BUILDINGS IN BARRELS, PART III

S. B. Swenson

U. S. Army Engineer Research and Development Laboratories

Fort Belvoir, Virginia

INTRODUCTION

First thinking and origin of the principles utilizing low bulk materials for rapid fabrication of structures in remote areas dates back many years and the origin is obscure; however, records of these Laboratories indicate some investigations were conducted as early as 1959, utilizing inflated structures, reinforced plastics and foam insulation. Lack of funds prevented any significant research and it remained for the Climatic Research and Test Branch of the Laboratories to place the impetus which finally accelerated the program with its presentation of the concept as the "Buildings in Barrels" approach to military structures.

In rapid order after this, a first building was designed, fabricated and exhibited in Puerto Rico in February 1961, and a second building was exhibited at the Pentagon in the same year.

Concurrently, plans were under way for participation in the Arctic Housing program during the 1961 summer season. For this the USAERDL rushed the construction of molds of improved design. During July, August and September of that year, the Task Group constructed two buildings in the Arctic: one, 16 feet x 30 feet located in an ice tunnel, and another, 16 feet by 70 feet located in a snow trench. This application of plastics in building construction drew wide attention and captured top honors at the Society of the Plastics Industry Conference Exhibit in 1962.

These original structures still stand as excellent examples from the standpoint of utility and after four years no new design has evolved which offers more simplicity of erection or better insulation or livability. It has been necessary, however, to sacrifice some of these advantages in favor of more important considerations, such as the reduction of man-hours and support equipment required.

We now entertain the possibility that many of the considerations in the concept which attract the earth-bound user also pertain to space applications. The following report is presented as a possible contribution toward advancement in that field.

DESCRIPTION OF ARCTIC BUILDING

The Arctic building was of modular design utilizing stressed skin panels of reinforced glass fiber with polyurethane foam core. Each module consisted of three distinct sections: Wall, ceiling and floor components. The modules were keyed to each other through the use of a tapered tongue and groove system and held together at the base by a clip angle and pressure sensitive tape over the wall and ceiling or roof joints. These basic modules were so designed that a combination of 4 wall panels, 4 floor panels and 2 ceiling panels would produce six linear feet of building. The end walls were fabricated in one piece. The equipment required to field fabricate these panels included: (a) Glass fiber-polyester spray equipment. (b) Polyurethane metering and mixing machine. (c) Molds (6 sets floor molds, 3 sets each ceiling and wall molds and 1 end wall mold). (d) Materials such as polyurethane foaming resins, polyester resins, and glass fiber roving.

The fabricating process was essentially as follows: (a) Disassembled molds were treated with parting compounds to facilitate casting release. (b) The mold faces were then sprayed with polyester resin and chopped glass fiber compacted by rolling with paint rollers. (c) The prepared molds were then assembled and predetermined amounts of foam were introduced into the mold cavity through charging holes. (d) After the foam had expanded to fill the cavity, the completed structural unit was removed from the mold and post cured for 24 hours prior to assembly.

TESTS, EVALUATION AND CONCLUSION (ARCTIC STRUCTURE)

The photographs, charts and notes, Figures 1 thru 12, following the text present a comprehensive test report on the Arctic Structures.

In evaluating the Arctic operation, the following conclusions were set forth:

Problems:

a. Rate of Production: It has been determined that the military target for acceptable field production rate should not be less than one 16 foot x 48 foot building in 8 hours with 8 men. The Arctic test proved, however, that considerable research and development in field fabrication technique was necessary to acquire the rate of production desired.

b. Equipment: A considerable amount of unnecessary and inefficient equipment was shipped to the Arctic for use in fabrication of the two buildings, most of which would have to be eliminated or reduced in bulk.

1. Polyurethane foam metering and mixing equipment: The mixing and metering machine used in the Arctic had a working capacity of approximately 10 pounds per minute. Complications arising from the low capacity of the machine considerably extended the pour time for each casting and was the cause of an excessive amount of reject panels.

2. Glass fiber-polyester spray laminating equipment: This equipment performed very well but in the final analysis, the spray process requires complicated equipment in the field, demands considerable time (mixing resins, spraying, rolling, cure time, trimming, and cleaning molds, applying wax and other mold release agents, etc.) and presents toxicity and waste problems. Since there is no logistic advantage in spray laminating in the field, methods or designs utilizing commercially available sheet stock are more attractive.

c. Complexity of Molds: The costs of polyurethane foam materials in the early stages of the program dictated that designs should observe maximum conservation of material consistent with good structural value. The final panel design had a nominal thickness of 2" and utilized a moulded in rib section around the perimeter as a load supporting member. This design increased the bulk of the mold and complicated fabrication. The number of molds required to fabricate the Arctic buildings also increased the amount of material shipped. A total of four different type molds was required i.e., end wall, side wall, roof panel and floor panel. To minimize the bulk of material shipped to the field for fabrication, it is desirable to design the building so that one mold can be utilized to fabricate several different components.

d. Snow and wind load requirements: Army regulations for the operation of material under extreme conditions of envirnment requires that such structures withstand a maximum of 40 pfs snow load and 80 mph winds with gusts to 120 mph. However, the configuration or slope of the elliptical arch design is such that snow will accumulate on no more than the middle two thirds of the roof. Also, because of their light weight, these plastics buildings will require tiedown arrangements to withstand lifting forces present under high wind conditions. Therefore, it is believed that snow and wind load requirements for the shaped arch building need not exceed 30 psf (uniform over entire building) and 80 mph, respectively.

SUMMARY OF FINDINGS (ARCTIC STRUCTURES)

In the statement under rate of production, the acceptable rate of production was indicated to be approximately 64 man-hours per 16 ft. x 48 ft. building. The 100 feet of building that was fabricated and erected in the Arctic consumed some 6000 man-hours. Even considering the experimental nature of the project, it is very evident that other designs or methods would have to be developed. Also, even though material shipping bulk coincided with the original logistic concept, the bulk of the support equipment assumed such large proportions as to far outweigh the original advantage, especially for low production requirements.

<u>Continuing research</u> was programmed to:

a. Evaluate other methods:
  1. Sprayed Shelters.
  2. Honeycomb Structures.

b. Modify design and techniques of the Arctic structures.

Two <u>sprayed shelters</u>, (Figures 13 and 14) were constructed at USAERDL, Fort Belvoir, neither of which offered enough advantages to warrant further study. The effort to spray glass fiber laminates and polyurethane foam on the interior of inflated shelters was beset by so many difficulties that the program was terminated.

A more lengthy study was made utilizing both plastics faced and aluminum faced <u>paper honeycomb core panels</u>, (Figures 15 and 16) as a building material. Shipping unexpanded paper honeycomb and processing in the field offers approximately the same logistic advantage as polyurethane foam as a core material. Moreover, equipment and techniques required for fabricating panels are very simple, and shaped panels utilizing honeycomb paper core develop tremendous strengths. There is however one major disadvantage in that the insulation value of this type of panel is low, and no practical field method has been found to improve it. Limited research continues along this line, but maximum effort has been concentrated on simplification of design and fabrication techniques of the original shaped panel building. The happy circumstance of declining cost of foaming materials (approximately $1.25 per lb. in 1960 to 40¢ - 50¢ per lb. for some that are available today) permitted a new look at the original approach and afforded greater extravagance in the use of material and increased design freedom. Whereas, ribs and buttresses had been necessary to attain desired strength, it was now possible to achieve the same results utilizing panels with flat skins and varying core thicknesses.

The <u>finalized modular design</u>, (Figure 17) permitted the use of a two-piece flat skinned arch thus eliminating the separate roof arch and doing away with the requirements for laminating equipment. Flat prefabricated skins can be shipped to the site in less space than an equivalent amount of laminating material, at the same time leaving equipment and waste at home. Another venture toward simplification was to revert to hand mixing (Figure 18) of the foaming material, thus eliminating the last bit of complicated machinery. This turned out to be highly successful and had become S.O.P. until recent developments in froth foaming, (Figure 19) projected a brighter picture. The adoption of flat skins or facing materials also opened the way for use of a variety of facing materials such as aluminum, steel, plywood, fiberboard, etc.

Further streamlining of the system was hampered by the cumbersome method of utilizing unit molds. The necessary bulk and handling of molds reduced productivity in the Arctic venture and much of this problem still existed.

To eliminate as much as possible the complexity and handling problem, a system of gang molds was devised whereby a practically continuous production line could be maintained, with minimum manipulation of mold components. Figure 20 shows a line drawing of the mold design together with building assembly diagrams.

This was the status of the project at the end of the second phase (Part II).

The system was checked out using a near prototype mold; a 3-man crew consistently produced satisfactory panels by this method, and there was therefore sufficient reason to maintain the assumption that a practical building and a method to produce it in the field is a feasible military objective.

In early 1964, a contract was awarded for the fabrication of a six cavity gang mold capable of producing 6 - 4 ft. wide half modules per production cycle with provisions for increasing this capacity if practicable. Molds for the end walls were fabricated at the USAERDL shops.

In the meantime, studies continued using a variety of skin materials other than glass reinforced plastics, including plywood, steel and aluminum. Variations of foam formulae and foam casting techniques were also studied in anticipation of ultimate application in the production molds. For practical reasons in present development, .032 aluminum sheet has been selected as surfacing material.

Although it does not necessarily follow that previous observations on the hand mixing and pouring of foaming materials should be modified, investigations of recent advances in froth foaming techniques have suggested an alternate procedure along these lines might be practicable: The complexity of metering machines is fast disappearing; the present system in use at the laboratories utilizes nitrogen pressurized supply tanks piped to metering pumps which discharge the chemical components into a labryinth mixing chamber. Despite simplicity of design, results with this equipment are very satisfactory. Foam quality is consistently good, capacity is relatively high (22 lb/min) and molds can be charged without risk of excessive pressure build-up.

The Contractor-supplied gang molds were set up for production in July 1964 and several experimental panels were made using both of the aforementioned charging techniques. It was found that with the use of conventional foaming techniques the risk of bursting the molds was extremely high, in fact, during one attempt to introduce a complete charge in one shot, several cheek pieces were ruptured and had to be repaired. Conversion to froth foaming techniques obviated this problem and in the first full cycle operation of the gang molds six panel cavities were charged with froth foam, averaging 90 seconds charging time each or 9 minutes for the group.

