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FOAM OVER AIR INFLATABLE STRUCTURE
FEASIBILITY STUDY

Alvin Smith, et al

Naval Ammunition Depot

Prepared for:

Air Force Civil Engineering Center

April 1974

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Block 20. continued

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FOREWARD

This report was prepared by the Naval Ammunition Depot, Crane, Indiana. Funds were provided by MIPR AFCEC 73-00068 and the work was administered under AFCEC, Tyndall AFB, FL.

This report summarizes work done between 23 April 1973 and 30 July 1973. Major William H. Ibsch was Project Manager.

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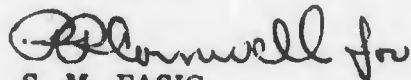
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FOAM OVER AIR INFLATABLE STRUCTURE
FEASIBILITY STUDY

By

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ABSTRACT

A study has been conducted to determine the feasibility and practicality of using dual-wall air inflatable sections as forms upon which can be constructed and fabricated a rigid foam shell that will be self-supporting and capable of withstanding certain conditions of environmental stress such as wind and snow loading.

The study also provided for the acquisition and compilation of data regarding equipment, tools, materials, mold releases, protective coatings and structural design. These data were compiled from laboratory studies, literature from industry, personal interviews and practical experience in applying rigid foams in various situations.

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The authors express gratitude and thanks to the personnel of the Air Force Civil Engineering Center (AFSC) - Maj. William Ibsch, project manager; Mr. Robert Van Orman; Captain Hanson; and Sargeants Tom Carroll and Bob Meece for assistance in design and testing.

Thanks also to company representatives of the various companies contacted for technical information which was readily supplied upon request. The mention of specific persons or companies is intentionally avoided.

Finally, a special thanks to Mr. Tom Bresse and associates at the U. S. Army Natick Laboratories for providing historical information on work performed there covering a period of more than ten years.

OBJECTIVE

The principal objective of the studies described herein was to determine the feasibility of using dualwall air inflatable shelter sections as forms or molds for constructing a rigid foam structure. Subsequent to construction of the foam structure, the air would be removed from the inflated structure and it would be removed for reuse. Data on all phases of the study were recorded for future use in the actual construction and finishing of general purpose arch structures in various locations.

INTRODUCTION

The Naval Ammunition Depot, Crane contracted with the Air Force Civil Engineering Center, Tyndall AFB to conduct a feasibility study involving the use of air inflatable dual-wall shelter section as forms for creating a rigid foam general purpose arch shelter. Funds were provided by MIPR AFCEC 73-00068.

The air inflatable sections, when erected, are semi-circular arches with a uniform outside radius of about 27 feet. Section wall thickness is about three feet and length is about 12 feet. Sections may be joined along the edges to form a shelter of any length in multiples of 12 feet. These inflated sections are capable of supporting a man and a reasonable amount of uniformly distributed weight of reinforcing materials and the like.

Laboratory studies, supplemented by literature information, personal interviews and practical experience in working with rigid foams, formed the data acquisition backbone of the study. Partial erection of a foam shell over two connected sections (kept inflated by continuous operation of inflator motors) was carried out in order to learn of the post-theoretical aspects of the feasibility study.

DISCUSSION

Upon the establishment of a MIPR from AFCEC to NAD Crane, a Statement of Work (SOW) (Appendix 1) and a Program Milestone Chart (Appendix 2) were agreed upon as being the basis for conduct of the feasibility study. Reference may be made to these appendices for specific requirements and conditions as well as a time table for the program.

DESIGN: NAD Crane selected certain conditions within the confines of the SOW as being a reasonable starting point for designing the structure. Basically, the starting point was selected based on one of the commercially available spray polyurethane foam systems which possesses the minimum physical properties likely to be found in competitive procurement. Calculations based on this system would then provide a structure which would be at least adequate and which would probably not be weakened by selecting any commercially available spray foam system.

Preliminary structural calculations inserted following this statement were performed based on assumptions as stated.

ARCH SHAPED BUILDING

(Refer to Fig. 1)

Preliminary calculations to determine thickness of foam necessary to carry a snow load of 40 psf and a horizontal wind load of 40 psf. Some assumptions will be made to simplify the calculations but these assumptions will result in a stronger building than would result otherwise.

Assumption No. 1: The snow load of 40 psf shall be considered to be uniform across a horizontal projection and used as a concentrated load. A one foot section of the building shall be used and the load and reactions due to the load shall be on a per linear foot of building basis.

(Refer to Fig. 2)

for a full semicircular arch with the load P at the centerline

$$H_A = H_B = 0.459P$$

$$V_A = V_B = P/2$$

$$M_A = M_B = 0.11PR$$

Therefore -

$$H_A = H_B = 0.459 (2160) = \underline{992 \text{ lbs.}}$$

$$V_A = V_B = 2160/2 = \underline{1080 \text{ lbs.}}$$

$$M_A = M_B = 0.11 (2160) (27) = \underline{6415 \text{ ft. lbs.}}$$

It is quite evident that the section modulus sufficient to resist this bending moment will have sufficient strength to carry the shear and compressive loads imposed at the bottom of the arch.

Now to calculate the section modulus needed to resist this bending moment.

