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Air-Mobility Rigid Shelter Systems

T. W. Reichard and L. F. Skoda

Structures, Materials and Safety Division
Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
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An Interim Report

Prepared for
Air Force Civil Engineering Center
Tyndall Air Force Base, Florida 32401

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U.S. DEPARTMENT OF COMMERCE, Rogers C. B. Morton, *Secretary*
James A. Baker, III, *Under Secretary*
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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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Abstract

Air-Mobility Rigid Shelter Systems
(Interim Report)
by
T. W. Reichard and L. F. Skoda

This interim report covers the first portion of a long-range investigation dealing with the design and durability of lightweight, rigid structures (shelters) used by the military as combination shipping containers and housing for tactical and life-support services. This report covers the results of field and laboratory studies intended to correlate functional and structural problems with in-service conditions. It was found that water leakage into the shelters and into the sandwich panels was probably the basic problem area although many shelters appeared to have been defective at the time of delivery. It was found that, under adverse conditions, a polyamid paper honeycomb core would be significantly better for the sandwich panels than is the kraft paper core now used. Major delaminations of the sandwich panels could not be correlated with impact damage such as would be caused by forklift bumps. Subsequent reports will present the results from a structural analysis of and field tests on shelters subjected to typical dynamic and static loading conditions.

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Martinsburg, West Virginia

Major Jack Taylor
41st Combat Support Hospital
Fort Sam Houston, Texas

SI Conversion Units

In view of the present accepted practice in this country for building technology, common US units of measurement have been used throughout this paper. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to US units used in this paper.

Length

1 in = 0.0254 meter (exactly)

1 ft = 0.3048 meter (exactly)

Force

1 lb (lbf) = 4.448 newton (N)

Pressure

1 psi = 6895 N/m^2 = 6895 pascal (Pa)

Temperature

°C = 5/9 (Temperature °F - 32)

1.0 Introduction

1.1 Background

All branches of the military use lightweight, air-transportable, rigid structures which serve as combination shipping containers and housing for tactical and life-support services. These structures are called "rigid shelters" by the military. This term differentiates the rigid shelters from other "shelters" such as tents, air-inflatables, and "prefabs." A "prefab" is a larger, relocatable, rigid structure which is erected on the site using a number of prefabricated components.

The rigid shelter in its shipping configuration is a rigid, box-like structure. When field-deployed, some shelters can be expanded to provide two, three, or more times the original space. Many shelters are designed to be connected with others to form a complex such as a field hospital or a command center.

The rigid shelters are designed to provide high strength to weight ratios. The high strength is required because of the extreme loads which they undergo when dropped from a helicopter, transported by rail, or even when pushed, fully loaded, off the back of a truck.

Weight limitations are based on the intended transportation method. The maximum gross weight for Air Force shelters is generally based on helicopter lift capacity, but for the Army, the gross weight may be based on truck capacity and even the necessity of man-handling under certain circumstances.

The high strength to weight ratios are achieved by using some type of structural sandwich panel in the construction of the shelters. Two types of sandwich panels are now being used: one is an aluminum-faced paper honeycomb sandwich, and the other is a pseudo-sandwich consisting of aluminum faces over a foamed-plastic core and with internal aluminum ribs; this second type is called "foam and beam" construction.

One of the prime considerations in the design of the shelters is reliability, which includes not only initial structural capability, but also durability. This investigation is concerned with both aspects of reliability.

1.2 Objectives

The principal long-term objectives of this investigation are: 1) to evaluate the effects of in-service loads, aging and weathering on the rigid shelters which have been subjected to field deployment, and 2) to recommend specific performance criteria and tests which can be used in the design and procurement of such shelters.

To accomplish these objectives, the investigation has been divided into seven phases of work as follows:

Phase I. Make a field inspection of approximately 25 shelters at Holloman AFB and other locations.

Phase II. Conduct an intensive laboratory inspection of two typical shelters and tests on samples removed from the two shelters.

Phase IIA. Provide a comparison of the performance of four different honeycomb core materials suitable for use in sandwich panels for the shelters.

Phase III. Provide a structural analysis for a rigid shelter subjected to typical dynamic and static loading conditions.

Phase IV. On the basis of the results of Phase III, determine critical stress points for each of the loading conditions so as to measure the response in an actual load test.

Phase V, VI, and VII. Measure and analyze the data from field tests on shelters at the Air Force Civil Engineering Center.

This interim report covers the work performed under Phase I, II and IIA. The work for Phase III is underway and will be covered by a subsequent report.

2.0 Phase I - Field Inspection of Shelters

2.1 Scope and Objective

A series of field inspection trips were made to evaluate apparent physical defects in field-deployed shelters. The first trip was to Holloman AFB (Oct. 1973) where a large number of general purpose and electronic shelters were being stored. Some shelters were also being used there for training and evaluation purposes. The purpose of the first trip was to acquire some first-hand information as to the magnitude and scope of the problem areas.

The purpose of the second trip (Nov. 1973) was to fully document the apparent defects in four typical shelters at Holloman and to extend the range of the information acquired during the first trip by making an inspection of additional shelters at Randolph and Bergstrom Air Force Bases and at Fort Sam Houston.

The objective of the Phase I inspection was to observe and document conditions or physical defects which have caused or might cause deterioration of the structure and/or loss in functional capability. Defects such as dents, punctures, warping of flat surfaces, bulging and buckles were considered to be important, expecially if they could be a possible cause of delamination.

2.2 Description of Shelters

2.2.1 Holloman AFB (Alamogordo, N.M.) Shelters (figure 2.1)

Most of the shelters inspected at this site were either EXP (Expandable Personnel) or ES/C (Expandable Shelter/Container) units. Chapter 3 of this report presents some details of these shelters.

The EXP units (figure 2.2) were made with aluminum-faced, paper honeycomb sandwich panels. All but two of the EXP units had been supplied under a 1969 contract number. The other two had been received from the manufacturer just prior to the inspection. For the purposes of this report the 1969 units are termed "old" and the others are termed "new."

There were three generations of ES/C units at this site. The units termed "old" in this report were constructed with 2 heavy, 4-inch deep, aluminum hat sections riveted to the external face of each fold-down floor panel (figure 2.3a). The "newer" units were similar but did not have the external hat sections (figure 2.3b and 2.3c). These "old" and "newer" units were foam-and-beam construction with aluminum faces. A third generation ES/C unit, termed "new", was similar to the "newer" units except that it was of honeycomb sandwich construction (figure 2.3d). Although the newer units appeared to be several years old most of them did not appear to have ever been expanded.

Other shelters briefly examined at Holloman included:

1. S-141 Electronic, foam and beam construction (figure 2.4)
2. S-280 Electronic, foam and beam construction.
3. "2 for 1" Expandable Electrical Equipment (figure 2.5), construction not known.
4. General Purpose prefabricated shelter, aluminum arch frame covered with fabric-connected rigid honeycomb sandwich panels (figure 2.6).
5. Expandable, aluminum faced paper, honeycomb construction, outfitted as kitchens, (figure 2.7).
6. Expandable, aluminum faced foam and beam construction, outfitted as latrines, (figure 2.8).

During the second inspection trip to Holloman, the shelters described in table 2.1 were intensively examined.

2.2.2 Randolph AFB (San Antonio, Texas) Shelters.

These shelters were all special purpose trailer units being used to house aircraft-control and electronic equipment (figure 2.9). All appeared to be of conventional cargo-trailer construction, but usually with extra insulation and with internal surfacing material. None of these shelters was of the type to be included in the investigation.

2.2.3 Bergstrom AFB (Austin, Texas) Shelters.

A large number of electronic shelters were inspected here. All appeared to be foam and beam construction and most were made to be transported with a mobilizer (figure 2.10). Among those inspected were the following:

1. A fairly large, tactical aircraft, command center complex consisting of about 9 rigid-panel shelters connected to a large, centrally located air-inflatable structure (figure 2.11). The air-inflatable had a rigid-panel floor system (foam and beam sandwich).
2. Teletype shelters made to fit in a 3/4 ton pickup.
3. S-138 Electronic, used for transporting classified material and equipment.
4. S-448 Electronic, brand new shelter containing radio equipment.
5. Radar Electronic shelter.
6. Telephone Central shelters.

2.2.4 Fort Sam Houston (San Antonio, Texas) Shelters.

A combat support hospital (U.S. Army), which utilizes MUST (Medical Unit, Self-contained Transportable) equipment, and a group charged with maintenance of that equipment was visited here. A MUST hospital unit (Figure 2.12) consists of a Ward Container shelter (Figure 2.13), Expandable shelters (similar to ES/C) (Figure 2.14), a Utility Pack, an Air-inflatable Hospital Ward, and ancillary mobile equipment such as a kitchen, latrine and mess hall. Most shelters were constructed of aluminum faced-paper honeycomb sandwich panels.

The maintenance group had a number of shelters in for repair and two were inspected. These two were Serial Nos. 45 and 76.

2.2.5 History of Shelters

Very few details were learned regarding deployment history of the shelters and in many cases the ages were unknown. Procurement contract numbers could probably be used to determine ages, but personnel changes and loss of records make deployment histories a matter of conjecture for most shelters more than one year old.

2.3 Inspection Procedure

2.3.1 Indentation and Punctures

Measurements of depth of indentation from intended plane were made at most damaged areas on the units surveyed. A surface flatness instrument equipped with a .001-inch dial gage was used to make these measurements. The instrument was designed so that the dial gage was centrally located between two reference pins which were three inches apart. The bottoms of the 3/8-inch reference pins had been machined flat and to the same plane. The stem of the dial gage was equipped with a pointed tip so that the very bottom of an indentation could be reached. The initial calibration reading was taken on a flat machined surface which established the zero reference plane. The device was then placed so that the dial gage stem was at the center of the indentation to be measured. The device was then moved about until a maximum reading was obtained. The difference between the maximum reading and the zero calibration reading was then reported as the depth of indentation.

The limitation of this device is that the span between reference pins was only three inches. This limitation did not pose a serious problem as no indentations encountered within the field of the panels exceeded this span. The only indentations that could not be measured by this method were damaged areas along the bottom edges of the units.

2.3.2 Delaminations

Large delaminated areas within a panel were easily located, especially when solar-heating had caused visible bulging. Movement of the facing could be felt by applying hand pressure to the bulging areas. In order to determine the boundaries of these delaminated areas and to locate other smaller delaminated areas, the "coin-tap" test was used. The coin-tap procedure was also used in the vicinity of all indentations and other damaged areas to determine the extent of delamination that may have resulted.

Delaminations about the periphery of panel sections were visible as separations between the facing and the edge members.

2.3.3 Leakage

Visual examinations of the units selected for survey were made to determine if any signs of leakage existed. Leakage is defined as either penetration of rain water into the interior of the shelter units or outflow of water from within the sandwich panels at discontinuities in the facing. The visual evidence of leakage is generally a stain on an exposed surface. Visual examination was made for leakage on the exterior of many of the shelters located at the Holloman AFB storage area.

2.3.4 Miscellaneous Defects

One of the primary purposes of this survey was to determine if impact loads were a factor in delamination. Impact damaged areas that may have been caused either by the fork lift trucks or other equipment used in placing units during deployment or by abuse or misuse of the shelters by users were noted. The shelters were also visually examined to determine if any defects existed other than those caused by impact. Particular attention was given to defects or inadequacies that may have originated as a result of the manufacturing process. Examples of such defects are, lack of proper dimensional tolerances, compliance of surfaces to intended plane, and fit of component parts.

2.3.5 Temperature Measurements

Surface thermometers were used to measure the skin temperatures of several units. The measurements were made when it was noticed that the sunny surfaces of units were distorted and appeared to be bulging out of intended plane while the shaded surfaces appeared to be flat. Skin temperatures and ambient temperatures were recorded at the time of day when the skin temperatures were at their maximum. Distortion of the panels was also measured at this time using a 12 ft. straight edge and two folding rules. Measurements were made on the south and north surfaces.

2.4 Results of Inspection

2.4.1 Expandable Personnel Shelters

Four Expandable Personnel Shelters (EXP's) were closely examined for indentation damage and delamination of the exterior skin. Particular attention was given to the indentations in an effort to determine if any extensive delaminations resulted from the indentations. Of the four shelters examined, two had been deployed several times and two had never been used since acceptance. The serial numbers of the two older shelters (similar to figure 2.2) were 267 and 285 and the warranty expiration dates were December 1970 and January 1971, respectively. The two newer shelters were serial numbers 0460 and 0464 with warranty expiration dates of September 1974 appearing on both units.

Several significant differences were apparent upon examination of the pairs of shelters. The loading cubage of the newer shelters was 40 cu. ft. less than that of the older shelters. This was a result of reducing the height of the new shelters by 2.5 inches and the width by 4 inches while increasing the length by 1.1 inches. The floor covering system in the older units was a liquid-applied elastomeric coating approximately .040 inches thick while the newer units were covered with a coated-cloth material bonded to the skin.

2.4.1.1 Old EXP's

Table 2.2 is a listing of the indentations and damaged areas found on units 285 and 267. Locations of these areas and delaminations are indicated in figures 2.15 and 2.16. The panel "names" given to the individual panels are those used by the field personnel. "Interior floor" panel means the fold-down floor panel which is closest to the center structure when the shelter is expanded. These two shelters were the outside (285) and middle (267) units of a three shelter assembly (see figure 2.2a). The most indentations occurred on the fold-down floor panel (interior or inboard floor panel when expanded) that is exposed to weathering during storage. Of all the indentations measured on the panels of both shelters, only one was deeper than 1/8 in. Three indentations were found on shelter 267, but with only one being of any consequence. The indentation at location 2 of 267 appeared to be caused by the fork of a lift truck. It was located adjacent to a designated lift point. The location of this indentation was such that measurement with available instrumentation was not possible but the estimated depth was about 1/4 in. Figure 2.17 is a photograph of a similar indentation from a lift-truck fork, but was in the front-end wall.

One puncture failure was found on the interior facing the fold-down panel of shelter 285. This penetration was triangular in shape and can be seen in Figure 2.18. A pencil probe inserted into the puncture extended all the way through the panel to the inside of the exterior facing.

The extent of delamination in the vicinity of each indentation was carefully probed by the coin-tap test. No delaminations were discernible outside of the immediate indented area. This condition was found in every case of indentation on the panels inspected. It was not possible to use the coin-tap test for determining delamination on the inside floor panels of these units due to the floor covering system. The floor covering system in these older EXP's appeared to be a synthetic rubber product approximately .040 inches thick. The resilience of this coating system was such that it created a sound-deadening effect that eliminated during the coin-tap test any audible difference in sound between areas that were tightly adhered and those areas that were thought to be delaminated.

The most extensive delaminations were found about the periphery of the exterior facing of the left fold-down floor panel on the outside unit (No. 285). This is the facing that was exposed to weathering during storage. Over 60% of the length of the outside edge was delaminated approximately 1 to 2 inches in from where the aluminum skin was attached to the edge members. Of the panels protected during storage, the exterior facing of the right fold-down floor section of No. 285 was delaminated about 29% of the length of the edge.

The edges of the fold-down panels of shelter No. 267 (the center unit of the three shelter assembly) were delaminated for only 8% of the length on the left panel and none was found on the right panel. Figures 2.15 and 2.16 are scale drawings of the exterior facing of the fold-down floor panels for the two shelters and show the location of the indentations and the delaminated areas. No delaminations were found on any other panels in this shelter. No large areas of delaminations were found on the panels of these two shelters such as were observed on some other stored EXP's (see figure 2.19).

Figure 2.20 is a photograph of water leakage from the fold-down floor of shelter No. 285. No evidence of this leakage was apparent on the shelter while it was in the stored position, but when the shelter was opened for inspection of the interior surfaces, water ran from the delaminated edge of this floor panel. A pool of water approximately 8 inches in diameter resulted and the leakage continued for about an hour. Figure 2.21 shows a brown colored residue of leakage similar to that observed on several shelters that were in the storage area. In general, this staining was observed at the outer edge of the mid-height joint in the facing of the exposed floor panels (figure 2.22). (Weather side during storage). Figure 2.23 is a photograph of visible water seeping from a puncture in the skin of the fold-down floor panel of a stored EXP.

Considerable bowing was noticed on the sunny side of the units during the first visit to the storage area at Holloman AFB. During the second visit surface temperature thermometers were placed on the sunny and shady sides of the EXP's in order to measure the maximum surface temperature achieved and to determine the time of day that this temperature occurred. The maximum temperature occurred at approximately 1:00 p.m., at which time a measurement of bowing was made by the use of a straight edge. Straight edge measurements were made on both the sunny and shady sides of the EXP's.

The results of the temperature measurements revealed that a maximum skin temperature of 135-140°F was reached on the sunny sides on the shelters when the ambient temperature was 82°F. Weather conditions at the time were bright and sunny with southerly winds of approximately 5 MPH. The shady-side surface temperature coincided with the ambient temperature.

Straight-edge measurements were taken at the start of the working day (8:00 a.m.) on both sides of the shelters and no measurable bowing was evident. Measurements were taken again at 1:00 p.m. on both sides of the shelters and a bowing displacement at the geometric center of the sunny side of approximately 1/2 in was measured. No measurable bowing was observed on the shady side.

2.4.1.2 New EXP's

The new EXP's examined consisted of a two-shelter assembly with Serial Numbers of 0460 and 0464. A thorough examination of both shelters revealed no indentation damage or delamination of exterior facing on any panel of either shelter. Also, no water leakage or staining was observed.

Surface temperature gages were applied, as in the case of the old EXP's, and the same results were evident. Temperatures on the sunny side were approximately 55 to 60°F higher than ambient. Measurements of bowing of the sunny side surface were made using the same procedure as was used on the old EXP's. The bowing was approximately 3/4 in at the geometric center of the sunny side but there was no measurable bowing on the shady side. The bowing on the new EXP's was 50% more than that measured on the old EXP's.

Two minor fabrication flaws, that had not been observed on the old ones, were observed on the new EXP's. These flaws were the result of the design change in the new shelters. The fabric floor covering had several blisters approximately 1/2 to 3/4 in diameter in the surface as seen in figure 2.24. These blisters appeared to be of air probably entrapped during the manufacturing process. The blisters were probed to determine if any liquid was present, but none was found.

The other flaw noticed was a black discoloration of the white finish on the interior of the exterior end wall of shelter No. 0464. This dark discoloration is visible in figure 2.25. It was not possible to determine what this discoloration is or how it became prominent. The discoloration appeared to be within the finished surface and was not water staining or fungus growth on the surface.

2.4.2 Expandable Shelter/Container (ES/C)

A cursory examination of all ESC's located in the storage area at Holloman AFB was completed on November 13th and 14th, 1973. Two newer ES/C shelters were opened for a more complete examination on the 14th of November. The range of deployments for the shelters examined was from none to several, but the two shelters opened for inspection had not been previously deployed, according to Base personnel.

2.4.2.1 The old ES/C's

The greatest single defect observed during the inspections of the old ES/C's was delamination of the aluminum skin from the foam core material. The delaminations observed were on the exterior of the fold-down floor panels that serve as side walls during storage. The extent of the delaminations varied from slight to almost complete. For examples of delaminated areas in old ES/C's see figure 2.3a and also figure 2.26.

Other defects were observed and are listed below:

1. The treated fabric weatherstrip closure over the roof panel hinge (figure 2.3a and 2.3b) on every ES/C shelter examined, had shrunk to the point where none of them could be properly closed to protect the hinge area from the weather.
2. All of the older shelters had indentations, mostly in the areas of lift-truck pickup points. None of the indentations is considered to be directly contributory to the extensive delaminations observed.
3. Extensive and varied repair procedures were observed on many shelters. Some of the repairs appeared to be field expedients. Figure 2.27 shows shop repairs being made at a fork-lift damaged area.

2.4.2.2 Newer ES/C's

The serial numbers of the two newer ES/C units (figure 2.3b) that were opened for inspection were No. 28 and No. 55. The storage dimensions of the units were 8 ft high by 13 ft long by 8 ft wide with a gross weight of 4,000 pounds. The contract number of both units was F33657-68-C-0507. No warranty expiration date appeared on either shelter.

The reason that these two shelters were chosen for close inspection is that their fold-down floor panels were good examples of two conditions which were common to most of the newer ES/C's. At some places in a panel the facing between the internal beams was depressed below the level of the beams while, at other places the facing was bulged above the beam level (figure 2.28). The occurrance of these two conditions in the same panel seems to indicate that lack of foam-thickness tolerances during fabrication may be the cause.

However, the floor panels that exhibited these conditions on the exterior were also distorted on the interior of the panel. On three of the four interior floor panels inspected, bulging of the facings was evident. Figures 2.29a and 2.29b depict the general magnitude of these bulging surfaces. Accurate measuring devices to profile the surfaces of the floor sections were not available but bulging as much as 3/4 inch out of the intended plane was noted.

In general, it can be said that, of the two conditions noted above, bulging of the facing is the dominant condition. For this reason it seems likely that foam-growth, sometimes exhibited in foam panels, is the primary factor in the out-of-planeness.

The bulging floor panels gave rise to several other problems. The floor bulging was a definite hindrance to the expansion of the unit for use. If the erection procedure was followed exactly, the units could not possibly be opened for use. With the entire unit leveled and the fold-down floor panel lowered and leveled, the end-sidewall section could not be pulled into place because of insufficient clearance between roof and the bulging floor panels. In order to expand the shelter it became necessary to lower the floor panel well below the intended final position so that the end sidewall section could be pulled into place.

Another problem that is directly attributable to the bulging floor problem of figure 2.29a and 2.29b is illustrated in figures 2.30a and 2.30b. The clearance necessary to properly close the floor section for storage was so reduced by the bulging that the paint on the interior floor was deposited on the fold-down roof section.

All of the bulging and depressed areas of these newer ES/C shelters were probed by the coin-tap test to determine if any delamination between foam and skin existed. No delaminations were found in any of the sections probed.

2.4.2.3 New ES/C

A new design ES/C is seen in figure 2.3d. The appearance of the panels of this shelter was excellent. All surfaces were flat with no noticeable bulging. The construction appeared to be of sandwich panels, but it was not determined whether the core material was foam or paper honeycomb.

The only obvious fault on this shelter was in the installation of the exhaust fan unit. This unit can be seen in figure 2.31 with the wires and starting condenser of the fan unit exposed to the weather.

The general appearance of this entire shelter was excellent with construction workmanship far exceeding any of the previous ES/C shelters inspected. However, this unit had just been received from the manufacturer.

2.4.3 Miscellaneous Shelters

2.4.3.1 Randolph AFB Trailers (Figure 2.9)

These trailers were found to be structurally satisfactory, but there was some evidence of rain leaks and of condensation around air conditioning inlets and ducts. User-complaints were minor except for those about insufficient or inefficient insulation. The insulation complaints were primarily for the units in which relatively good temperature control was required for computers.

2.4.3.2 Bergstrom AFB Shelters (Figures 2.10 and 2.11)

The two major complaints expressed by the shelter-users at this base were rain-leaks and soft-floors (delamination). Soft-floors are considered to be primarily a functional problem because of the user's hesitancy to load the floors.

Most rain-leaks appear to be at the roof-edge extrusions and rivets or at through-panel cutouts for air conditioning and other supplies. Many of these rain-leaks are probably a result of transportation or thermal stressing which gradually breaks the seal at joints and rivets. There were indications that the original seals around some through-panel cutouts are not satisfactory. Punctures in facings such as would be caused by localized impacts did not appear to be a factor.

Some of the soft-floors were probably caused by overloading of good panels, but many appeared to be the result of moisture penetration into the interior of the panels. Although the foams used for such panels are usually considered to be relatively unaffected by moisture they do soften appreciably when wet. It is thought that impacts, or even normal loads, will deflect the facings over moisture-weakened areas in panels and gradually induce delaminated areas between the internal beams.

Some of the individual panels used as flooring in the air-inflatable structures were soft (delaminated). These panels appeared to be foam and beam. The cause of the delaminations was not apparent, but at least one delaminated panel showed evidence of water leakage from the underside.

Many shelters exhibited delaminations in other than the floor panels. The users were not perturbed by these because they felt that the shelters were still functionally satisfactory. The reason for these other delaminations was not determined but they were especially noticeable when sun-heating formed the characteristic bulging in the facings.

2.4.3.3 MUST Shelters at Ft. Sam Houston (Figures 2.12, 2.13, and 2.14).

These shelters were made from honeycomb panels and many panels had delaminations (figure 2.32) which made the shelters unusable for their purpose. All of the MUST shelters inspected appeared to be well-used and were about 5 years old. There were punctures in the facings of some panels, predominantly in floor panels (figure 2.33), but no correlation between these punctures and delaminations could be found. In fact, the punctured panel of figure 2.33 was not delaminated. It should be noted that punctures are normally repaired by field personnel and it is possible that the delaminated panels did have punctures at some time.

The maintenance personnel stated that all delaminated panels which they have repaired had water in them. The maintenance people also stated that their major repair work for these shelters was in three problem areas: (1) Panel delamination, (2) Failure of panels around inserts to which jacking-brackets are fastened (figure 2.34), and (3) Pole-brackets on the edge of the fold-up roof panel that had twisted loose and/or out of shape (figure 2.35a and 2.35b). They have "fixes" for these problems (figures 2.36a and 2.36b), but they felt that they are greatly handicapped in repairing delaminated areas because they cannot get new honeycomb except for the four small pieces in a repair kit that costs over $1000.

No conclusions were reached in attempting to assess probable reasons for delamination of the honeycomb panels in these shelters. The fact that all the MUST shelters inspected were made by the same manufacturer and at about the same time, appears to cancel substandard fabrication facilities as a basic fault. Although it was stated that all delaminated panels which were repaired had water in them, it is not known if all delaminated panels have water in them or if all good panels are dry. However, it is reasonable to assume that design loads can induce delamination of wet panels, because the strength and stiffness of the paper honeycomb is greatly reduced when it becomes wet. In addition, degradation of the adhesive bond can be accelerated in the presence of moisture.

2.5 Conclusion

1. Unless grossly misused, impact loadings did not appear to be a significant factor in causing structural problems in the shelters examined.
2. Leakage of rain water into the shelters is a very significant factor in causing functional problems with electronic and electrical equipment within the shelters.
3. Water inside the sandwich panels is often found concurrently with both functional and structural problems, although it cannot be stated at this time that the water was a contributing factor to the problems.
4. Lack of maintenance guidance and materials is a major complaint made by the users of the shelters. The users have no complaints regarding the basic functional concepts of the shelter programs.
5. Many of the defective shelters appear to have been defective at the time of delivery from the factory. This indicates that the quality assurance procedures were inadequate.
6. It seems likely that foam-growth was the primary factor in causing out-of-planeness in the panels of the newer ES/C's.
7. Improper lifting with forklifts can cause significant damage, but does not seem to be a major problem.
8. Solar heating of panels accentuates the bulging and buckling of delaminated and undelaminated facings. It is not possible to say, at this time, that solar heating is a cause of delaminations, but it seems obvious that it can worsen delaminations.
9. Most of the major delaminations, such as are illustrated by figures 2.19, 2.26, and 2.32, cannot be correlated to external loadings with the possible exception of solar heating.

3.0 Phase II - Laboratory Evaluation of Shelters

3.1 Objective and Scope

The principal objective of this phase of the investigation was to evaluate in the laboratory the effects of in-service loads, aging and weathering on the shelters and on the sandwich panels used in constructing the shelters.

This chapter describes the laboratory inspection of two types of shelters (EXP and ES/C) and the subsequent tests made on specimens cut from the two shelters.

The two shelters were furnished by the Air Force and had been deployed at Holloman Air Force Base. Both shelters were of the first generation, i.e., original, production-contract units and are the same as were termed "old" in Chapter 2 of this report, (see 2.2.1). The Air Force is now purchasing second-generation units of one type (EXP) and third-generation of the other type (ES/C).