The end wall design consisted of 4 vertical panels 4 ft. wide. The molds were designed so that each production cycle would produce a right and left hand component. The end wall production cycle also coincided with the module production rate so that two end walls would be produced for each 24 feet of building.

Although floor panel molds were designed that could be used in the same manner as the module gang molds, there seemed to be many situations where this type of floor would not be required. There was also some indication that a system could be devised that would permit the floors to be poured in place. Further work on the development of the floor system has been held up pending the results of research presently in progress.

Sub-surface Lunar installations, among others visualized in some space engineering concepts, bear remarkable similarity to present installations in the Arctic and Antarctic. In such applications where structures are isolated from exterior forces, whether it be snow, wind, rain or other phenomena, designs, techniques and materials would have to be developed which are compatable with the circumstances. It is conceivable that the inherent structural strenth of polyurethane or other foam material developed for space application could obviate the requirement for core facing materials. Several prototype all-foam panels have been produced. Weighing only one half as much as the faced-foam core panels and possessing otherwise favorable characteristics, they are specially adaptable to low load applications.

FABRICATION

In October of 1964, a detail of six Army enlisted men were assigned to the USAERDL to be trained in the operation of the molds and equipment and to test the kit under near-field-conditions. By mid December, these six men had erected a 28 foot structure at Camp A.P. Hill in Virginia.

The process as now set up is as devoid of sophistication as our four years of research has been able to attain; aluminum skins are supplied on pallets, precut, prime-ciated and ready for placement in the molds. After being placed in the molds, the cover plates are positioned and draw bars are inserted through the cover plates and mold cavity and engaged in threaded inserts in the base. These bars hold the whole assembly in alignment and contain the pressure of the expanding foam in the molds. The raceway, or hole, left in the casting when the bars are withdrawn is later used to hold the modules and end walls together in assembly by passing steel tie rods through the holes from end wall to end wall and drawing the entire structure together. To obviate the necessity of handling overly long tie rods, the rods are made up in sections with threaded ends that can be coupled together as they are passed through the panels. Taping the joints with pressure sensitive tape and cutting doors and windows, as required, completes the job.

Since the Camp A.P. Hill operation, several other structures have been fabricated. Another building, under construction as of this writing, is a special purpose structure for electronic testing, it is being fabricated with glass fiber laminate facings and will be entrely devoid of metallic parts except for screws fastening the building to the anchor sills.

With experience gained from experimental and test production studies, it has been possible to project an estimate of personnel and equipment requirements, and material and man-hour cost for producing a 16' x 32' structure in the field.

NOTE: Although the time studies were conducted as accurately as possible, emphasis should be placed on the fact that the man-hour figures indicated in the following outline are based on prototype production. Factual figures will not be available unless or until a production run of several units are fabricated under field conditions.

OUTLINE OF REQUIREMENTS

EQUIPMENT:

1 set each-gang molds for walls.

1 set each-gang molds for end walls.

Polyurethane froth foam dispenser.

Portable air compressor - approximately 1/4 H.P.

Electric power for dispenser, portable tools and for heating molds, if necessary.

Minimum shelter for initial operation, 16' x 24' heated structure in low temperature applications. (In tropics or temperate environment, minimal shelter can be fabricated on site).

MATERIAL:

a. Foam - (2.2 lbs per cu. ft. density)
   Eight 4 ft. Modules @ 100 lbs. per module - 800 lbs.
   Two End Walls @ 100 lbs. per end wall - 200 lbs.
   Total Requirements, Foam - 1000 lbs.@ $0.60/lb. = $600.00

b. Aluminum Sheet (Alloy 3105-H25 .032 in. thick)
   Eight 4 ft. Modules @ 104 lbs per module - 832 lbs.
   Two End Walls @ 124 lbs. per end wall - 248 lbs.
   Total Requirements, Aluminum Sheet - 1080 lbs.@ $0.443/lb.= 478.00
   Total Material Cost, basic 16' x 32' w/o Floor =$1078.00

LABOR:

(8-man team with minimum training of 100 hrs. per man)

a. Fabrication:
   1. Modules - One gang mold casting cycle per 24 M.H. yields 6 panels (3 Modules) at an average of 4 man-hours per module.
   Eight 4 ft. Modules @ 4 M.H. per module - 32 M.H.
   2. End Walls - One gang mold casting cycle per 6 M.H. yields 4 panels (1 end wall)
   Two End Walls @ 6 M.H. per end wall - 12 M.H.
   Total Fabrication time - 44 M.H.

b. Assembly:
   One 16' x 32' structure can be field erected on a prepared base or level ground in 40 man hours. An additional 8 man hours may be required to provide doors and windows. - 48 M.H.

TOTALS:

Labor as calculated - 92 M.H.
Labor incidental to operations (average) - 8 M.H.
Total Labor - 100 M.H.

Labor Cost, Basic structure w/o Floor (@ $5.00/M.H.) = $500.00
Material Cost, basic structure w/o Floor = 1078.00

Total Cost per 16' x 32' Basic Unit = $1578.00
(Each additional 4' module: Material - $106.00; Labor - $20.00 = $126.00)

SUMMARY

The concentrated research into the uses of expandable materials in field fabrication of military structures is bearing fruit. Buildings are presently in service and seemingly doing a good job and individual panels and modules are undergoing test. Modifications on the mold design are now underway and final tests are being programmed.

CONCLUSIONS

Our conculsions should be tempered by the fact that the research program "Buildings in Barrels" is not completed. We can, however, make certain observations on the basis of experience to date. We have witnessed the practicability of special purpose buildings in the Arctic and have fabricated and tested many shapes and designs which exceed requirements. There are many avenues of research still to be explored; design criteria must be stabilized, fabrication technology broadened and foaming equipment and materials can be improved.

The development of this concept at the laboratories has been viewed with interest by both the military and civilian. The desirability of exploring its potential for civilian application is evident. Easily heated, structurally sound and insect and vermin proof, such structures should find an attractive market for farm buildings, grain storage, etc. Emergency housing and Civil Defense are also a consideration.

Now, with the rapid mastery of space travel and exploration, the requirement for materials and methods for space fabrication of structures becomes more pressing. Expandable materials and collapsible molds, modified for operation in space atmospheres could be a solution. The past research of the plastics industry has developed polyurethane foam materials to the present state in little more than a decade. It should be logical to assume that with comparable diligence the next decade could turn up a material applicable to space structures. Progress and achievement is largely dependent upon the continued interest and participation of the plastics industry and various research organizations, both Government sponsored and commercial. Continued collaboration among these groups is essential for achievement of our goals.

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3. Abraham Perez and S. B. Swenson, USAERDL, Ft. Belvoir, Va., Memorandum Report, Rigid Foam Plastics Shelter by Spray Apllication to an Air Supported Mold, 30 July 1963.

4. S. B. Swenson, USAERDL, Ft. Belvoir, Va., "Buildings in Barrels" - Part II, Paper report to the Society of the Plastics Industry, Reinforced Plastics Division, 6 February 1964.