The properties we will be concerned with are:

Compressive strength

Parallel to rise 26 psi

Perpendicular to rise 14 psi

FIG. 3a

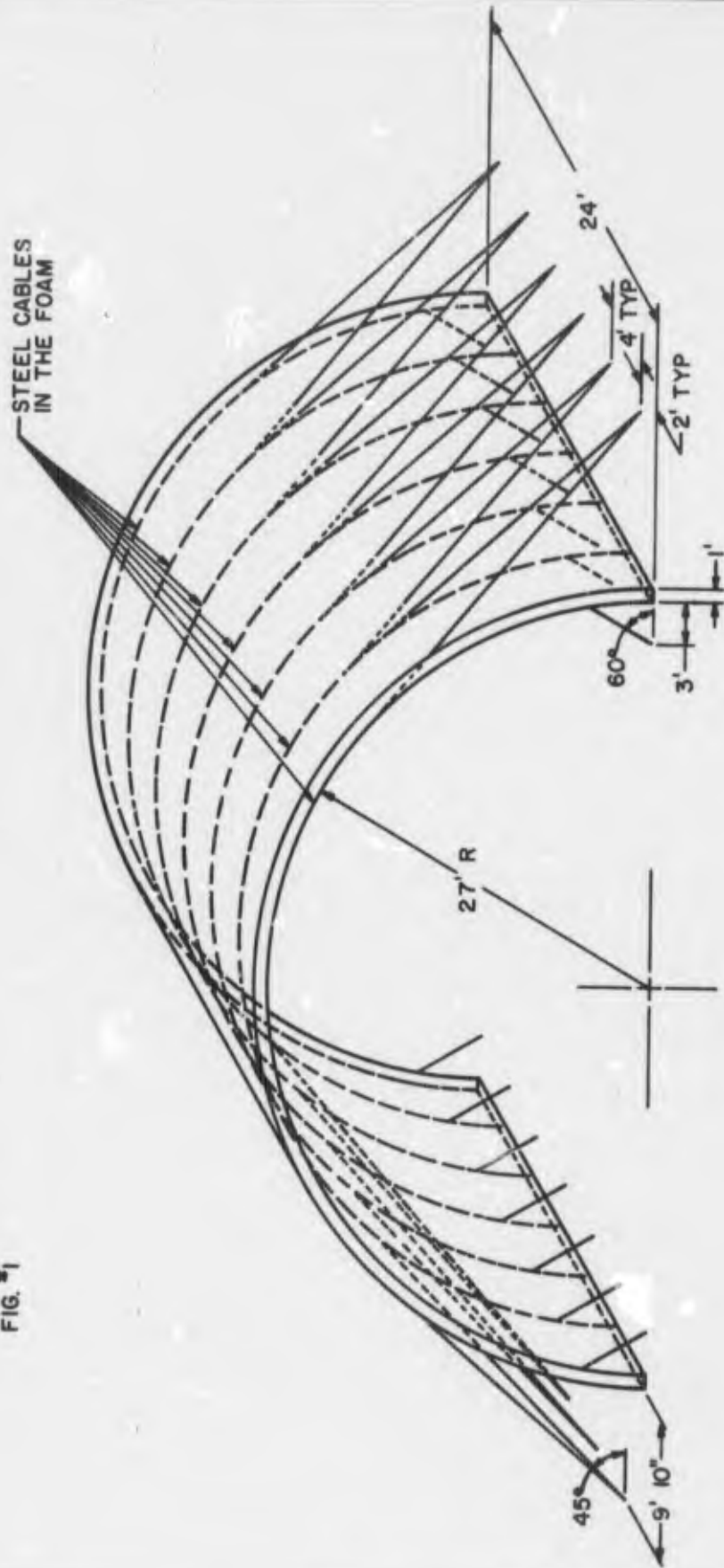


FIG. #2
SNOW LOADING

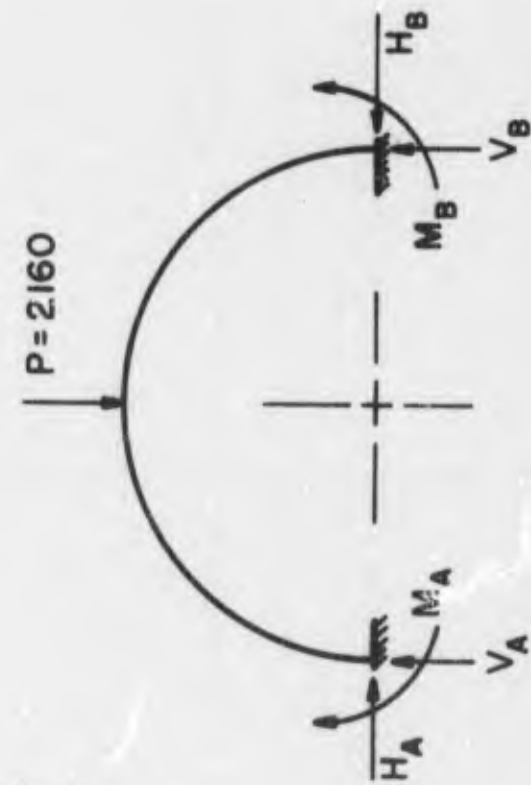
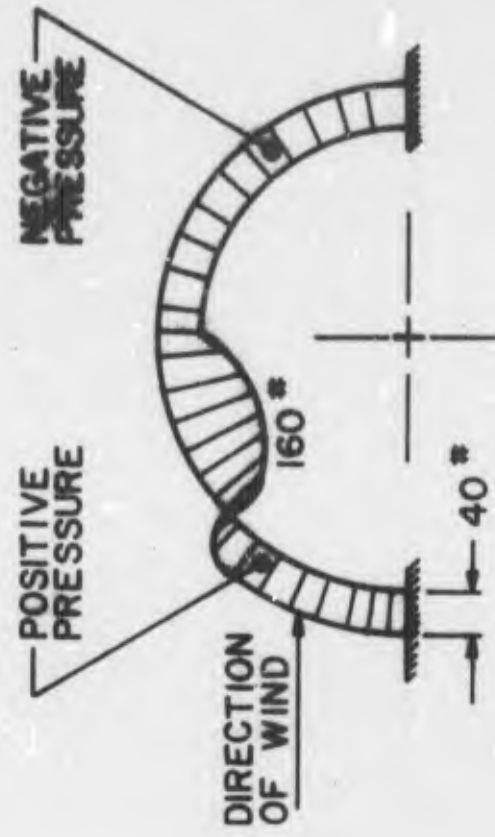