3.2 Description of Shelters

3.2.1 Expandable Personnel Shelter (EXP)

3.2.1.1 Functional Features of EXP Shelter

This shelter (figure 3.1) is a self-contained unit which unfolds from a 3 ft. x 8 ft. x 13 ft. center structure (figure 3.1b) into a 33 ft. long structure (figure 3.1c) about 8 ft. high and 13 ft. wide. In the shipping (and storage) configuration, three units are normally connected together (figure 3.1a), although they may also be shipped as a pair, or individually. When expanded, the EXP shelter is intended for use as troop billet, but it has been used for other purposes.

3.2.1.2 Structural Features of EXP Shelter

The major structural components of the EXP Shelter (figure 3.2) are: (a) the center structure which is a rigid, open-sided box of honeycomb panel construction, (b) four honeycomb panel (figure 3.3) floor sections, (c) two honeycomb panel end-wall sections with a door and three windows in each, (d) six aluminum box beams for support of roof, and (e) two fold-away folded-plate roof and sidewall sections constructed of paper faced urethane foam sandwich panels covered with a rubberized fabric.

Each end-wall and two of the floor sections are hinged to each other and to the center structure in such a way that, when folded up, one of the floor sections on each side (panel 14) performs as one side of the center-structure box.

3.2.2 Expandable Shelter/Container (ES/C)

3.2.2.1 Functional Features of ES/C Shelter

This shelter (figure 3.4) is an expandable unit which unfolds from an 8 ft. x 8 ft.-9 in. x 13 ft. long center structure into an 8 ft. x 13 ft. x 24 ft. long structure. When expanded, the ES/C is a multi-function shelter which can be used for maintenance shops, administrative, medical and other services. The test unit had obviously been used as a welding or machine shop.

3.2.2.2 Structural Features of the ES/C Shelter

All panels in the ES/C are of foam and beam construction with aluminum facings (figure 3.5). The major structural components of the ES/C are (figure 3.6): (a) the center structure which is a rigid, open-sided box with a door in each end, (b) two fold-down floor panels (panel No. 5R and 5L), (c) two fold-up roof panels (panel No. 6R and 6L), (d) two pull-out end-wall panels (panel No. 9R and 9L), and (e) eight fold-out side-wall panels (panel No. 7R 8R, 10R, 11R, 7L, 8L, 10L, and 11L).

The end-wall and side-wall panels are hinged to each other and to the center structure so that when expanded, they rest on the fold-down floor and support the fold-up roof. External aluminum hat-sections are welded to the fold-down floor which is the external panel when the shelter is in the storage configuration.

3.3 Inspection of Shelters

3.3.1 Inspection of EXP Shelter

3.3.1.1 Identification of EXP Shelter

The identification labels fastened to the shelter included the following information:

1. Manufacturer
2. Contract No. - F33657-69-C-0773
3. Serial No. - 289
4. Warranty expiration - End of January 1971
5. Basic weight - 2650 lbs.
6. Shelter - Bare Base, Personnel

The floor panels (panels 14 and 15) were constructed with each facing made of two sheets of aluminum spliced with internal butt plates. This method resulted in a flush external joint which after fabrication was practically invisible. As will be described later, this joint does not always remain invisible. It was also found that the core used in these panels was the 15-in. wide honeycomb and that the core pieces were not spliced so as to prevent water migration.

3.3.1.2 General Impressions of the EXP

Except for some obviously delaminated areas, the shelter appeared to be in good condition inside and out. There were a number of impact-damaged spots, but these were relatively small in area and did not seem to have directly affected the performance of the shelter.

3.3.1.3 Delamination Survey of the EXP

Delaminations were found only in the panels which are exterior in the unexpanded (shipping) configuration. Prior to cutting pieces from the panels, major delaminations were found only in the fold-down floor panels and only on the exterior facing of these panels. The coin-tap test which was used for this survey was not satisfactory for locating delaminations of the interior facings of the floor panels because of the sound-deadening effect of the thick floor coating. Major delaminations of these interior facings were found later when the panels were cut, and during the core-water survey.

Figure 3.2 is a schematic drawing which indicates the panel numbering system used for this study. Figures 3.7, 3.8, and 3.9 are drawings of individual panels and show the delaminated areas (cross hatched) on each. The numbers in the squares outlined by the grid lines were used to identify samples cut from the panels.

It should be pointed out that portions of the mid-height splices in the exterior facings of the 14R and 14L floor panels were loose so that water could penetrate. Major delaminations were found near these loose splices, especially below the splice (figure 3.7 and 3.8). From these two figures it appears that the upper corners of these panels were also vulnerable to delamination. Only minor delaminations were found on the center-structure panels, as indicated on figure 3.9, although the delamination at the bottom of the front panel (Panel No. 1) might have caused structural problems if the shelter had been dropped.

3.3.1.4 Damaged-Area Survey of EXP

There were numerous indentations at various locations on the exterior facings of the No. 14 fold-down floors (figure 3.10, 3.11, and 3.12). Some of the smaller ones appeared to have been made by a hammer, and the larger ones appeared to have been made by fork-lift trucks. Most of these indentations were less than 1/4 in. deep, and none appeared to be serious or to have initiated any major delaminations. The coin-tap test indicated that only the immediate area of most indentations was delaminated, but two indentations (panel 14L, squares 23 and 26) were within major delamination areas.

When the facings were later removed, it was found that the honeycomb was broken (crushed) at the indentations. This broken honeycomb did not extend more than about 1/2 in. from the indentation in any direction.

3.3.1.5 Core-Water Survey

When the EXP was first expanded, brown stains were noticed below the screws holding communication jacks to the interior of the front panel (panel 1) to the center structure. It was obvious that water had leaked out of the panel at these points. Just opposite these jacks, on the exterior of the panel, was a roof-access step. This step was removed and the core within the panel at that point was found to be full of water. The core was not delaminated from the interior facing, but it peeled off relatively easily (bond failure). Free water was also found behind the other three steps when they were removed.

Water was also found in the core of panel 14R, when squares were cut from it. In fact, squares 20, 26, and 27 were completely filled.

Following removal from the panels of the squares for test specimens, each panel was thoroughly surveyed by removal of the exterior facings. It was found that all exterior panels (in the storage mode) except the center structure roof (panel 2) and floor (panel 3) were either soaking wet or, at best, damp (see figures 3.13, 3.14, and 3.15). In general, the bond was poor in all the wet areas. It was observed that the water had caused a darkening of the honeycomb and had extracted a brown substance from the honeycomb. This brown substance had not only stained the adhesive but in many areas had stained the aluminum facing directly below the honeycomb cell edges.

The effect of water on the honeycomb was most obvious in panels 2 and 3. Panels 1 and 4 were completely wet but panels 2 and 3 were wet only near the corners where they connected to panels 1 and 4. The color of the honeycomb in panels 2 and 3 was light amber (original color) over most of the area, but close to the corners, where water was present, the color became much darker. The center-structure panels had no close-outs at these corners. Therefore, liquid water entering at these corners would tend to run down into the vertical panels (1 and 4), with very little penetration into the horizontal panels (2 and 3).

There was an apparent anomaly in the condition of the roof panel (No. 2). Near the center of this panel was a hole gouged through the facing about 1 in long and as much as 1/8 in wide. This hole had been formed in such a way that any water on the roof would funnel down into the panel. The hole was not new, so it was assumed that rain must have entered this panel at some time. However, from the appearance of the core it could not have rained much because the honeycomb was not darkened and the adhesive was stained only directly below the hole.

3.3.2 Inspection of the ES/C Shelter

3.3.2.1 Identification of the ES/C

Identification labels fastened to the shelter included the following information:

1. Manufacturer
2. Contract No. - F33657-68-C-0507
3. Serial No. - 82
4. Cubage - 102.5 cu. ft.
5. Made for - Air Mobility Division (ASD), USAF
6. Shelter - Expandable Shelter/Container (ES/C)

3.3.2.2 General Impressions of the ES/C

This shelter had seen very rough treatment. There were a large number of indentations, (many of which had been repaired by patching and by injection of an adhesive), punctures, fork lift bumps and even a door hinge had been pulled off (door No. 2). There were a large number of major delaminated areas, both interior and exterior. Although in general, the shelter appeared to be still usable, it would not have been weather-tight as the weather-stripping was either missing or in poor condition.

3.3.2.3 Delamination Survey of the ES/C

All panels except the center-structure roof (panel 2) had delaminations, although some were minor. Typical delaminations are shown on figures 3.16, 3.17, and 3.18. Two panels (5R and 6R) had been repaired by complete removal, replacement and rebonding of the exterior facings. The repaired facing of 6R was completely delaminated, but that of 5R was only partially delaminated. Neither repair had been made with appearance as a consideration.

3.3.2.4 Damaged-Area Survey of the ES/C

There were so many damaged spots and areas on this shelter that it was difficult to find an area without some type of existing or repaired damage. Through-panel holes were found in panels 5L and 6L. They must have been made when the shelter was closed as the individual holes lined up on these two panels.

When the interior facing was removed from panel 5L, a crack through the foam core was found near where a repair had been made by rebonding. (Evidence of 2 different repair adhesives was found here.)

The exterior facing of the center-structure floor (panel 3) was partially delaminated, but in the area where it was slightly dented by a fork-lift, it was not delaminated.

No major, structural-weakening damaged areas were evident except at the ripped-off hinge of door 2. Because of the numerous damaged areas, no conclusion could be made regarding the effect of these areas on delamination.

3.3.2.5 Core Water Survey

Water was found in only one panel (6R) although water staining on peeled facings was found in several panels.

3.4 Description of Panel Material Test Methods

Test specimens were prepared from squares cut from panels of each shelter. These squares were chosen so as to get a range in panel-material properties. For example, squares of honeycomb panel material cut from the EXP shelter were used to prepare specimens that would represent good, delaminated and near-delaminated areas. Test specimens from delaminated areas were specially prepared for testing by rebonding a facing to the delaminated side of the core with a room-temperature cure adhesive. All test methods were essentially as described in MIL-STD 401B[1/] and in the referenced ASTM method.[2/]

3.4.1 Climbing Drum Peel Test (ASTM D 1781)

3.4.1.1 Preparation of Peel Test Specimens

The test specimens were prepared from 3 in wide and 12 in long pieces of the panel. The EXP honeycomb specimens were cut so that the honeycomb paper ribbons were parallel to the length ("L" direction). The facing to be peeled from the sandwich was left 12 in long. The rest of the sandwich was trimmed to be 9 in long, with 1-1/2 in of the long facing extending from each end of the specimen. These extensions of the facing were gripped by the climbing-drum peel test equipment.

1/ U.S. Dept. of Defense, Military Standard MIL-STD 401B; Sandwich Constructions and Core Materials, General Test Methods: Sup. of Doc., U.S. Gov't. Printing Office, Washington, D.C. 20402.

2/ 1974 Annual Book of ASTM Standards, Parts 22 and 25, American Society for Testing and Materials, Philadelphia, Pa. 19103.

3.4.1.2 Peel Test Procedure

The specimens were loaded in a screw-gear testing machine at a cross-head speed of 1.2 in/min. Continuous autographic recording of machine load vs cross-head movement was made for each specimen. The machine load reported for each specimen is an average value determined with a planimeter on the autographic recording. The recorded machine load for each sandwich specimen represented the sum of the load required to bend the facing and the load required to peel the facing from the sandwich. To determine the peel load, the load to bend the facings was measured on facing-only specimens and deducted from the machine load recorded for the sandwich specimens.

For the drum peel test equipment and specimen size used the reported peel-torque is equal to 1/6 the peel load.

3.4.2 Flatwise Tensile Strength Test (ASTM C 297)

3.4.2.1 Preparation of Flatwise Tensile Test Specimens

This test was performed on specimens from each shelter. Two types of specimens were used. The first type was a 2-in x 2-in section cut from the sandwich panel; most specimens were of this type. The second type was a 3-in x 3-in section cut from the ES/C panels so that the hat-section extrusion would be included in the specimen. Tensile loads were applied to the specimens through 1-1/4 in thick steel blocks which were bonded to the facings with an epoxy adhesive.

3.4.2.2 Tensile Test Procedure

All tensile tests performed at room temperature (73°F) were made in a hydraulic testing machine at a rate of loading so that failure would occur in 2 to 3 minutes. The elevated temperature tests were performed in the screw-gear testing machine equipped with a thermal chamber.

3.4.3 Flatwise Compressive Strength Test (ASTM C 365)

3.4.3.1 Compressive Test Procedure

Test specimens, 2 in. x 2 in. in cross section, were loaded in the screw-gear testing machine at a cross-head speed of .02 in/min. The compressive strengths reported are based on the maximum load resisted by the specimens. All tests were performed at 73°F.

3.4.4 Conditioning of Test Specimens

3.4.4.1 Aging

Some honeycomb panel specimens were artificially aged, prior to test, by exposure at 200°F and 100% rh for 14 days. This aging condition was produced by sealing the specimens in polyester oven bags containing a small quantity of free water and then placing the sealed bags in an oven controlled at 200°F. All specimens aged by this procedure had 3/64 in. holes drilled through the core and into each cell at mid-height for better circulation of the moisture.

3.4.4.2 Oven-Drying

Some honeycomb panel specimens were dried for 7 days in a ventilated 200°F oven. Some of these specimens were dried after being aged by the procedure of 3.4.4.1 and some were dried without any preconditioning.

3.4.4.3 Elevated Temperature Tests

Some specimens were tested at elevated temperatures. Honeycomb panel specimens were tested at an elevated temperature of 200°F and foam and beam specimens were tested at 180°F.

The elevated temperature tests were performed in a thermal-chamber accessory to the screw-gear testing machine.

3.5 Test Results for Panel Material

3.5.1 Honeycomb Panel (EXP) Test Results

3.5.1.1 Peel Test Results

A summary of the peel test results for the honeycomb panel specimens is given in table 3.1. The range and distribution of the individual test values are shown on figure 3.19. Table 3.2 lists the individual test values determined on the facing materials. The data of table 3.2 points out the necessity of measuring the bending load on actual facings when evaluating peel strength of the bond.

One peel test specimen gave an abnormally high value (10.6 in-lb/in). Close inspection of this specimen revealed that it had a double-thickness of adhesive over most of its area. This specimen is included in the table 3.1 and figure 3.19 data for the set with an average of 5.8 lb-in. The average for this set with the abnormal value deleted was 4.6 lb-in. as indicated by parenthesis in table 3.1.

3.5.1.2 Tensile Test Results

A summary of the tensile test results on the honeycomb specimens is given in table 3.3. It should be noted that all tests were performed at 73°F and none at 200°F. Unfortunately, the adhesive used for bonding the steel plates to the test specimens did not have sufficient strength for the 200°F test. This meant that in most attempted tests, the bond to the steel plates failed prior to failure in the sandwich.

The range and distribution of the individual test values are shown in figure 3.20.

3.5.1.3 Compressive Test Results

The summary for the compressive test results on honeycomb specimens is given in table 3.4, and the range in individual values is indicated in figure 3.21. The purpose of these tests was to determine the effect of long-term exposure to water on the strength properties of the honeycomb. The honeycomb of panel 15R looked like new while much of the honeycomb in panel 14R was water-logged, was very dark brown, and looked as if it may have deteriorated. All tests were performed at 73°F.

3.5.2 Foam and Beam Panel (ES/C) Test Results

A summary of the results for all the tests on the foam and foam-and-beam specimens are presented in table 3.5. It had been planned to develop shear-strength data on this material using shear-flexure tests. However, using the flexure-type test, no apparent shear-failure in the core or bond could be induced.

3.6 Discussion of Inspections and Test Results

3.6.1 EXP Shelter

Many of the general conclusions which are made regarding this EXP shelter and which are based on both visual inspection and test results could now be made after only a visual inspection of the panel material. From the experience gained during this study, it is now obvious that visible changes in the honeycomb core and the adhesive could be correlated with the possibility of delamination occurring. This means that an artificial aging procedure can be used to "test" for future delamination in panels fabricated similar to those of this EXP.

For example, the artificial aging procedure used in this study changed the color of the like-new core and adhesive in a manner similar to that due to the natural aging which had occurred in panel 14R and in other panels which were found to be wet. Oven drying (at low rh) without aging also caused a change, but not as great as the artificial aging. The visible changes caused by the artificial aging, and the oven drying, were not as pronounced as were those caused by the natural aging and there was no brown stain deposited on the facing during the aging. The fact that most of the core in the roof panel of the center structure was light amber in color indicates that solar heating will not cause darkening of the honeycomb core.

Thus, it would appear that a more realistic, artificial-aging procedure might be one in which the specimens are in a super-saturated condition at all times.

No serious effort was made to determine if the brown stain, per se, was a factor in delamination or simply an innocent bystander. It was determined that the stain was a water soluble mixture of phenol and lignin residue.

3.6.1.1 Delaminations of EXP Panels

All delaminations found in the EXP panels were bond failures, except for the very small areas at indentations in the facings where the core was crushed. There was no indication that the crushed core induced a spreading of the delaminated area. The physical appearance of the material at the delaminations supports the conclusion that long-term exposure to greater than 100% rh was a significant factor in the delamination.

It seems reasonable to assume that the interior of a panel containing a significant quantity of free water would be at nearly 100% rh even in the areas of the panel that do not contain free water. Delaminations were found only in areas which either contained free water or where the core showed evidence of being wet at some previous time. The areas of the panel which were not wet did not show evidence of being wet previously, were not delaminated but the bond was degraded. This indicates that 100% rh conditions affected the bond but at a slower rate than free water conditions.

In general, the bond to the interior facings of the panels was affected in the same way as to the exterior facings.

3.6.1.2 Water Entry Into EXP Panels

All panels which were exterior on the shelter in the shipping configuration (panels 14R, 14L and center structure panels) contained considerable water. The horizontal panels (roof and floor of center structure) contained water only near the ends where they connected to the vertical panels. The panels and the center structure were fabricated so that water was free to circulate naturally, i.e., under gravity. The core itself appeared to be a very low-water migration type, but there were many water paths, vertically and horizontally, between core sections and along the edges.

Most of the water must have entered as liquid water, not vapor, as evidenced by the distribution pattern of the free water within the panels. Leaks were found to explain entry of the water into all wet panels.

For example, the corners of the center structure where the vertical panels connected to the roof panel were sealed with an aluminum angle bonded to the exterior facings. There was clear evidence that this seal had been broken at both corners and rain water had entered under the horizontal legs of the angles. Figure 3.22 shows this corner with the angle peeled off.

Water entered the fold-down floors (panels 14R and 14L), initially at the top corners, and in panel 14L at one of the fasteners used to hold the floor to the roof of the center structure. Figure 3.23 indicates the corner holes which permitted entry of water.

When the shelter was received, the exterior mid-height splices of the two aluminum sheets comprising the exterior facings of these floor panels were loose over a portion of their length. The loose splices were such that water running down the face of the panel could run directly into the panel. Distribution of water within the panels indicated that the primary entry point of the water was probably not the loose splices, but the upper corners.

There was no evidence that condensation of water vapor within the panels was a major source of the water. There is no doubt that some water did enter as vapor, but the major source must have been rain water.

3.6.1.3 Strength Tests of EXP Panel Material

For this material the data indicate that the tensile tests are a better method of evaluating the bond than the peel test. First, the spread in the average strength between poor and good bonds was five times greater in the tensile test than in the peel test. Second, the peel strength was greater at 200°F than at 73°F while the tensile bond strengths could be expected to be lower at 200°F. (Based on data in the literature.)

The only obvious advantage the peel test appears to have is that the coefficient of variation is significantly less than for the tensile test. The average coefficient of variation for nine sets of peel-test data was 15% while for 10 sets of tensile-test data the average was 25%. As could be expected, the coefficient of variation for the compressive strength tests was the lowest of three types of tests, since only the core is being tested. The average coefficient of variation for six sets of compressive strength data was 8%.

The compressive strength values appear to be directly related to the moisture content of the specimens when tested. The lowest values are for wet core, and the highest values are for the oven-dry specimens. Significantly, the compressive strength of the dried core from the area which had been filled with water for a considerable period of time was about the same as was the dried core which was judged to be as good as new.

3.6.2 ES/C Shelter

No clear-cut conclusions can be made regarding this foamand-beam shelter except that the test unit had suffered from some very severe treatment. There had been many attempts to repair delaminations, but most did not appear to be very successful.

Apparently, two repair methods had been used. The first method was the injection of an adhesive into voids through holes in the facings. The second method was the spreading of the adhasive on the peeled-off facing. The first method was probably used for relatively small delaminated areas.

At least two different repair adhesives had been used. One must have been an unfilled, amber colored liquid adhesive and the other, a filled, dark-gray paste adhesive similar to an auto body putty. The gray paste adhesive had been also used for repair of punctures and deep indentations.

The facings generally peeled off the foam easily with all the adhesive remaining on the foam. This is in contrast with the tensile test where the failures were almost 100% in the foam at the foam-adhesive interface.

3.6.2.1 Inspection of ES/C Panels

All delaminations found in the ES/C panels were either a bond failure at the adhesive-facing interface or foam failure just at the adhesive-foam interface. Most large delaminations which had not been repaired were bond failures.

Water was found only in one of the fold-up roof panels (6R). This panel had been repaired by removal of the exterior facing and rebonding. The facing had been replaced in three pieces in such a way that the seams around the edges and between pieces were difficult to seal. The repair adhesive was not uniformly placed so that at some places it was as thick as 3/8 in. while at other places there was practically none.

The foam in this panel looked dry, but water could be squeezed out of it. A piece of foam removed, and oven dried, had 380% of water by weight. This means that the wet foam weighed almost 10 lb/ft^3, which is 5 times its dry weight of 2 lb/ft^3. The presence of water stains on the facings was taken as evidence that water had been present at some time in other panels, but it could not be determined if the water contributed to the delaminations.

There was no clear indication that impact loads had caused any delamination, although in square 23 of the fold-down floor panel 5L, a crack through the foam was found in an area that had been repaired by injection of an adhesive. This crack might have been caused by an impact, but probably after delamination.

The exterior facing of the fixed floor panel (panel No. 3) was partially delaminated near one of the fork-lift slots. This facing had been slightly dented by the forks, but the facing was not delaminated at these indentations.

3.6.2.2 Strength Tests of ES/C Panel Material

Strength tests were performed only on specimens from the fold-down floor panel 5L. The dry density of the foam in this panel was approximately 3 lb/ft^3.

The compressive test results are usable only as a measure of the strength of the foam. These results indicate that the compressive strength of this foam at 180°F was about 53% of its strength at 73°F.

Since failures in the tensile tests were also in the foam the tensile test results are an indication of the tensile strength of the foam. In the tensile tests at 180°F, the strength of the foam was about 72% of its strength at 73°F. At 180° F the tensile and compressive strengths were about equal, but at 73°F the tensile strength was lower than the compressive strength.

The significance of these test values with regard to the performance of the shelter cannot be judged. However, in light of the visual inspections of delaminations it can be assumed that the peel strength values may have more relevance to this study than the tensile strength values. In the peel tests (at 73°F) the initial failure was at the foam-adhesive interface at a peel torque of 1.1 lb-in/in of width. It was noticed during the peel test, that after the initial failure, a slight additional bend in the facing caused a rapid failure in the bond as the stiff adhesive layer tended to split off the facing in sheets. The original adhesive layer for these ES/C panels had many air bubbles in it and at each bubble the facing-side of the adhesive bubble was found to be well-bonded to the aluminum. It is possible that the stiff adhesive layer in combination with the relatively soft core may result in initiation of major delaminations at indentations caused by concentrated loads. However, no clear evidence of this effect was found in this shelter.

3.7 Conclusions for Phase II

3.7.1 EXP Shelter

1. All delaminations found in the EXP panels were caused by bond failure except for small areas directly under indentations where the core was crushed.
2. There was no indication that the crushed core in the EXP was a significant factor in delamination.
3. All major delaminations in the EXP were in areas that were either wet when the panels were opened or showed evidence of having been wet previously.
4. Water soaking of the kraft paper honeycomb core darkened it; phenol and lignin residues leached from the core by the water were deposited on the adhesive and, in some areas, on the aluminum facing beneath the adhesive. These residues were also found on the outside of the EXP panels where water had leaked from the panel.
5. Solar heating of the dry core in the center-structure roof panel did not darken the core or adhesive appreciably. However, oven heating of test specimens at 200°F did darken the core and adhesive slightly.
6. Distribution of water within the EXP panels indicated that most of the water was probably rain and not condensation.
7. Water was found only in EXP panels which were exterior in the storage configuration and leakage paths were found to explain entry of rain.
8. The bond to both the interior and exterior facings of the wet EXP panels was degraded to the same extent.
9. The test results on the EXP panel material indicate that the compressive strength of the core was not degraded significantly by an extended period of exposure to liquid water.

3.7.2 ES/C Shelter

1. The ES/C shelter had seen such severe service and had been repaired so many times and at so many places that no conclusions were reached on causes of delaminations.
2. The bond and core strengths, as measured by both peel and tensile tests of the "good" ES/C panel material were quite low.
3. When peeling large sections of the ES/C facing from the core by hand the adhesive separated from the facing. This is in contrast to the failures in the tensile and peel tests where initial failures were by separation of the adhesive layer from the foam core (3 lb/ft^3 core).
4. Water was found only in one ES/C panel. This was a fold-up roof panel which was

inside in the storage mode. The foam core (2 lb/ft^3) in this panel had as much as 380% of absorbed water by weight.

5. No clear evidence was found to indicate that either impact or concentrated loads were factors in delamination of ES/C panels. However, from observations made during the tests, it seems likely that loads which will bend the facings locally and depress the foam will tend to cause the adhesive layer to separate from the facing.
6. The tensile strength of the 3 lb/ft^3 foam was less than the compressive strength at 73°F, but was about equal at 180°F.

4.0 Phase IIA - Evaluation of Four Honeycomb Cores

4.1 Introduction

4.1.1 Statement of the Problem

The Air Force is considering the use of a polyamide paper honeycomb (Nomex)[3/] in lieu of the kraft paper honeycomb (WR II)[3/] now used for the core in mobile-shelter sandwich panels. Among the factors that will be considered in determining the cost effectiveness of such a change is the performance, under adverse conditions, of the Nomex core as compared with that of the WR II core. The study described in this report is a comparison of the compressive strengths for three Nomex cores and one WR II core before and after artificial aging. Under some service conditions encountered by the mobile shelters, the currently used WR II cores are said to be unsatisfactory. It has been suggested that the performance of the Nomex cores would be satisfactory under the same conditions. This study was set up to help the Air Force determine if the long-term performance of the Nomex is sufficiently better than the WR II to justify a greater cost.

4.1.2 Objective

The specific objective of this study was to determine the relative efficiencies of the four honeycomb core materials under long-term service conditions. Although the strength data in this report are limited to flatwise compression, it can be reasonably assumed that the shear and tensile strengths would be similarly affected by the same conditions.

4.1.3 Description of Honeycomb Samples

Four 2-ft x 2-ft x 1-in thick samples of aluminum faced, honeycomb core, sandwich panels were received from the sponsor. The facings were 0.032 in, 6061-T6 aluminum,

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[3/] Nomex and WR II are proprietary names. These names are used merely to accurately identify the core material. Their use does not imply an endorsement by the National Bureau of Standards.

which had been bonded to the cores with a modified epoxy adhesive. Table 4.1 is a description of the cores used in the four samples and includes the identification symbol (Type) for each.

4.2 Specimen Preparation

4.2.1 Cutting of Specimens

Each 2-ft. x 2-ft. sample was cut into 2-in x 2-in x 1-in thick specimens with a skip-tooth blade in a band saw. Rough, turned-up edges left by the saw were removed by a hand file. Ninety-six specimens from each sample were separated into 16 sets of 6 specimens each. Each specimen was marked with a symbol which identified sample number (Type), aging procedure, test temperature, and the aging period.