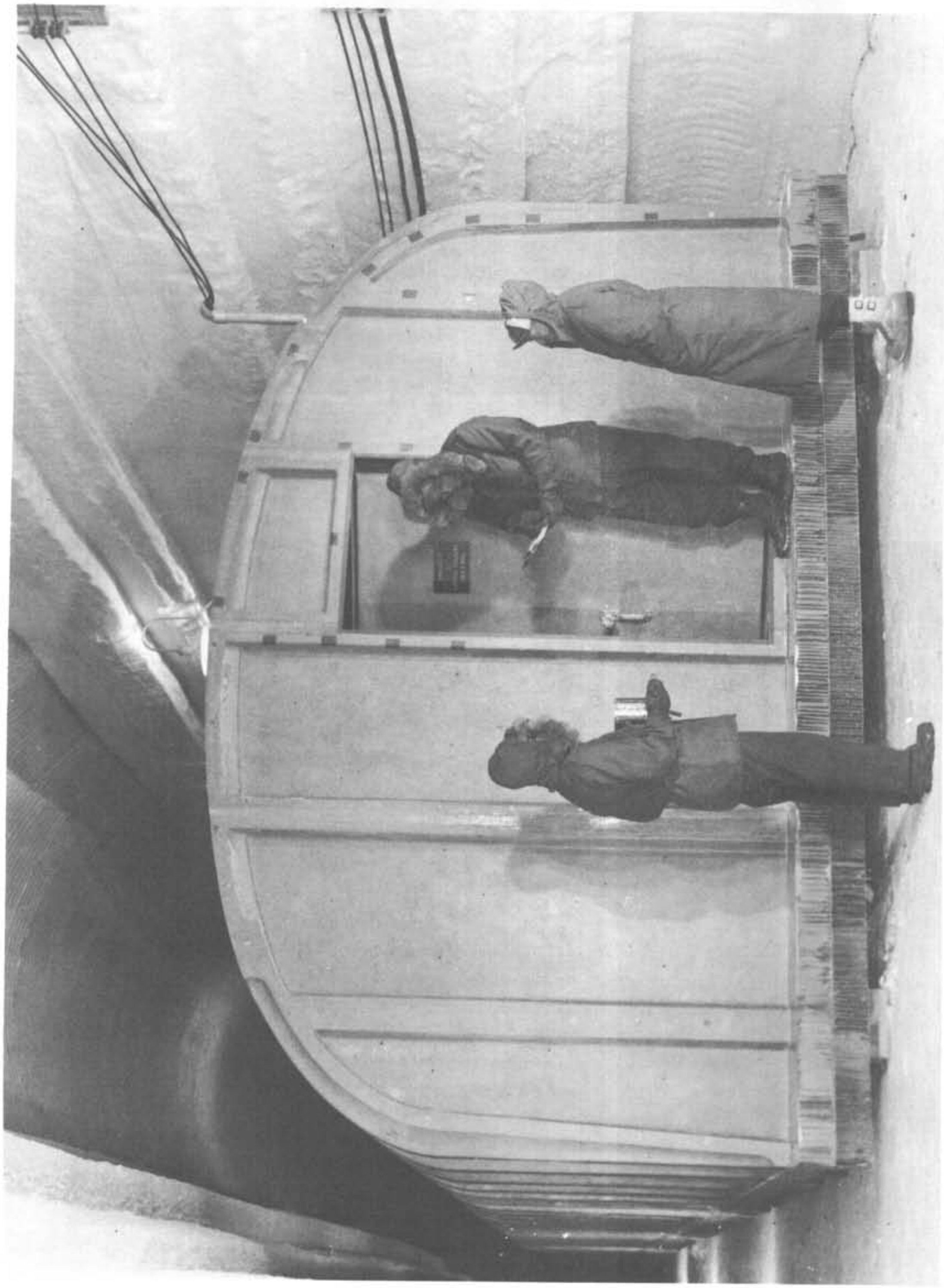


Figure 1. Glass Fiber, Polyurethane Plastics Building Located in a Snow Tunnel

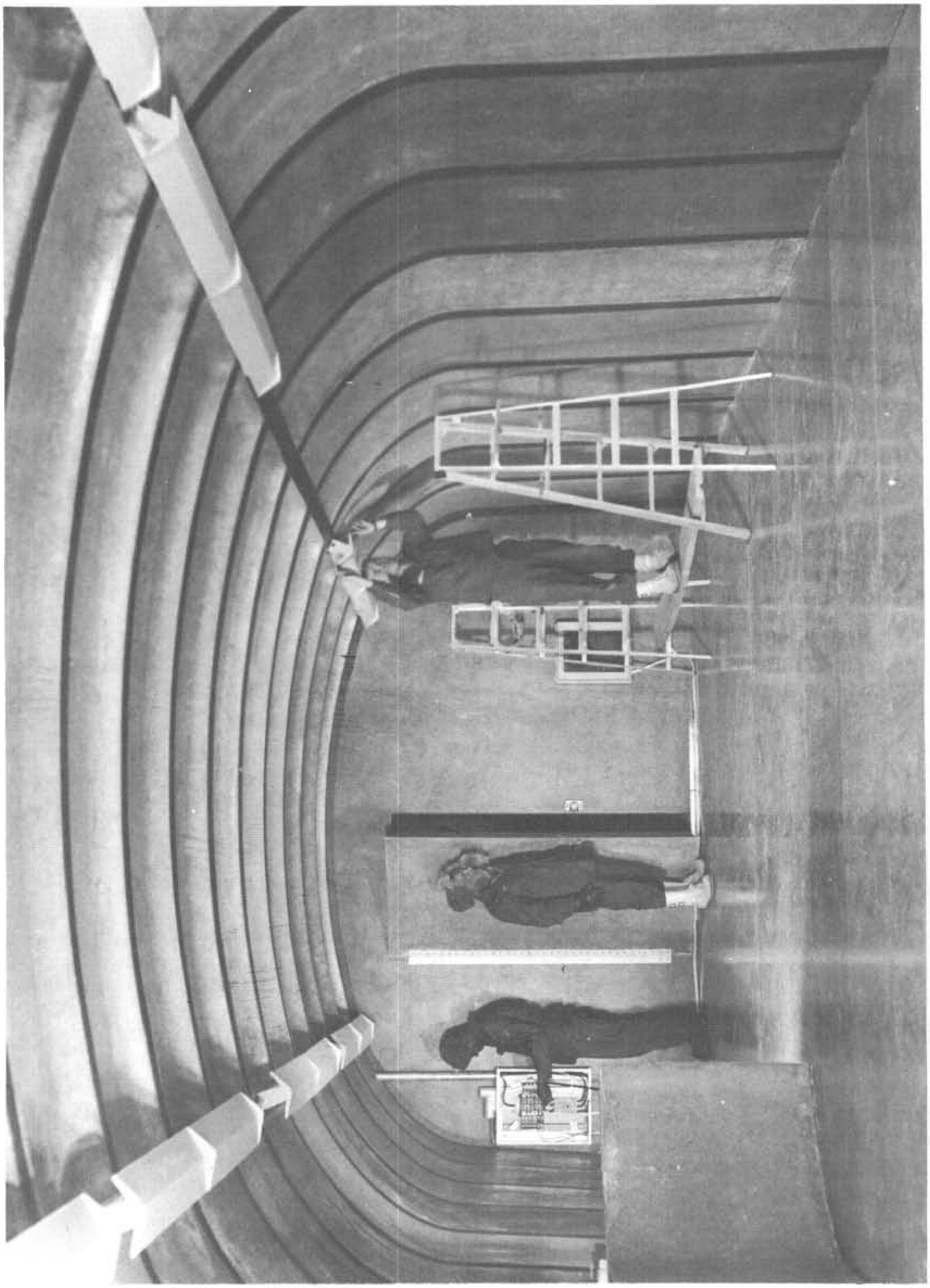


Figure 2. Interior of Plastics Building Illustrated in Figure 1

DESIGN WIND PRESSURES											
WIND VEL. MPH	q PSF	C	WINDWARD WALL	C	LEEWARD WALL	C	WINDWARD 1/4 ROOF	C	CENTER 1/2 ROOF	C	LEEWARD 1/4 ROOF
40	4.1	0.70	2.9	-0.50	-2.0	-0.51	-2.1	-0.95	-3.9	-0.58	-2.4
50	6.4		4.5		-3.2		-3.3		-6.1		-3.7
60	9.2		6.4		-4.6		-4.7		-8.7		-5.3
70	12.5		8.8		-6.3		-6.4		-11.9		-7.3
80	16.4		11.5		-8.2		-8.4		-15.6		-9.5
90	20.7		14.5		-10.4		-10.6		-19.7		-12.0
100	25.6		17.9		-12.8		-13.0		-24.3		-14.9

NEGATIVE VALUES INDICATE EXTERNAL SUCTION ON BUILDING SURFACE.

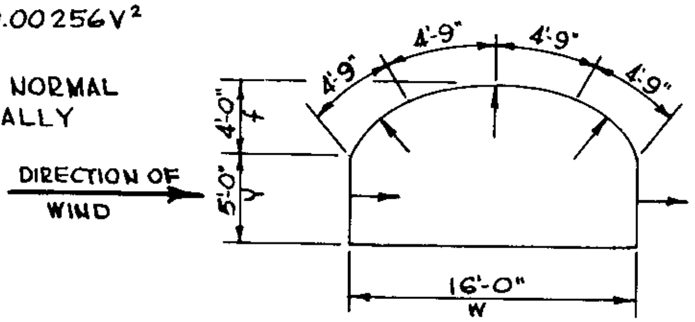
V=WIND VELOCITY IN MILES PER HOUR

q=VELOCITY PRESSURE = $0.00256V^2$

C= SHAPE COEFFICIENT

p=DESIGN WIND PRESSURE NORMAL TO SURFACE (ACTING RADIALLY ON ROOF)

p=cq IN LBS. PER SQ.FT.



$\frac{f}{W} = \frac{4}{16} = 0.25$

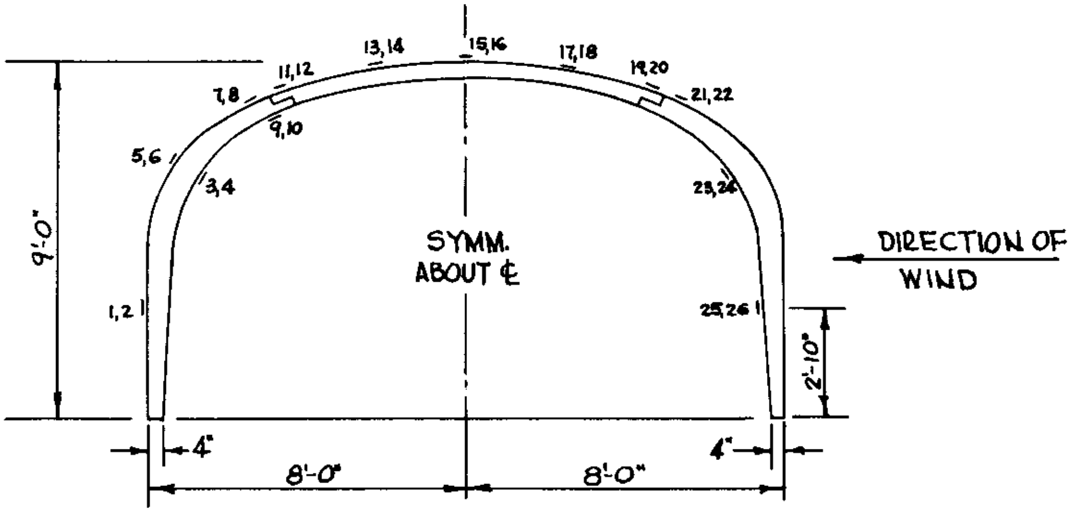
$\frac{y}{W} = \frac{5}{16} = 0.30$

FIG. 3

WIND PRESSURE DISTRIBUTION

TOTAL APPLIED WIND LOAD ON 9'-0" SECTION OF BUILDING										
VELOCITY MPH	WINDWARD WALL		LEEWARD WALL		WINDWARD 1/4 ROOF		CENTER 1/2 ROOF		LEEWARD 1/4 ROOF	
	AREA-SF.	P-LBS.	AREA-SF.	P-LBS.	AREA-SF.	P-LBS.	AREA-SF.	P-LBS.	AREA-SF.	P-LBS.
40	45	130.5	45	-90.0	42.75	-89.7	85.5	-333.3	42.75	-102.6
50		202.5		-144.0		-141.0		-521.4		-158.1
60		288.0		-207.0		-201.0		-743.7		-226.5
70		396.0		-283.5		-273.6		-1,017.3		-312.0
80		517.5		-369.0		-359.1		-1,333.8		-406.2
90		652.5		-468.0		-453.0		-1,684.2		-513.0
100	↓	805.5	↓	-576.0	↓	-555.6	↓	-2,077.5	↓	-636.9

FIG. 4



LOCATION OF STRAIN GAGES
WIND LOAD TEST

FIG. 5

NOTE:
1. STRAIN GAGES LOCATED ON BOTH SIDES OF LONGITUDINAL JOINT, ALONG RIB PORTION OF PANEL.

$E = 0.80 \times 10^6$ PSI.
STRESSES: KSI.

