof dead load	15 psf
Floor dead load	14 psf
Partition dead load (2 x 4 wood stud w/wood lath and plaster)	12 psf (surface area) 8 psf (floor area)
Masonry dead load (15% wall openings, thickness varies from 13 in. to 17 in.)	130 psf (surface area) 60 psf (floor area)
Parapet dead load	10 psf (floor area)

b. Total Unit Weights

Roof		Floor	
Roof	15 psf	Floor	14 psf
Parapet	10 psf	Partitions	8 psf
1/2 Masonry Wall	30 psf	Masonry Wall	60 psf
Total	55 psf	Portion of Live Load	10 psf
		Total	92 psf

c. Total Weight (Tributary to portion of floor area shown in Figure 5-5)

Floor: 92 psf x 21.5 ft x 20 ft = 39,600 lb
Roof: 55 psf x 21.5 ft x 20 ft = 23,700 lb

Weight 3-Story Building (W_3)

$$W_3 = 23{,}700 \text{ lb} + 2(39{,}600 \text{ lb}) = 102{,}900 \text{ lb}$$

Weight 2-Story Building (W_2)

$$W_2 = 23{,}700 \text{ lb} + 39{,}600 \text{ lb} = 63{,}300 \text{ lb}$$

5.4.2 LATERAL SEISMIC SHEAR CARRIED BY PARTITIONS

The linear feet of transverse partitions effective as shear walls is shown in Figure 5-5 for the portion of floor area used for lateral seismic force calculations. Two criteria are indicated for determining effective shear wall lengths, one based on partitions that have a length to height ratio (L/H) of one or greater, and the other based on partitions that neglect this ratio when door openings in partitions result in short sections of wall on either side of the opening.

The average maximum partition shear values are shown below for the two building heights and for the two shear wall L/H criteria.

a. Three-Story Building

$L/H \geqq 1.0$

$$\text{Shear Load/ft} = \frac{(0.1)(102{,}900)}{25} = 412 \text{ lb/ft}$$

Neglect L/H at Door Openings

$$\text{Shear Load/ft} = \frac{(0.1)(102{,}900)}{32} = 322 \text{ lb/ft}$$

b. Two-Story Building

$L/H \geqq 1.0$

$$\text{Shear Load/ft} = \frac{(0.1)(63,300)}{25} = 253 \text{ lb/ft}$$

Neglect L/H at Door Openings

$$\text{Shear Load/ft} = \frac{(0.1)(63,300)}{32} = 198 \text{ lb/ft}$$

5.4.3 SUMMARY

The shear wall test results indicated in Table 3-2 for Specimen D (wood lath and plaster) and in the load/deflection curve plotted in Figure 3-12 are compared in Table 5-1 with partition lateral seismic shears calculated in Section 5.4.2. Factors of Safety (FS) are shown relating test results to calculated partition shears.

Based on assumptions made as to the length of transverse partitions considered effective in resisting lateral seismic loads, it appears that wood stud partitions with wood lath and plaster might possess the shear strength required to resist the seismic loading associated with the 2- to 3-story masonry apartment houses considered in this study. This observation may be premature since it is based on the results of only one test for this type of construction and depends on the factor of safety to be assigned for wood lath and plaster facing material.

As noted in Table 5-1, the FS for a two-story building varies from 3.7 to 4.7 based on ultimate shear values. The FS for the three-story building varies from 2.3 to 2.9 based on ultimate shear and could be considered marginal for life safety without further research and evaluation. However, the FS values associated with yielding and first cracking loads for the three-story building vary from 1.3 to 1.9 and are also indicative of the potential shear resistance inherent in this type of partition construction.