FIG. #3
WIND LOADING



Shear strength
Parallel to rise 23 psi

Tensile strength
parallel to rise 45 psi
perpendicular to rise 25 psi

$$S = \frac{M}{Z}$$

Where S = stress = 14 psi = 2016 psf
M = bending moment = 6415
Z = section modulus = ?

$$\therefore Z = \frac{M}{S} = \frac{6415}{2016} \text{ ft}^3 = 3.18$$

$$+Z = \frac{bh^{-2}}{6} = 3.182$$

$$h = \sqrt{\frac{6z}{b}} = \sqrt{\frac{6 \times 3.182}{1}} = 4.37 \text{ ft.}$$

Where b = width = 1 ft.
h = height of section = 4.37 ft.

Conclusion: This thickness of foam is impractical.

WIND LOADING

Assumption No. 2: The cables used to tie down the structure will carry all the load due to the wind, the foam will transfer all the load to the cables. The wind load shall be assumed to take the shape as pictured in Fig. No. 3.

Now assuming the cable embedded in the foam and one cable at 45° to the horizontal on the side will carry the suction or negative pressure which would average approximately 70 psf. The total load per linear ft. of building would be:

$$70 \times 85 = 5950 \text{ lbs./ft.}$$

Now assuming these cables are on 4' centers, the load carried by each cable would be:

$$\frac{5950 \times 4}{2} = \underline{11900 \text{ lbs.}}$$

One cable on the side at 45° to the horizontal would carry the positive pressure which on a vertical projection would be:

$$27 \times 40 = 1080 \text{ lbs.}$$

With cables on 4' centers the load imposed would be:

$$\frac{4 \times 1080}{\text{COS } 45^\circ} = \underline{6110 \text{ lbs.}}$$

Cable sizes necessary to carry these loads would be 3/8" wire rope.

Now to calculate the section modulus necessary to transmit the load to the cables. The extreme case shall be considered, that being the load

being concentrated at the center of the building section 4' in width and 19.08' tall, refer to Fig. No. 4. Load carried on each section shall be:

$$4 \times 19.08 \times 40 = 4053 \text{ lbs.}$$

$$\text{Moment arm} = 19.08/2 = 9.54 \text{ lbs.}$$

$$\text{Let } S = 2017 \text{ psf}$$

$$\text{Using } S = \frac{M}{Z}$$

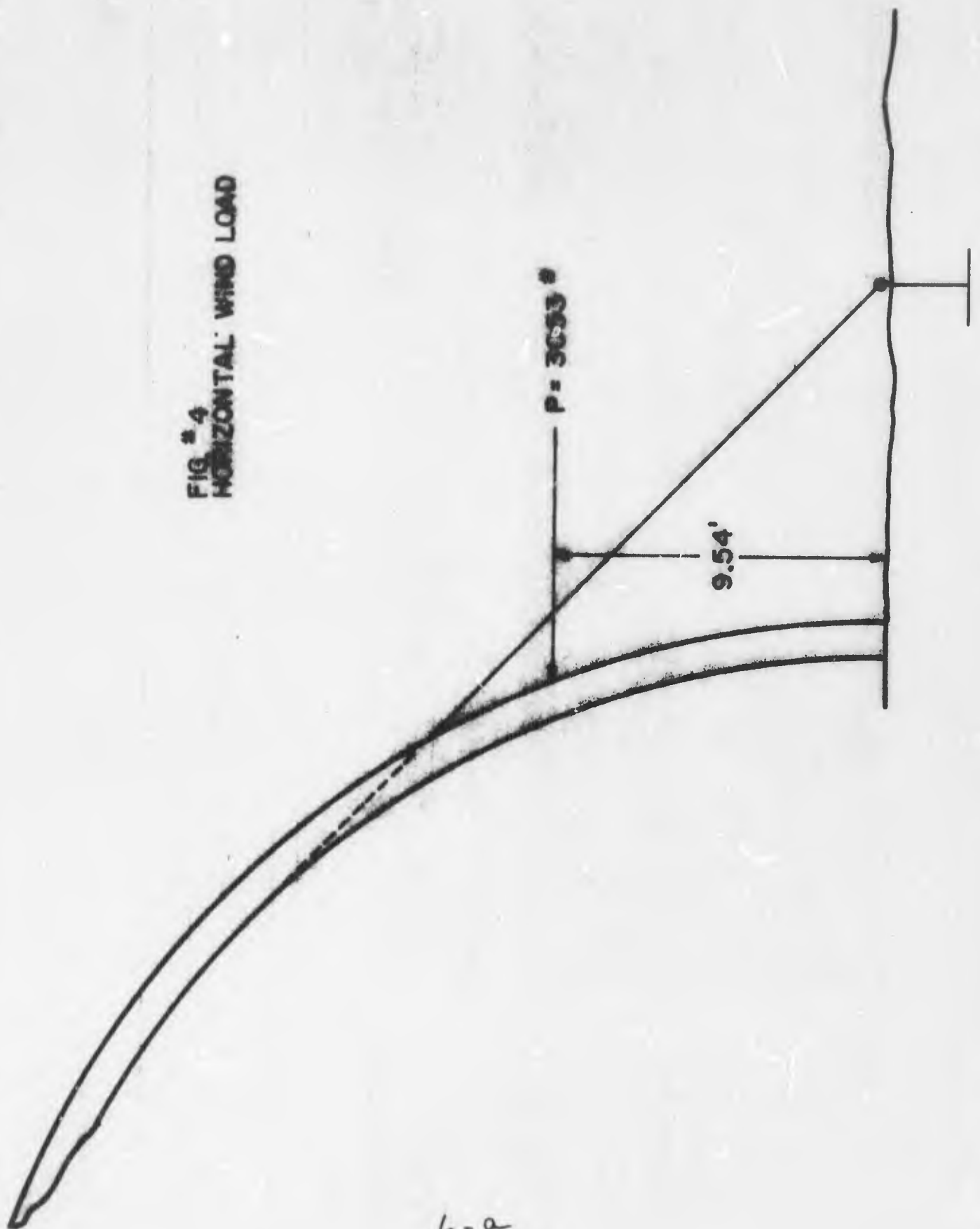
$$Z = \frac{9.54 \times 3053}{2016} = 14.45 \text{ ft}^3$$