4.2.2 Specimen Conditioning Procedures

The 16 sets of specimens from each sample were conditioned prior to the compressive test by one of the following procedures:

1. Two sets of control specimens were stored at 73°F, 50% rh. One set for one week and the other for six weeks.
2. Two sets were soaked in 73°F tap water for one week just prior to test. The two sets were tested at two dates, six weeks apart.
3. Two sets were heated to 180°F for one hour just prior to test and were tested at two dates, six weeks apart.
4. Two sets were heated to 210°F for one hour just prior to test and were tested at two dates, six weeks apart.
5. Four sets were aged at 180°F, 100^{+}% rh[4/] until tested. One set was tested after each of four aging periods (2, 6, 12 and 24 weeks). These specimens were placed in sealed plastic pans containing water and stored in an oven controlled at 180 ± 2°F. The water levels within the pans were maintained so that approximately the bottom half of each specimen was in the water.
6. Four sets were aged at 210°F, 95% rh until tested. One set was tested after each of four aging periods (2, 6, 12 and 24 weeks). These specimens were placed above water in sealed plastic pans and stored in an oven controlled at 208 ± 2°F.

4.3 Testing Procedure

The compressive strength determinations were made in accordance with ASTM C 365. The rate of head movement was generally 0.012 in per min although a few specimens were tested at 0.008 in per min. All tests were performed in a thermal-chamber attachment to the screw-gear testing machine. All specimens were tested at the conditioning temperature and moisture content.

[4/] 100^{+}% rh indicates that there was free water on these specimens.

Continuous recordings of head movement and load were made for each specimen. Core strains were not measured.

4.4 Test Results

Average test results for each conditioning procedure are presented in table 4.2. Average stress-deformation data for sets of Type 4 and 6 core specimens are shown in figures 4.1 and 4.2.

Tables 4.3 and 4.4 present statistical data for the test data from each conditioning procedure.

The effect of conditioning on strength is shown graphically on figure 4.3 and in table 4.5.

Figure 4.4 indicates the effect of temperature on the strength of air dried specimens. Figure 4.5 shows the effect of temperature on the strength-density relationship.

4.5 Discussion

The purpose of this study was to determine the relative efficiencies of the four types of core under less than optimum conditions and after exposure, for various periods, to these adverse conditions. The adverse conditions were either elevated temperatures, high moisture conditions or a combination of the two. The data of table 4.5 is probably the most significant for this purpose.

From the relative strength data of table 4.5 it can be seen that increasing the test temperature above 73°F has a very significant effect, although less for the Nomex cores than for the WR II core. The loss in strength for the Nomex cores was about 11% at 180°F and 13% at 210°F, but for the WR II, the losses were over three times greater.

Exposing the cores to these temperatures and to high humidity at the same time causes a further loss. This could be expected since the data in the fourth column has shown that just wetting reduced the strength significantly. The test data cannot be used to show that the effect of exposure to the elevated temperatures plus high humidity is time dependent.

If we add the losses indicated for the wet specimens (fourth column) to those for just the elevated temperature, (fifth or tenth column) the total losses are approximately the same as those indicated for the long-term exposure to the combination conditions. This indicates that a 24-week exposure to high humidity would have no significantly greater effect than a 7-day exposure to water at room temperature.

Overall, the Nomex cores performed much better than the WR II core. There was a significantly greater deterioration in the WR II with long-term exposure to the 210°F test conditions than to the 180°F conditions. However, the strength of the WR II core under both these conditions was so low that the difference has little practical significance.

If we average the relative strengths for the three Nomex cores (No. 3, 4 and 5) and compare them with those for the WR II core (No. 6) we can make the following statements. The Nomex cores were better than the WR II core by the following factors:

1.4 - When tested at 73°F after being soaked in water for 7 days.

1.4 - When tested air-dry at 180°F.

1.6 - When tested air-dry at 210°F.

4.1 - When tested at 180°F after 24 weeks exposure to 180°F, 100^{+}% rh.

8.3 - When tested at 210°F after 24 weeks exposure to 210°F, 95% rh.

4.6 Conclusions for Phase IIA

1. The compressive strengths of the four honeycomb cores varied inversely with the test temperature. (See figure 4.4.) However, the loss in strength for the WR II was about three times greater than for the Nomex cores when the temperatur was changed from 73°F to 210°F.
2. Using the relative strength values of table 4.5, the average Nomex core performed better than the WR II by factors as great as 8.3.
3. The strength of the WR II core was too low to have practical value after 24 weeks exposure to high humidity and either 180°F or 210°F. (See table 4.2 or 4.5 and figure 4.2 or 4.3.)
4. There are indications that the losses in strength after long-term exposure to high humidities and elevated temperatures may be a result of deterioration from the elevated temperatures alone, but there are insufficient data to demonstrate this point conclusively.
5. The compressive strength of all four cores, in the air-dry condition and at 73°F, are roughly proportional to their air-dry density. (See figure 4.5.) However, at 180°F and 210°F test temperatures, the strength to density ratios for the WR II core are much lower than those for Nomex cores.

Table 2.1 Shelters Examined at Holloman AFB (second trip)

Type	Serial No.	Age [a/]	Construction	Approximate Size, ft width x height x length	
				In Storage	Expanded
EXP	267	Old	Honeycomb	3 x 8 x 13	33 x 8 x 13
EXP	285	Old	Honeycomb	3 x 8 x 13	33 x 8 x 13
EXP	0460	New	Honeycomb	2-2/3 x 8 x 13	33 x 8 x 13
EXP	0464	New	Honeycomb	2-2/3 x 8 x 13	33 x 8 x 13
ES/C	28	Newer	Foam & Beam	8 x 8 x 13	24 x 8 x 13
ES/C	55	Newer	Foam & Beam	8 x 8 x 13	24 x 8 x 13
ES/C	0519	New	Honeycomb	8 x 8 x 13	24 x 8 x 13

[a/] Due to lack of documentation the exact age of the shelters was not determined. See Section 2.2.1 of this report for an explanation of the terms used under this heading.

Table 2.2 - EXP Indentation Locations

Shelter No.	Panel[a/]	Surface[b/]	Location No.[c/]	Indentation Depth Inches
285	Left Interior Floor	Exterior	1	.043
285	Left Interior Floor	Exterior	2	.054
285	Left Interior Floor	Exterior	3	.033
285	Left Interior Floor	Exterior	4	.052
285	Left Interior Floor	Exterior	5	.069
285	Left Interior Floor	Exterior	6	.041
285	Left Interior Floor	Exterior	7	.064
285	Left Interior Floor	Interior	8	.127
285	Left Interior Floor	Interior	9	.053
285	Left Interior Floor	Interior	10	.098
285	Right Interior Floor	Exterior	1	.095
285	Right Interior Floor	Exterior	2	.056
285	Right Interior Floor	Exterior	3	.047
285	Right Interior Floor	Exterior	4	.026
285	Right Interior Floor	Interior	5	- [d/]
267	Left Interior Floor	Exterior	1	.155
267	Left Interior Floor	Exterior	2	- [e/]
267	Right Interior Floor	Interior	1	.105
267	Front End Wall	Exterior	See figure 2.17	- [e/]

[a/] Instruction plate side of unit was designated as the front. Positions (left and right) defined when facing instruction plate. "Interior floor means the fold-down panel which becomes the floor closest to the center structure when the shelter is expanded

[b/] Exterior = weather side; Interior - inside

[c/] Refer to Figures 2.15 and 2.16 for location no.

[d/] Triangular puncture (See figure 2.18)

[e/] Lift truck fork damage. No measurement made.

Table 3.1 Summary of Drum Peel Tests
(EXP Honeycomb Panel Material)

Average[a/] Peel Torque lb-in/in	Facing Peeled	Failure[b/] Mode	Average Machine Load		Initial Condition of Material	Specimen Conditioning[c/]		Test Temperature	Panel No.	Square No.
			Sandwich lb	Facing lb		Prior to Test	For Test			
3.3	Floor	B	100.9	80.9	Delaminated	None	None	73°F	14R	8
3.6	Exterior	A	90.5	68.7	Good	Aged	OD	73°F	15R	17&24
3.8	Exterior	B & A	91.5	68.7	Good	Aged	None	73°F	15R	17&24
4.1	Exterior	A & C	93.4	68.7	Good	None	None	73°F	15R	17&24
4.8	Exterior	A	97.5	68.7	Good	None	None	73°F	15R	17&24
5.0	Exterior	A & C	96.9	66.9	Good	Aged	OD	200°F	15R	17&24
[d/] 5.8(4.6)	Exterior	A	101.7	66.9	Good	None	None	200°F	15R	17&24
6.4	Exterior	B	107.3	68.7	Near Delamination	None	None	73°F	14R	27
6.6	Exterior	B	106.7	66.9	Good	Aged	None	200°F	15R	17&24

a/ Average of 6-3in. X 12in. specimens

b/ Failure mode - "A" indicates cohesive failure in adhesive at scrim cloth.
"B" indicates bond failure to aluminum facing.
"C" indicates failure in core.

c/ Specimen Conditioning - "Aged" indicates specimens preconditioned for 2 weeks at 200°F, 100% rh
"OD" indicates specimens oven dried at 200°F after preconditioning.

d/ (4.6) is average value for set after deleting one specimen with peel torque of 10.6 lb.-in.

Table 3.2 Drum Peel Bending Tests on EXP Facings

Facing[a]	Coatings on Facing	Test Temperature	Avg Mach Load
Exterior	Paint & Adhesive	200°F	66.9 lb.
Exterior	Paint & Adhesive	73°F	68.0 lb.
Exterior	Paint & Adhesive	73°F	69.3 lb.
Exterior	None	73°F	65.7 lb.
Exterior	None	73°F	66.2 lb.
Floor	Covering & Adhesive	73°F	80.0 lb.
Floor	Covering & Adhesive	73°F	81.7 lb.
Floor	None	73°F	66.0 lb.
Floor	None	73°F	64.9 lb.
Floor	Covering & Adhesive	200°F	75.2 lb.
Floor	Covering & Adhesive	200°F	75.2 lb.

[a] The bare aluminum facing material was .032 in. thick in all cases. The coatings (paint, adhesive or floor covering) were removed with a solvent before testing those indicated as having "none".

Table 3.3 Summary of Tensile Tests
(EXP Honeycomb Panel Material)

Maximum[a/] Tensile Stress psi	Failure[b/] Mode	Failure Side	Initial Condition of Material	Specimen Conditioning[c/]		Test Temperature	Panel No.	Square No.
				Prior to Test	For Test			
36	B	Flooring	Near Delamination	None	OD	73°F	14R	18
45	B	Flooring	Near Delamination	None	None	73°F	14R	18
109	B & A	Flooring	Delaminated	None	None	73°F	14R	8 & 9
116	B	Flooring	Delaminated	None	OD	73°F	14R	8 & 9
152	B & C	-	Good	Aged	OD	73°F	15R	17&24
163	B	Exterior	Near Delamination	None	None	73°F	14R	9
169	B	Exterior	Near Delamination	None	OD	73°F	14R	9
185	B & C	-	Good	Aged	None	73°F	15R	17&24
277	B,A& C	Floor&Exterior	Good	None	OD	73°F	15R	18
388	A & C	Floor&Exterior	Good	None	None	73°F	15R	18

a/ Average of 6-2in. X 2in. specimens

b/ Failure Mode - "A" indicates cohesive failure in adhesive at scrim cloth.
"B" indicates bond failure to aluminum facing.
"C" indicates failure in core.

c/ Specimen conditioning - "Aged" indicates specimens preconditioned for 2 weeks at 200°F, 100% rh.
"OD" indicates specimens oven dried at 200°F after preconditioning.

Table 3.4 Summary of Compressive Tests
(EXP Honeycomb Panel Material)

Compressive[a/] Strength psi	Initial Condition of Material	Specimen Conditioning[b/]		Panel No.	Square No.
		Prior to Test	For Test		
191	Wet, Near Delamination	None	None	14R	13
279	Wet, Delamination	None	None	14R	13
347	Air Dry, Good	Aged	Air Dried	15R	17-24
356	Air Dry, Good	Aged	Oven Dried	15R	17-24
519	Air Dry, Good	None	None	15R	25
536	Wet, Delamination	None	Oven Dried	14L	16

a/ Average of 6-2in. x 2in. specimens tested at 73°F

b/ Specimen Conditioning - "Aged" indicates specimens were preconditioned for 2 weeks at 200°F, 100° rh.

"Oven Dried" indicates specimens were oven dried at 200°F after preconditioning.

Table 3.5 Summary of Test Results
(ES/C Foam & Beam Panel Material)

Maximum Stress [a]	Type of Test	Type of Specimen [b]	Failure Mode	Test Temperature	Initial Condition of Material	Panel No.	Square No.
36 psi	Compression	Foam	Foam, Crushed	180°F	Good	5L	17 & 24
56 psi	Compression	Foam	Foam, Crushed	73°F	Near Delamination	5L	23
63 psi	Compression	Foam	Foam, Crushed	73°F	Good	5L	17 & 24
38 psi	Tension	Foam	Foam, Cohesive	180°F	Good	5L	17 & 24
39 psi	Tension	Foam	Foam, Cohesive	180°F	Near Delamination	5L	23
53 psi	Tension	Foam	Foam & Bond	73°F	Good	5L	17 & 24
54 psi	Tension	Foam	Foam, Cohesive	73°F	Near Delamination	5L	23
77 psi	Tension	Extrusion	Wood & Bond	180°F	Good	5L	16
121 psi	Tension	Extrusion	Wood Cohesive	73°F	Good	5L	16 & 17
1.1 lb-in/in	Peel	Foam	Foam & Bond [c]	73°F	Good	5L	24

a/ Average of 6 specimens

b/ "Foam" indicates a 2in. x 2in. facing-foam-facing sandwich specimen. Foam density was $3 lb/ft^3$.
"Extrusion" indicates a 3in. x 3in. facing-hat section-wood-facing composite specimen, but facing welded to the hat section beam was removed for test.

c/ Both failure modes occurred during each test, however the initial failure appeared to be at the foam-adhesive interface. The adhesive-bond failure occurred shortly after when the adhesive split off the facing in relatively large sheets.

Table 4.1 Description of the Four Honeycomb Cores

Identification Type	Type of Paper[a]	Cell[a] Size	Core[a] Density	Compressive Strength[b] (Air dry at 73°F)	Compressive Strength to Density Ratio
		in.	pcf	psi.	psi./pcf.
3	AFC Nomex	1/4	4.8	710	148
4	HRH Nomex	1/4	4.0	499	125
5	HRH Nomex	1/8	3.0	346	115
6	WRII Kraft	3/8	3.8	462	122

[a] Data supplied by producer.

[b] Average for 12-2" x 2" specimens at equilibrium with lab air.

Table 4.2 Summary of Compressive Strength Data
(Average values for sets of 6 specimens)

Core Type	Test Temp. °F	Compressive Strength, psi											
		Dry[a]	Wet[b]	Aged[c] at 180°F 100$^+$% rh					Aged[c] at 210°F 95% rh				
				0 wks	2 wks	6 wks	12 wks	24 wks	0 wks	2 wks	6 wks	12 wks	24 wks
3	73	710	554	--	--	--	--	--	--	--	--	--	--
	180	--	--	614	493	482	483	490	--	--	--	--	--
	210	--	--	--	--	--	--	--	614	491	497	507	472
4	73	499	350	--	--	--	--	--	--	--	--	--	--
	180	--	--	433	316	308	313	313	--	--	--	--	--
	210	--	--	--	--	--	--	--	409	300	323	316	261
5	73	346	293	--	--	--	--	--	--	--	--	--	--
	180	--	--	323	262	262	262	264	--	--	--	--	--
	210	--	--	--	--	--	--	--	315	225	241	248	192
6	73	462	254	--	--	--	--	--	--	--	--	--	--
	180	--	--	295	94	88	100	77	--	--	--	--	--
	210	--	--	--	--	--	--	--	256	85	61	52	33

a/ Average for 2-sets of specimens stored at 73°F, 50% rh. One set of six was stored for 1 week and the other set for 6 weeks.

b/ Average for 2-sets of specimens soaked in 73°F tap water for 1 week just prior to test. The two sets were tested at two dates, six weeks apart.

c/ All aging periods are based on time being 0 at initiation of aging exposure. (Approx. Sept. 3, 1974, for most sets of specimens). Data for 0 wks are for 2-sets of specimens tested on 2 different dates, six weeks apart. These 0-wk specimens were dry, but were placed in a chamber at the stated temperature for one hour prior to test.

Table 4.3 Range in Compressive Strength Values for Sets of Six Specimens

Core Type	Test Temp. °F	Range in Compressive Strength Values, Percent of Average											
		Dry[a]	Wet[a]	Aged at 180°F-100^{+}% rh					Aged at 210°F-95% rh				
				0 wks[a]	2 wks	6 wks	12 wks	24 wks	0 wks[a]	2 wks	6 wks	12 wks	24 wks
3	73	19	9	----	----	----	----	----	----	----	----	----	----
	180			20	10	12	15	18	----	----	----	----	----
	210			----	----	----	----	----	22	17	17	14	24
4	73	9	7	----	----	----	----	----	----	----	----	----	----
	180			9	3	3	4	6	----	----	----	----	----
	210			----	----	----	----	----	8	8	9	5	13
5	73	9	18	----	----	----	----	----	----	----	----	----	----
	180			13	13	7	11	12	----	----	----	----	----
	210			----	----	----	----	----	19	27	20	11	32
6	73	11	18	----	----	----	----	----	----	----	----	----	----
	80			10	29	15	22	17	----	----	----	----	----
	210			----	----	----	----	----	14	25	18	36	42

a/ Average value for 2 sets of specimens.

Table 4.4 Variability in Compressive Strength Values for Sets of Six Specimens

Core Type	Test Temp. °F	Coefficient of Variation for Each Set, Percent of Average											
		Dry[a/]	Wet[a/]	Aged at 180°F-100^{+}% rh					Aged at 210°F-95% rh				
				0 wks[a/]	2 wks	6 wks	12 wks	24 wks	0 wks[a/]	2 wks	6 wks	12 wks	24 wks
3	73	6.2	3.1	---	---	---	---	---	---	---	---	---	---
	180	---	---	8.2	4.6	5.4	5.3	7.5	---	---	---	---	---
	210	---	---	---	---	---	---	---	7.6	5.9	5.9	5.5	8.9
4	73	4.1	2.4	---	---	---	---	---	---	---	---	---	---
	180	---	---	3.3	1.1	0.9	1.6	2.2	---	---	---	---	---
	210	---	---	---	---	---	---	---	3.4	2.7	3.3	2.1	4.6
5	73	3.6	8.3	---	---	---	---	---	---	---	---	---	---
	180	---	---	5.3	5.5	2.2	4.2	4.4	---	---	---	---	---
	210	---	---	---	---	---	---	---	6.2	9.3	6.6	4.9	12.6
6	73	4.4	7.7	---	---	---	---	---	---	---	---	---	---
	180	---	---	3.6	11.3	8.3	9.4	5.7	---	---	---	---	---
	210	---	---	---	---	---	---	---	5.6	8.3	5.9	13.6	15.7

a/ Average value for 2 sets of specimens.

Table 4.5 Effect of Conditioning on Relative Compressive Strength for Each Type of Honeycomb Core

Core Type	Test Temp. °F	Relative Strength, Percent of Dry Strength at 73°F											
		Dry	Wet	Aged at 180°F- 100^{+}% rh					Aged at 210°F- 95% rh				
				0 wks	2 wks	6 wks	12 wks	24 wks	0 wks	2 wks	6 wks	12 wks	24 wks
3	73	100	78	---	---	---	---	---	---	---	---	---	---
	180	---	---	87	69	68	68	69	---	---	---	---	---
	210	---	---	---	---	---	---	---	87	69	70	71	66
4	73	100	70	---	---	---	---	---	---	---	---	---	---
	180	---	---	87	63	62	63	64	---	---	---	---	---
	210	---	---	---	---	---	---	---	82	60	65	63	52
5	73	100	85	---	---	---	---	---	---	---	---	---	---
	180	---	---	93	76	76	76	76	---	---	---	---	---
	210	---	---	---	---	---	---	---	91	65	70	72	56
6	73	100	55	---	---	---	---	---	---	---	---	---	---
	180	---	---	64	20	19	22	17	---	---	---	---	---
	210	---	---	---	---	---	---	---	55	18	13	11	7

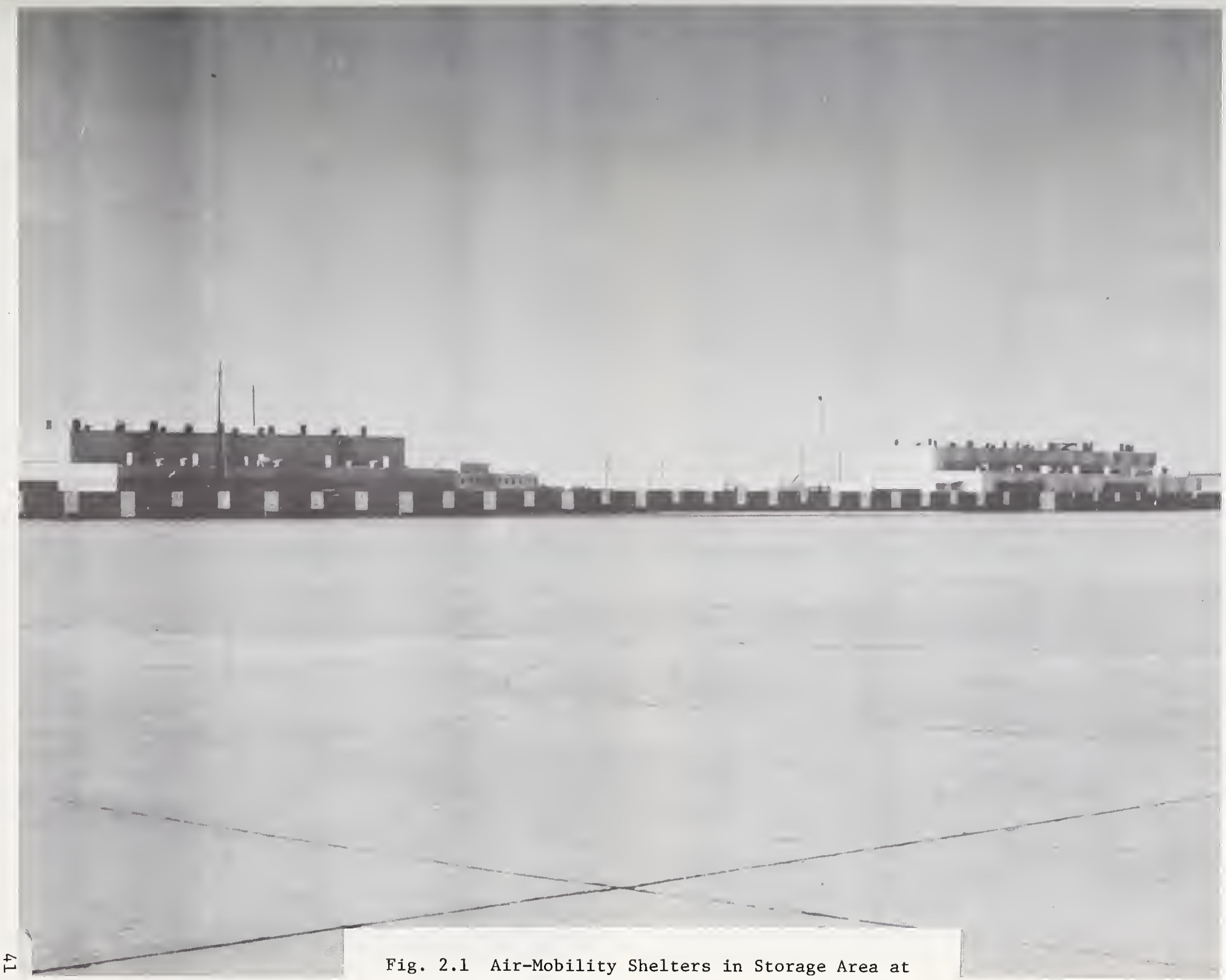
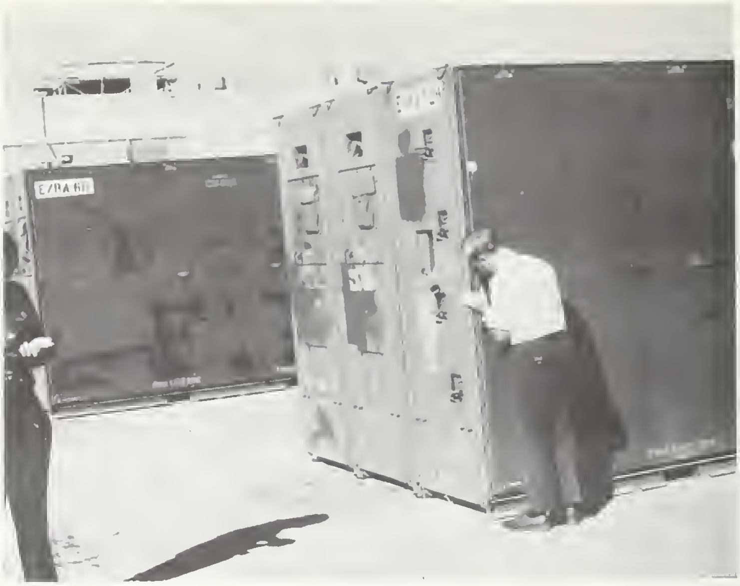


Fig. 2.1 Air-Mobility Shelters in Storage Area at Holloman A.F.B.