TABLE 5-1. COMPARISON OF TEST RESULTS WITH PARTITION SHEARS

Test Panel Results lb/ft		Lateral Seismic Shear in Partitions							
		Three-Story Building				Two-Story Building			
		lb/ft (L/H ≧ 1.0)	FS	lb/ft (L/H not considered)	FS	lb/ft (L/H ≧ 1.0)	FS	lb/ft (L/H not considered)	FS
1st Cracking Shear	518	412	1.3	322	1.6	253	2.0	198	2.6
Effective Yield Shear	625	412	1.5	322	1.9	253	2.5	198	3.2
Ultimate Shear	930	412	2.3	322	2.9	253	3.7	198	4.7

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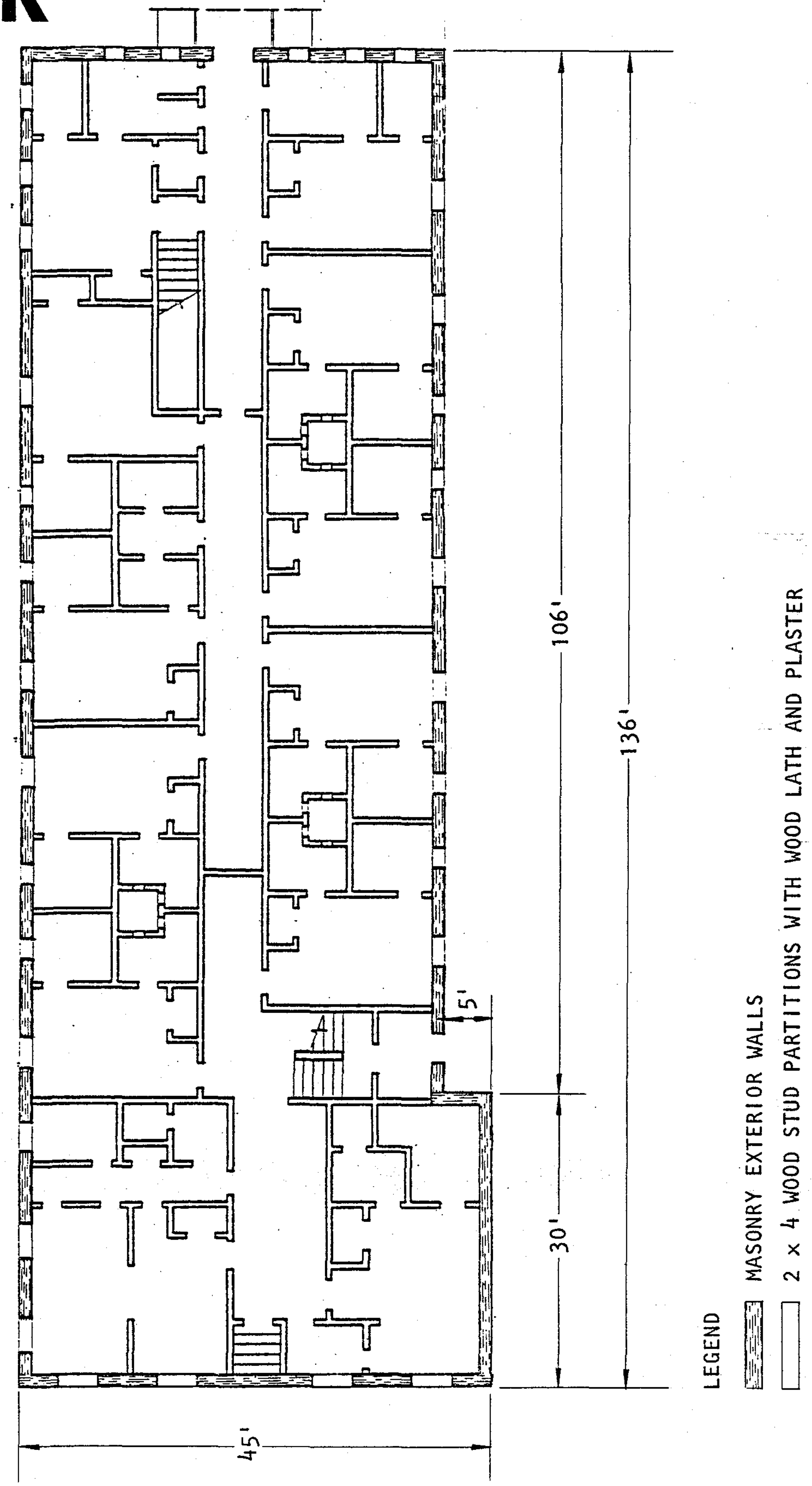
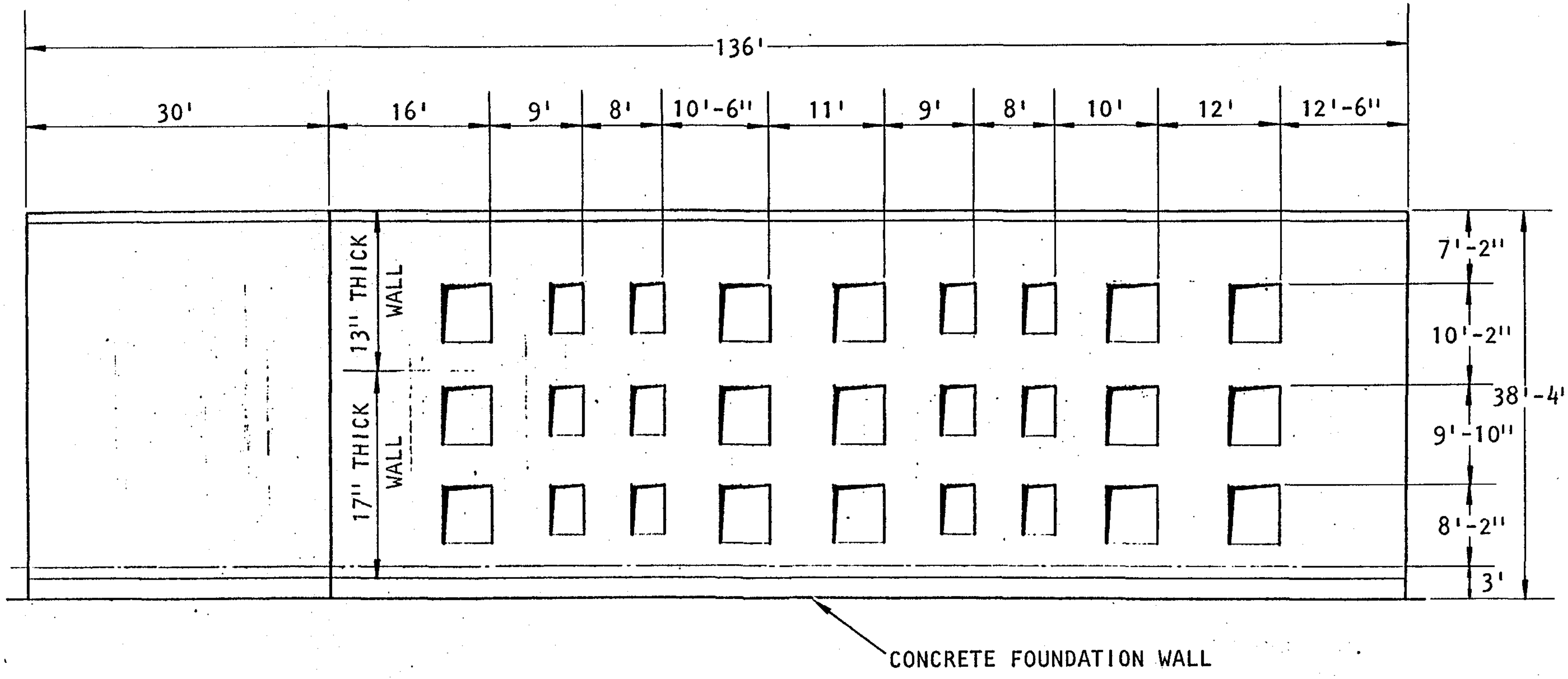