$$\text{Now } h = \sqrt{\frac{Z \times 6}{b}} \quad \text{where } b = 4$$

$$h = \sqrt{\frac{14.45 \text{ ft}^3 \times 6}{4}} = \underline{4.6 \text{ ft.}}$$

Conclusion, this foam thickness is impractical.

FIG. # 4
HORIZONTAL WIND LOAD



6-a

LABORATORY STUDIES: Concurrently with structural calculations, laboratory studies were set up using various reinforcing materials. A synopsis of sample configuration and construction and test results are provided in the following insert:

LABORATORY TESTING

Results from simple beam testing, 6 different types specimens were used:

1. All foam:
2. Insect screen on 1 side (tension)
3. Chicken wire on 1 side (tension)
4. Insect screen on both sides.
5. Chicken wire on both sides
6. Fiberglass on one side

Loads and stresses given are at breaking strength.

All foam

Load - 21 lbs.

Stress - 41 psi

Load - 27 lbs.

Stress - 53 psi

Insect screen on one side (tension)

Load - 130 lbs.

Stress - 135 psi

Load - 145 lbs.

Stress - 141.6 psi

Chicken wire on both sides

Load - 60 lbs.

Stress - 49 psi

Insect screen on both sides

Load - 125 lbs.

Stress - 78.125 psi

Fiberglass on one side

Load - 175 lbs.

Stress - 194 psi

Chicken wire on one side

Load - 55 lbs.

Stress - 50 psi

Expected wall thickness with strengths of sandwich construction

1. Insect screen on one side:

$$M = 6415 \text{ ft.}/\text{lb.}$$

$$Z = ? \quad b = 1 \text{ ft}^2$$

$$S = 133 \text{ psi} = 19,872 \text{ lb.}/\text{ft}^2$$

$$S = \frac{M}{Z}, \quad Z = \frac{bh^{-2}}{6} = \frac{M}{S}$$

$$\circ \circ \quad Z = \frac{6,415 \text{ ft.}/\text{lb.}}{19,872 \text{ ft}^2} = 0.323 \text{ ft}^3$$

$$h = \frac{Z \times 6}{b} = \frac{0.323 \times 6}{1} \text{ ft}^2$$

h = 1.4 ft. wall thickness

2. Chicken wire on one side

$$M = 6415 \text{ ft}/\text{lb.}$$

$$Z = ? \quad b = 1 \text{ ft.}$$

$$S = 50 \text{ psi} = 7,200 \text{ psi}$$

$$Z = \frac{6415 \text{ ft/lb}}{7200 \text{ ft}} = 0.892$$

$$h = \sqrt{\frac{0.892 \text{ ft}^3 \times 6}{1 \text{ ft.}}} = 2.32 \text{ ft. wall thickness}$$

3. Insect screen on both sides

$$M = 6416 \text{ ft./lbs.}$$

$$Z = ? \quad B = 1 \text{ ft.}$$

$$S = 78 \text{ psi} = 11,232 \text{ lb/ft}^2$$

$$Z = \frac{6415}{11,232} = 0.573 \text{ ft.}^3$$

$$h = \sqrt{\frac{0.573 \text{ ft}^3 \times 6}{1 \text{ ft.}}} = 1.85 \text{ ft. wall thickness}$$

4. Chicken wire on both sides

$$M = 6415 \text{ ft/lbs.}$$

$$Z = ? \quad b = 1 \text{ ft.}$$

$$S = 49 \text{ psi} = 7056 \text{ lb/ft}^2$$

$$Z = \frac{6415}{7056} = 0.91 \text{ ft}^3$$

$$h = \sqrt{\frac{0.91 \times 6}{1}} = 2.33 \text{ ft. wall thickness}$$

5. Fiberglass on one side

$$M = 175 \text{ lbs.}$$

$$Z = ? \quad b = 1 \text{ ft.}$$

$$S = 194 \text{ psi} = 27,936$$

$$Z = \frac{6415}{27936} = 0.23$$

$$h = \sqrt{\frac{0.23 \text{ ft}^3 \times 6}{1 \text{ ft.}}} = 1.175 \text{ ft. wall thickness}$$

DESIGN REVIEW: When the preceeding work had been completed , a design review meeting was held at NAD Crane. Present were Major Ibsch and Mr. Van Orman, AFCEC, and Mr. Alvin Smith and Mr. Larry Craig of NAD Crane. During the review, it was decided that rather than using 40 psf load factors, 20 psf would be adequate. Also provided by AFCEC was information on anchors and anchoring studies and a simplified equation which greatly helped in the recalculation to the 20 psf criteria. This simplified equation was prograded and run on a computer with the able assistance of Pat Arvin of NAD Crane.

REDESIGN: Results of recalculations are given:

DISCUSSION OF EQUATION AND TABLE OF LOADS FACTORS

Doublewall tent

Known Shape

Purpose: To estimate lift, aerodynamic drag, aerodynamic overturning moment, and anchor loads.

Given: Double wall cylinder with flat ends

Width - 56 ft.

Length - 24 ft.

Height - 28 ft.