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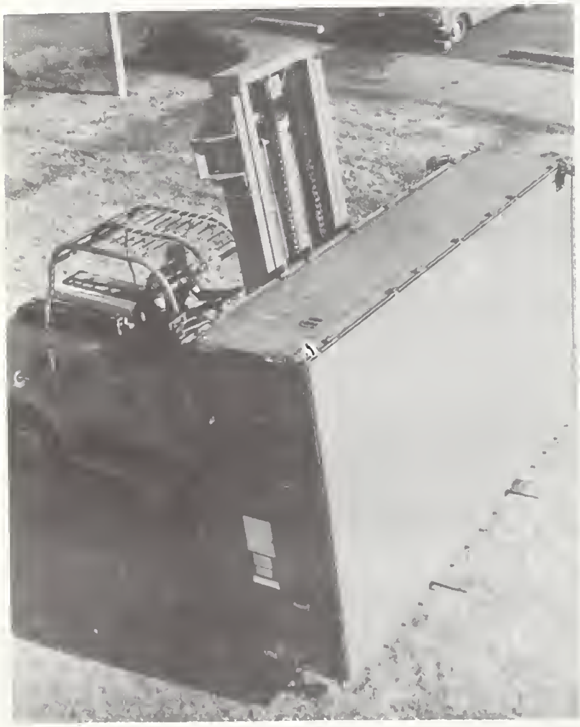


b

c

Fig. 2.2 Expandable Personnel Shelters (EXP)

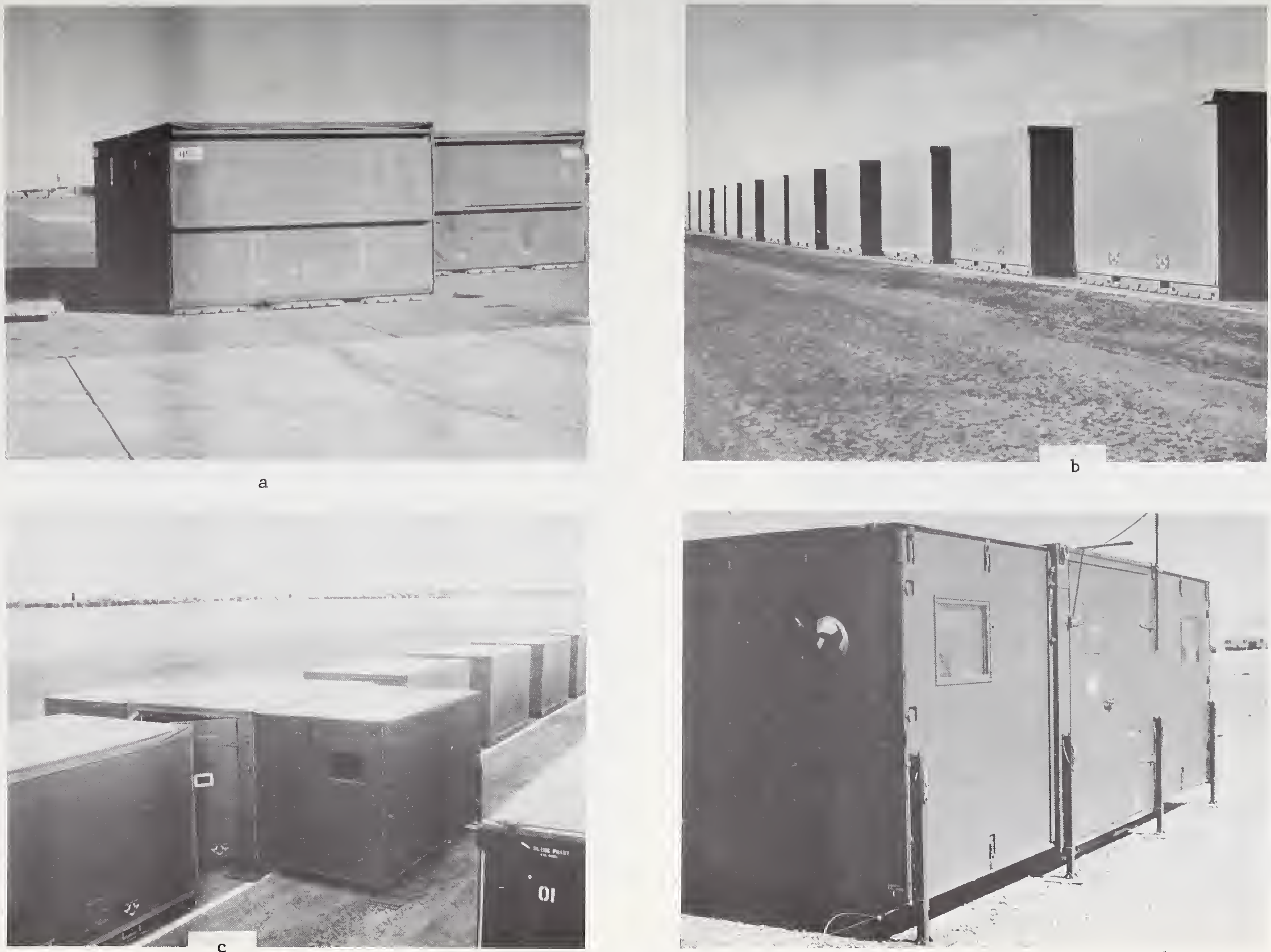


Fig. 2.3 Expandable Shelter/Containers (ES/C)

Fig. 2.4 S-141 Electronic Shelter

Fig. 2.5 "2 for 1" Expandable Electrical
Equipment Shelter

Fig. 2.6 General Purpose Aluminum Arch Frame Shelter (Portion of Mess Hall Complex)

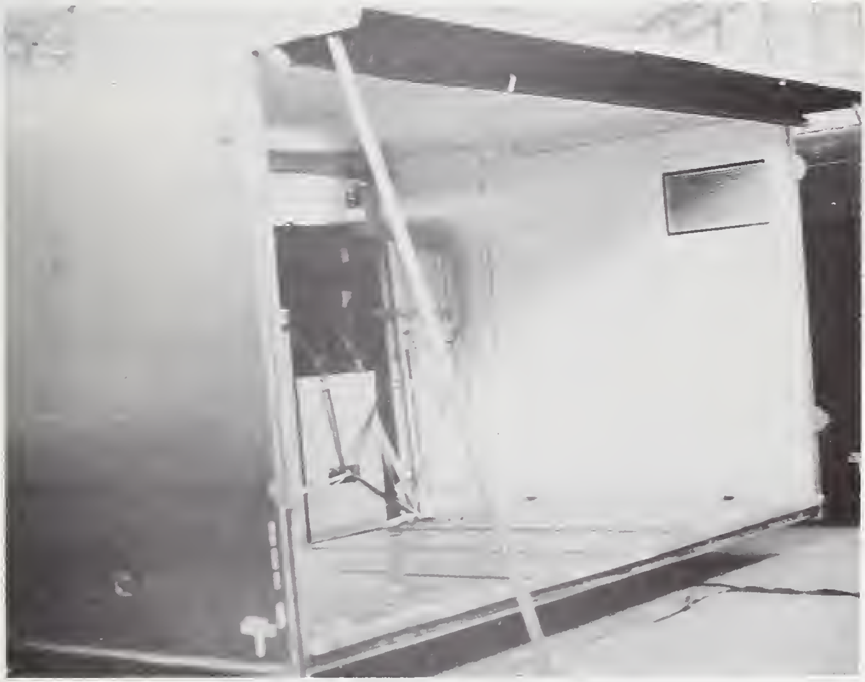


Fig. 2.7 Expandable Kitchen Shelter

Fig. 2.8 Expandable Latrine Shelter

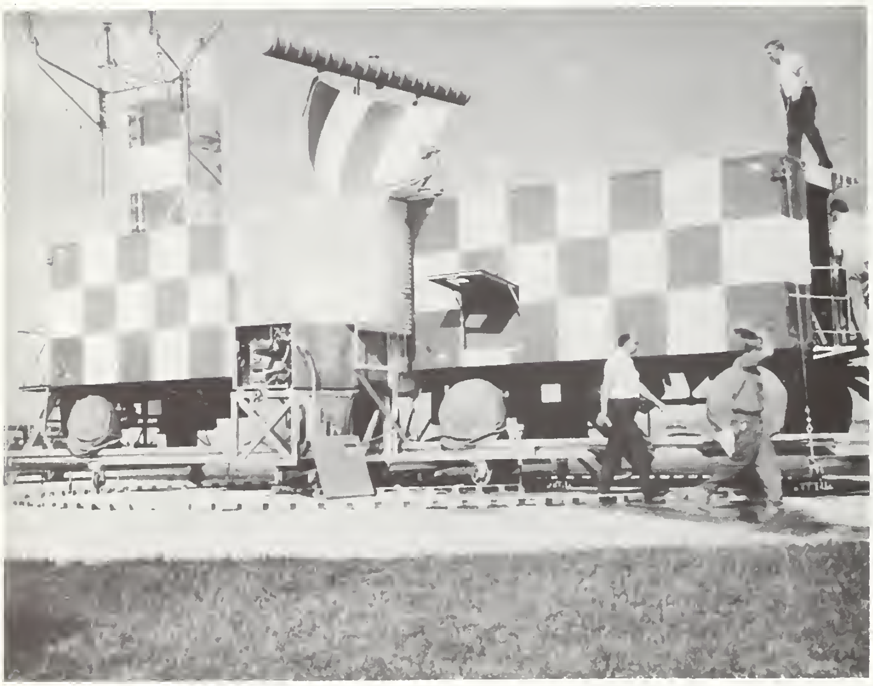
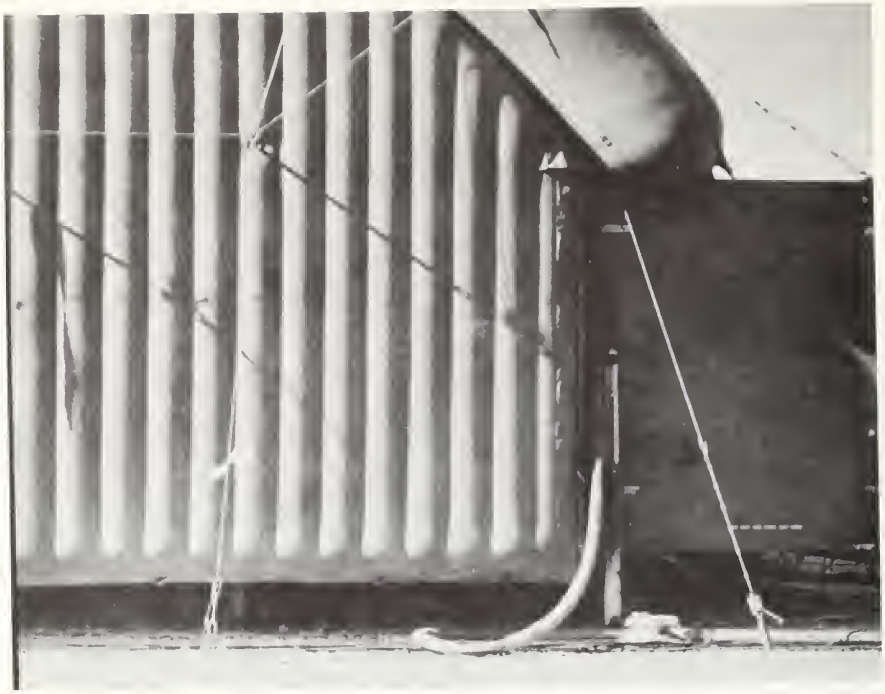


Fig. 2.9 Special Purpose Trailer Unit,
Electronic Equipment Shelters

Fig. 2.10 Electronic Shelters Equipped with Mobilizers



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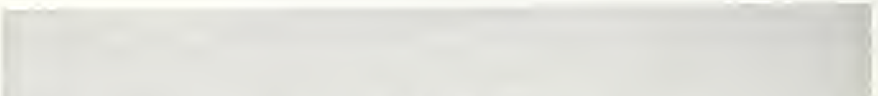


b

Fig. 2.11 Air-inflatable Command Center Complex

Fig. 2.12 MUST Hospital Unit

Fig. 2.13 MUST Ward Container

Fig. 2.14 MUST Expandable Shelter

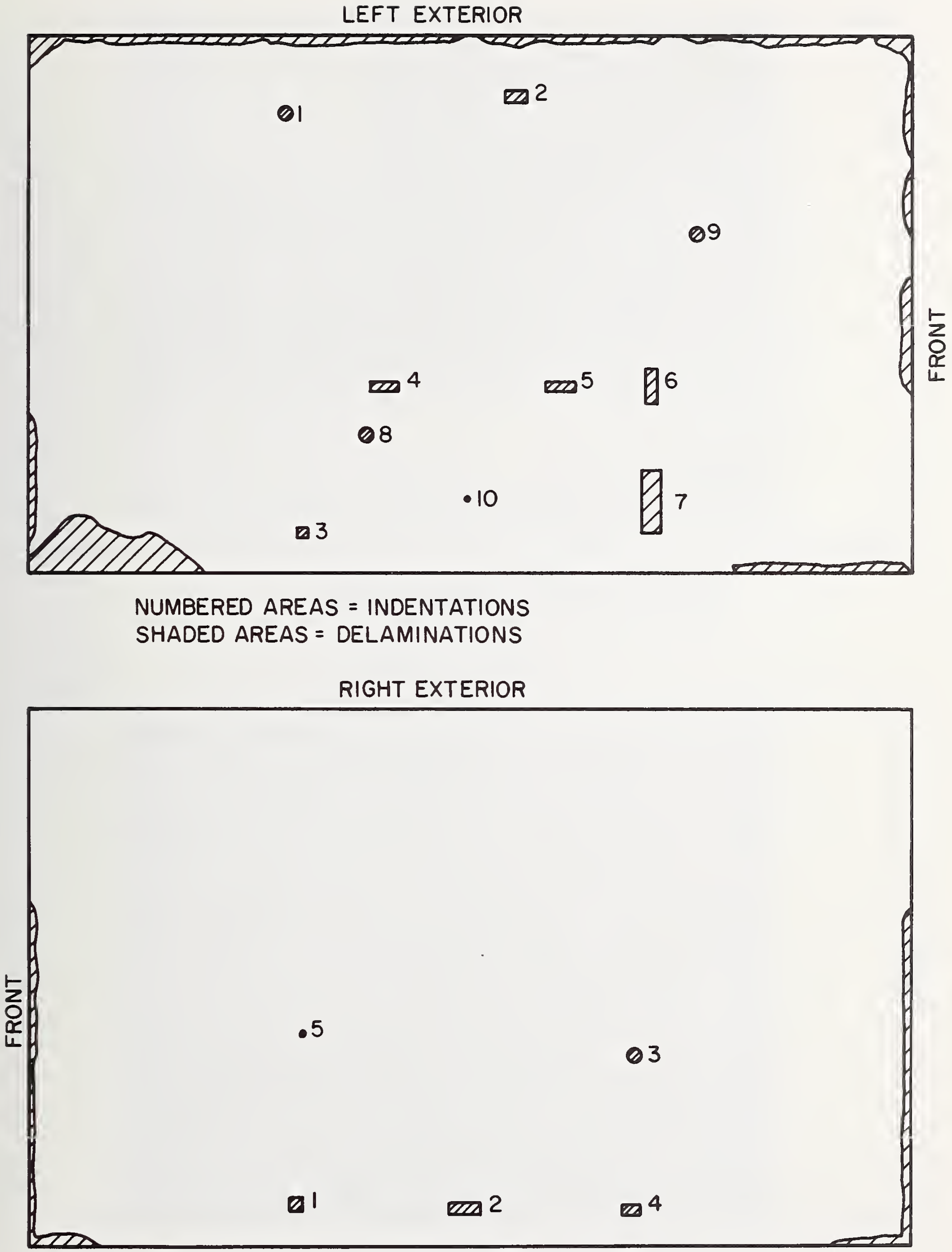
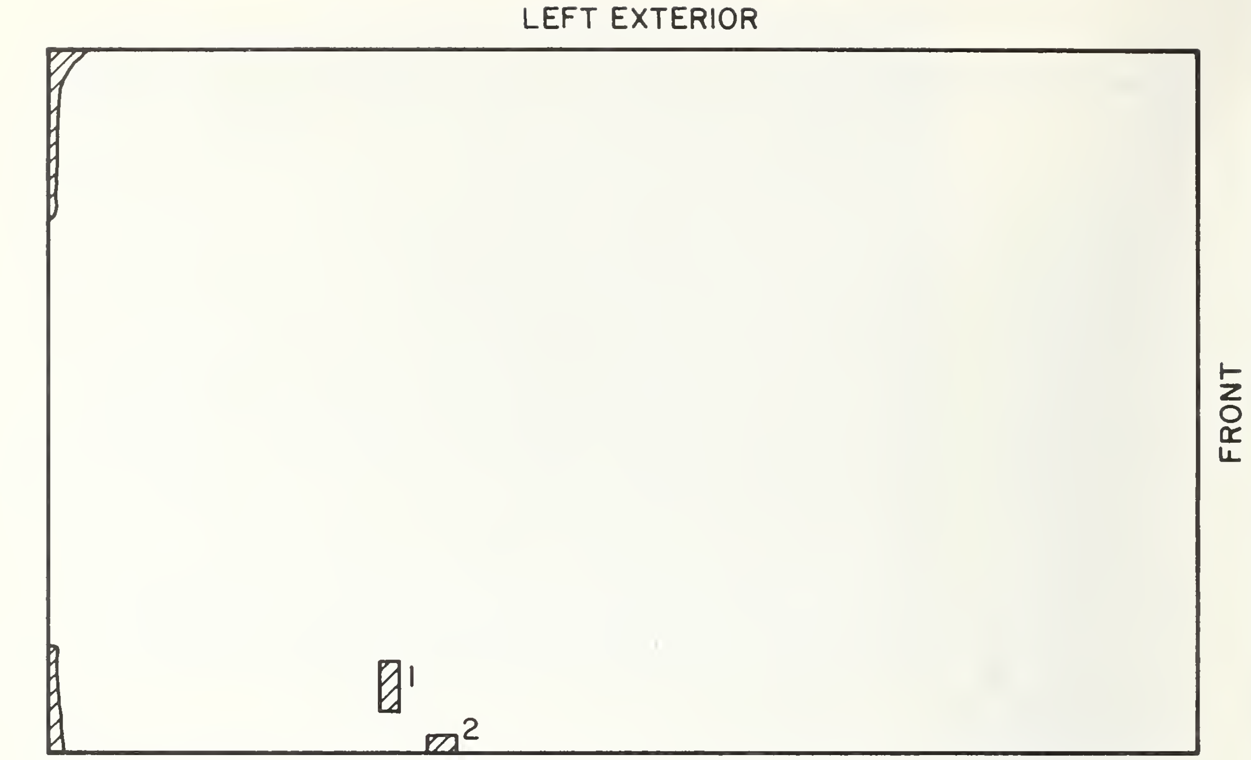


Fig. 2.15 Indentations and Delaminations, EXP Shelter 285



NUMBERED AREAS = INDENTATIONS
SHADED AREAS = DELAMINATIONS

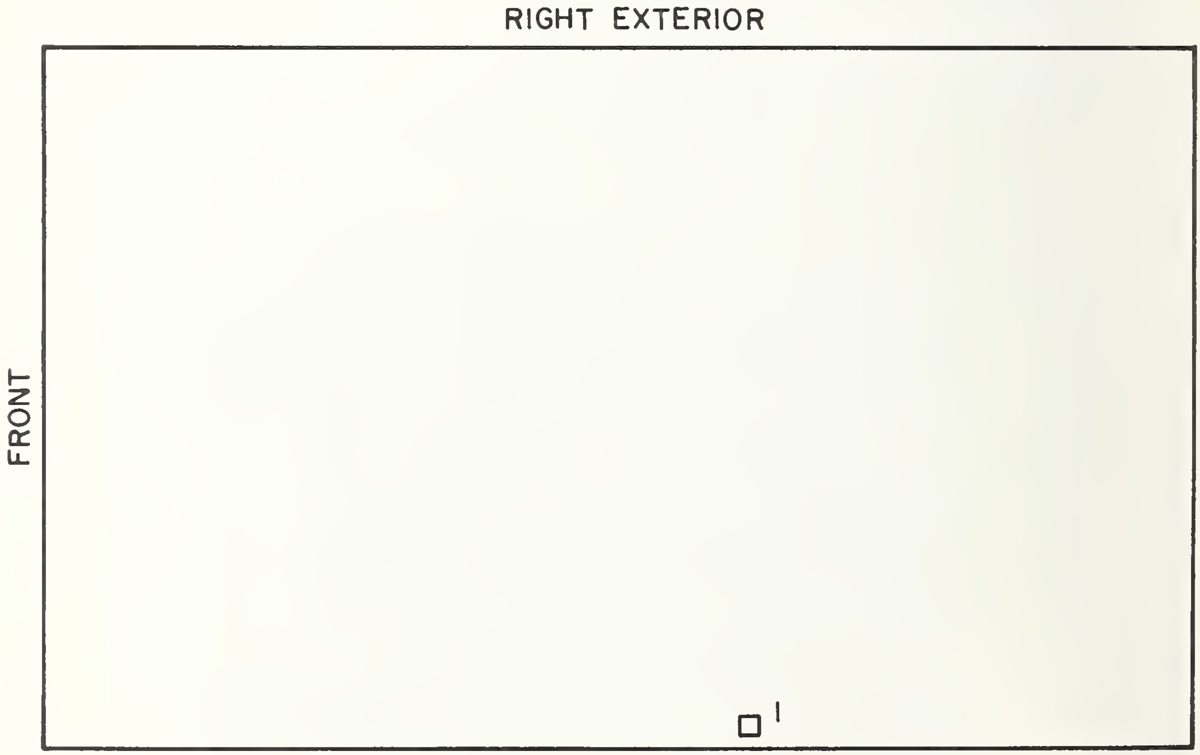


Fig. 2.16 Indentations and Delaminations, EXP Shelter 267

Fig. 2.17 Lift Truck Fork Damage

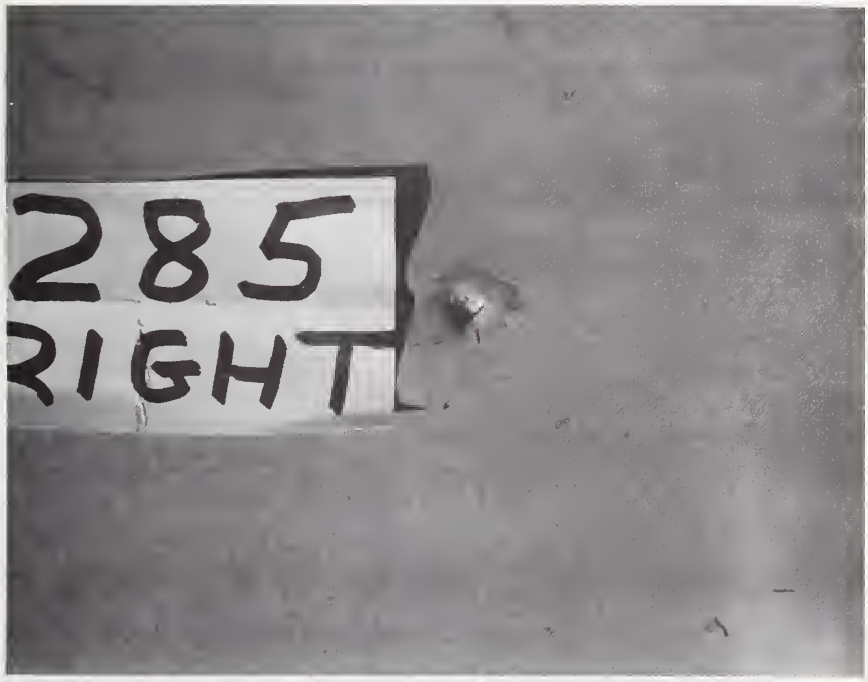


Fig. 2.18 Puncture Damage, Floor Panel of EXP

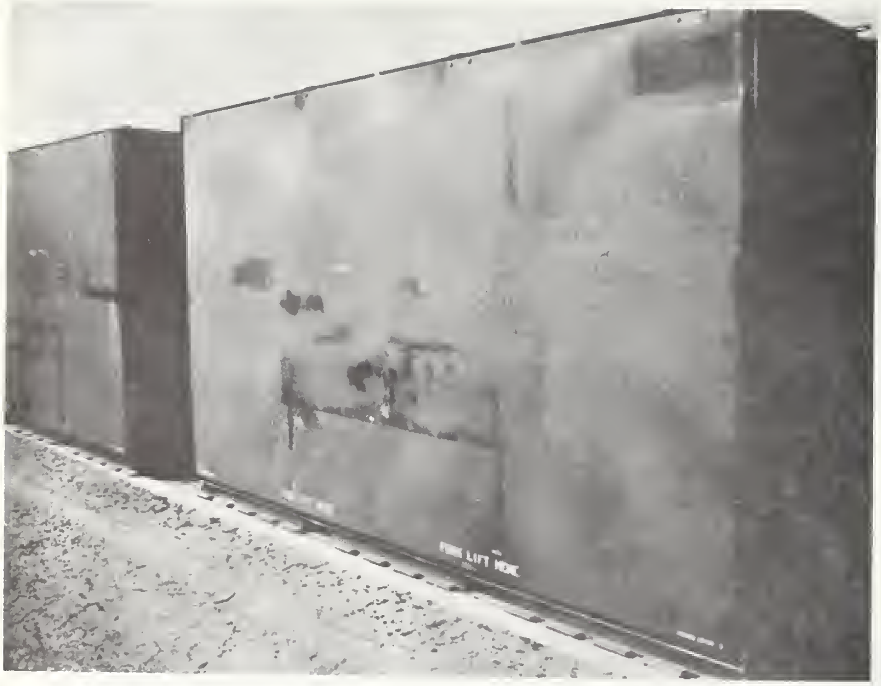


Fig. 2.19 Extensive Delamination of Interior Floor Panel of Stored EXP

Fig. 2.20 Water Leakage at Mid-span Seam of Interior Floor Panel, EXP 285

Fig. 2.21 Brown Leakage Stain Emanating from Mid-plane Joint of EXP

Fig. 2.22 Leakage Stain at Mid-plane Joint Near Edge of EXP

Fig. 2.23 Visible Water Leakage at Puncture in Facing of EXP

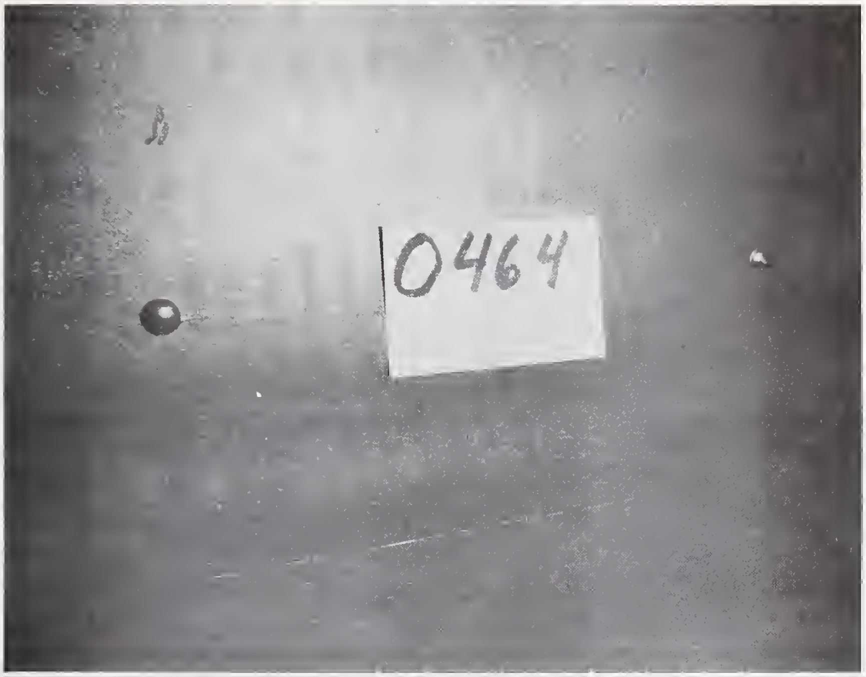


Fig. 2.24 Blisters in Floor Covering Material
- New EXP

Fig. 2.25 Discoloration on Interior Wall Panels
- New EXP

Fig. 2.28 Bulging of Foam and Beam Floor Panels - Newer ESC

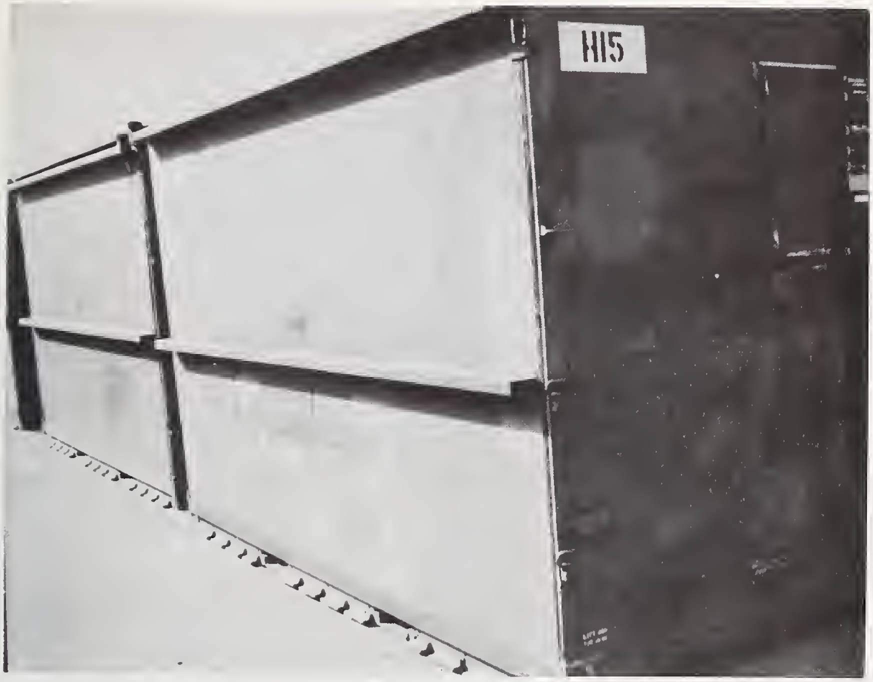


Fig. 2.26 Delaminations in Fold-down Floor Panel - Old ESC

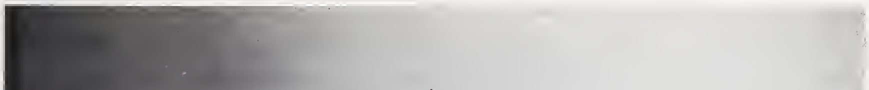


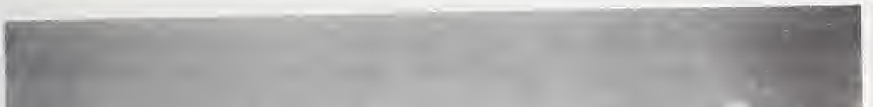
Fig. 2.27 Repair Being Made at Fork-lift Damage Point

a

b

Fig. 2.29 Bulging of Interior Facing on Foam and Beam Floor Panels - Newer ESC

a



b

Fig. 2.30 Paint Deposits on Roof Panel of Newer ESC

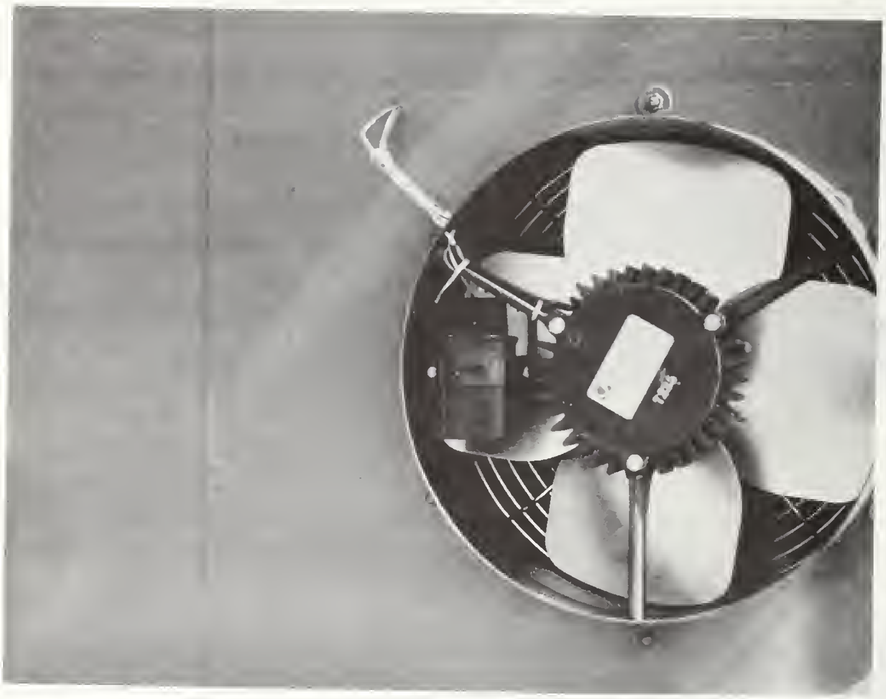
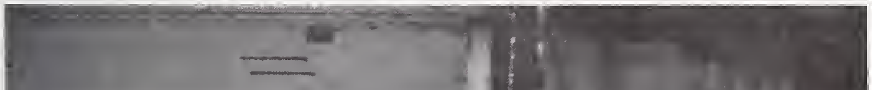