(a) Typical floor plan

FIGURE 5-1. THREE-STORY UNREINFORCED MASONRY BEARING-WALL APARTMENT BUILDING (Schmid et al., 1978)



(b) North elevation

FIGURE 5-1. (CONCLUDED)

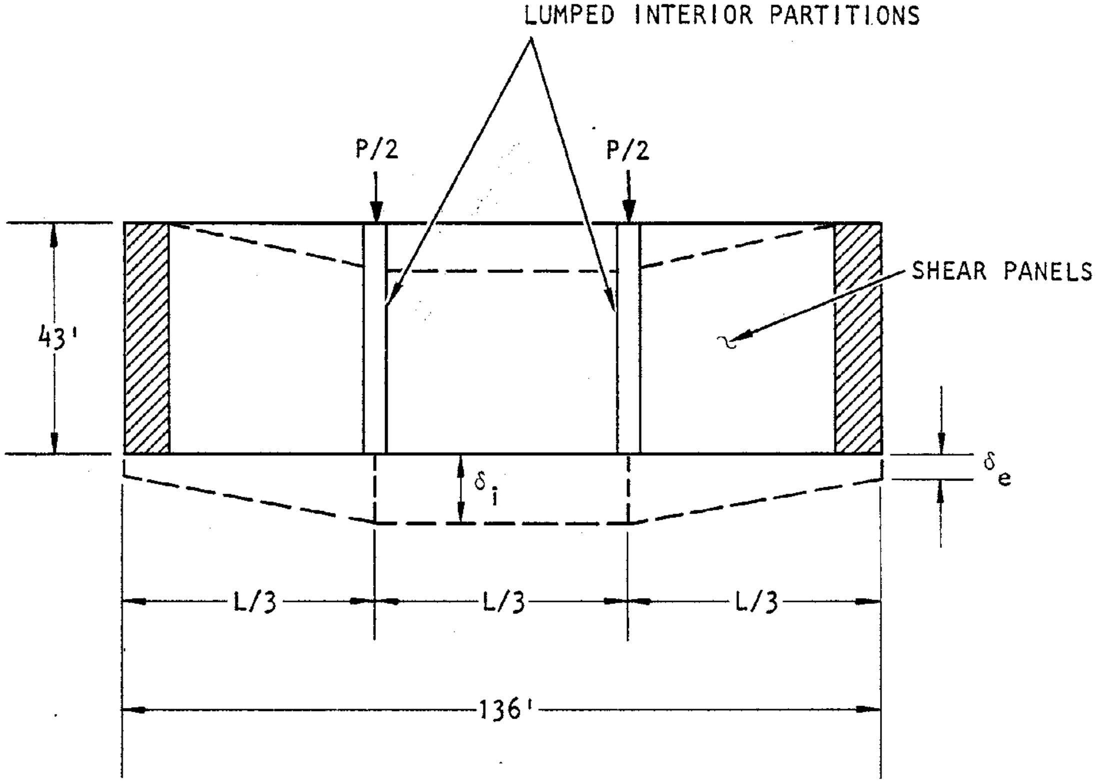