Height/diameter ratio - 1/2

Width/length ratio - 0.5

Cell radius - not needed

Dynamic pressure is given as 20 psf - 0.139 psi

Solution:

1. Planform area A_p

$$A_p = WXL = 56 \times 24 = 1344 \text{ ft}^2$$

2. Wind floor area A_f

$$A_f = WXL = 56 \times 24 = 1344 \text{ ft}^2$$

3. Surface area A_s

$$A_s = 4l_b r \left(\frac{OB}{57.3} \right)$$

$$\begin{aligned} A_s &= 4(56)(24) \left(\frac{90}{57.3} \right) \\ &= 3444 \text{ ft}^2 \end{aligned}$$

End curtains A_s

$$\begin{aligned} A_s &= 2r^2 \left(2 \frac{OB}{57.3} - \sin OB \cos OB \right) \\ &= 2(28)^2 \left(2(1.5\%) - 0 \right) \\ &= 4924 \text{ ft}^2 \end{aligned}$$

Length of anchored sides

$$2(24) = 48$$

4. Final aerodynamic L, D, and M

Lift - $C_l Q A_p$

Where $C_l = 0.65$ from Figure 10

$$L = 0.65(20)(1344) = 17,472 \text{ LB} \quad \text{Drag} = C_d Q A_p$$

Where $C_d = 0.275$ from Fig. 12

$$D = 0.275(20)(1344) = 7,392 \text{ LBS.}$$

Overturning Moment =

$C_m Q A_p$

Where $C_m = 0.508$

$$M_{ot} = (-0.508)(20)(1344) = 13,655 \text{ ft./lb.}$$

Base anchor load

$$P_{BL} = C$$

Base anchor load

$$P_{BL} = C_{BL} Q A_p \quad \text{use } w/l_n = 1$$

Where $C_{BL} = 0.52$ from fig 21

$$P_{BL} = (0.52) (20) (1344) = 14,000 \text{ LBS.}$$

Number base anchors

$$N/A = \frac{P_{BL}}{1500} = \frac{14000}{1500} = 9.3$$

Base anchor spacing

$$AS = \frac{48}{10} = 4.8 \text{ ft.}$$

Guy line load

$$P_{gl} = C_{gl} Q A_p \quad w/l_h = 1/2 \text{ was used}$$

Where $C_{gl} = 0.45$ from fig. 22

$$P_{gl} = 0.45 (20) (1344) = 12096$$

Find number of guy lines required

$$NGL = \frac{12096}{1500} = 8$$

Foam thickness due to snow load, assuming the cables will carry the wind load: maximum moment due to snow is 1302 ft/lb at $x = 3'$, $51'$ $y = 12.37'$

Section modulus (z) needed to resist this bending moment would be

stress = 150 psi

$$\text{Moment} = 1302 \text{ ft/lb.} = 15,624 \text{ in/lb} \quad Z = ?$$

From any standard "strength of materials" text

$$S = \frac{M}{Z}$$

$$Z = \frac{M}{S}$$

$$= \frac{15,624 \text{ in.}}{150 \text{ in}^2} = 104.16 \text{ in}$$

$$Z = \frac{bh^2}{6}$$

$$b = 12 \text{ in.}$$

$$h = ?$$

$$Z = 104.16 \text{ in}^3$$

$$104.16 = \frac{2 \times h^2}{1}$$

$$h^2 = \frac{104.16}{2} = 52.08; h = 7.216 \text{ in. Use 8 in. of foam using a}$$

7.5 oz. fiberglass tension member where the positive bending moment of the computer readout represents tension on the inside of the structure and negative bending moment represents tension on the outside of the member.

10 Realm 1, M2, M3, M5

20 HH = 229

30 W = 20

40HH2 = 384.

50 HH3-186

60 V= 540

70 V2 - 135

80 M5-0.0

90 X = 0.0

100 X2 - 27

110 XMAX = 54

120 1 Y = SQRT (54.*X-X**2)

130 M1=V*(54.-X)-HH*Y-20.*(54-X)**2/2

140 IF(X.GT.X2) GO TO 3

150 GO TO 5

160 3 M5=W*(27.-Y)*(27.-Y)/2

170 5 M2=-HH3*Y-HH2*Y+V2*X+V2*(54.-X)-W*Y*(Y/2.)-M5

180 M3=-HH3*Y-HH2*Y+V2*X+V2*(54.-X)-W*Y*(Y/2.)-M5+V*(54.-X)-HH

185+ *Y-20.*(54-X)**2/2

190 WRITE (9,13) X, Y, M1, M2, M3

200 13 FORMAT (5F 12.2)