Fig. 2.31 Exhaust Fan Unit - New ES/C

a



b

Fig. 2.32 Delamination of Honeycomb Panels
- MUST Shelters

Fig. 2.33 Puncture in Floor Panel of MUST Shelter

Fig. 2.34 Jacking Bracket Failure of MUST Shelter

a

b

Fig. 2.35 Roof Support Bracket Failure of MUST Shelters

Fig. 2.36(a) Jacking Bracket "Fix" for MUST Shelter

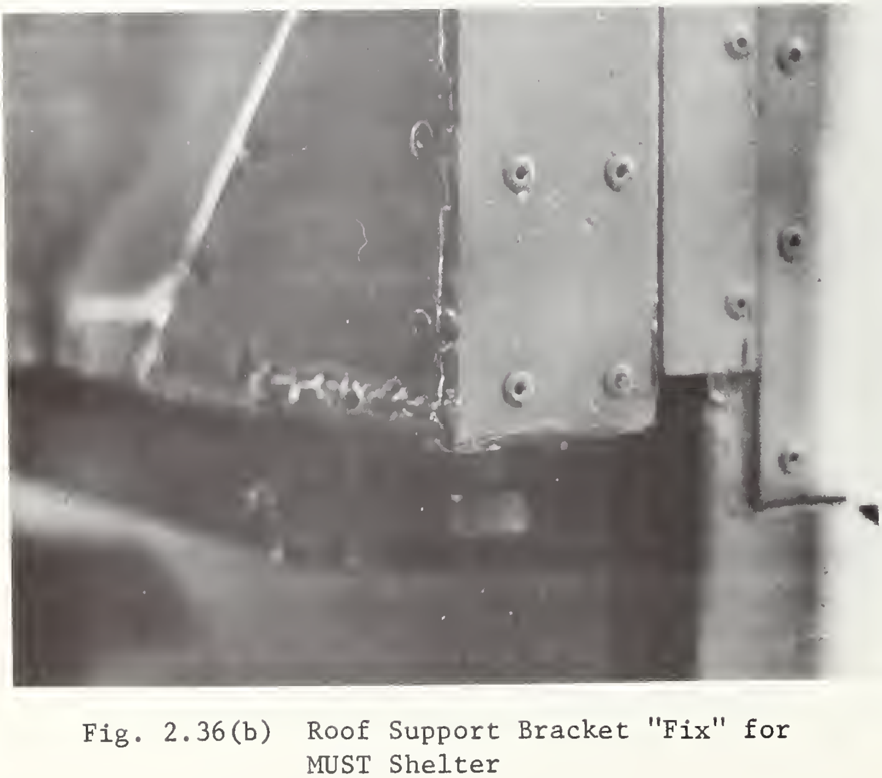
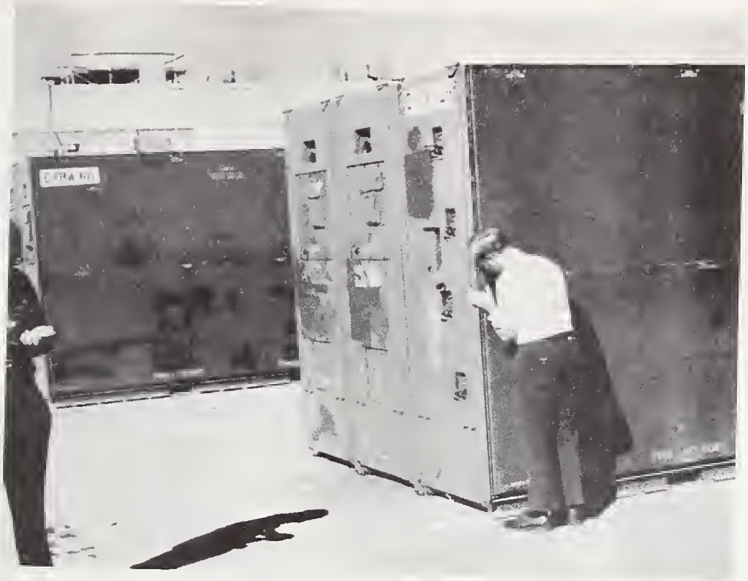
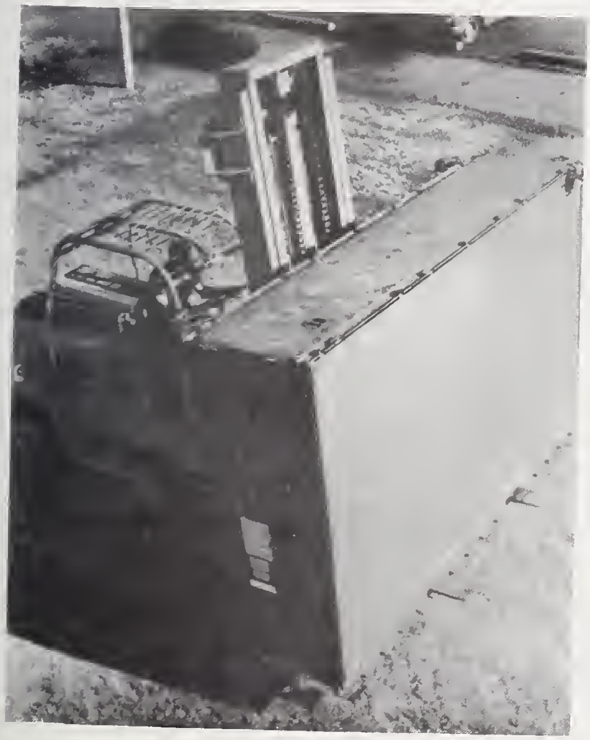


Fig. 2.36(b) Roof Support Bracket "Fix" for MUST Shelter



a



b

c

Fig. 3.1 EXP, Expandable Personnel Shelter

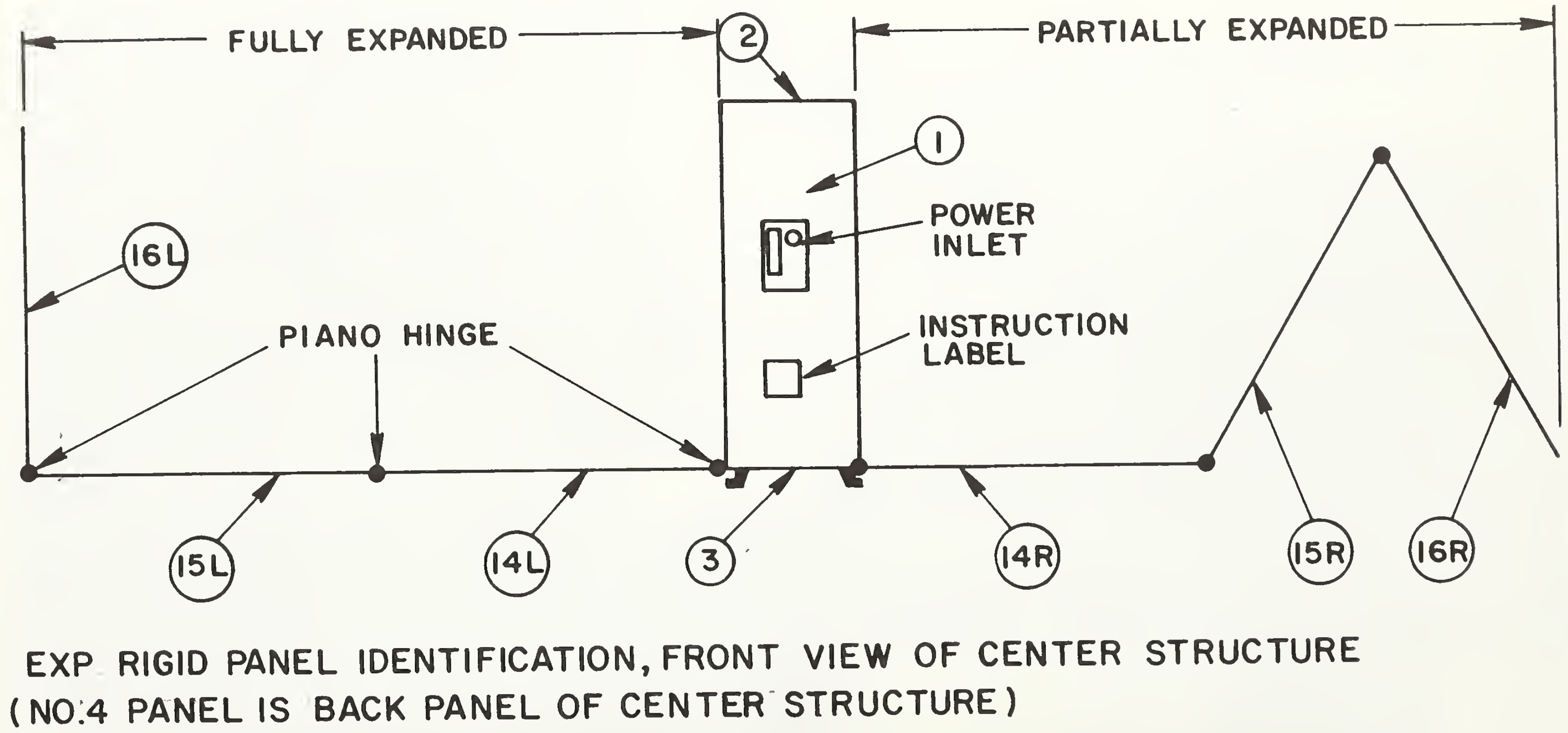
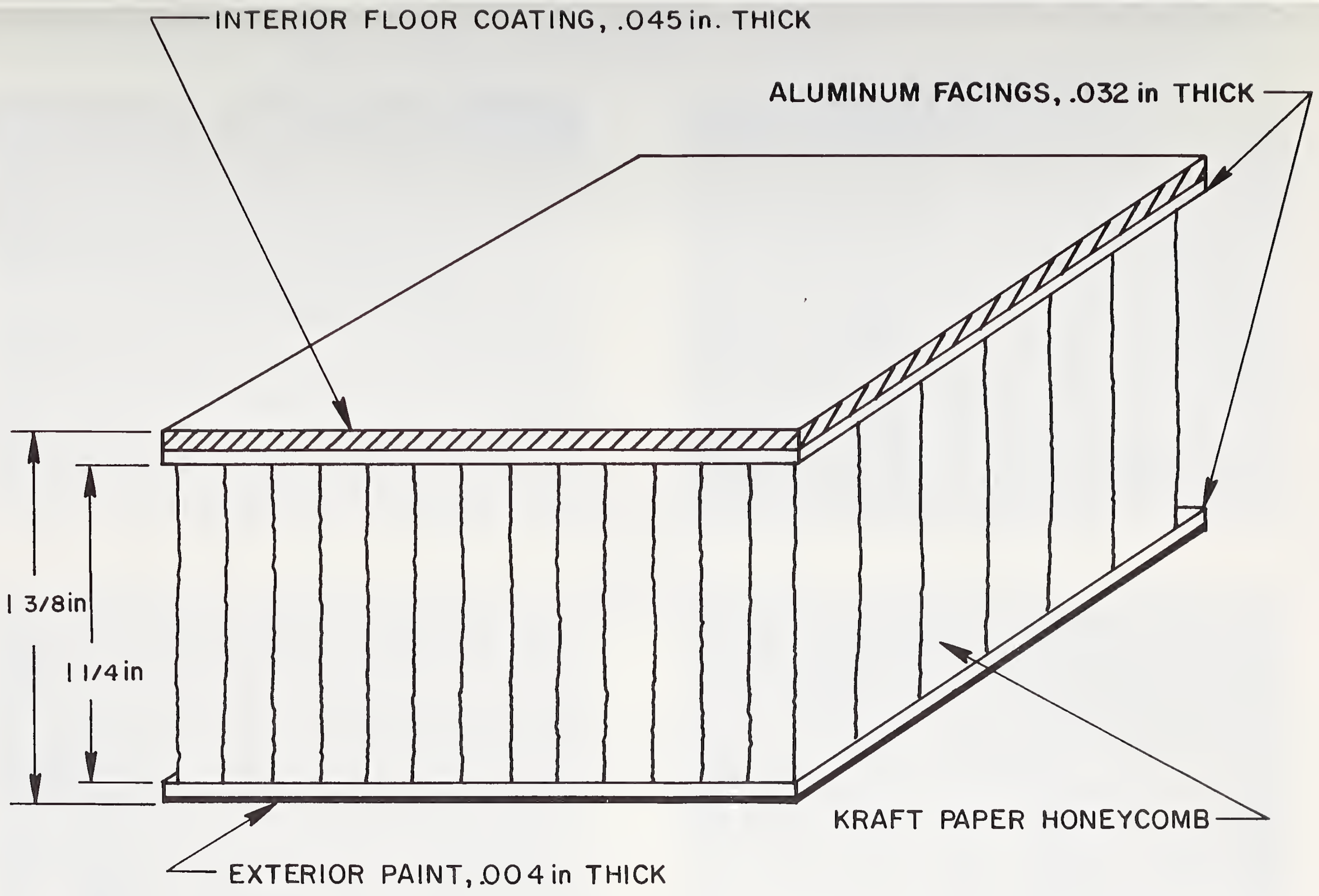
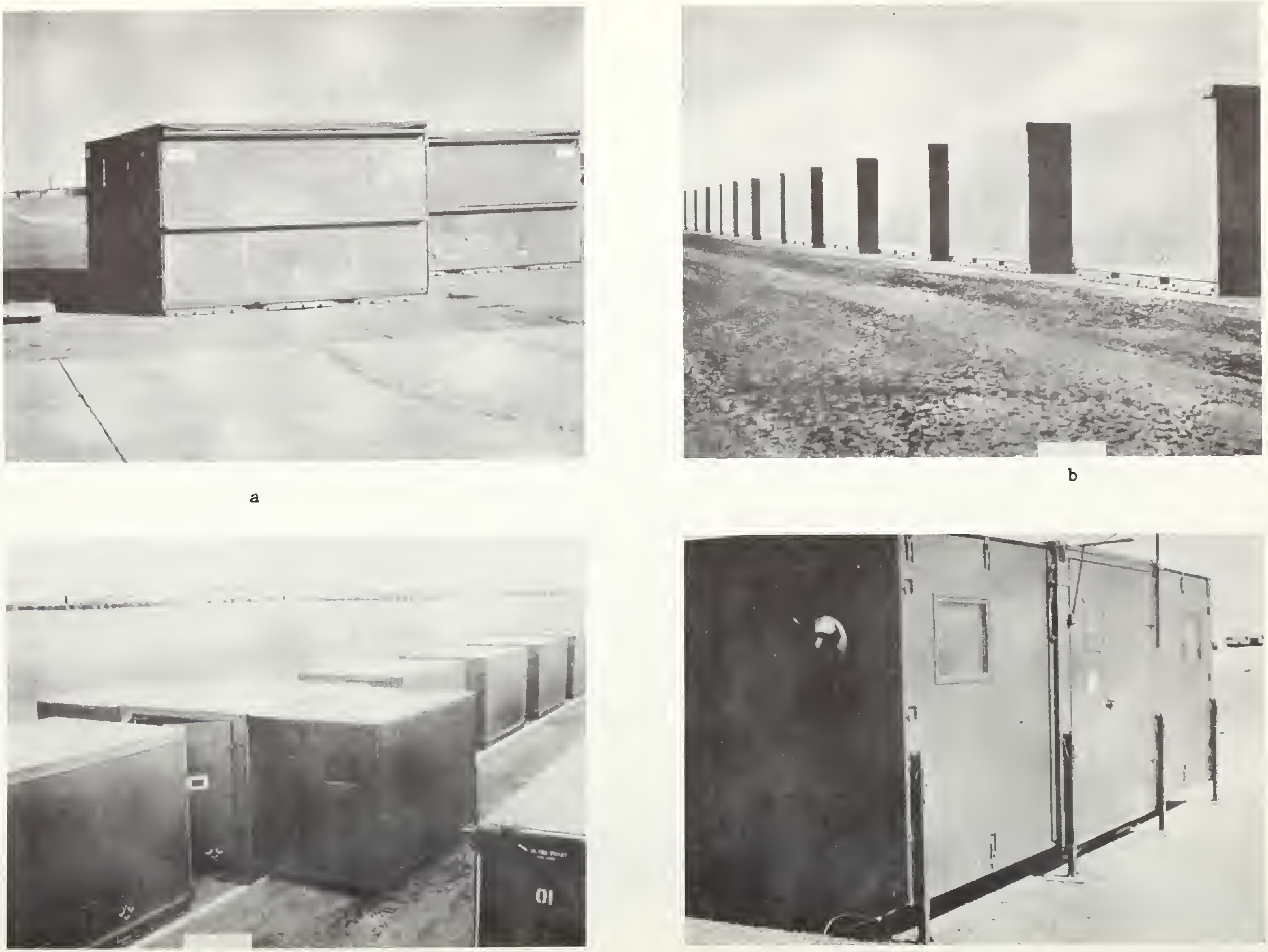


Fig. 3.2 Schematic of EXP shelter with identification of individual panels



EXP FLOOR PANEL CONSTRUCTION

Fig. 3.3 Section through EXP floor panel



a b c d

Fig. 3.4 ES/C, Expandable Shelter/Container

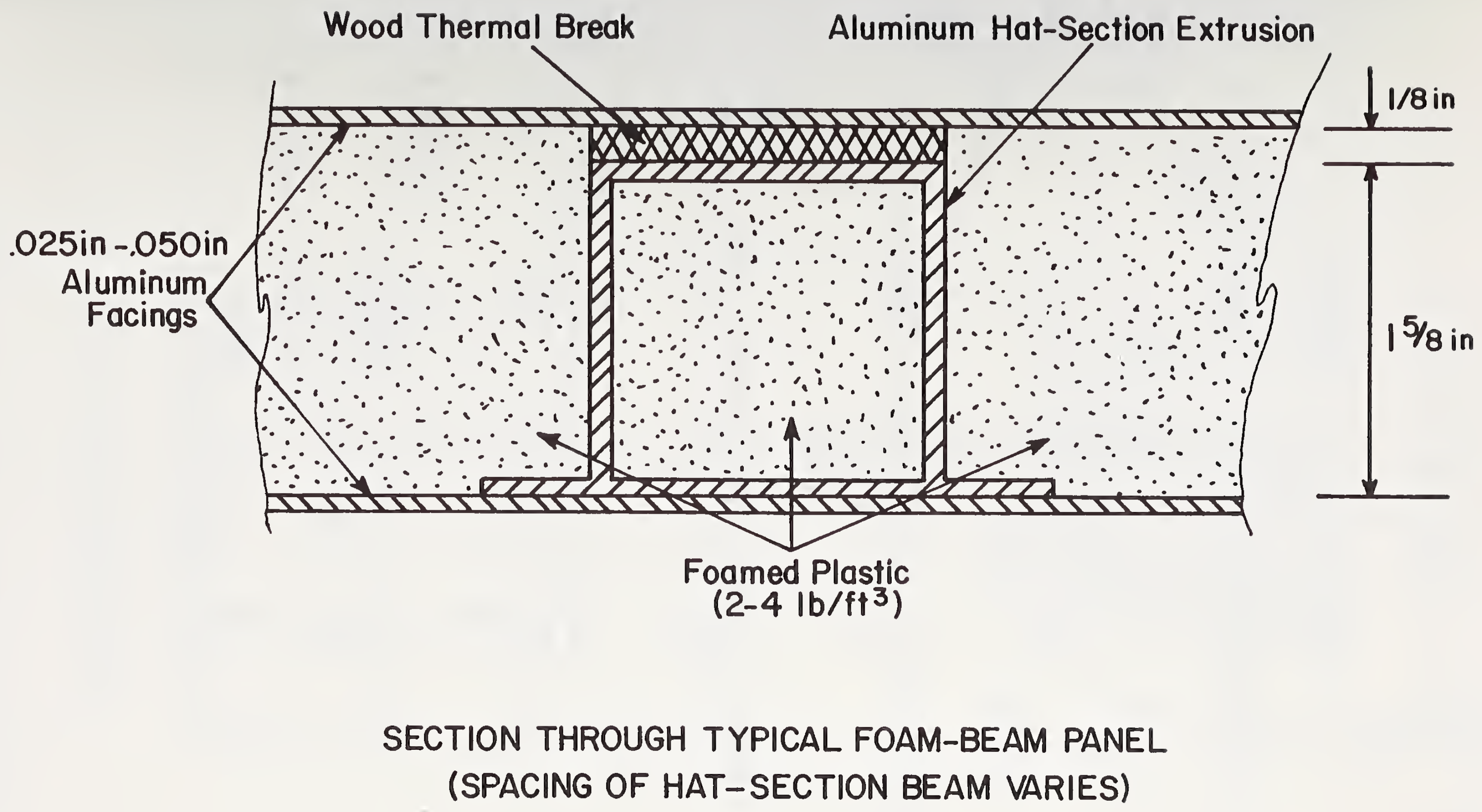
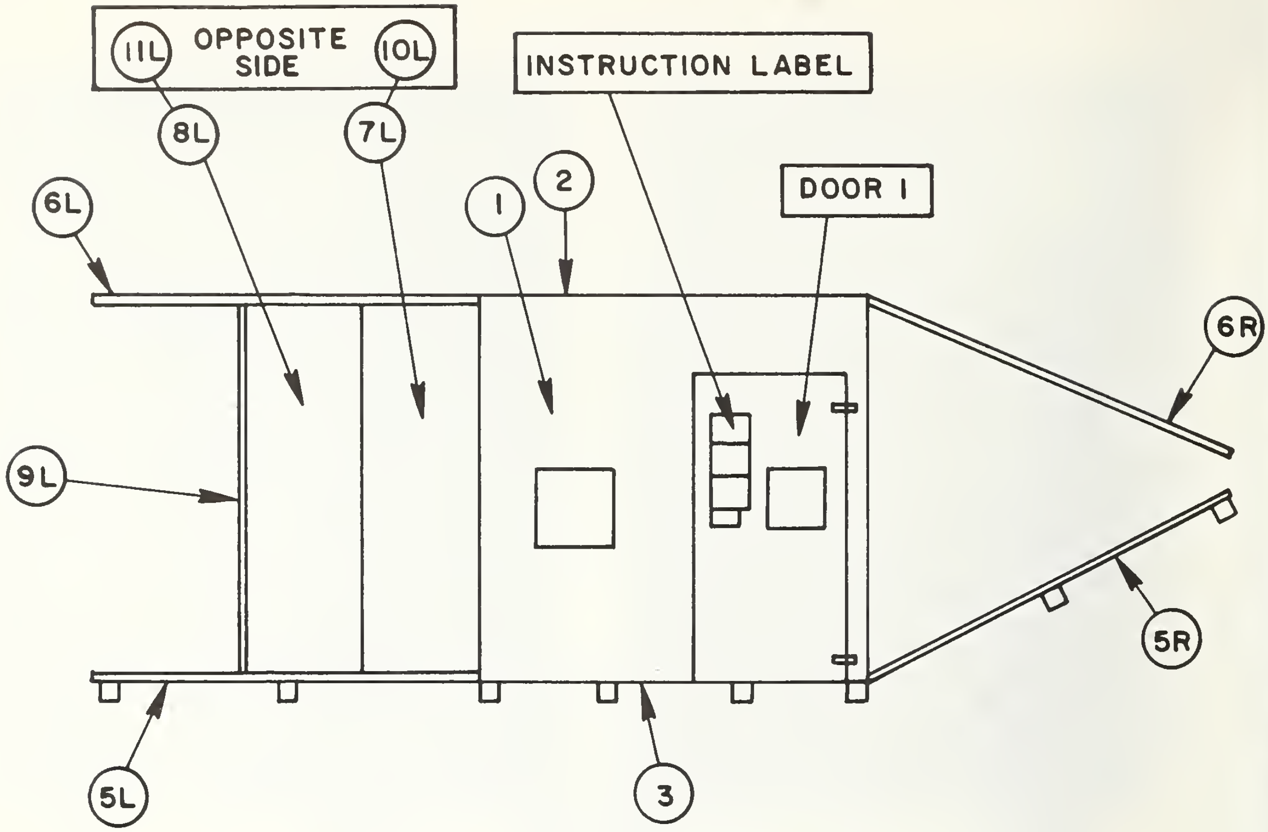
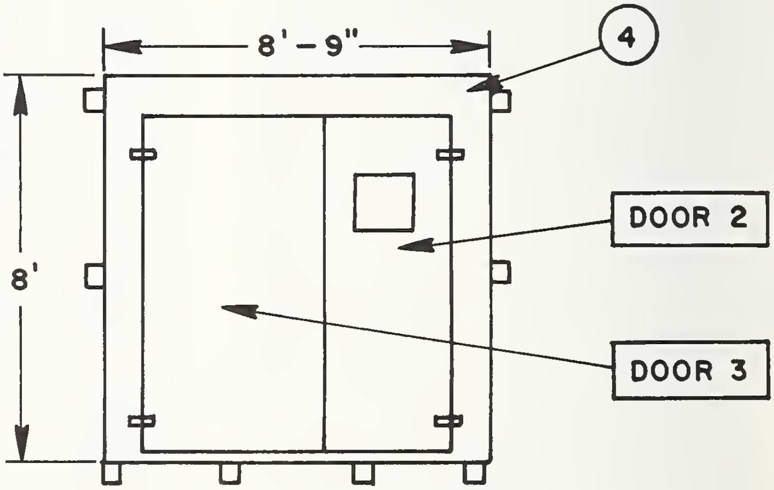