FIGURE 5-2. SIMPLIFIED STRUCTURAL MODEL OF DIAPHRAGM

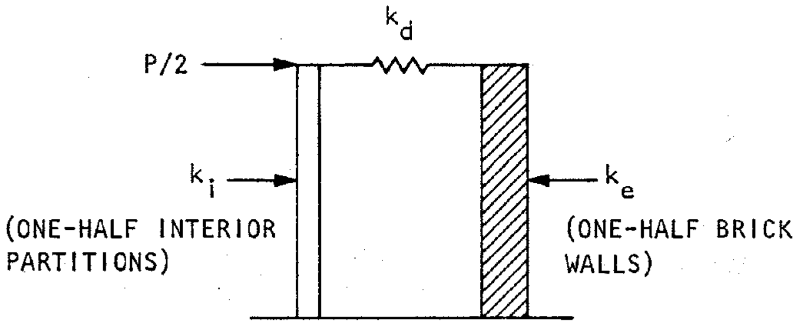


FIGURE 5-3. MATHEMATICAL MODEL

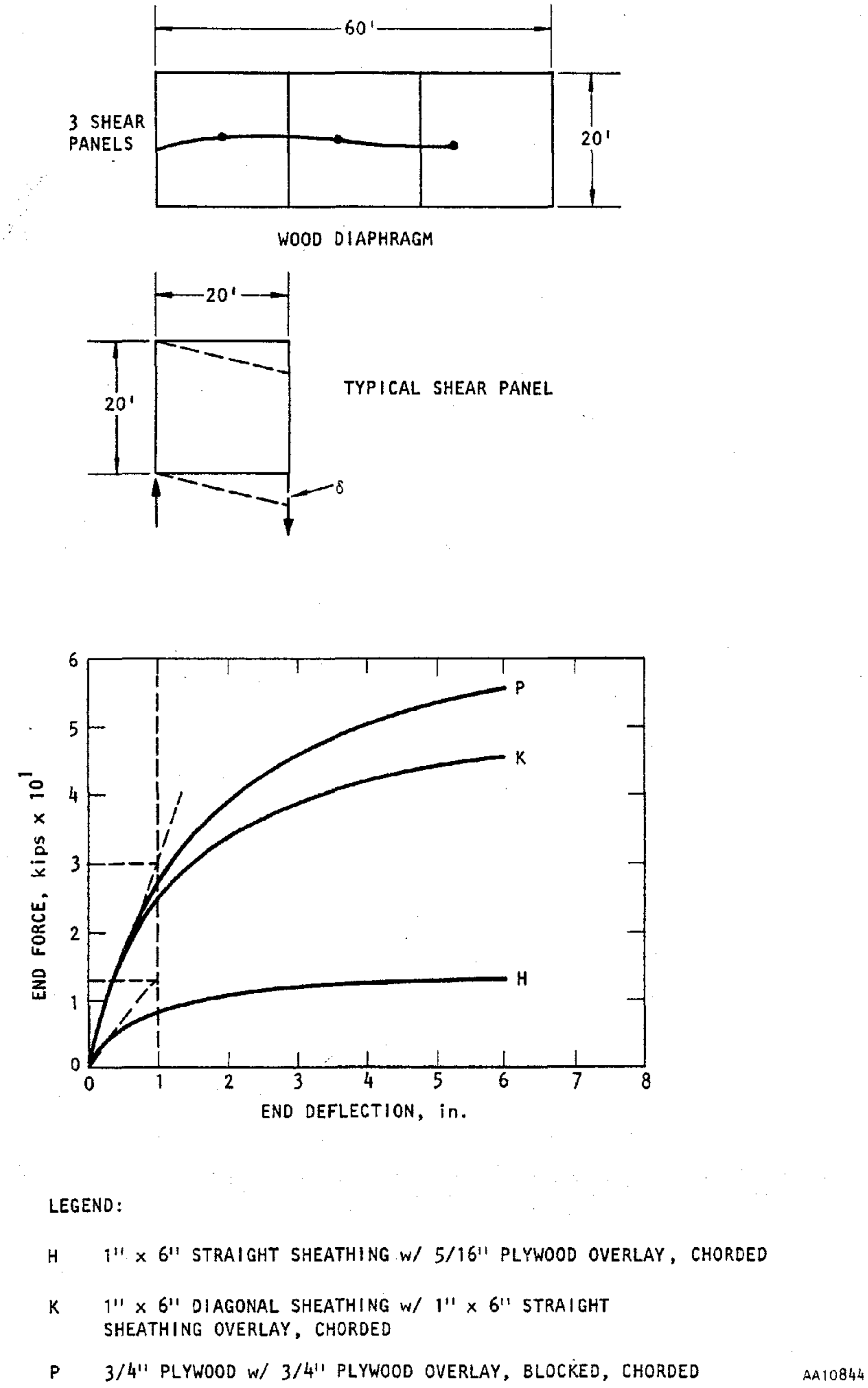
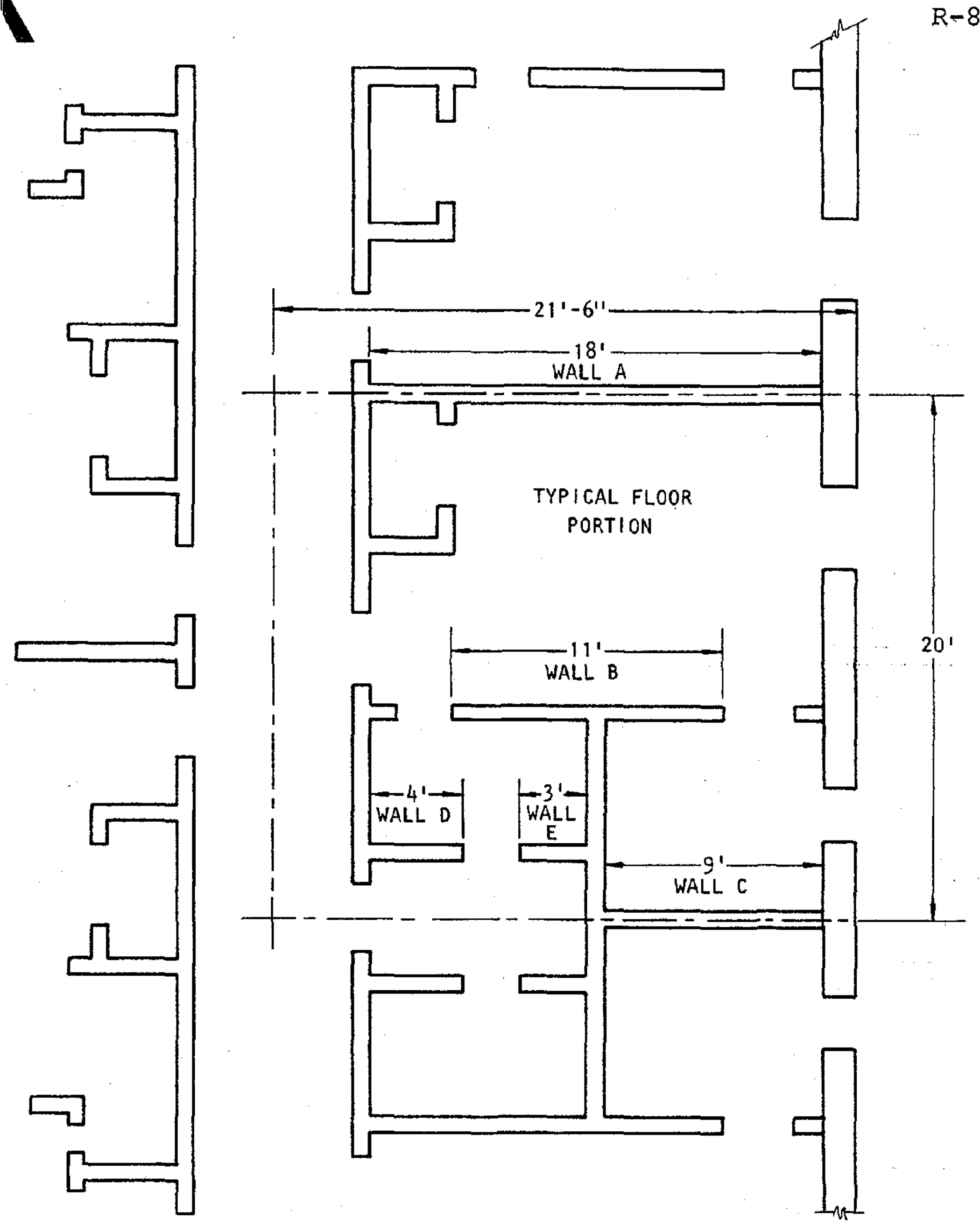