WIND LOAD STRESSES
PLASTIC BUILDING - 16'-0" × 9'-0"

Wind Velocity - MPH.		50	70	90	100	
GAGES	1	0.088	-0.016	0.184	FAILURE NO READINGS	
	2	0.084	-0.020	0.176		
	3	-0.088	-0.440	-0.616		
	4	-0.092	-0.428	-0.616		
	5	—	—	—		
	6	0.116	0.572	0.828		
	7	-0.108	-0.204	-0.008		
	8	-0.020	-0.108	-0.008		
	9	0.088	0.288	0.268		
	10	0.068	0.212	0.240		
	11	0.004	-0.028	0.060		
	12	-0.004	-0.036	0.052		
	13	0.080	0.344	0.664		
	14	0.088	0.384	0.760	FAILURE NO READINGS	
	15	0.188	0.780	1.380		
	16	0.188	0.796	1.400		
	17	0.060	0.300	0.520		
	18	0.064	0.296	0.500		
	19	-0.024	-0.144	-0.264		
	20	-0.020	-0.132	-0.248		
	21	-0.044	-0.276	-0.516		
	22	-0.060	-0.324	-0.604		
	23	0.116	0.452	0.928		
	24	0.136	0.512	1.000		
	25	0.132	0.372	0.944		
	26	0.140	0.388	0.904		
Deflections - ins.	VERT.	0.125	0.5625	1.125		
	HOR.	0.000	0.3125	1.3125		

FIG. 6.

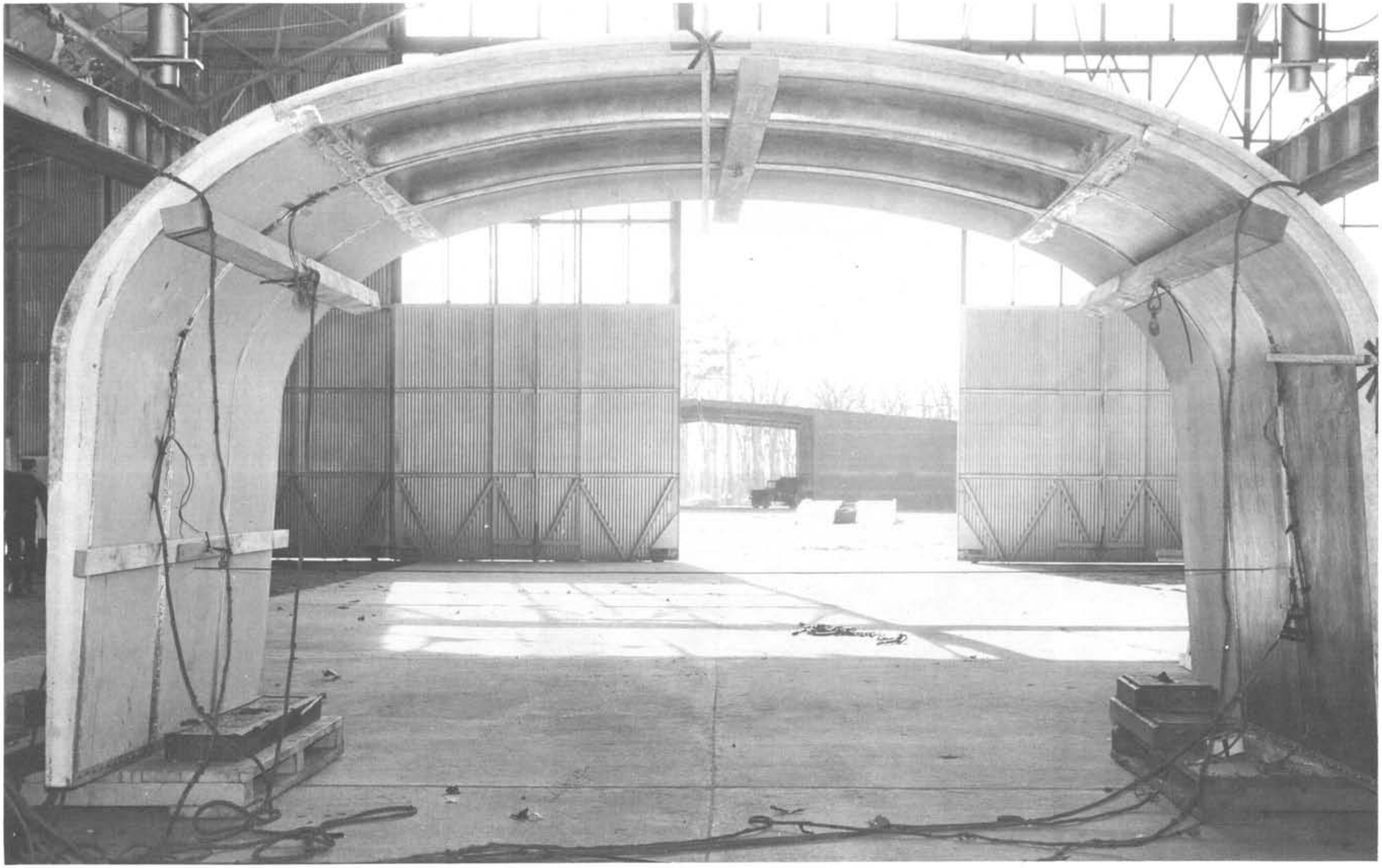


Figure 7. Test Setup for Application of Simulated Wind Forces on Shelter Test Module

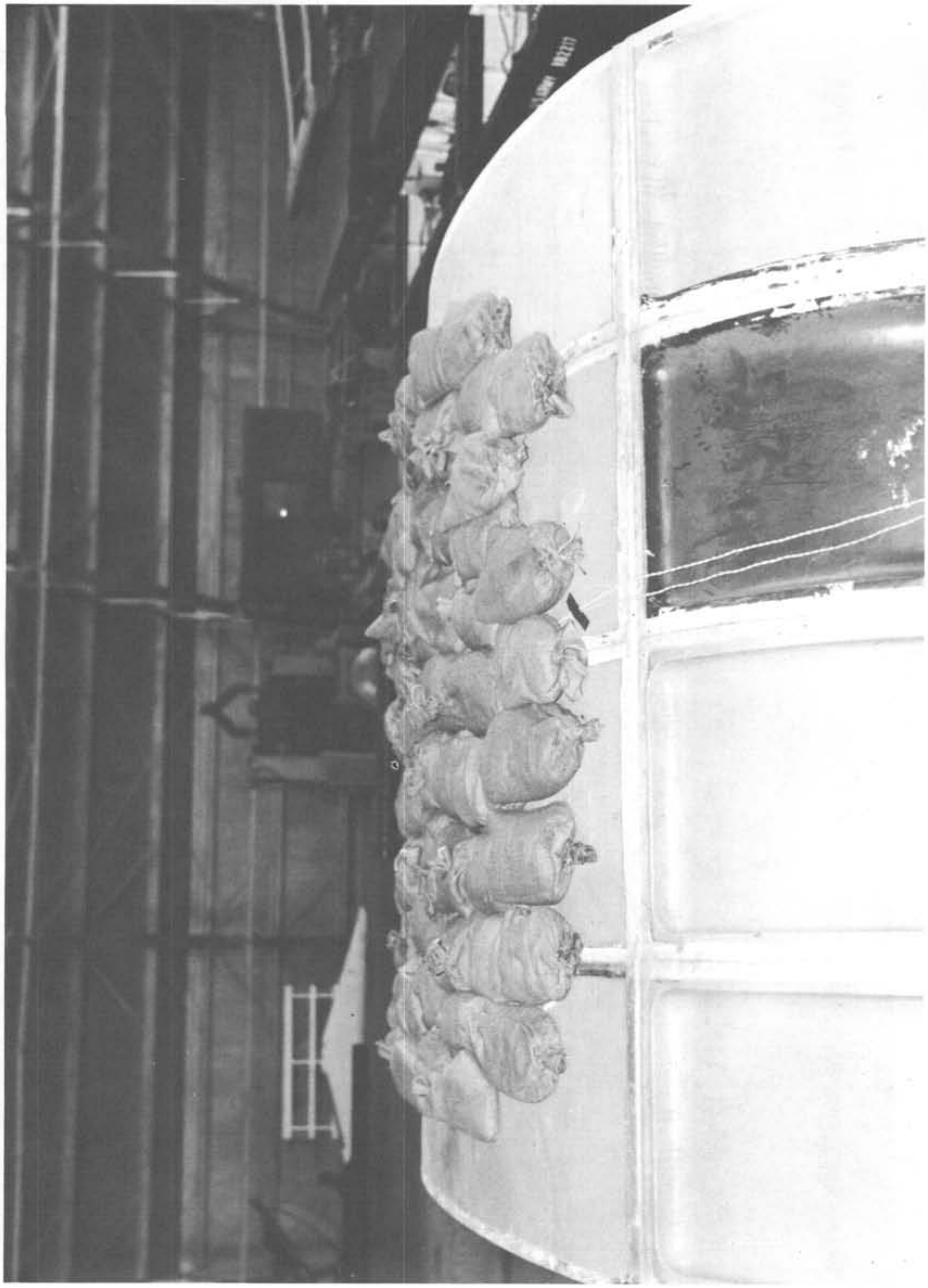


Figure 8. Test Setup for Application of Simulated Snow Load on Shelter Test Module