210 X=X+1

220 IF (X.GT.XMAX) GO TO 69

230 GO TO 1

240 69 CONTINUE

250 STOP

260 END

<u>X</u>	<u>L</u>	<u>M₁</u>	<u>M₂</u>	<u>M₃</u>
0.00	0.00	0.00	7290.00	7290.00
1.00	7.28	-1137.14	2610.34	1473.19
2.00	10.20	-1295.35	437.12	-858.23
3.00	12.37	-1302.57	-1290.51	-2593.09
4.00	14.14	-1238.55	-2771.02	-4009.57
5.00	15.65	-1134.42	-4081.91	-5216.33
6.00	16.97	-1006.26	-5263.22	-6269.48
7.00	18.14	-863.68	-6338.87	-7202.55
8.00	19.18	-712.98	-7324.50	-8037.48
9.00	20.12	-558.54	-8231.03	-8789.57
10.00	20.98	-403.54	-9066.42	-9469.97
11.00	21.75	-250.42	-9836.69	-10087.11
12.00	22.45	-101.04	-10546.47	-10647.51
13.00	23.09	43.13	-11199.47	-11156.35
14.00	23.66	180.87	-11798.67	-11617.80
15.00	24.19	311.23	-12346.46	-12035.24
16.00	24.66	433.40	-12844.87	-12411.47
17.00	25.08	546.71	-13295.53	-12748.82
18.00	25.43	650.61	-13699.83	-13049.22
19.00	25.79	744.64	-14058.93	-13314.29
20.00	26.08	828.41	-14373.78	-13545.37
21.00	26.32	901.60	-14645.19	-13743.59
22.00	26.53	963.94	-14873.81	-13909.87
23.00	26.70	1015.23	-15060.18	-14044.95
24.00	26.83	1055.29	-15204.71	-14149.42
25.00	26.93	1083.99	-15307.72	-14223.73
26.00	26.98	1101.24	-15369.44	-14268.20
27.00	27.00	1107.00	-15390.00	-14283.00
28.00	26.98	1101.24	-15369.45	-14268.20
29.00	26.93	1083.99	-15307.77	-14223.79
30.00	26.83	1055.29	-15204.99	-14149.70
31.00	26.70	1015.23	-15061.06	-14045.83
32.00	26.53	963.94	-14875.99	-13912.05
33.00	26.32	901.60	-14649.75	-13748.15
34.00	26.08	828.41	-14382.30	-13553.89
35.00	25.79	744.64	-14073.63	-13328.99
36.00	25.46	650.61	-13723.68	-13073.06
37.00	25.08	546.71	-13332.40	-12785.69
38.00	24.66	433.40	-12899.73	-12466.34
39.00	24.19	311.23	-12425.61	-12114.38
40.00	23.66	180.87	-11909.93	-11729.06

41.00	23.09	43.13	-11352.61	-11309.48
42.00	22.45	-101.04	-10753.50	-10854.54
43.00	21.75	-250.42	-10112.46	-10362.88
44.00	20.09	-403.54	-9429.29	-9832.83
45.00	20.12	-558.54	-8703.74	-9262.28
46.00	18.18	-712.98	-7935.50	-8648.48
47.00	18.14	-863.68	-7124.15	-7987.84
48.00	16.97	-1006.26	-6269.12	-7275.38
49.00	15.65	-1134.42	-5369.58	-6503.99
50.00	14.14	-1238.55	-4424.26	-5662.81
51.00	12.37	-1302.57	-3431.08	-4733.65
52.00	10.20	-1295.35	-2385.94	-3681.29
53.00	7.28	-1137.15	-1278.40	-2415.55
54.00	0.00	0.00	0.00	0.00

M_1 = Moment due to snow load

M_2 = Moment due to wind load

M_3 = Moment due to snow and wind loads combined

As can be seen, a foam thickness of eight inches with fiberglass cloth reinforcing on the inner face overall and on the outer face on the sides to a height of 22 feet was shown to be adequate.

MOLD RELEASE: A mold release study had been performed in order to find a material which would allow removal of the inflatable from the foam without causing detrimental effect on the rubberized fabric.

A mold release was selected and a 240 hour test in which a coupon of the inflatable section fabric was completely submerged in the mold release in a closed container was conducted. The purpose was to detect any softening of the rubber coating which would indicate solvent/vehicle attack and damage to the fabric.

The mold release was deemed satisfactory since there was no apparent damage to the rubber was noted. The mold release selected is SP 169 formulated by the Brulin Co., Indianapolis.

COATING: No coating materials were actually tested. Experience indicates that any exterior grade paint which will adhere to freshly sprayed foam will serve as a ultraviolet light screen and prevent deterioration of the foam by weathering.

Light colored or aluminized asphalt based roof paints are preferred. Several special elastomeric coatings with special properties are available commercially for over-coating sprayed foam but are generally fairly expensive and their use can be justified only where special endurance is required.

The basic key to successful coating, and protection of the foam is the immediate and complete coating of the foam after it is cured. A sample of foam was coated with a single coat of white exterior latex paint soon after foaming and then continuously exposed to outdoor weathering conditions at NAD Crane for over two years without ill effects on the foam.

PHYSICAL PROPERTIES OF FOAM: The physical properties of the foam depend, in part, on the accuracy of metering of the machine, the technique of spraying and environmental conditions of temperature and humidity at the time of spraying. In general, shrinkage at -50°F will be 1% by volume, or less. Volume expansion at temperatures in excess of 200°F can be as much as 6 to 8%. Coating of the material to prevent any moisture absorption is important as the slight amounts of moisture at 200°F and above cause significant volume expansion.

CONSTRUCTION

Construction of a full scale model was planned as a means of identifying as many of the problems associated with the eventual use of the method. Since laboratory studies had indicated that a system of foam/reinforcement composite could be built up on a practical scale, it remained only to provide insight of and solutions to the problems of actually building the structure.

In order to simulate actual use conditions as nearly as possible, it was decided to keep the use of sophisticated and specialized equipment or tools to a minimum. In keeping with this attitude, only minimum site preparation was performed.

The site selected was chosen in order to allow the use of regular distribution system electricity and air. In order to do this, a reasonably level spot encompassing part of a rail spur was picked. No levelling or shifting of earth was necessary. Removal of weeds and grass was the only preparation required.

According to the design, anchors were required along the base of each side of the section and at several spots a short distance away from the base and parallel to the sides. Figure 1 gave the approximate locations.

Anchors were driven into the ground at the required spots. Arrowhead anchors were used. Other kinds of anchors may be used provided they give the necessary resistance to the lift forces created by the wind.

Two shelter sections were attached by tie chains, anchored to the base anchors and inflated until they were standing erect. It was necessary to assist inflation by lifting and directing the shelter sections. Once fully erected, it was possible to climb to the top of the sections and to walk about on them. The tie chains were utilized as a ladder for going up and down the sides.