FIGURE 5-4. FORCE DEFLECTION ENVELOPES FOR WOOD DIAPHRAGMS (Ewing et al., 1980)



EFFECTIVE PARTITION LENGTHS

1. ASSUME LENGTH/HEIGHT RATIO ≥ 1.0 (APPROXIMATELY)
   $L_e = A + B + C = 18/2 + 11 + 9/2 = 24.5$ ft
   USE 25 ft

2. LENGTH/HEIGHT RATIO NOT CONSIDERED FOR WALLS AT DOOR OPENINGS
   $L_e = A + B + C + D + E = 9 + 11 + 4.5 + 4 + 3 = 31.5$ ft
   USE 32 ft

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FIGURE 5-5. REPRESENTATIVE PORTION OF FLOOR AREA TYPICAL OF PARTITION LAYOUTS

SECTION 6

CONCLUSIONS OF PHASE I STUDY AND RECOMMENDATIONS FOR PHASE II STUDY

6.1 CONCLUSIONS OF PHASE I STUDY

1. The shear wall resistance of wood stud partitions with wood lath and plaster facing material may contribute significantly to the lateral load resistance of masonry buildings. Additional research is justified to further evaluate and extend the findings of Phase I.

2. The wood lath and plaster test specimen proved to be stronger and stiffer than the other three facing materials tested, i.e., gypsum lath and plaster and gypsum wallboard with joints arranged either horizontal or vertical.