Fig. 3.5 Section through ES/C panel



PARTIALLY EXPANDED, FRONT VIEW



UNEXPANDED, REAR VIEW

Fig. 3.6 Schematic of ES/C shelter with identification of individual panels

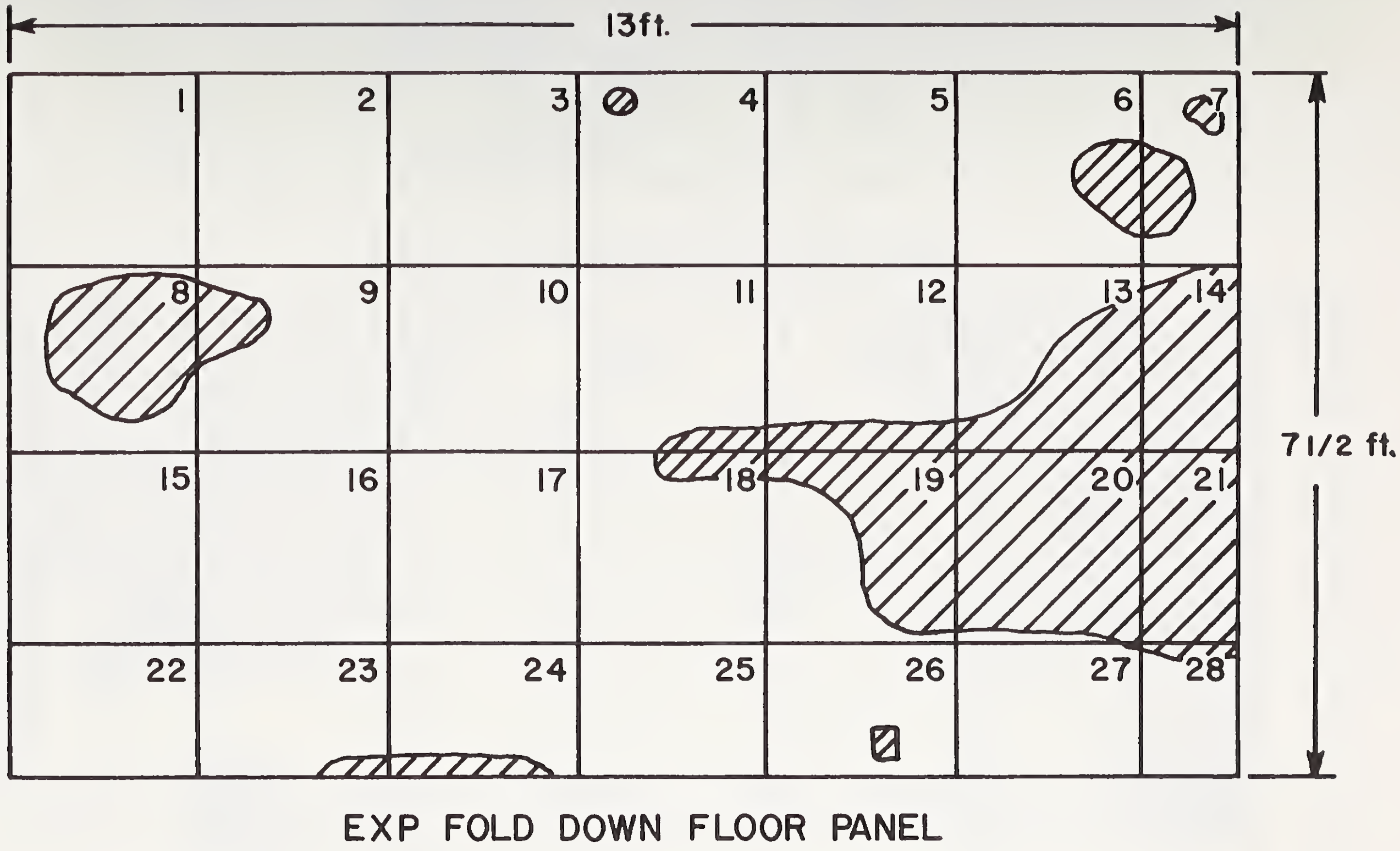


Fig. 3.7 Delaminations of exterior facing on EXP Panel 14 R

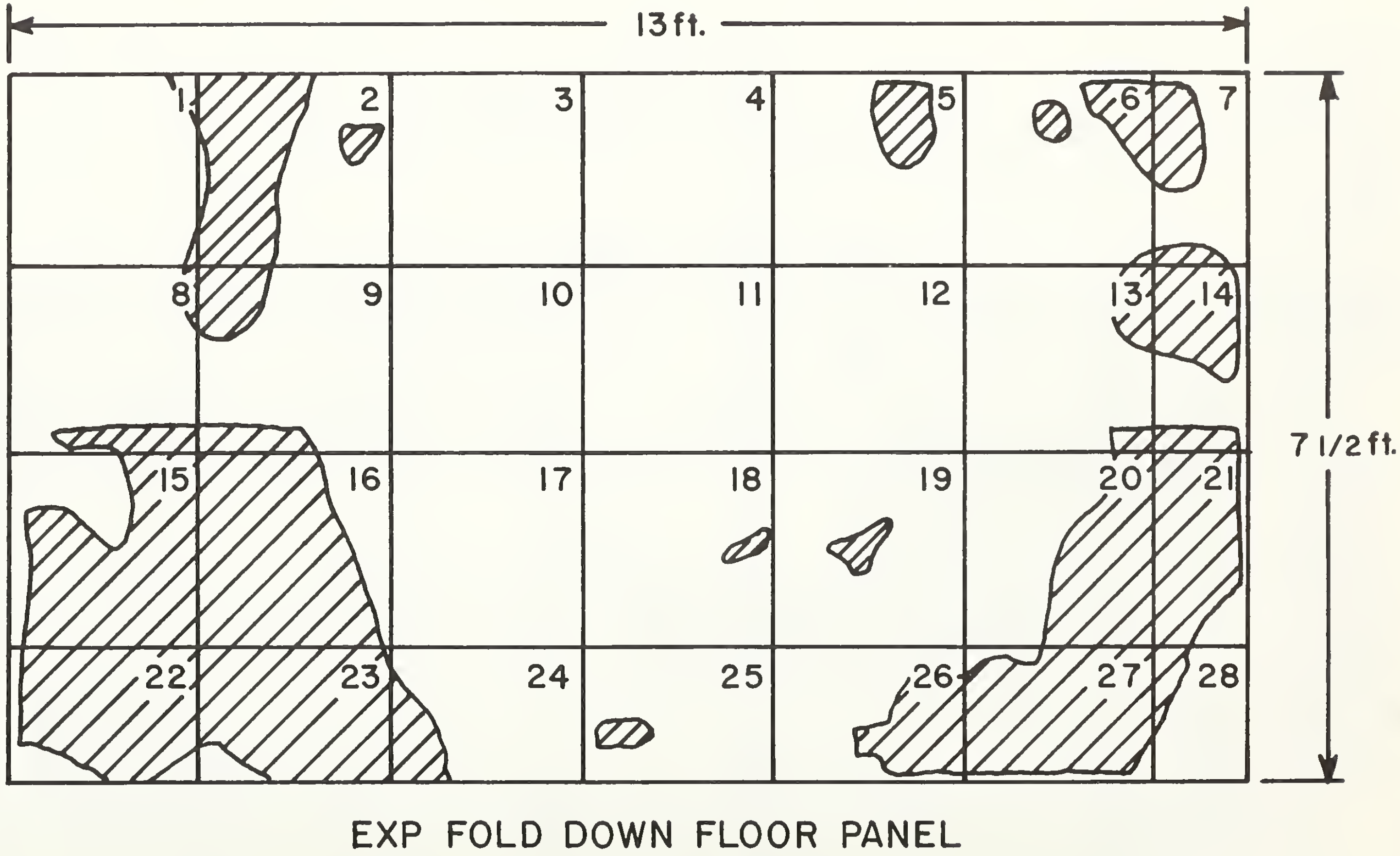


Fig. 3.8 Delaminations of exterior facing
on EXP Panel 14 L

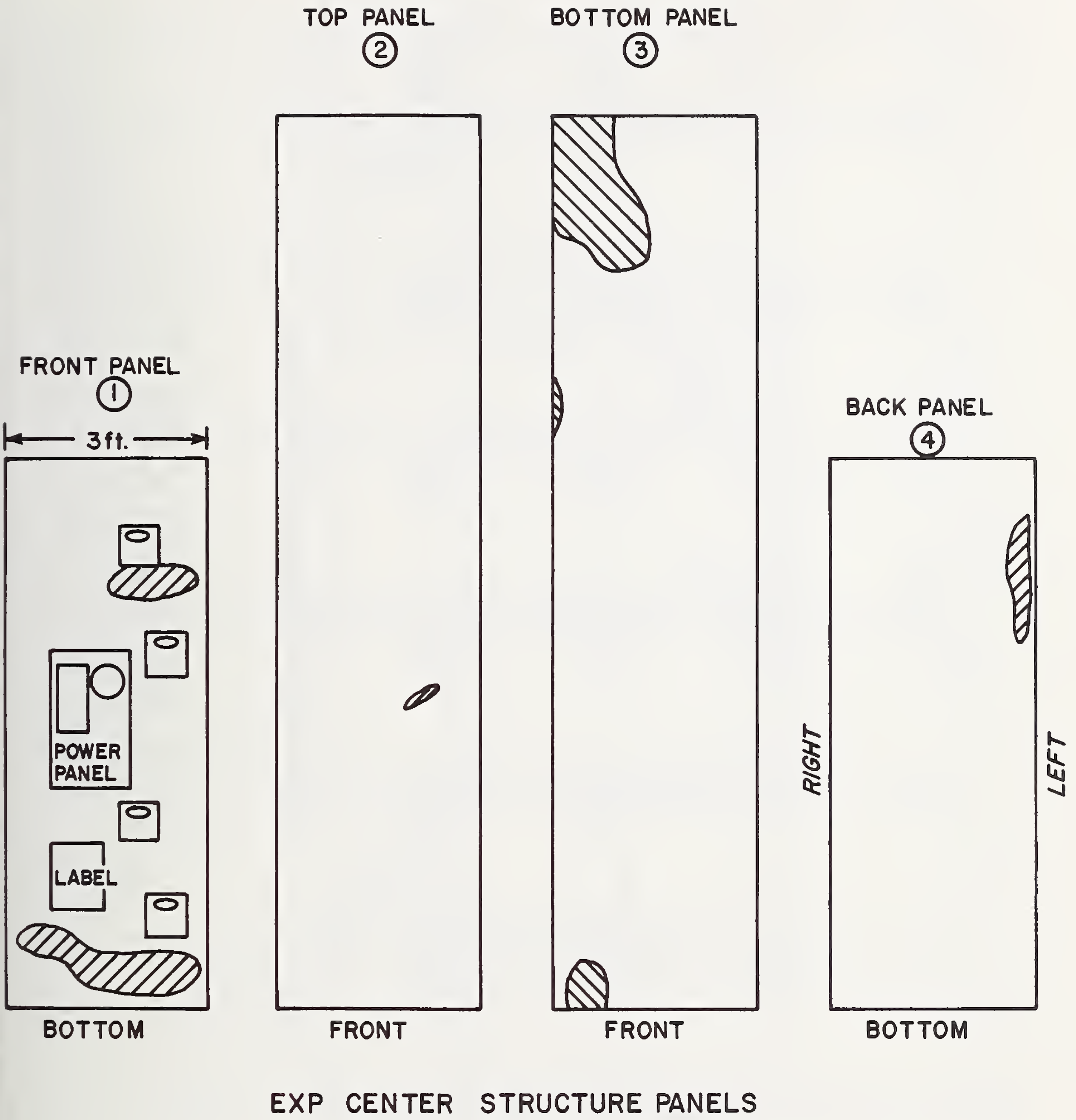


Fig. 3.9 Delaminations of exterior facings on EXP center-structure panels

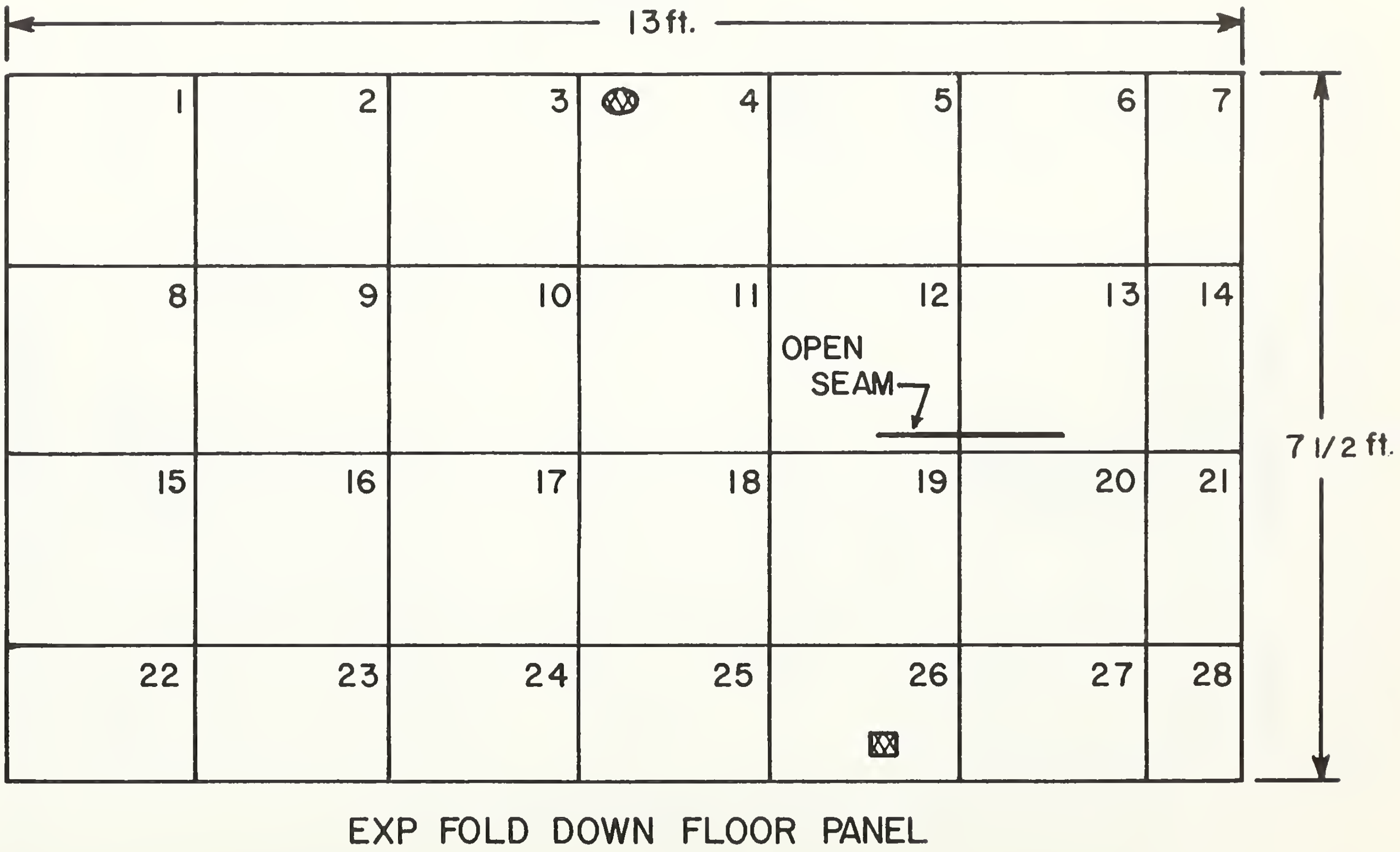


Fig. 3.10 Indentations and damaged areas on exterior of EXP Panel 14 R

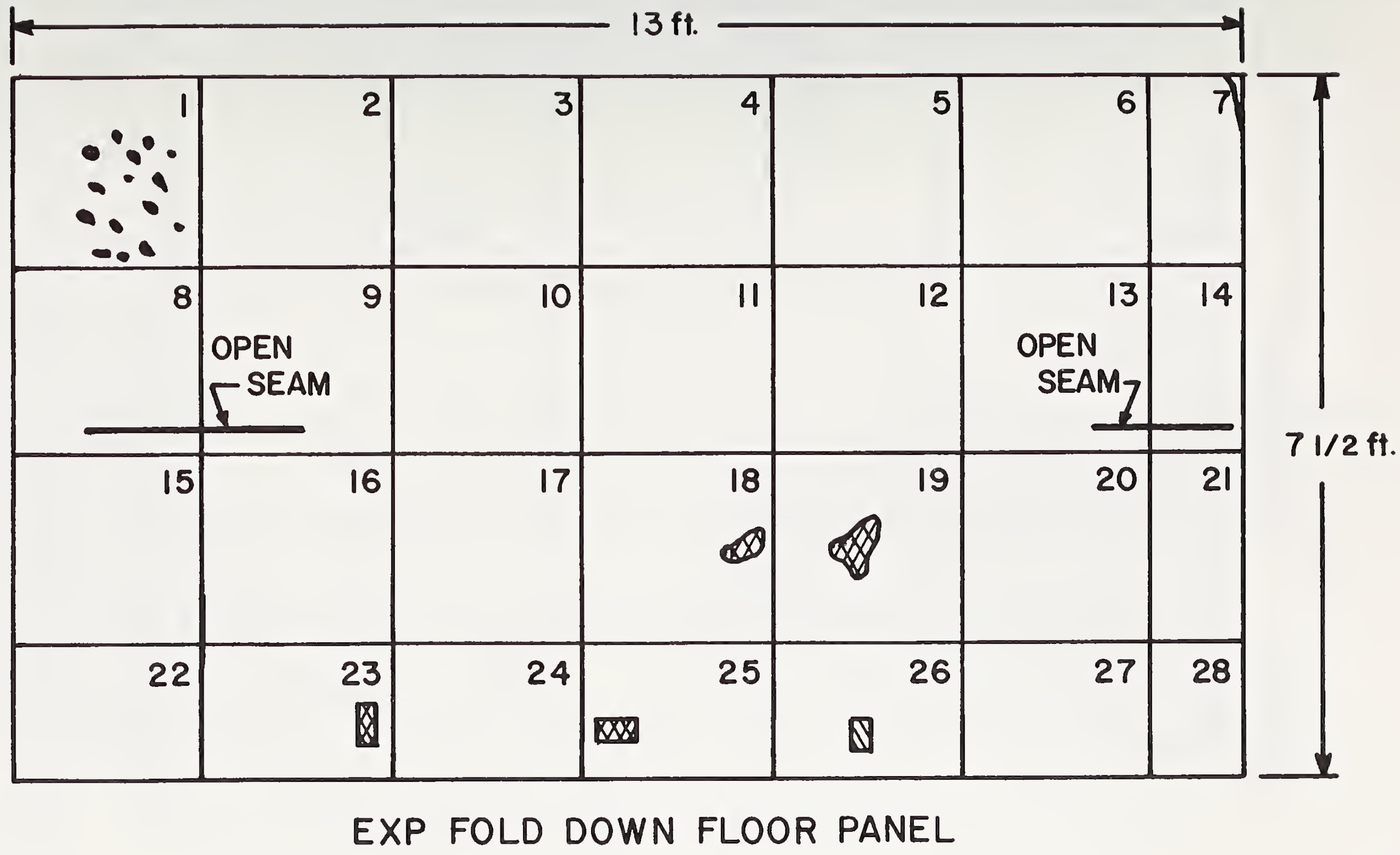


Fig. 3.11 Indentations and damaged areas on exterior of EXP Panel 14 L

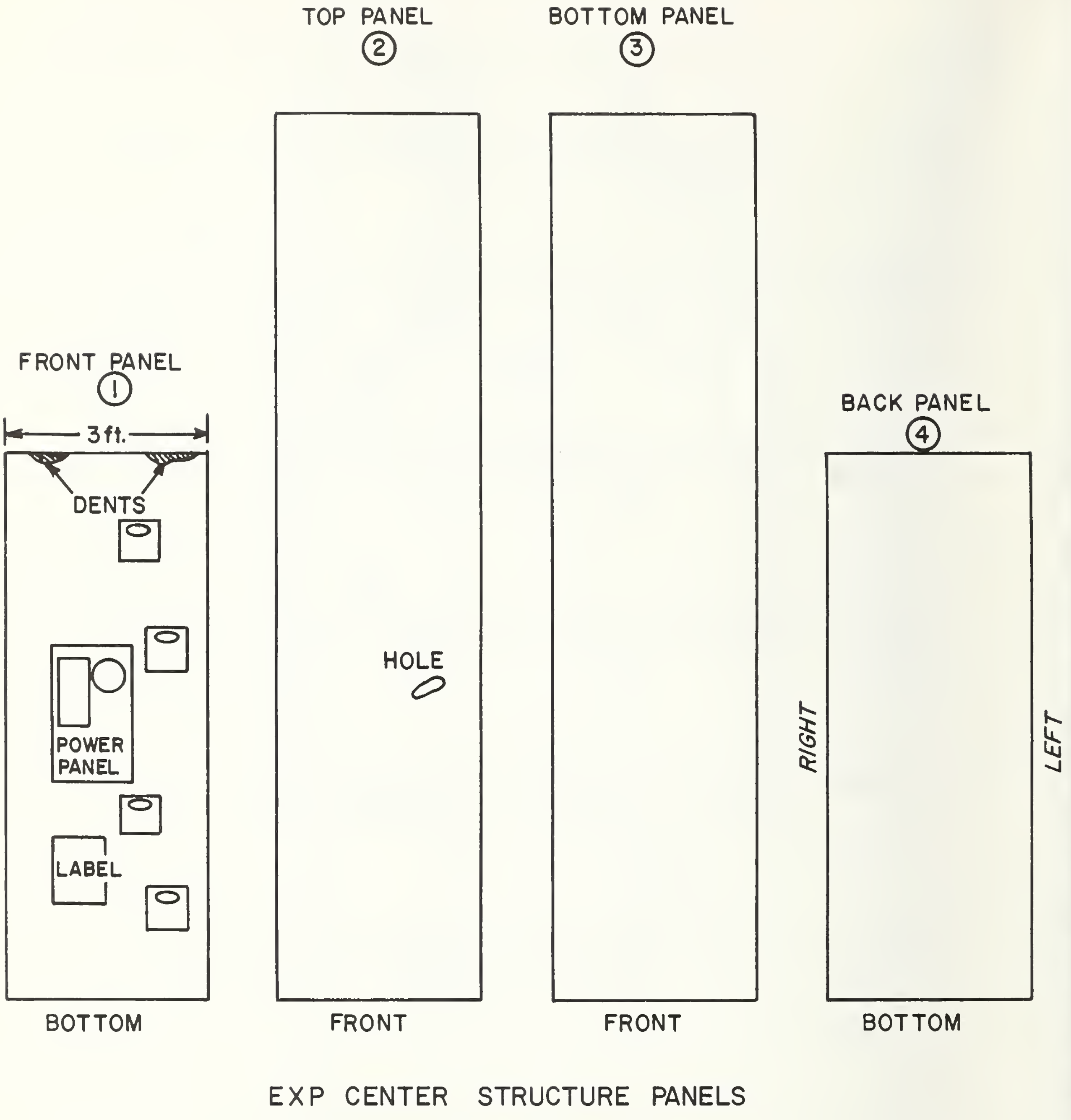
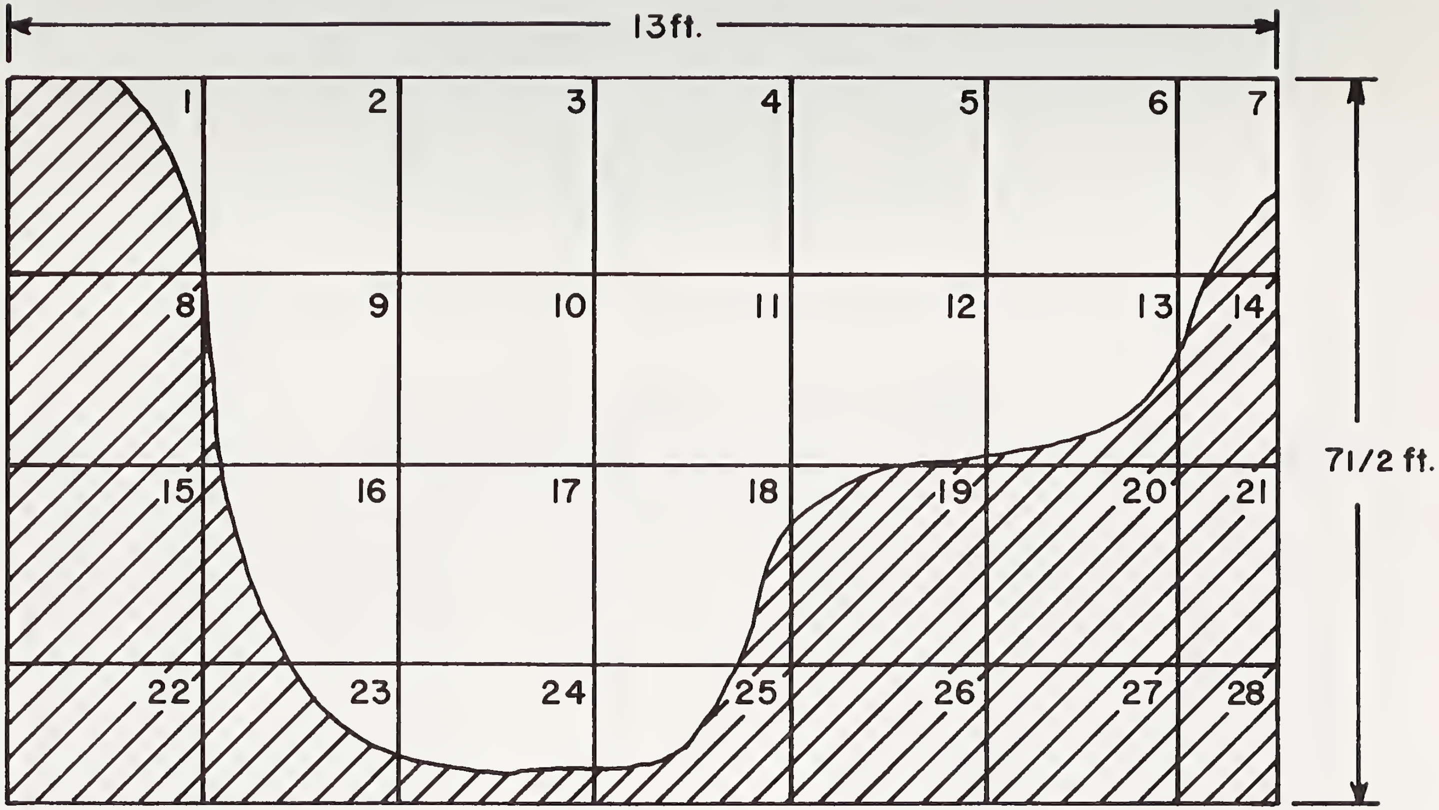