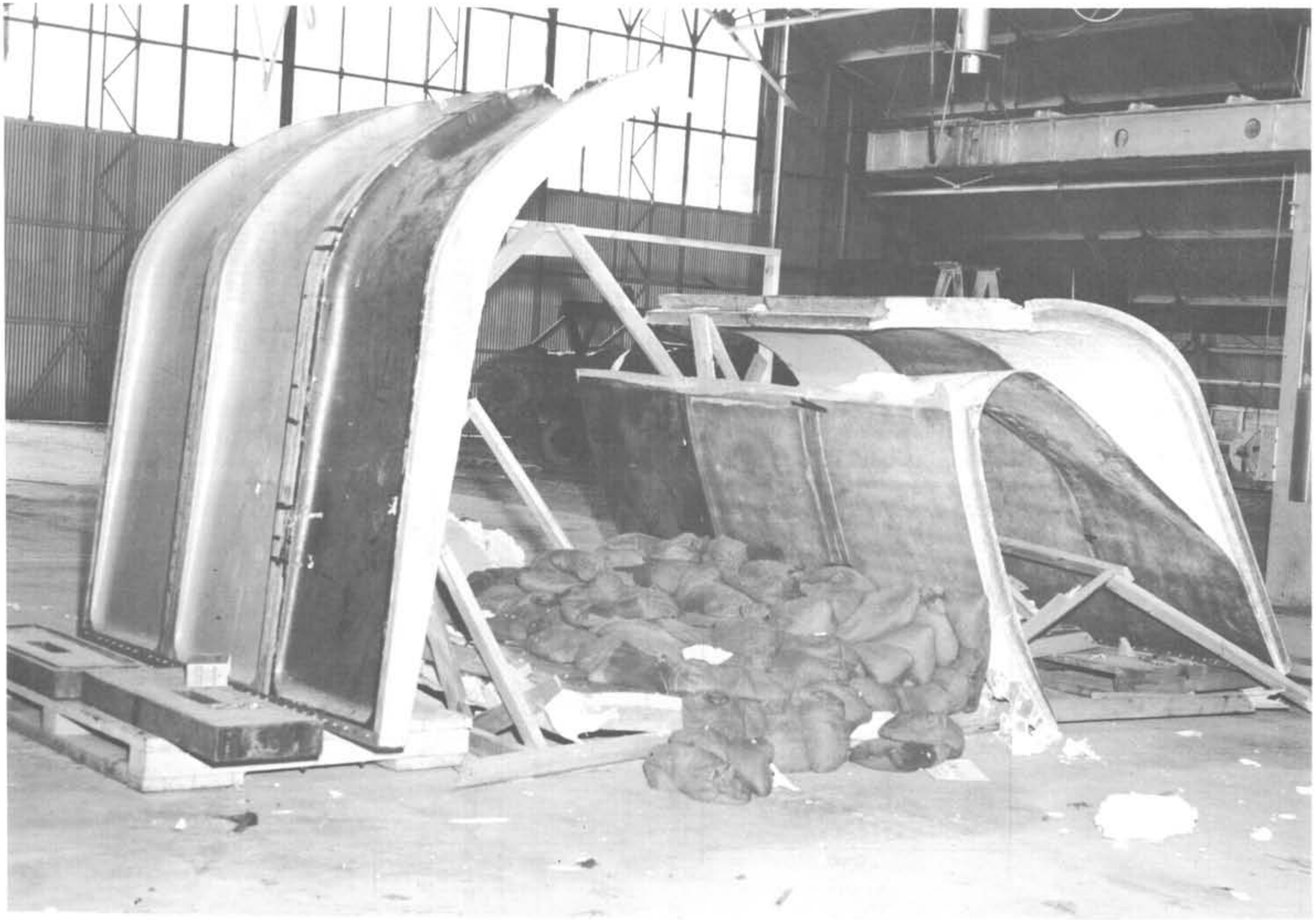
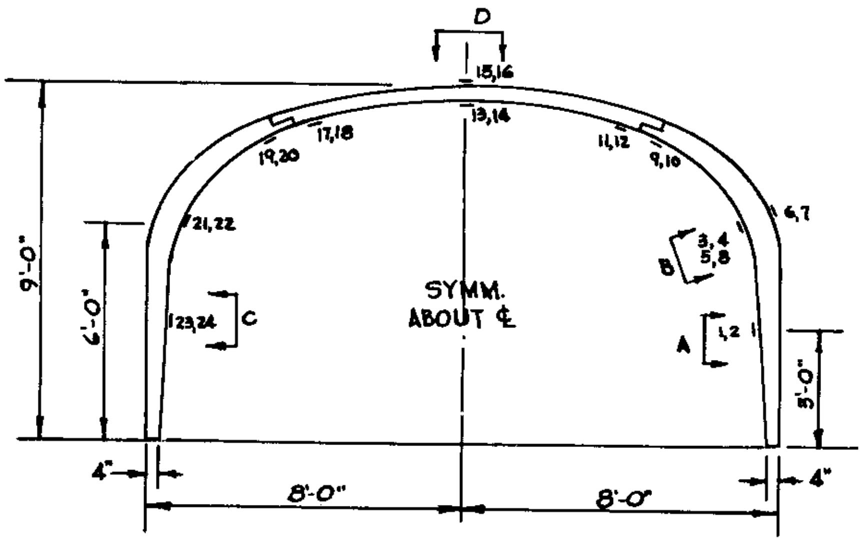
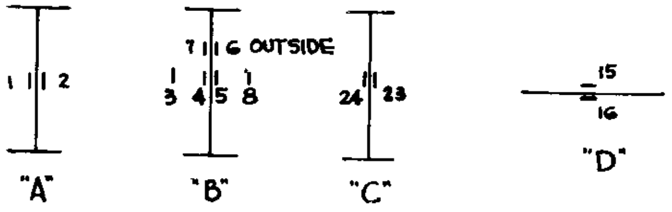


Figure 9. Failure of Shelter Test Module Under 50 PSF Sustained Simulated Snow Load



LOCATION OF STRAIN GAGES
SNOW LOAD TEST



NOTES:

1. STRAIN GAGES LOCATED ON BOTH SIDES OF LONGITUDINAL JOINT, ALONG RIB PORTION OF PANEL, EXCEPT FOR GAGES 3 + 8 THAT WERE POSITIONED MIDWAY ON THE PANEL FACE.
2. GAGES 6, 7, 15 + 16 WERE LOCATED ON THE OUTSIDE SURFACE OF SHELTER; THE REST, ON THE INTERIOR SURFACE OF IT.

FIG. 10

E=0.80×10⁶ PSI
STRESSES: PSI
MOMENTS: FT-LBS.

SNOW LOAD TEST
PLASTIC BUILDING - 16'×12'

LOAD	450#		900#		1350#		1590#		1830#		2070#		2310#	
GAGES	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT
1	-136	35.8	-180	47.4	-260	68.5	-292	76.9	-348	91.6	-380	100.1	-348	91.6
2	-124	32.6	-196	51.6	-260	68.5	-308	81.1	-348	91.6	-380	100.1	-348	91.6
3	-148	17.4	-260	30.5	-372	43.7	-420	49.4	-484	56.9	-532	62.5	-508	59.7
4	-252	74.6	-500	147.9	-740	218.9	-884	261.5	-1020	301.8	-1164	344.4	-1212	358.6
5	-248	73.4	-496	146.7	-736	217.7	-888	262.7	-1000	295.8	-1128	333.7	-1176	347.9
6	276	81.6	544	160.9	824	243.8	976	288.7	1152	340.8	1296	383.4	1528	452.0
7	272	80.5	536	158.6	816	241.4	960	284.0	1128	333.7	1272	376.3	1496	442.6
8	-124	14.6	-252	29.6	-332	39.0	-412	48.4	-452	53.1	-508	59.7	-476	55.9
9	-188	40.7	-352	76.3	-424	91.9	-480	104.0	-600	130.0	-632	136.9	-552	119.6
10	-180	39.0	-328	71.1	-416	90.1	-488	105.7	-584	126.5	-624	135.2	-720	156.0
11	-108	23.4	-184	39.9	-168	36.4	-184	39.9	-256	55.5	-216	46.8	-272	58.9
12	-108	23.4	-180	39.0	-164	35.5	-164	35.5	-236	51.1	-204	44.2	-244	52.9
13	640	93.9	1152	169.0	1576	231.1	1760	258.1	1936	283.9	2056	301.5	2072	303.9
14	636	93.3	1156	169.5	1572	230.6	1788	262.2	1940	284.5	2052	301.0	2084	305.6
15	-428	62.8	-532	78.0	-668	98.0	-724	106.2	-772	113.2	-828	121.4	-948	139.0
16	-724	106.2	-724	106.2	-916	134.3	-1052	154.3	-1124	164.8	-1172	171.9	-1308	191.8
17	-104	22.5	-156	33.8	-204	44.2	-260	56.3	108	23.4	140	30.3	124	26.9
18	-104	22.5	-196	42.5	-204	44.2	-236	51.1	-28	6.7	20	4.3	12	2.6
19	-172	37.3	-336	72.8	-448	97.1	-544	117.9	-496	107.5	-512	110.9	-568	123.1
20	-208	45.1	-216	46.8	-312	67.6	-416	90.1	-224	48.5	-296	64.1	-392	84.9
21	-224	66.3	-424	125.4	-608	179.9	-744	220.1	-824	243.8	-888	262.7	-1080	319.5
22	-268	79.3	-484	143.2	-716	211.8	-876	259.2	-972	287.6	-1052	311.2	-1260	372.8
23	-116	30.5	-196	51.6	-284	74.8	-364	95.9	-396	104.3	-396	104.3	-548	144.3
24	—	—	-224	59.0	-312	82.2	-392	103.2	-416	109.5	-400	105.3	-592	155.9
℄ Δ	0.250"		0.5625"		1.0625"		1.250"		1.375"		1.50"		1.625"	