3. A significant increase in the shear wall allowable currently permitted by the Los Angeles building ordinance for wood lath and plaster may be justified based on the factors of safety indicated for first cracking load, yield load, and ultimate load (Table 3-2). Tests conducted on the lateral strength of nails used to attach the wood lath to the studs indicated that the lateral resistance of the nails is adequate to transfer the measured shear loads between the partition framing and wood lath and plaster facing material.

4. The shear wall allowable currently permitted by the Los Angeles building ordinance for gypsum lath and plaster is probably realistic and consistent with the factors of safety obtained from the test (Table 3-2).

5. Conclusions made by other researchers were confirmed, that gypsum wallboard partitions act stronger as shear walls if the joints between sheets are placed vertically.

6.2 RECOMMENDATIONS

In order to further evaluate and extend the findings of Phase I, the following recommendations are given for a Phase II study.

1. Additional testing of wood-stud partitions using wood lath and plaster facing materials is needed to further investigate the ultimate in-plane shear resistance of this type of construction. The experimental program should include racking tests of shear wall panels using static cyclic loading to determine strength and stiffness characteristics and degradation due to shear stress and deformation under load reversal. Test panels should include:

    - New 8 ft x 8 ft wood lath and plaster panels constructed of three-coat lime plaster that simulates materials and mix proportions used prior to the 1930's
    - Same as (1) to investigate effects of length to height (L/H) ratios on shear strength by testing panels with L/H ratios less than 1.0; keep 8 ft height and reduce panel width
    - Same as (1) but include door opening in panel to investigate influence of opening on shear resistance of partitions and failure characteristics of the narrow wall piers adjacent to opening

- Specimens cut from actual wood lath and plaster wood-stud partitions available from pre-1933 buildings that are to be demolished or undergo extensive renovation

2. An investigation should be made of construction practices that were used prior to the 1930's to attach partitions to floors, ceilings, and cross-walls and of the manner in which seismic loads are transferred to lateral-resistance structural elements or systems through these connections. Consideration should be given to:

    - Identifying ultimate capacity of connections and their failure modes
    - Determining methods for strengthening existing connections to ensure that partitions function as shear walls
    - Testing the effectiveness of connections commonly used with existing construction, including proposed methods for strengthening existing connections
    - Investigating the significance of differences in test panel boundary or fixity conditions when compared with actual partition support or restraint conditions and determining implications on test data results and interpretation

3. Investigate methods of strengthening existing wood lath and plaster partitions using an overlay of plywood or gypsum wallboard. Use racking tests as in (1) to determine effectiveness of overlay in increasing strength and stiffness characteristics of existing partitions to in-plane shear loads.

4. Perform three-dimensional finite element static analyses of a typical 2- and 3-story masonry apartment building where extensive use has been made of floor-to-ceiling wood-stud and wood lath and plaster walls to partition off floor space. Model exterior walls, partitions, and diaphragms by finite elements. Use results of experimental program outlined above to assign strength and stiffness characteristics to partitions based on non-linear models that are more representative of the actual shape of the load/ deflection curves. Properties for the wood floor and roof diaphragms can be based on results of current research, sponsored by NSF, to develop a methodology for mitigation of seismic hazards in existing unreinforced masonry buildings (Ewing et al., 1980). Three separate analyses of the entire building should be performed, each corresponding to one of the following assumptions:

   - that existing partitions contribute to the resistance of the structure to lateral seismic loading

   - that existing partitions do not contribute to the resistance of the structure to lateral seismic loading

   - that existing partitions have been strengthened to increase resistance of shear walls and connections to lateral seismic loading

5. Based on the research outlined in this section, evaluate the contribution of partitions to the lateral load resistance of masonry apartment-type buildings that make extensive use of partitions. Include the effect of partitions that have been strengthened for additional

shear and connection resistance. Compare allowable building code values (LAMC, 1981) for shear wall partition construction or for strengthened partitions with allowable shear stresses determined experimentally. If appropriate, recommend revisions in allowable code values for consideration by building officials. Prepare guidelines for use in the seismic evaluation and upgrading, if required, of existing masonry building in which partitions can be expected to contribute to the resistance of the structure to earthquake forces.

SECTION 7

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Pages A-1 to A-5 have been removed.

Due to legibility problems, the following has been omitted:

Appendix A: Los Angeles Municipal Code "Earthquake Hazard Reduction in Existing Buildings"