Fig. 3.12 Indentations and damaged areas on exterior of EXP center-structure panels



EXP FOLD DOWN FLOOR PANEL

Fig. 3.13 Location of water found in core of EXP Panel 14 R

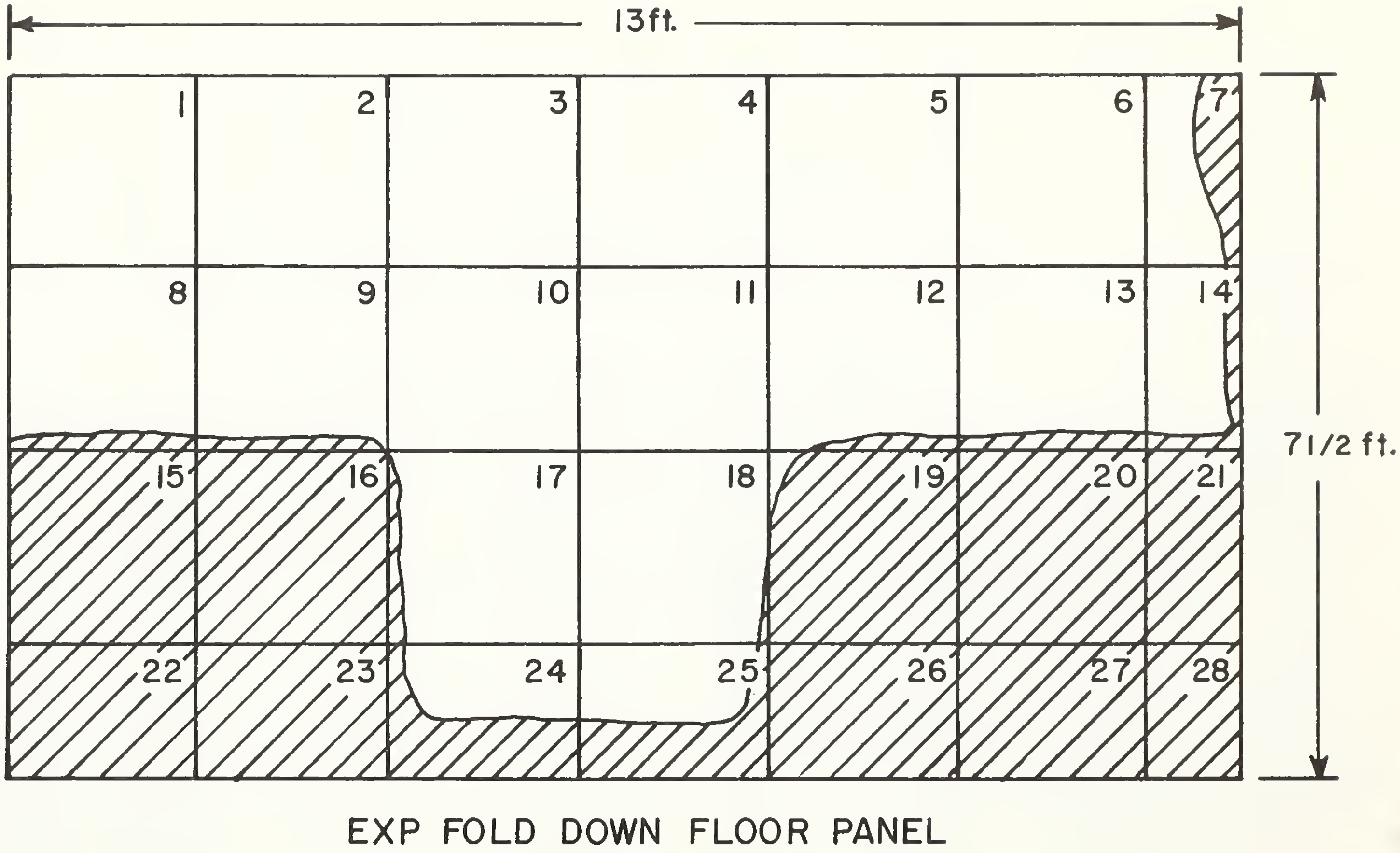


Fig. 3.14 Location of water found in core of EXP Panel 14 L

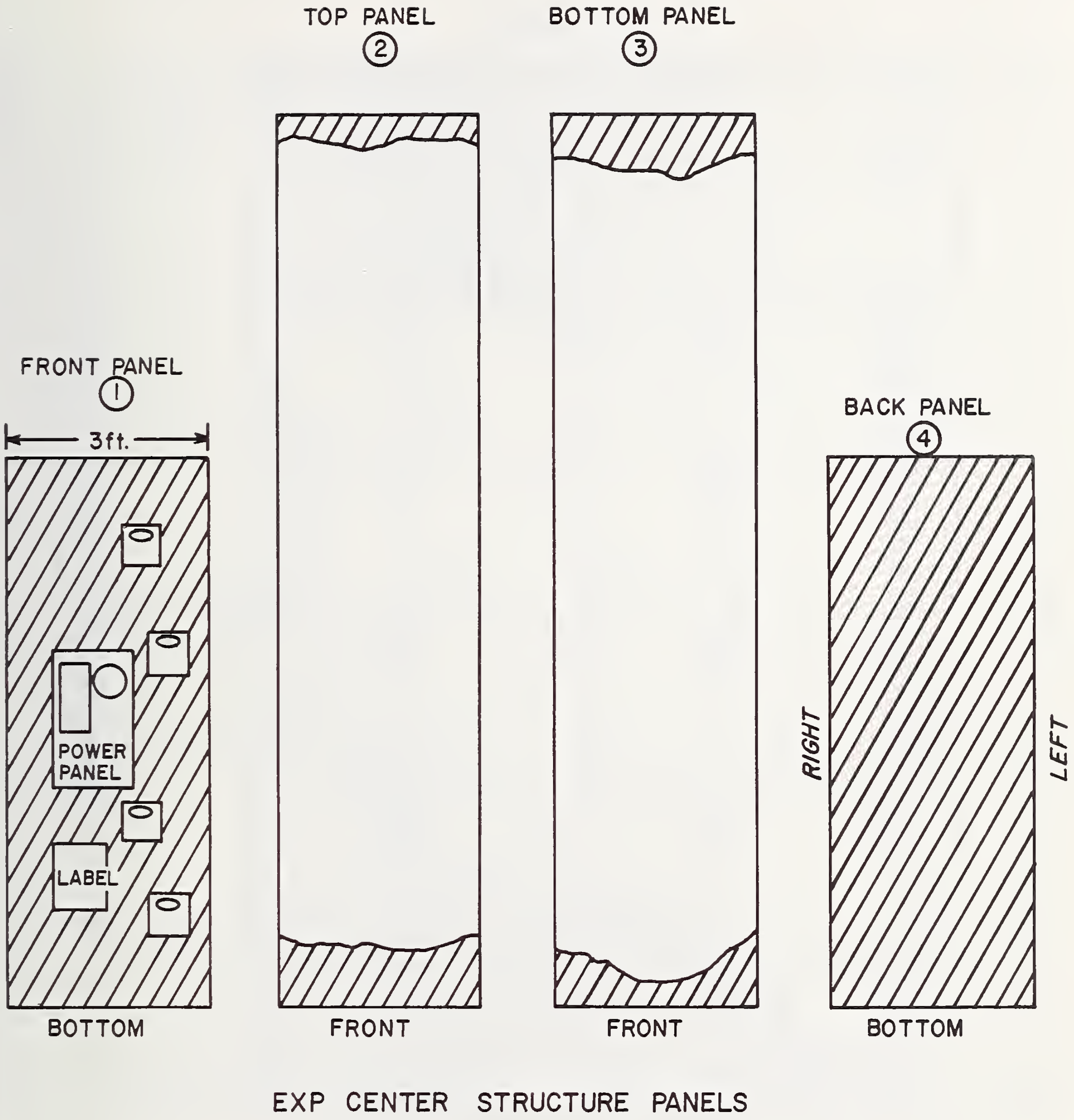


Fig. 3.15 Location of water found in core of EXP center-structure panels

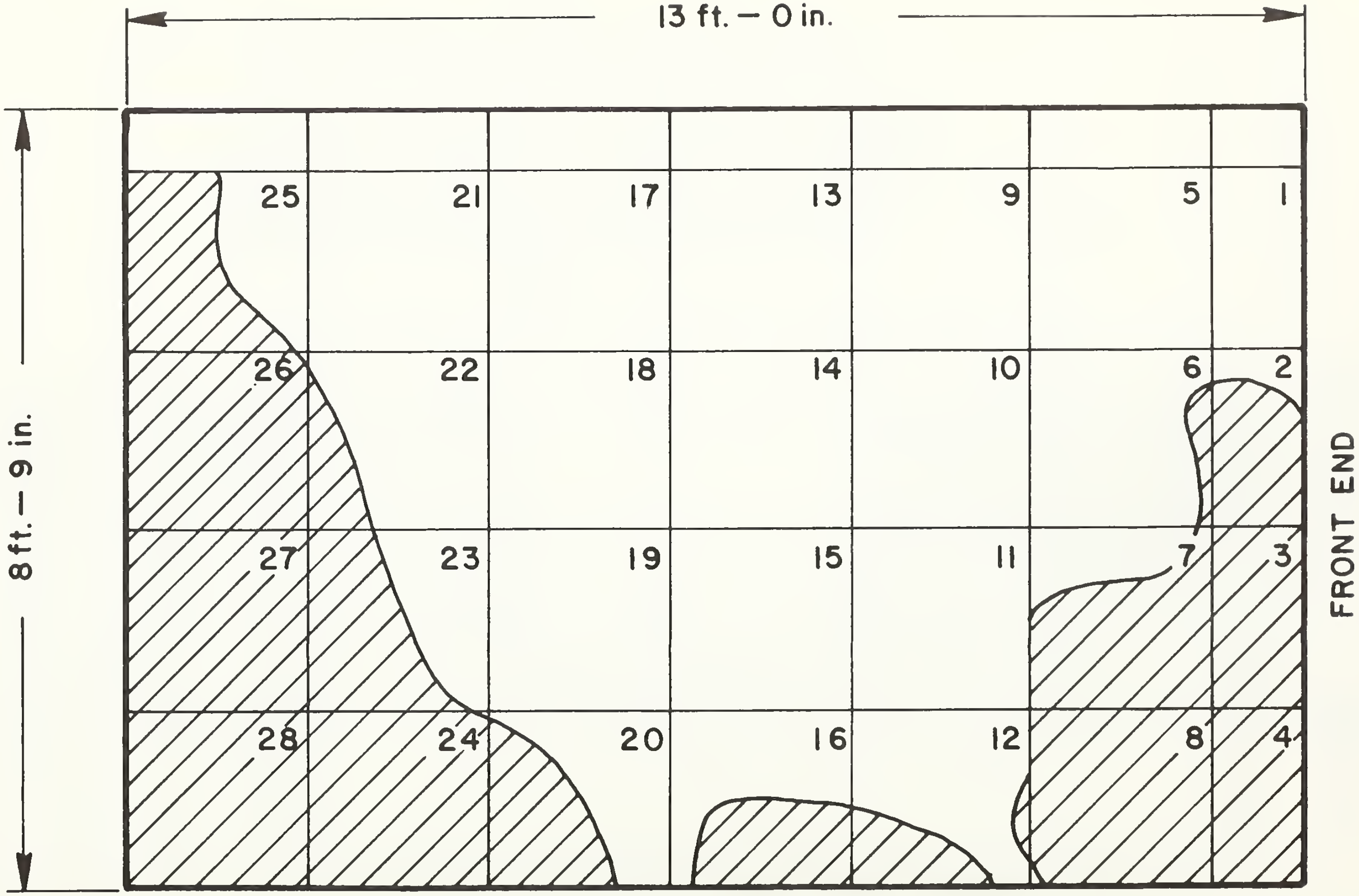


Fig. 3.16 Delaminations of interior facing on ES/C Panel 3 (Fixed floor panel)

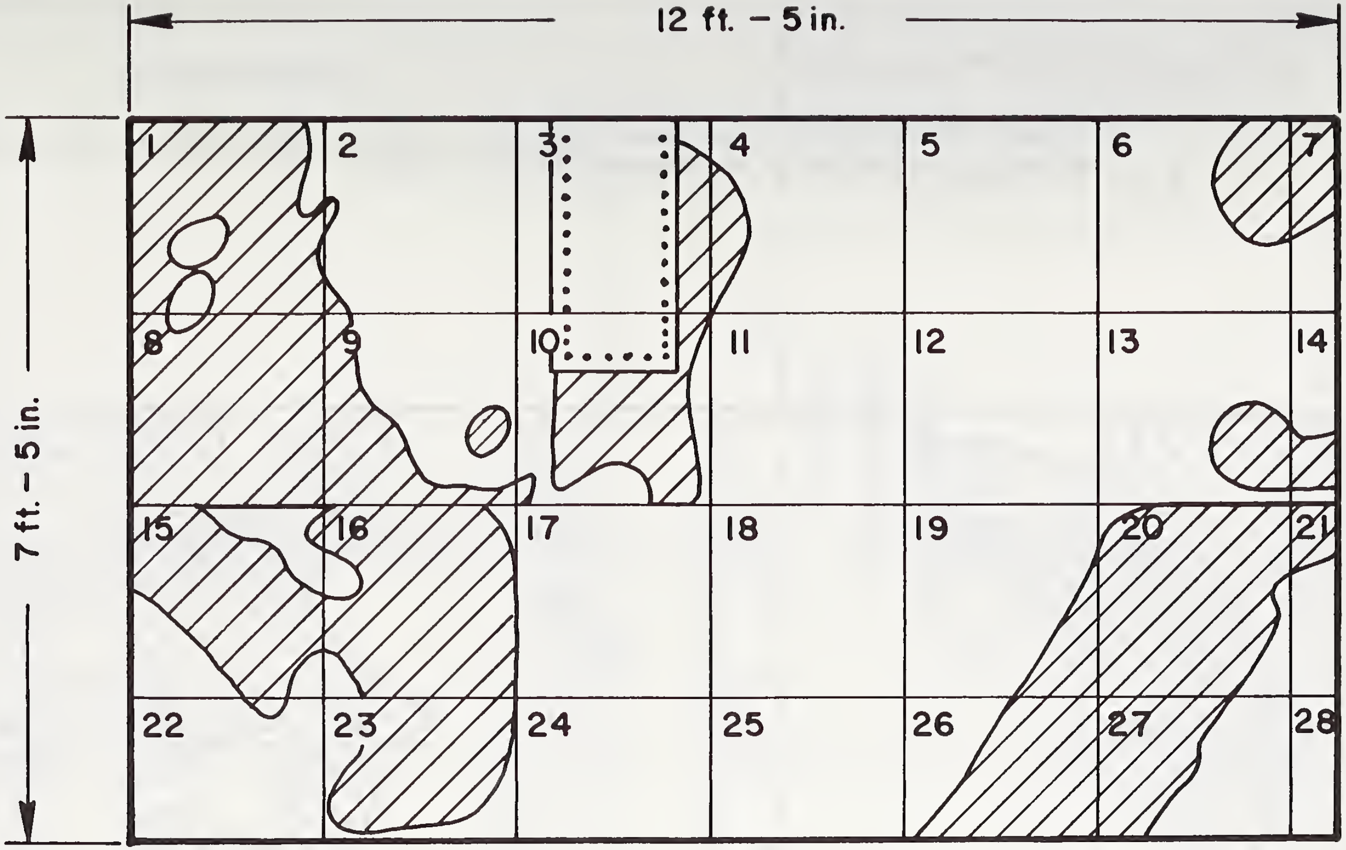


Fig. 3.17 Delaminations of exterior facing on ES/C Panel 5 R (Fold-down floor panel)

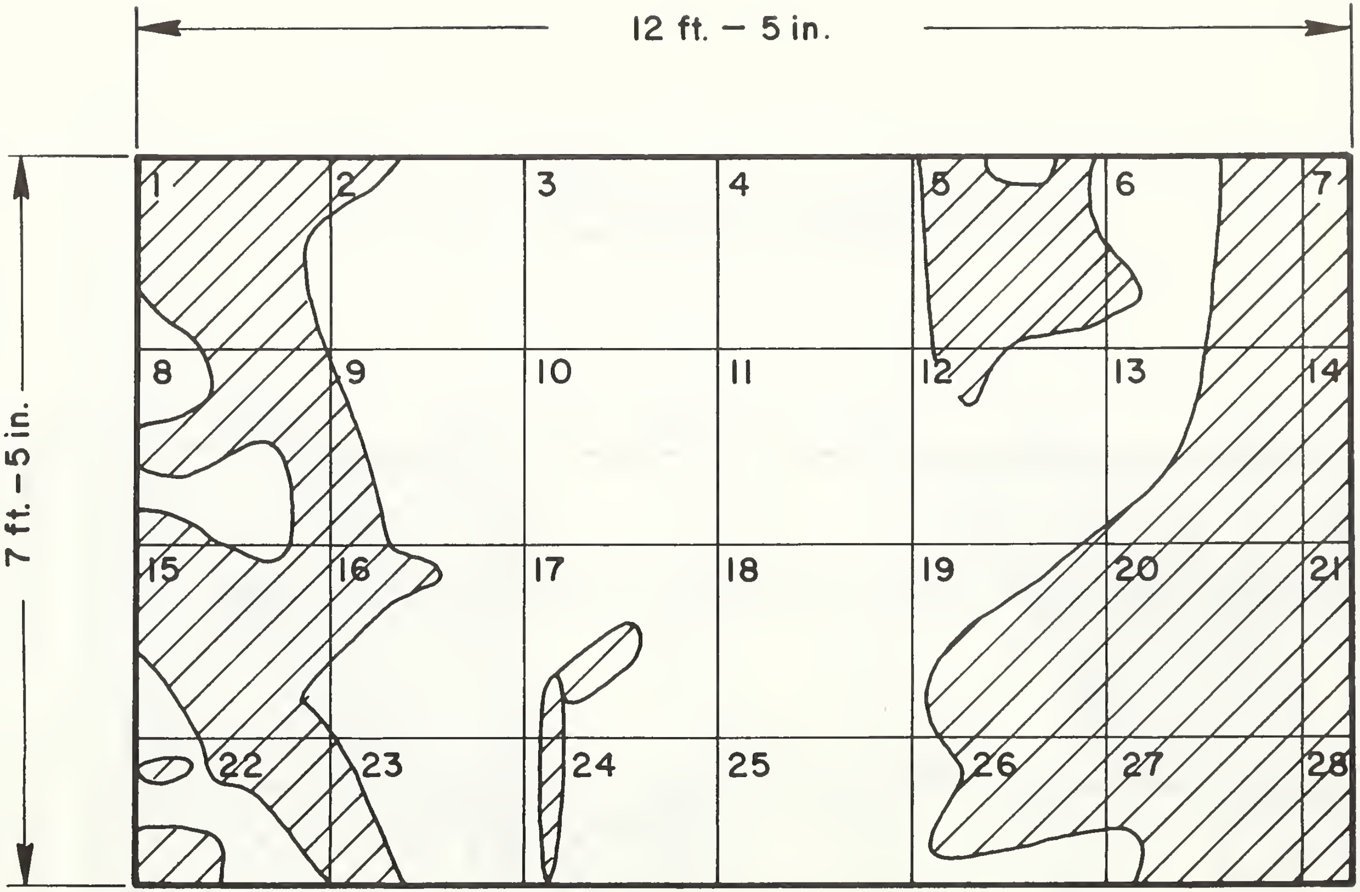
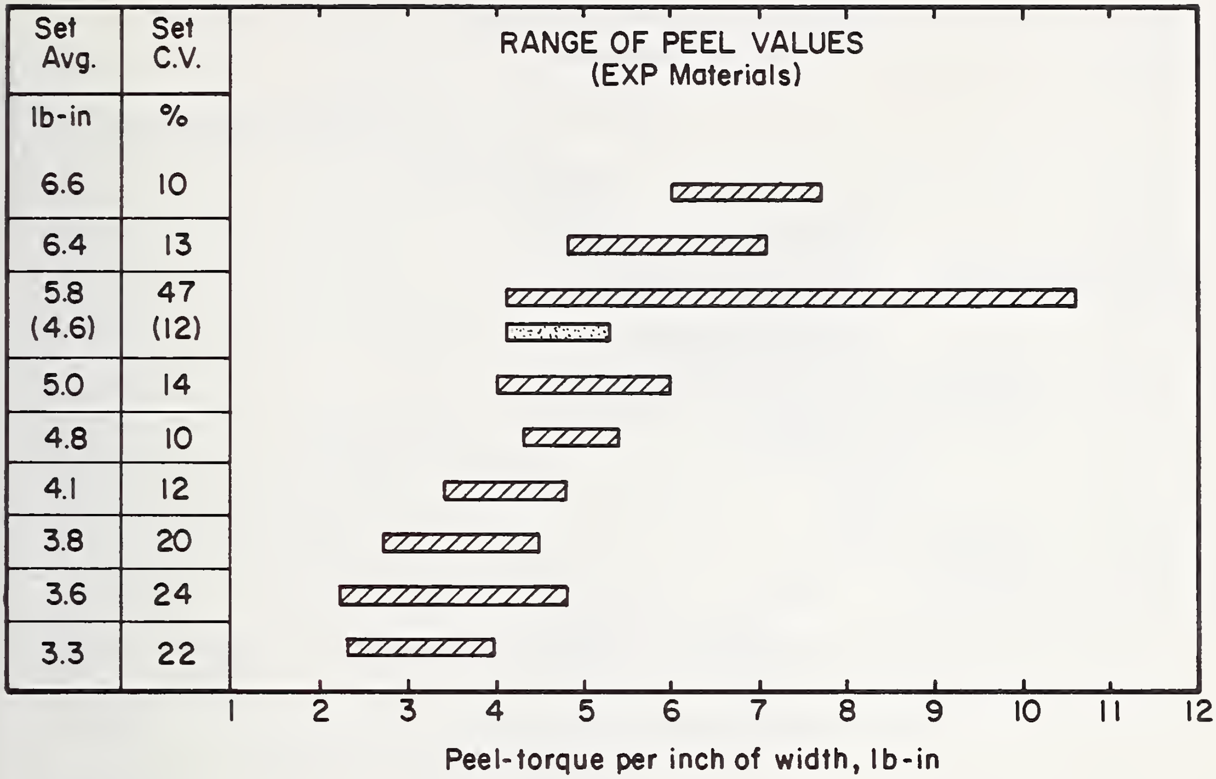


Fig. 3.18 Delaminations of exterior facing on ES/C Panel 6 L (Fold-up roof panel)



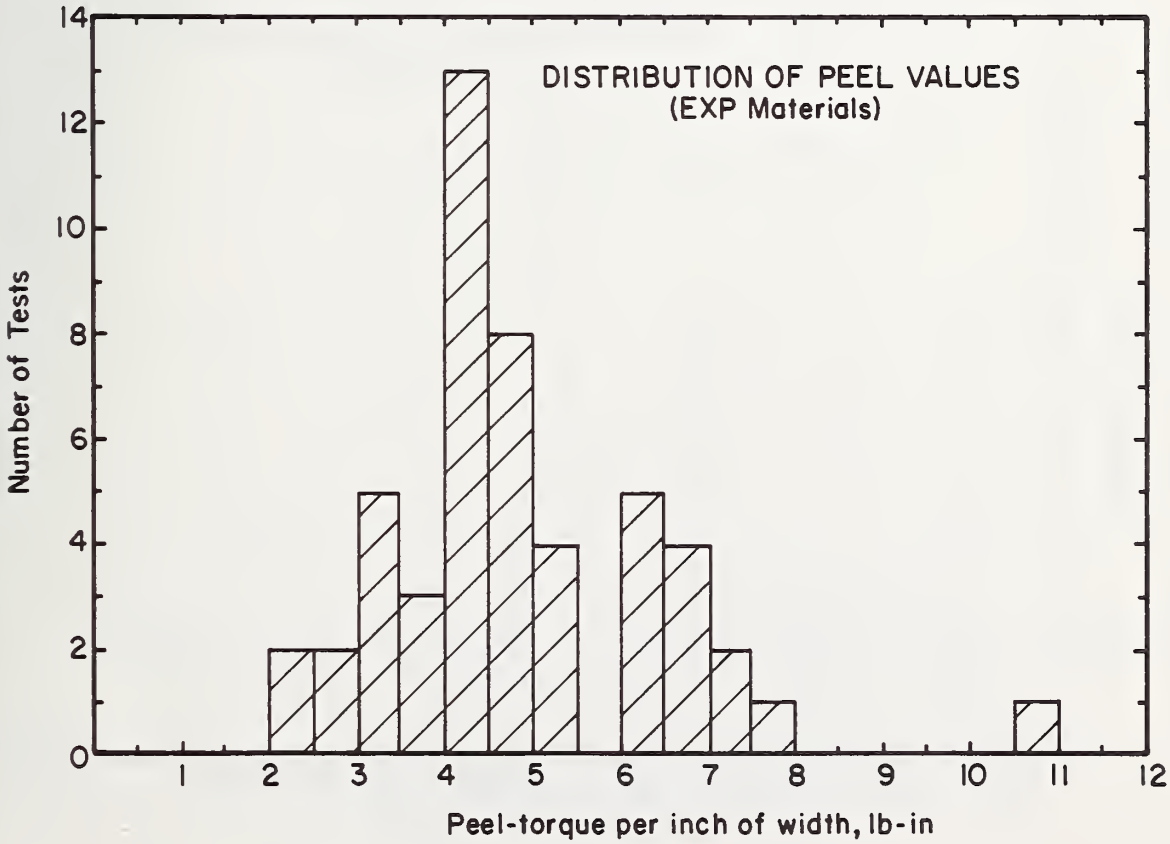


Fig. 3.19 Distribution and range of individual values for peel tests on EXP panel material