Mold release was applied to the outer surface of the sections. It was determined that a better way of coating with mold release would be to spray it onto the sections prior to their erection rather than after they were up, since standing up on the inflated sections was very much like walking on a two-story high curved trampoline. Even with the use of safety ropes and a back up man, the application of mold release was very slow, and due to the uncertain footing, probably quite non-uniform. Of lesser importance was also the loss of material due to overspray and coating too heavily in some spots.

After the mold release had dried, fiberglass cloth was placed over the outer edges of the sections. The cloth was about three feet wide, as can be seen in Photograph 1, and was cut into strips long enough to reach from the ground on one side of the section across the top and down to the ground on the other side. Two strips were placed side by side and taped down to the outer edge of each section. Fiberglass cloth was left off the balance of the sections at this point so that walking around on top would be possible while the first part of the spraying of foam took place. It is believed that the portion of reinforcing

cloth (fiberglass) necessary at this point could be arranged on the sections while they were still deflated (after application of the release agent) and raised into position with the sections as they were inflated. This would eliminate some of the climbing up and down which is both time consuming and fatiguing.

Foam spray was applied to the top outer edges of the sections where the fiberglass cloth had been placed. A layer of about six inches thickness was built up by spraying several passes. Foam was applied to the top first to allow the installation of anchor cables near the top surface of the foam in the upper portions of the structure to better resist wind lift. Foam was thus applied to two areas about 25 feet long and about five feet wide on each edge of the top of the sections. On top of the foam was placed a doubled layer of one inch hexagonal wire netting about 40 feet long by three feet wide. The purpose of this wire was to spread load stresses into a large area of the foam material. The wire, coated with foam, is shown in Photograph 23. On top of the wire netting was placed the anchor cables. The first cables were located about three feet in from each outer edge of the sections. These cables (four total) reached from the base anchors on one side to the base anchors on the other side. Attached to the primary cables were cables strung to anchors about twenty feet away from the base, through loops and back up to the inner runs of cables. This arrangement was selected to provide both sideways stability and a degree of endwise resistance to being shifted by the wind.

Prior to the installation of the two inner runs of primary cables, additional strips of cloth were placed on the sections and a six inch layer of foam applied in the manner previously described. There appeared to be

some sagging of the inflatables at this time and it was decided to commence spraying foam on the sides from the ground up in order to provide additional support to the approximately 600 pounds of materials on the top. The foam was applied in this way first on one side of the arch and then the other to keep the weight against the inflatables balanced. Thickness of the foam varied from about seven inches near the outer edges to about three inches as the tie together area was approached. This tapering of foam was intended so that when the joint was covered with cloth and foam, a blending technique would result in a uniform thickness of foam.

When the balance of the sections had been coated in this manner, the inner two cables, with strips of hexagonal netting were put into place much as the two outer ones had been. Foam was then sprayed onto and through the hex netting to give the final design thickness. After this was completed, the final phase of covering the joint with cloth and foam was prepared for. In order to keep the foam from penetrating (Photograph 24) the cloth and fouling the chains holding the shelter sections together, a strip of polyethylene film about three feet wide was to be used.

All along the sides of the arch, up to a height of about 24 feet, additional strips of fiberglass cloth were to be incorporated into the outer inch of foam. The purpose of this cloth was to give the necessary tensile strength to resist the outward acting bending forces which the computer program had indicated would be acting under certain loading conditions.

Unfortunately, before the final foam and reinforcement could be installed, two unforeseen, though not totally unanticipated, events occurred. First, during non-working hours, one of the electrical

inflator motors ceased to function resulting in the deflation of one of the sections. See Photograph 2-6. The weight of this section and the materials which had been applied to it were too much for the other section to support. Consequently, the other section was canted far over on its side and the foam and reinforcement on it were cracked in two places (Photograph 7-9) and pulled away near one side base (Photograph 10).

It is interesting to note that in the section that collapsed one of the failure points was very noticeably near the area predicted to be under maximum stress in such a situation (Photographs 11 and 12).

It was decided that the foam on the collapsed section was irreparably damaged but that the other section could probably be salvaged. Accordingly, the tie chains connecting the two sections were disconnected and the second section set upright by means of a chain hoist and rope. After righting the second section was completed, repair and completion of that portion of the arch shelter appeared even more favorable. Photograph 13 shows the righted section. Photograph 14 shows the closure of one of the cracks (as seen in Photograph 8).

During the following night, possibly as a result of a severe thunderstorm, the area suffered a power outage of about 45 to 60 minutes duration. While the power was off the second section deflated and the foam was damaged beyond repair. Photographs 15 through 17 are various views of the whole effort spread upon the ground.

Since the feasibility study was funded at a minimal level,
it was not possible to start from scratch and erect another structure.

CRITIQUE

As a result of the destruction of the structure, several facts were made apparant. The information presented is of considerable value in anticipating constructing the next shelter model.

First, the application of mold release agent should be done while the shelter sections are spread out flat on the ground. The fiberglass cloth should also be spread upon the sections after the release agent has dried but before inflation. Wider widths of cloth could be used.

Second, when the spraying starts, it should continue until the structure is completed, with as few interruptions as possible. Strict preventive and operational maintenance to equipment should be performed according to the manufacturers directions. Hoses from the pump unit of the spray equipment should be long enough (perhaps 150 feet) to allow reasonable freedom in moving around without restriction or moving the machine. Two operators for the spray equipment are absolutely necessary for good performance. Specific care in keeping pumping pressures balanced must be exercised in order to avoid spots of improperly mixed foam as shown in Photograph 18. Foam layer build-up should be as uniform as possible (Photograph 19). A powered means of moving, supporting and locating the sprayer is essential. It was very evident on the structure attempted that operator stability was plainly visible in terms of smoothness and evenness of the foam applies (Photographs 20 and 21). One reason for the structural failure of the attempted arch shelter was the fact that it was not completed when the blower and power

failures occurred. The reasons the structure was incomplete included the methodical, problem solving, step-by-step approach to construction and some maintenance/operation problems with spray equipment and the lack of knowledge regarding the time which would be required in solving problem situations as they arose.