LOAD	2550#		3000#		3300#		3600#		3900#		4200#		4500#	
GAGES	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT	STRESS	MOMENT
1	-524	138.0	-668	175.9	-692	182.2	-796	209.6	-804	211.7	-852	224.4	-900	237.0
2	-532	140.1	-844	222.2	-692	182.2	-804	211.7	-828	218.0	-860	226.5	-908	239.1
3	-692	81.3	-908	106.7	-940	110.4	-1076	126.4	-1116	131.1	-1172	137.7	-1252	147.1
4	-1444	427.2	-1756	519.5	-1892	559.7	-2132	630.7	-2244	663.8	-2412	713.6	-2572	760.9
5	-1408	416.5	-1688	499.4	-1864	551.4	-2072	613.0	-2224	657.9	-2328	688.7	-2512	743.1
6	1488	440.2	1760	520.7	1944	575.1	2096	620.1	2296	679.2	2504	740.8	2664	788.1
7	1448	428.4	1712	506.5	1888	558.5	2032	601.1	2232	660.3	2432	719.5	2592	766.8
8	-652	76.6	-788	92.6	-884	103.9	-1004	118.0	-1044	122.7	-1076	126.4	-1124	132.1
9	-680	147.3	-640	138.7	-800	173.3	-904	195.9	-960	208.0	-944	204.5	-920	199.3
10	-664	143.9	-648	140.4	-784	169.9	-888	192.4	-944	204.5	-920	199.3	-896	194.1
11	-200	43.3	-136	29.5	-224	48.5	-272	58.9	-304	65.9	-192	41.6	-144	31.2
12	-180	39.0	-84	18.2	-196	42.5	-228	49.4	-268	58.1	-148	32.1	-100	21.7
13	2168	318.0	2416	354.3	2784	408.3	2952	433.0	3264	478.7	3536	518.6	3880	569.1
14	2156	316.2	2396	351.4	2724	399.5	3076	451.1	3316	486.3	3532	518.0	3772	553.2
15	-948	139.0	-1060	155.5	-1244	182.4	-1364	200.0	-1380	202.4	-1444	211.8	-1532	224.7
16	-1388	203.6	-1492	218.8	-1772	259.9	-1972	289.2	-2044	299.8	-1756	257.5	-2324	340.9
17	420	91.0	580	125.7	572	123.9	428	92.7	108	23.4	108	23.4	124	26.9
18	12	2.6	180	39.0	164	35.5	36	7.8	156	33.8	140	30.3	116	25.1
19	-592	128.3	-528	114.4	-632	136.9	-784	169.9	-752	162.9	-816	176.8	-904	195.9
20	-384	83.2	-424	91.9	-528	114.4	-712	154.3	-880	190.7	-952	206.3	-1000	216.7
21	-1192	352.6	-1304	385.8	-1488	440.2	-1648	487.5	-1704	504.1	-1824	539.6	-1920	568.0
22	-1380	408.2	-1508	446.1	-1724	510.0	-1900	562.1	-1988	588.1	-2116	626.0	-2236	661.5
23	-644	169.6	-668	175.9	-812	213.8	-852	224.4	-860	226.5	-908	239.1	-932	245.4
24	-688	181.2	-712	187.5	-856	225.4	-904	238.0	-904	238.0	-960	252.8	-976	257.0
℄ Δ	1.6875"		1.875"		2.25"		2.3125"		2.5625"		2.7500"		2.875"	

FIG. 11.

SNOW LOAD TEST
LONG RANGE LOADING

LOAD PSF	DATE	DEFLECTIONS- INS.	
		FRONT	BACK
0	3/9/62	0	0
20	3/9/62	1.125	1.250
20	3/12/62	1.250	1.1875
0	3/12/62	0.125	0.250
30	3/12/62	1.500	1.3125
30	3/13/62	1.750	1.5625
0	3/13/62	0.375	0.3125
40	3/13/62	2.125	2.000
40	3/14/62	2.375	2.375
0	3/14/62	0.625	0.4375
50	3/14/62	3.250	3.000
50	3/14/62	FAILURE	

FIG. 12.

Figure 13. Spraying Glass Fiber Laminate on Interior of Inflated Structure

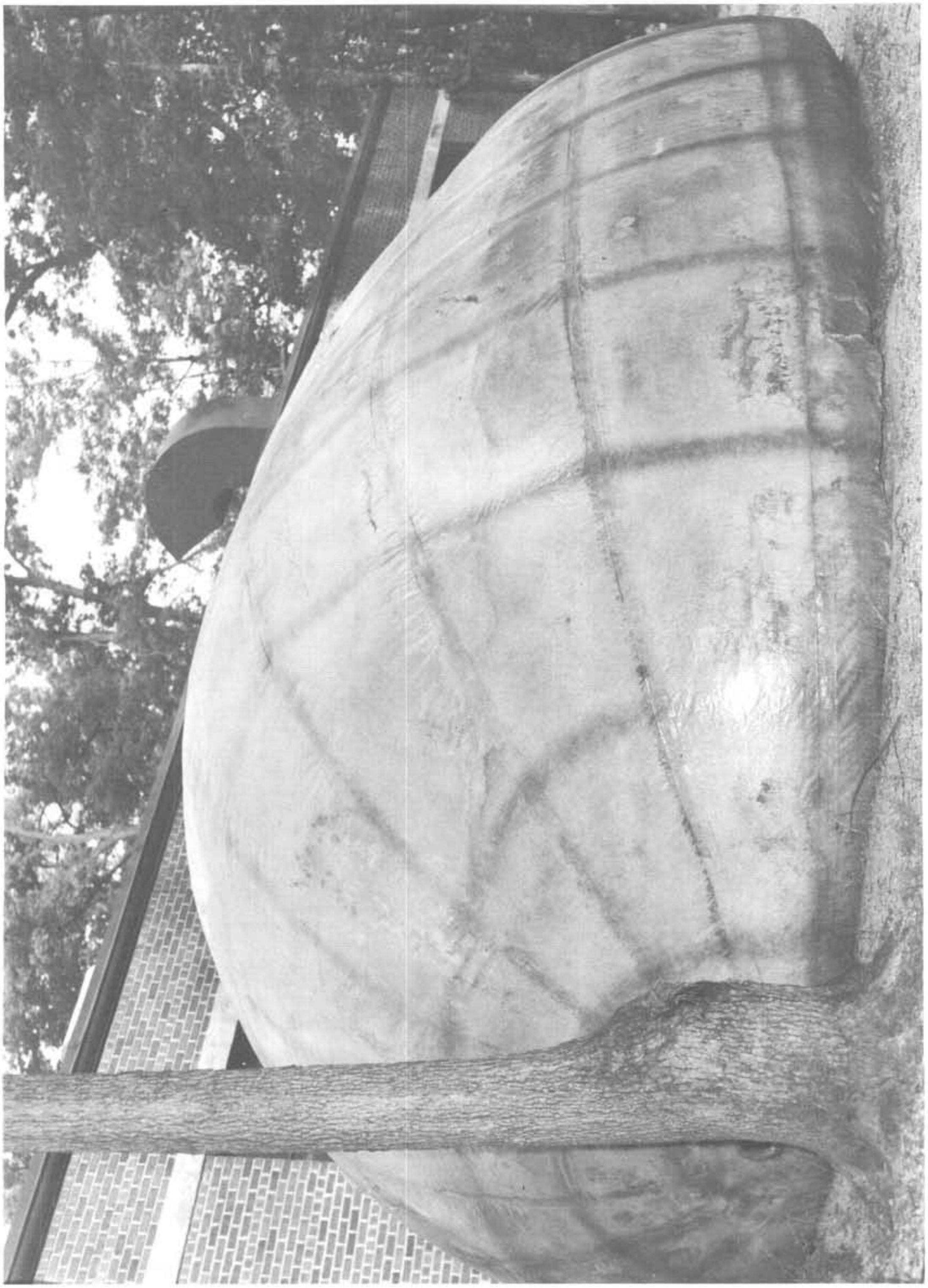


Figure 14. Exterior of Sprayed Shelter. The Structure Consists of A 3" Foam Core with Interior and Exterior Skin of Reinforced Plastic

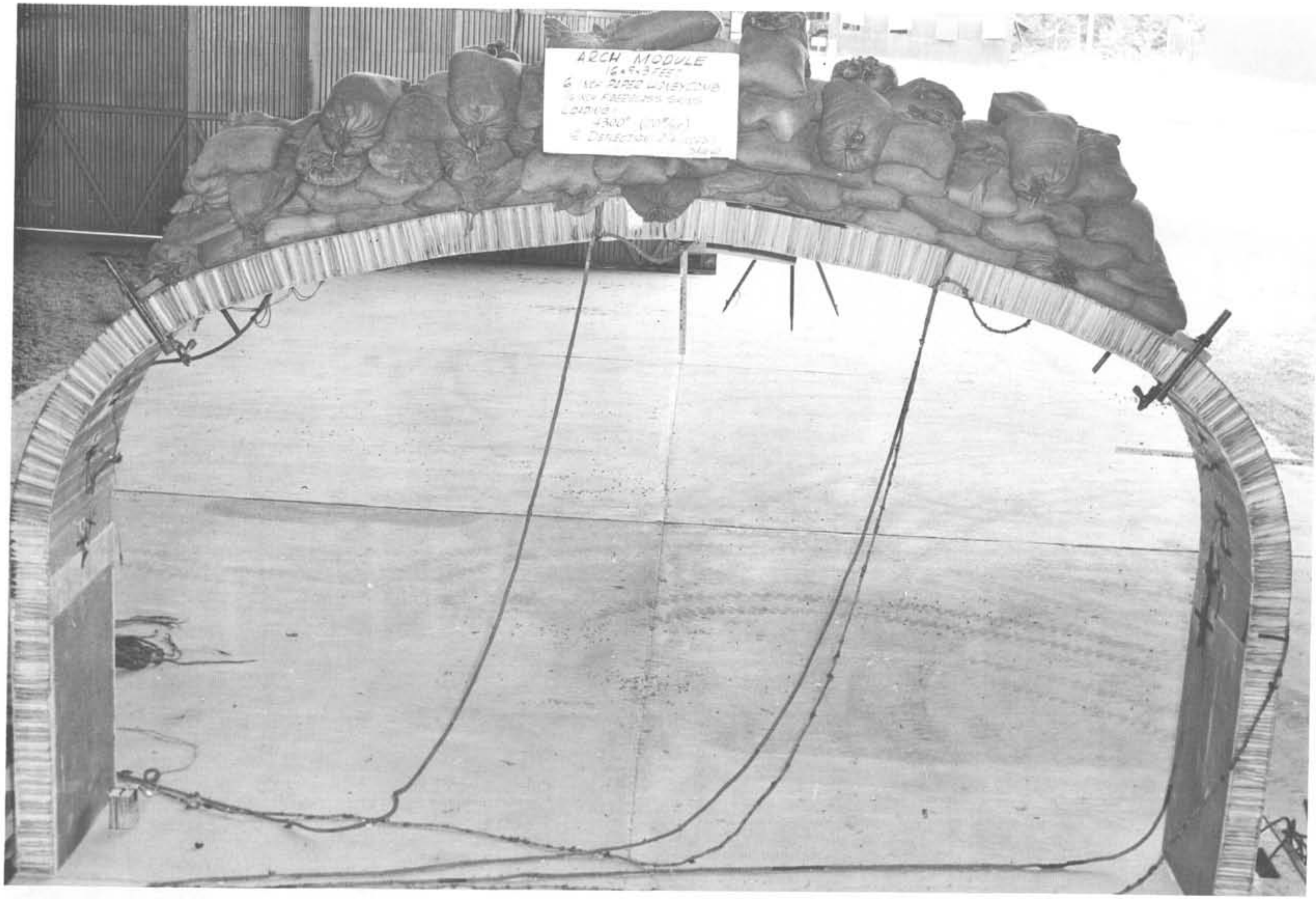


Figure 15. One of the Several Paper Honeycomb Shaped Panels Designed and Tested at Usaerdl. Note the Extreme Loading of 120 lb./sqx ft.