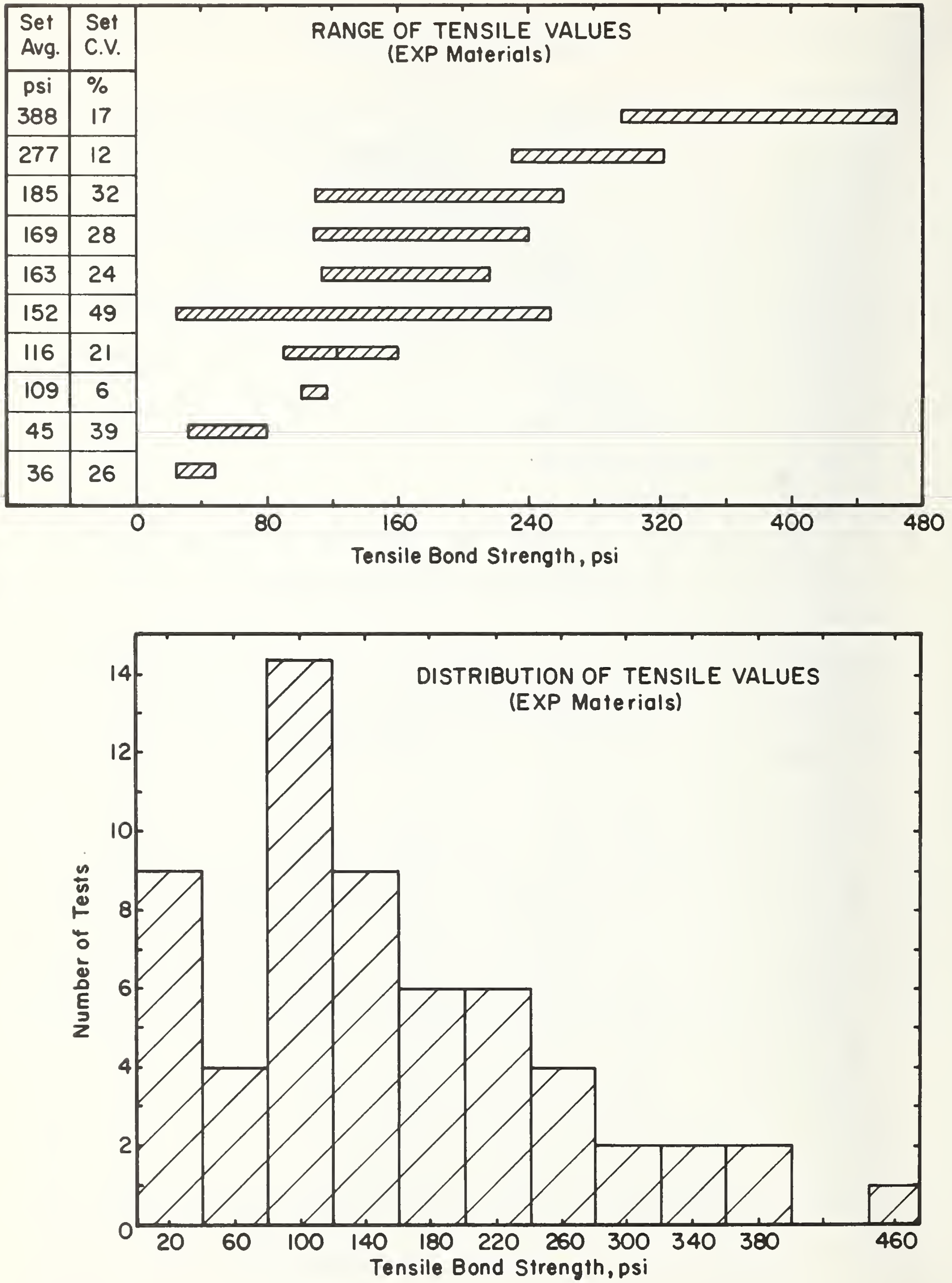


Fig. 3.20 Distribution and range of individual values for tensile tests on EXP panel material

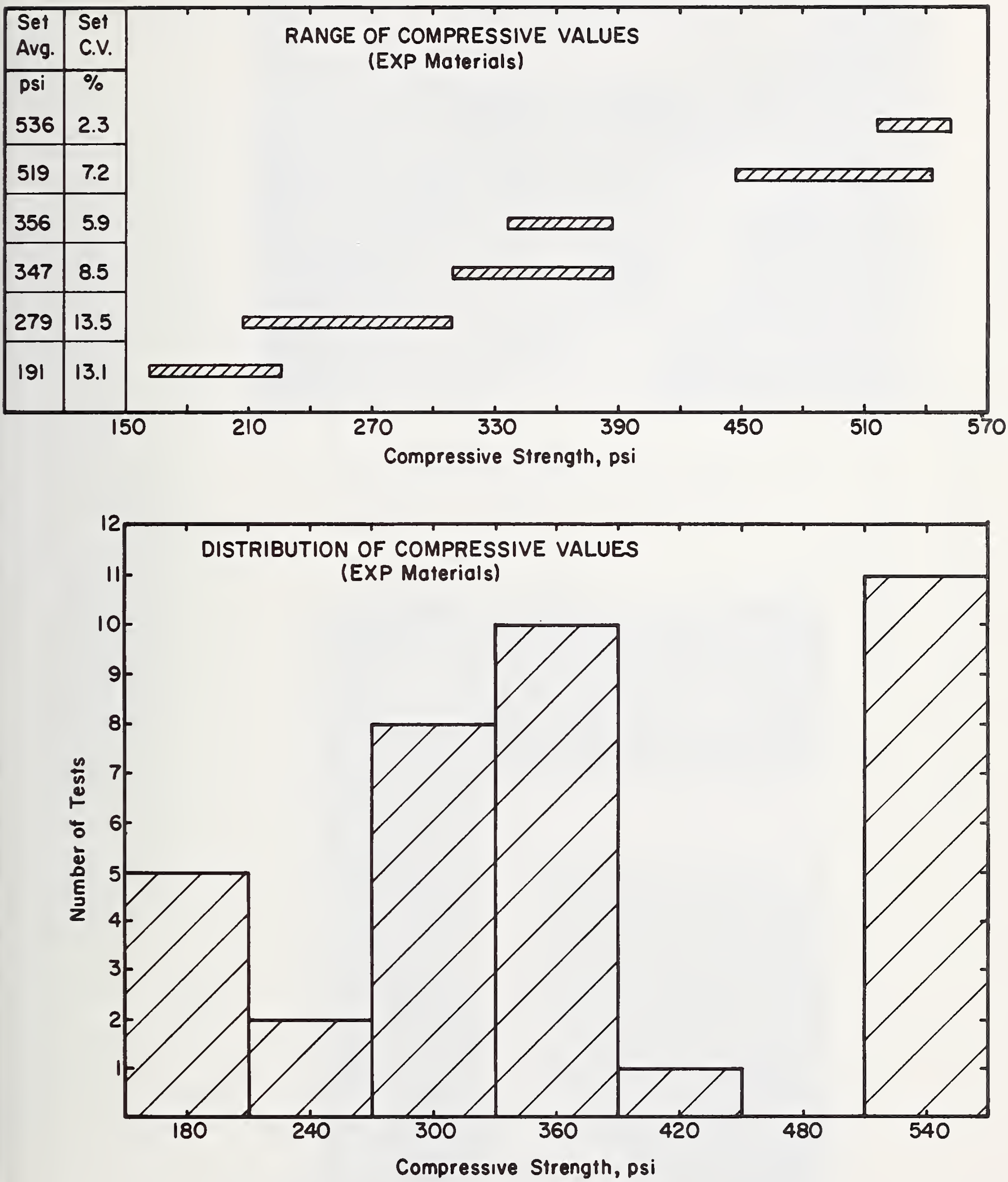


Fig. 3.21 Distribution and range of individual values for compressive tests on EXP panel material

Fig. 3.22 Water-entry point on upper corner of EXP center structure (Aluminum corner seal removed)

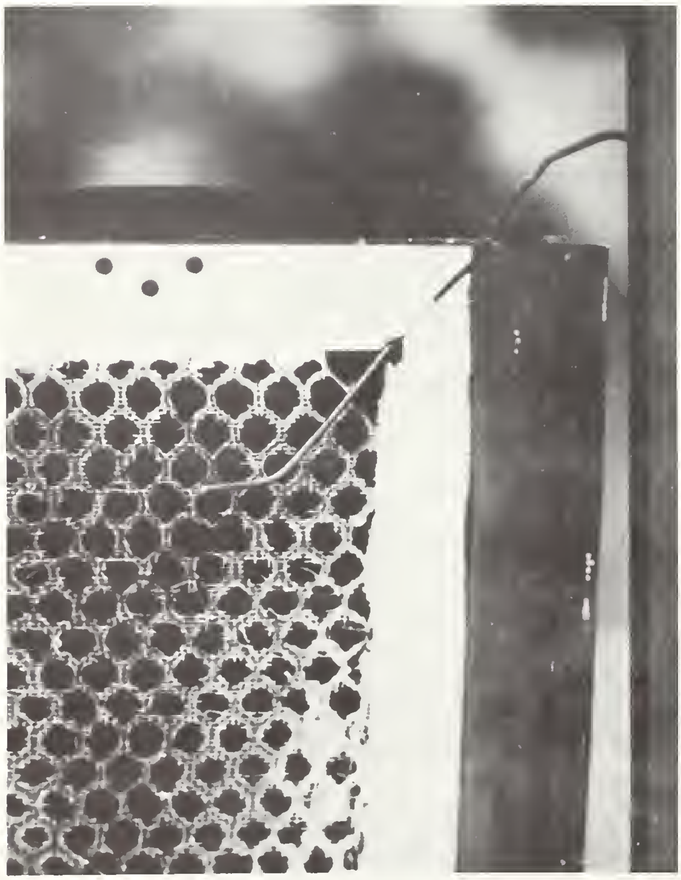


Fig. 3.23 Water entry point on upper corner of EXP Panel 14 L (Fold-down floor panel)

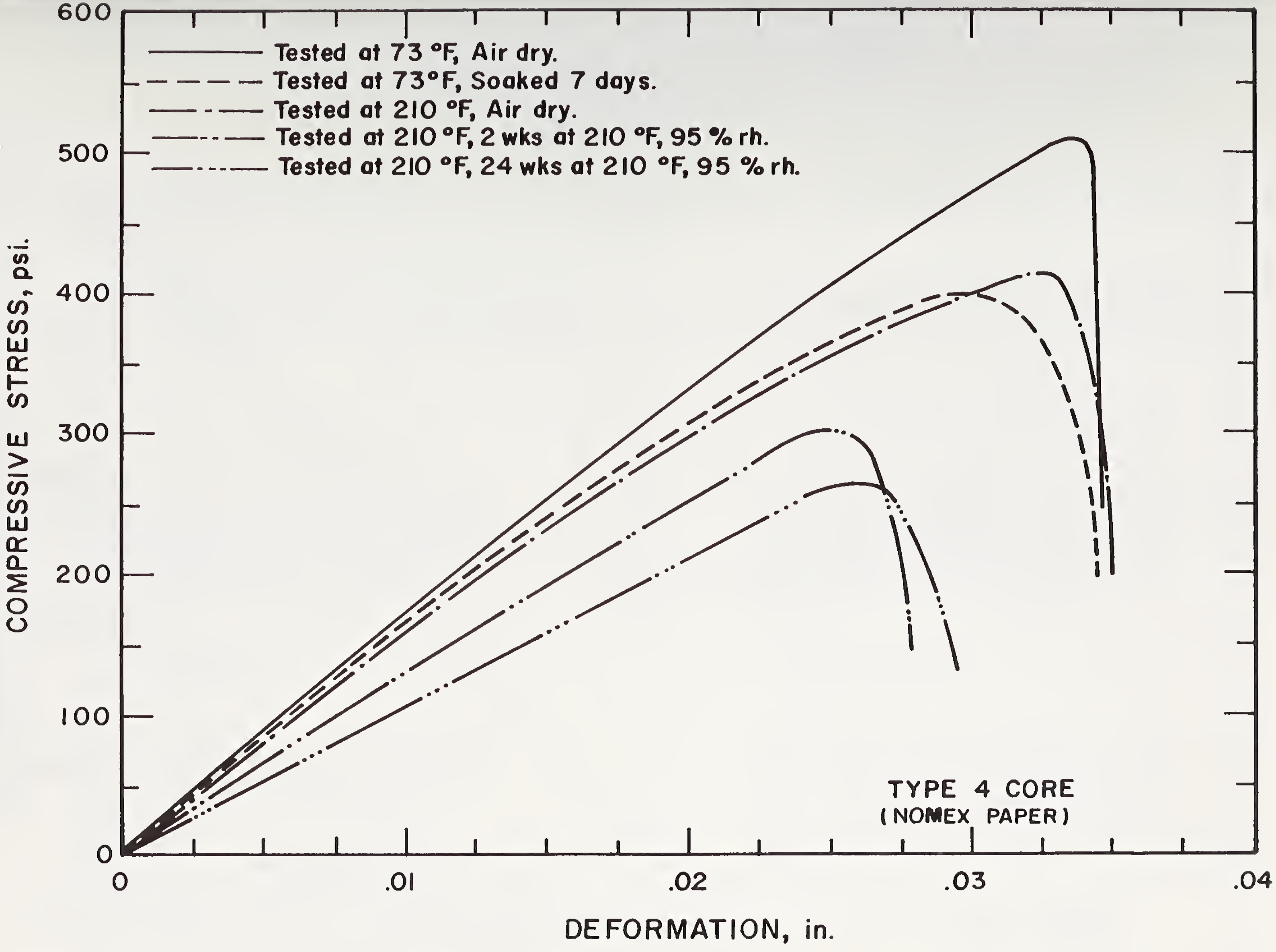


Fig. 4.1 Average stress-deformation data for sets of Type 4 Core specimens

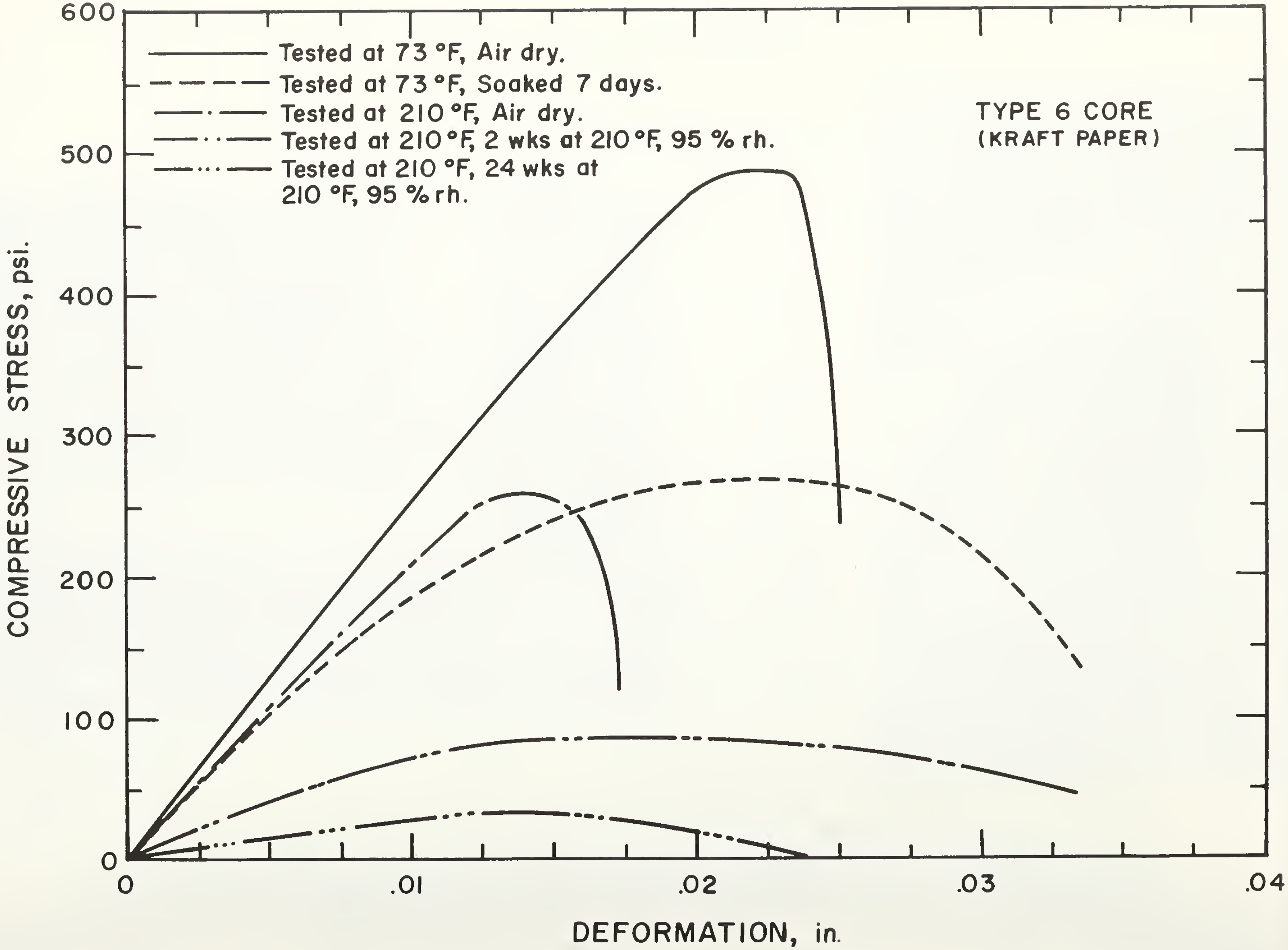


Fig. 4.2 Average stress-deformation data for sets of Type 6 Core specimens

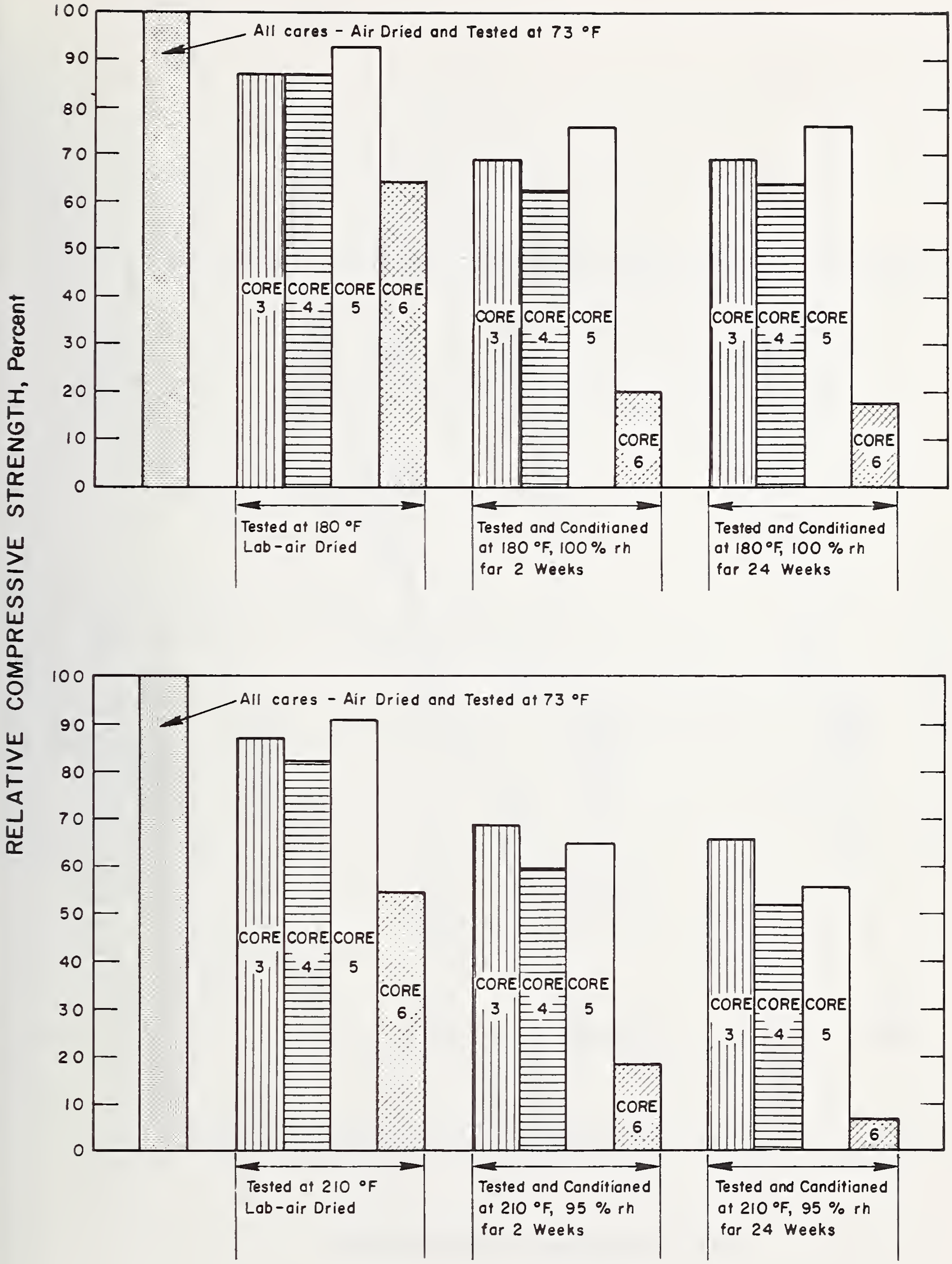


Fig. 4.3 Effect of the conditioning method on the relative strength for the four types of core

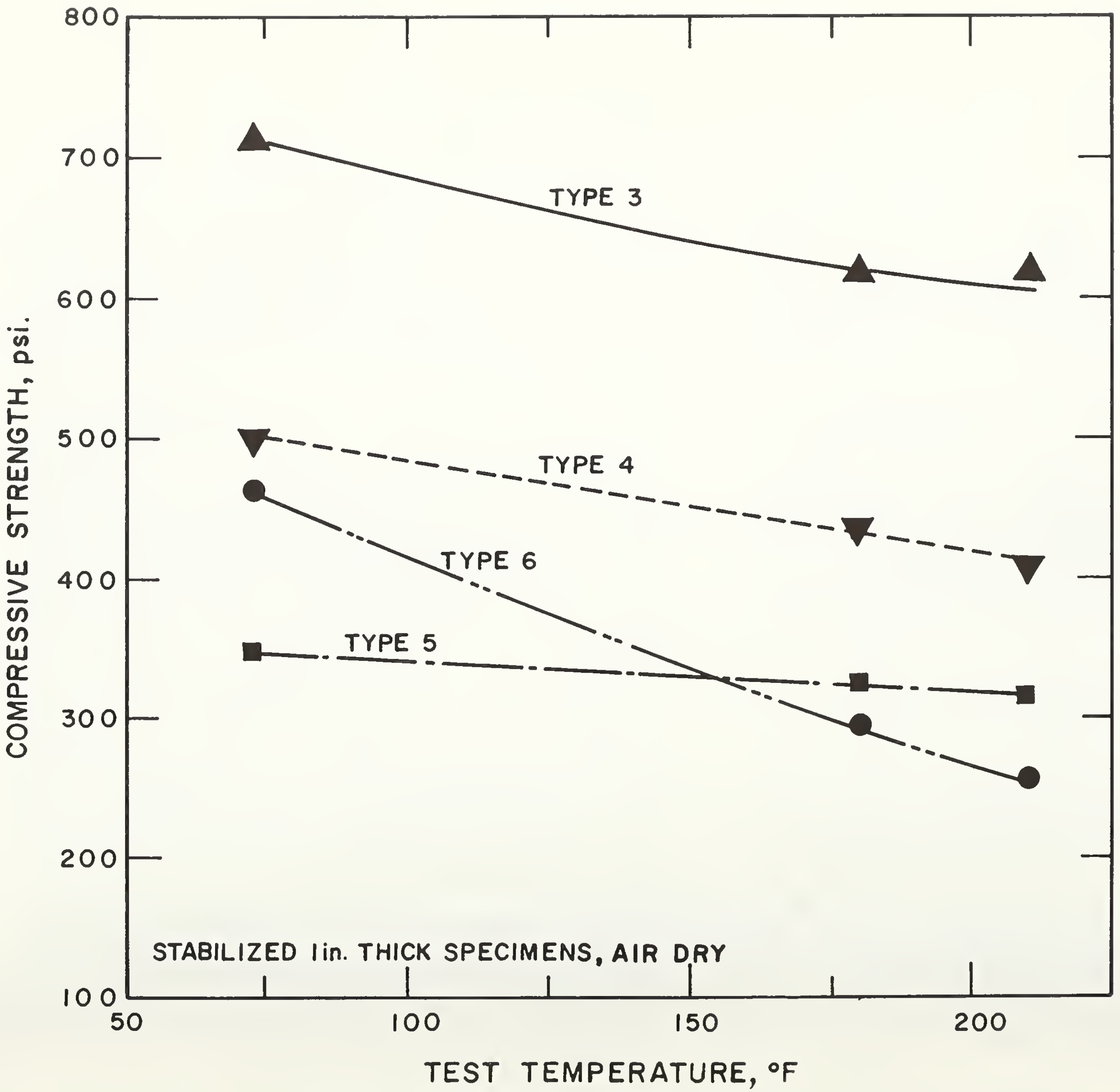


Fig. 4.4 Effect of test temperature on compressive strength for the four types of core

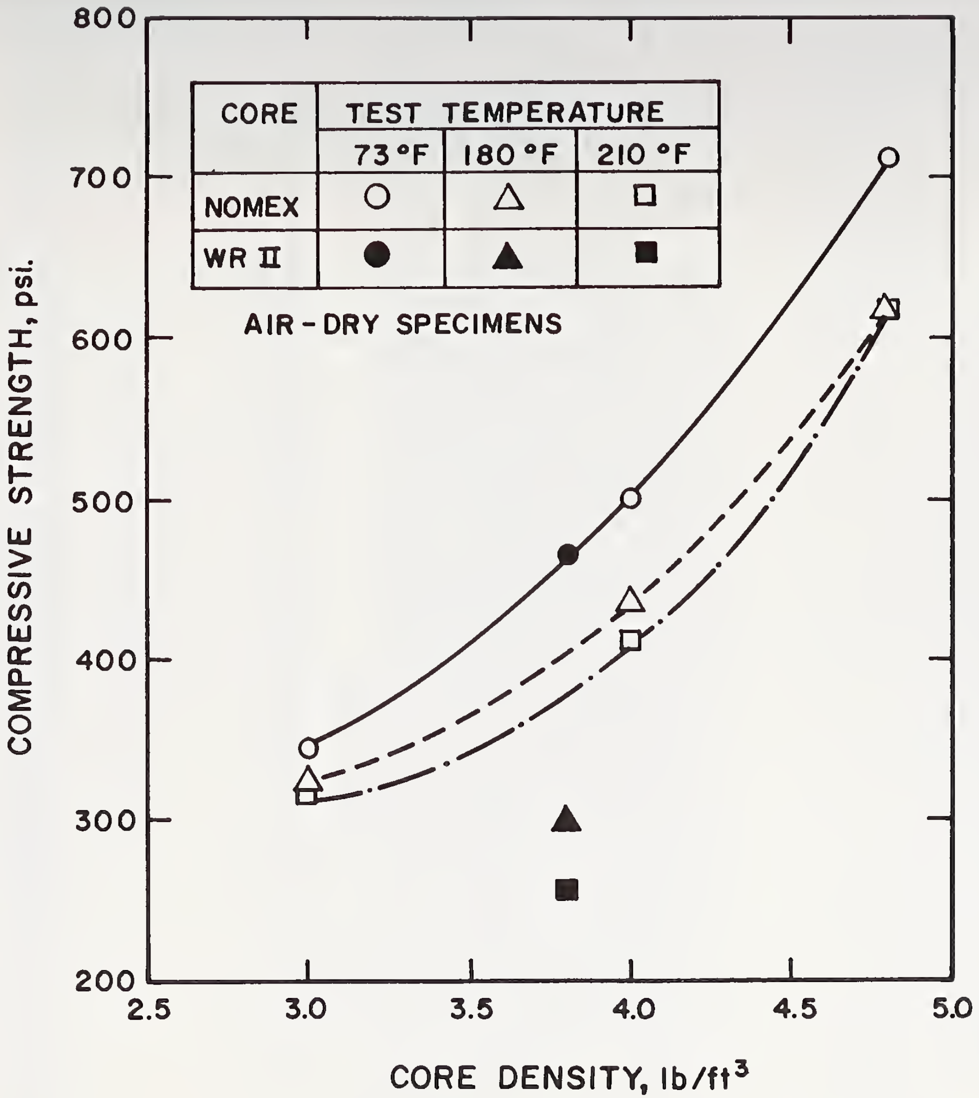


Fig. 4.5 Effect of core density on the compressive strength for the four types of core at various temperatures.

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15. SUPPLEMENTARY NOTES

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

This interim report covers the first portion of a long-range investigation dealing with the design and durability of lightweight, rigid structures (shelters) used by the military as combination shipping containers and housing for tactical and life-support services. This report covers the results of field and laboratory studies intended to correlate functional and structural problems with in-service conditions. It was found that water leakage into the shelters and into the sandwich panels was probably the basic problem area although many shelters appeared to have been defective at the time of delivery. It was found that, under adverse conditions, a polyamid paper honeycomb core would be significantly better for the sandwich panels than is the draft paper core now used. Major delaminations of the sandwich panels could not be correlated with impact damage such as would be caused by forklift bumps.

Subsequent reports will present the results from a structural analysis of and field tests on shelters subjected to typical dynamic and static loading conditions.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Durability; field inspection; foam and beam; honeycomb; impact; lightweight structures; military; reliability; sandwich panel; shelter.

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