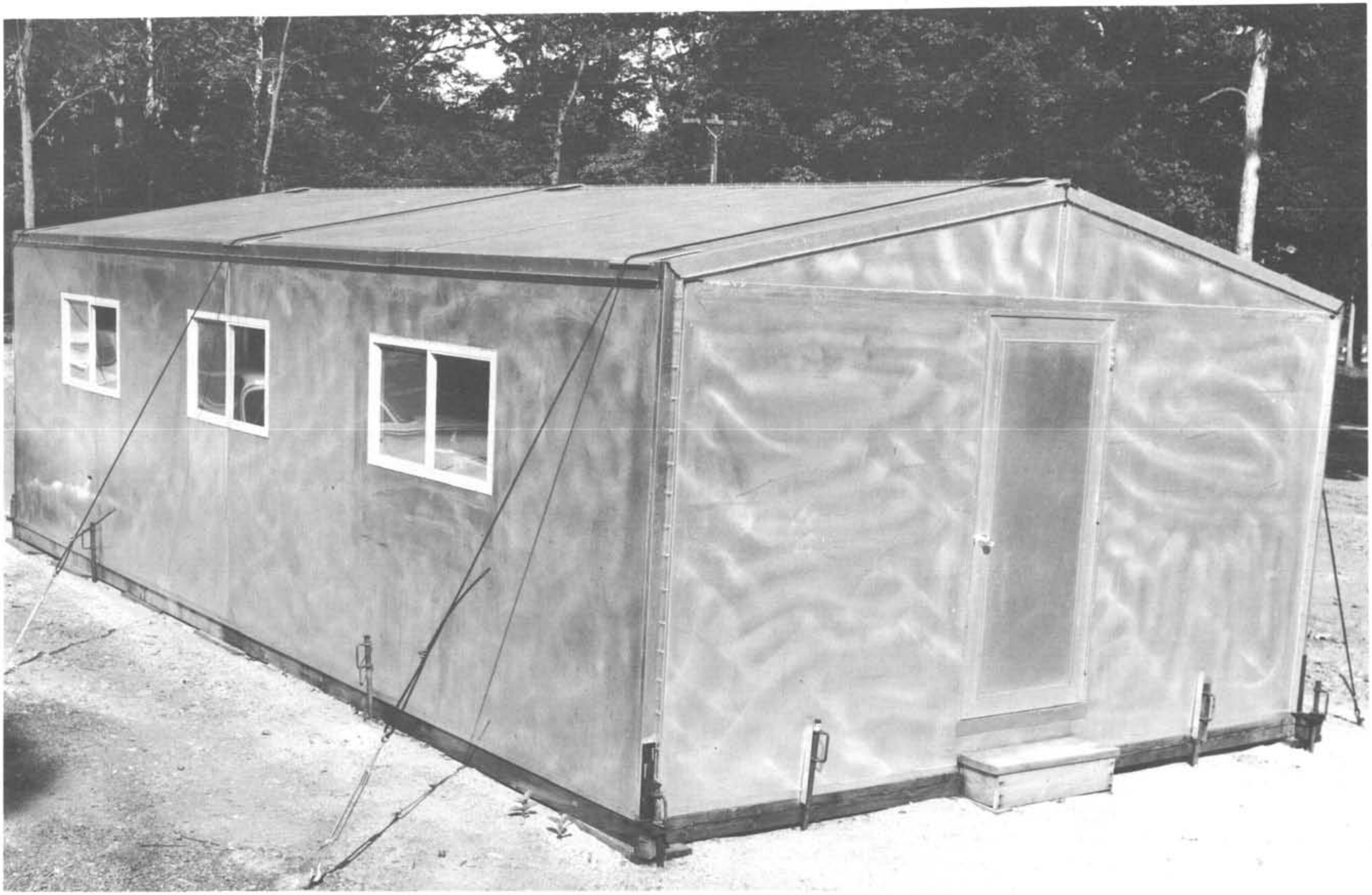


Figure 16. Aluminum Faced Paper Honeycomb Core Structure. Excessive Fabrication Time Caused Abandonment of this Design

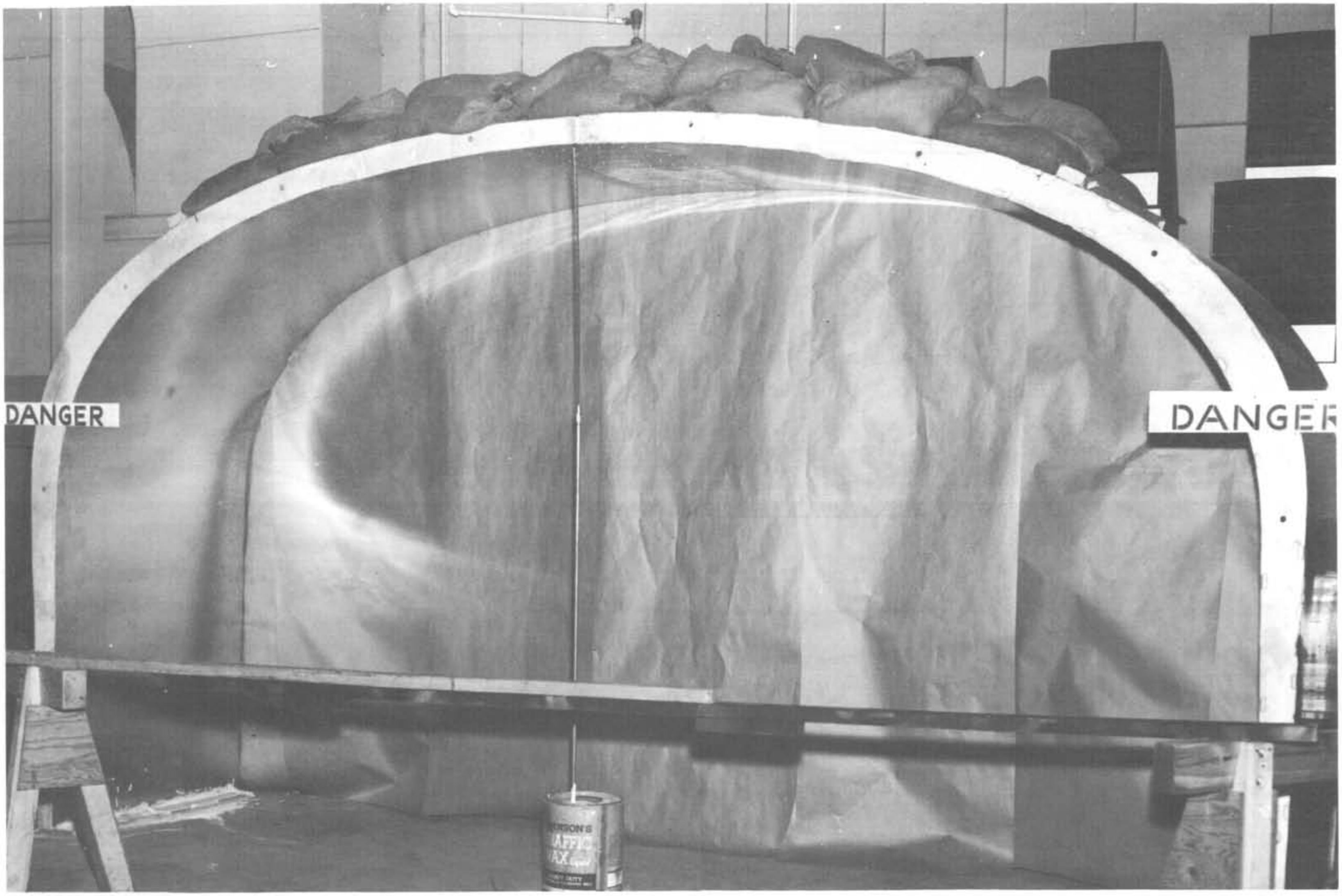


Figure 17. Present Module Design -----Taking Observations of Deflections and Creep under 50 P.S.F. Loading

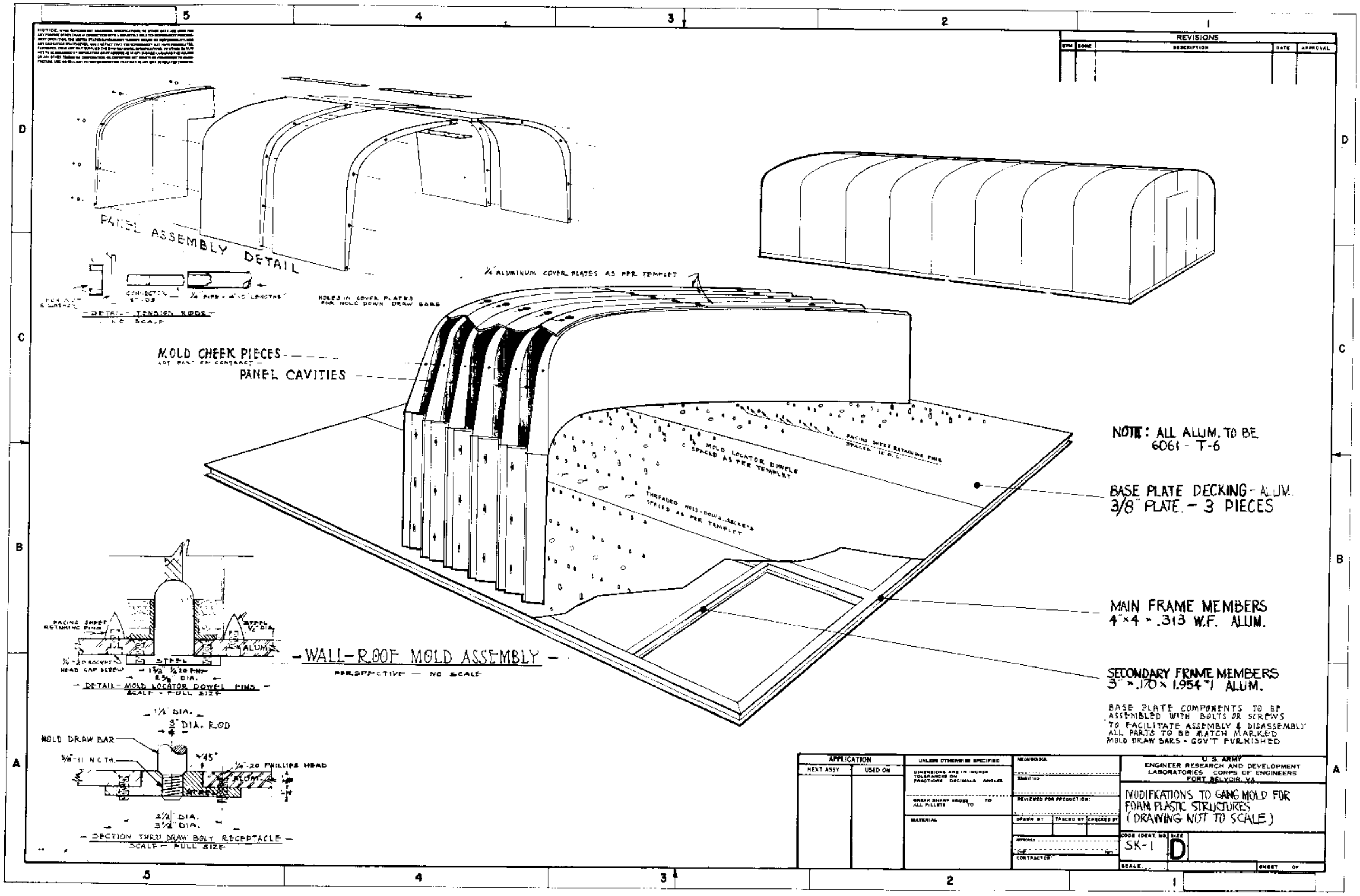


Figure 18. Line Drawing of Molds and Building. A Similar System of Molds is used for Producing End Wall Units

Figure 19. The Materials and Equipment used in the Process that Preceded the Froth Foam System. It is all that is Necessary to Fill a Half Module with Foam of 2 lb/cu.ft. Density

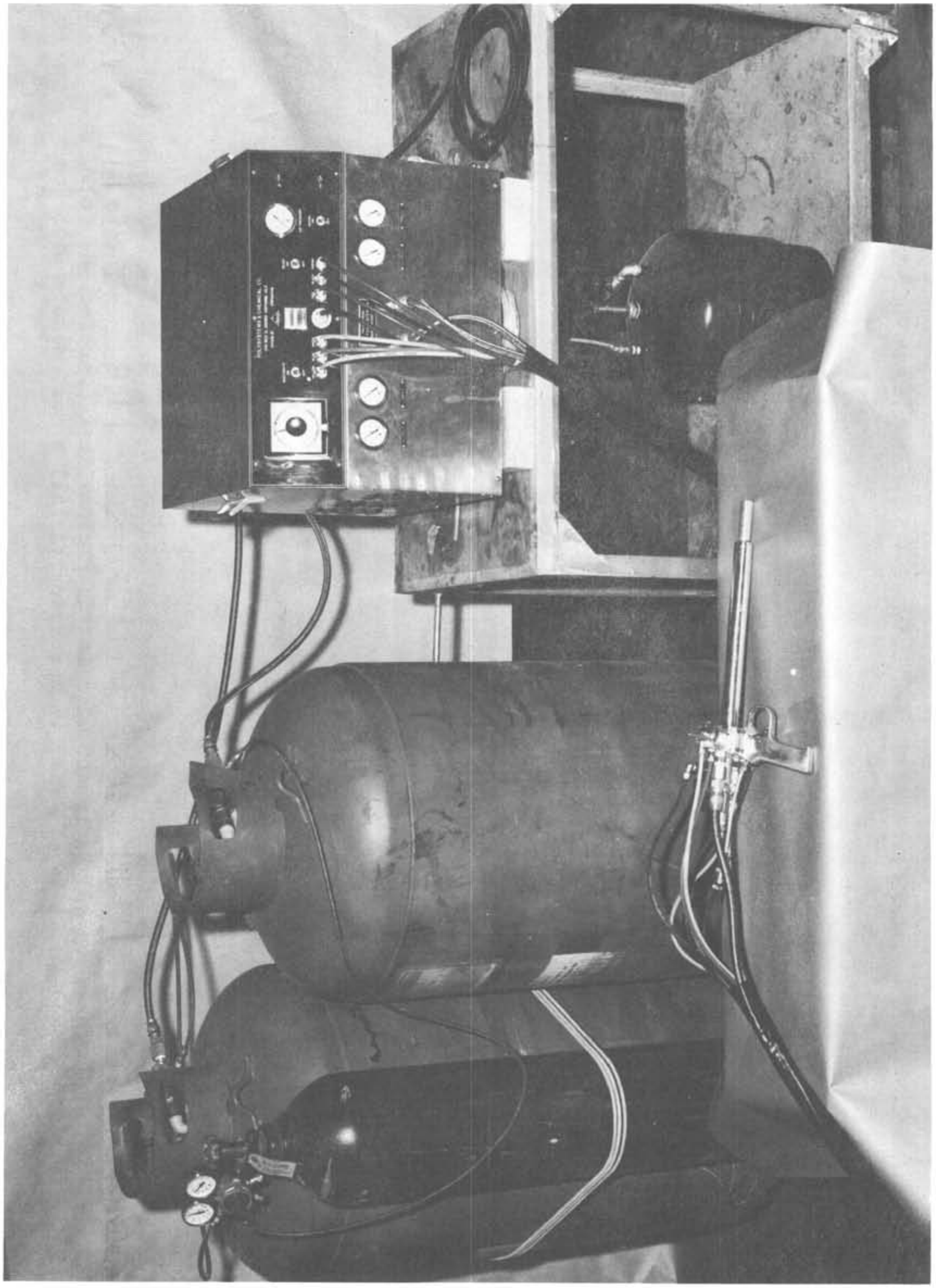


Figure 20. The Polyurethane Froth Foam Dispenser Presently Used in the System

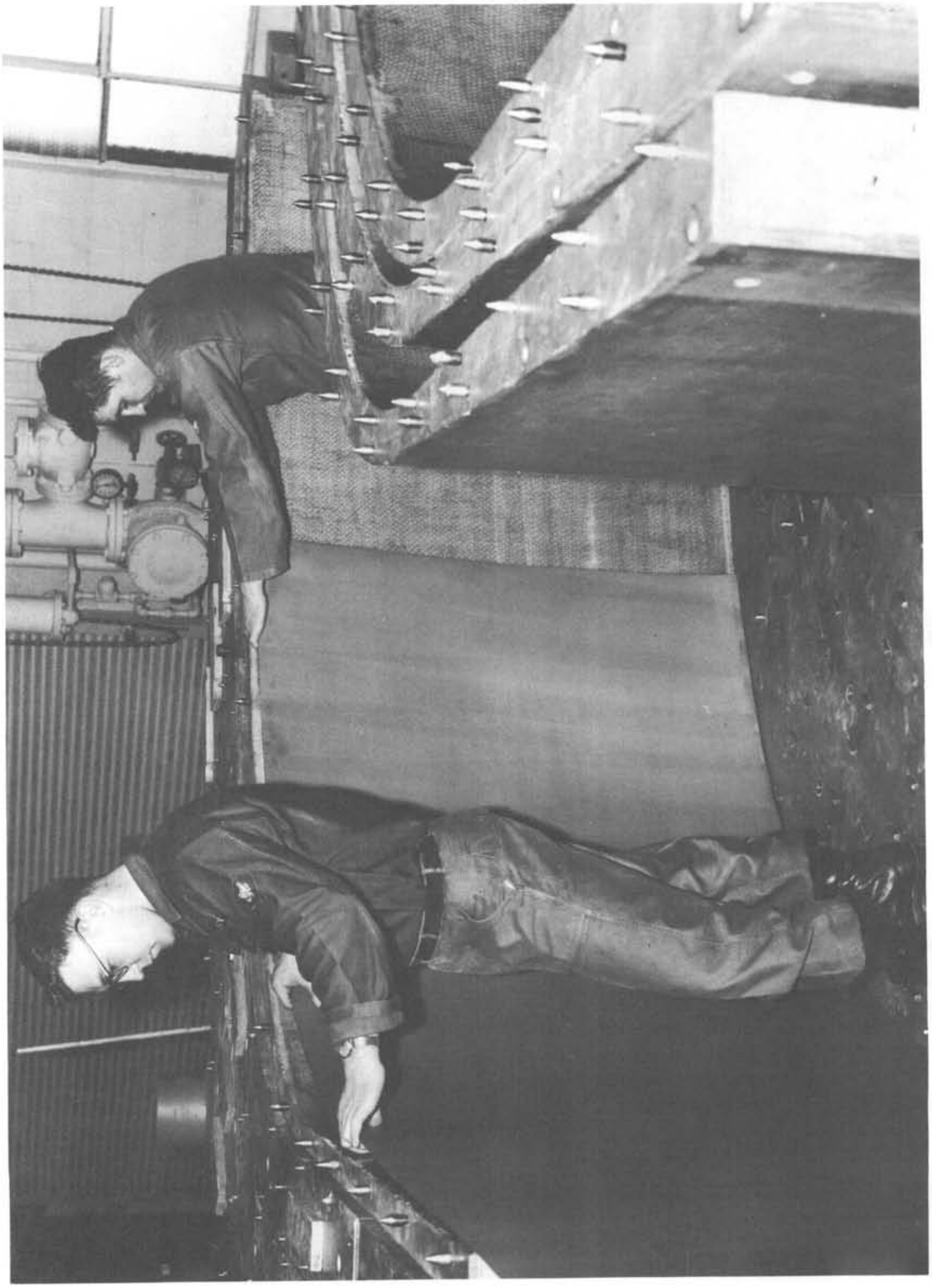


Figure 21. Placing Aluminum Facing Sheet in Mold Preparatory to Casting

Figure 22. Injecting 2 lb. per cu. ft. Froth Foam into the Six Cavity Mold

Figure 23. One of Six Completed Panels Removed from Mold

Figure 24. The Typical 16' Wide Aluminum Faced Foam Plastics Structure Installed at Camp A.P. Hill, Va.