Third, controlled deflation rates of shelter sections are essential. The mold release selected works (Photographs 22 - 23). However, to do a proper job, the slowly deflating sections must be manually stripped away from the foam, which can be done with little effort. Ropes that control the maximum radius can be used to restrict the sidewise collapse of the deflating section (Photograph 1).

Fourth, the selected coating must be applied to the outer surface of the foam immediately after the foam is cured in order to get the best bond possible and to prevent any absorption of water which might interfere with coating adhesion.

Fifth, as a matter of thought observation only, it might be a reasonable approach to lay a section on its edge, anchor it and control its shape and then apply mold release, reinforcing, foam, cables, etc., and then set it up as an arch. By using this technique, no one would need to be more than about 10 feet off the ground and scaffolding could afford good footing. Sections, once stood up side by side, could be joined by foaming the joint closed and then coated. This approach would appear to be worthwhile where a long, or several structures are to be erected. No effort has been expended in developing this approach.



PHOTOGRAPH 9
DAMAGED STRUCTURE SHOWING
ANCHOR CABLES

24-a



PHOTOGRAPH 10
FOAM LAYER PUSHED AWAY FROM
INFLATABLE DURING DEFLATION

24-6



PHOTOGRAPH 11
ONE END OF FIRST DEFLATED SECTION
SHOWING BREAK AT THEORETICAL POINT

24-C



PHOTOGRAPH 12
ANOTHER VIEW OF PHOTO 11



PHOTOGRAPH 13

RIGHTED SECTION WITH FOAM ON TOP

24-e



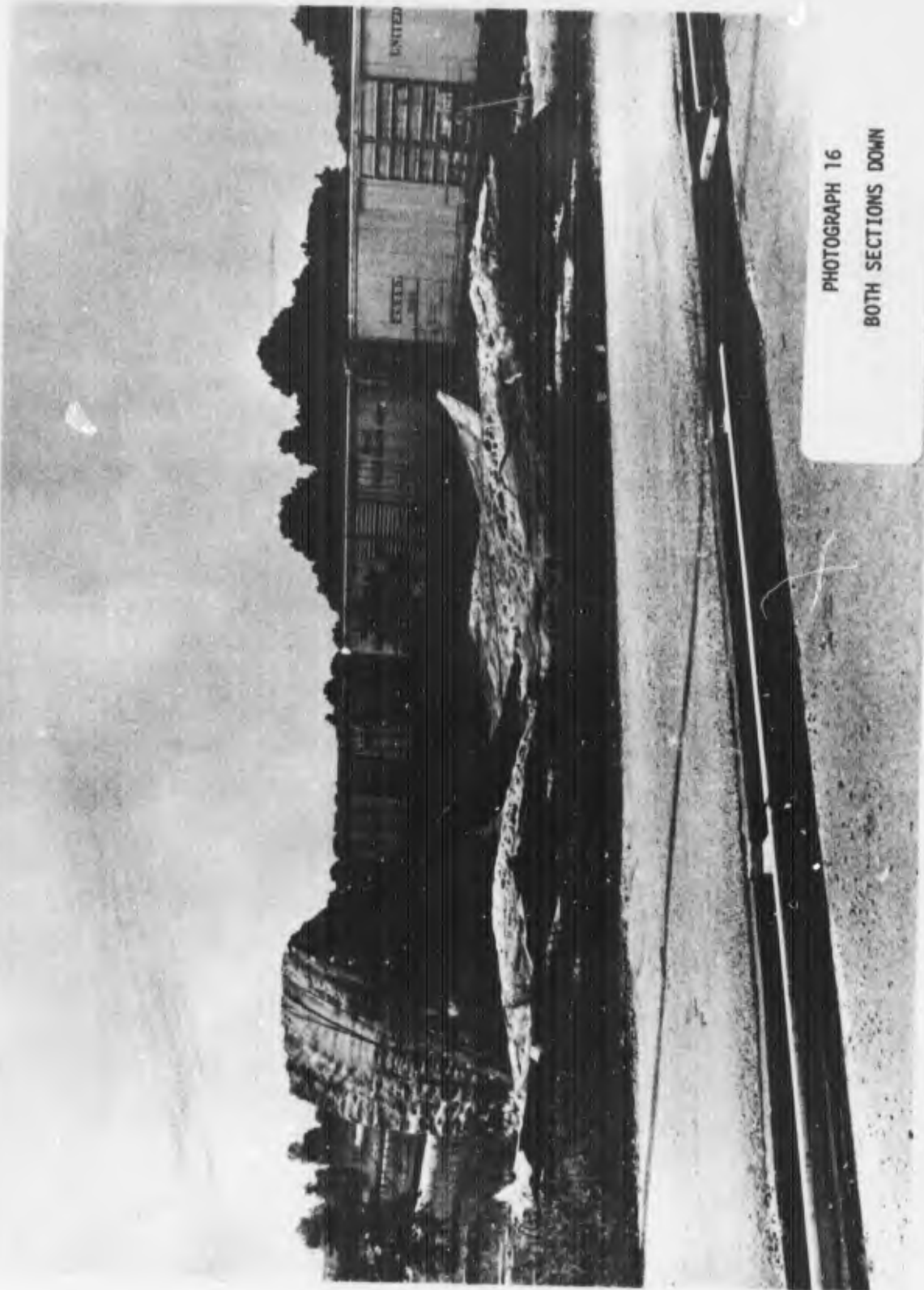
PHOTOGRAPH 14
SHOWS CLOSURE OF LARGE CRACK
IN FOAM IN PHOTO 8

24-f



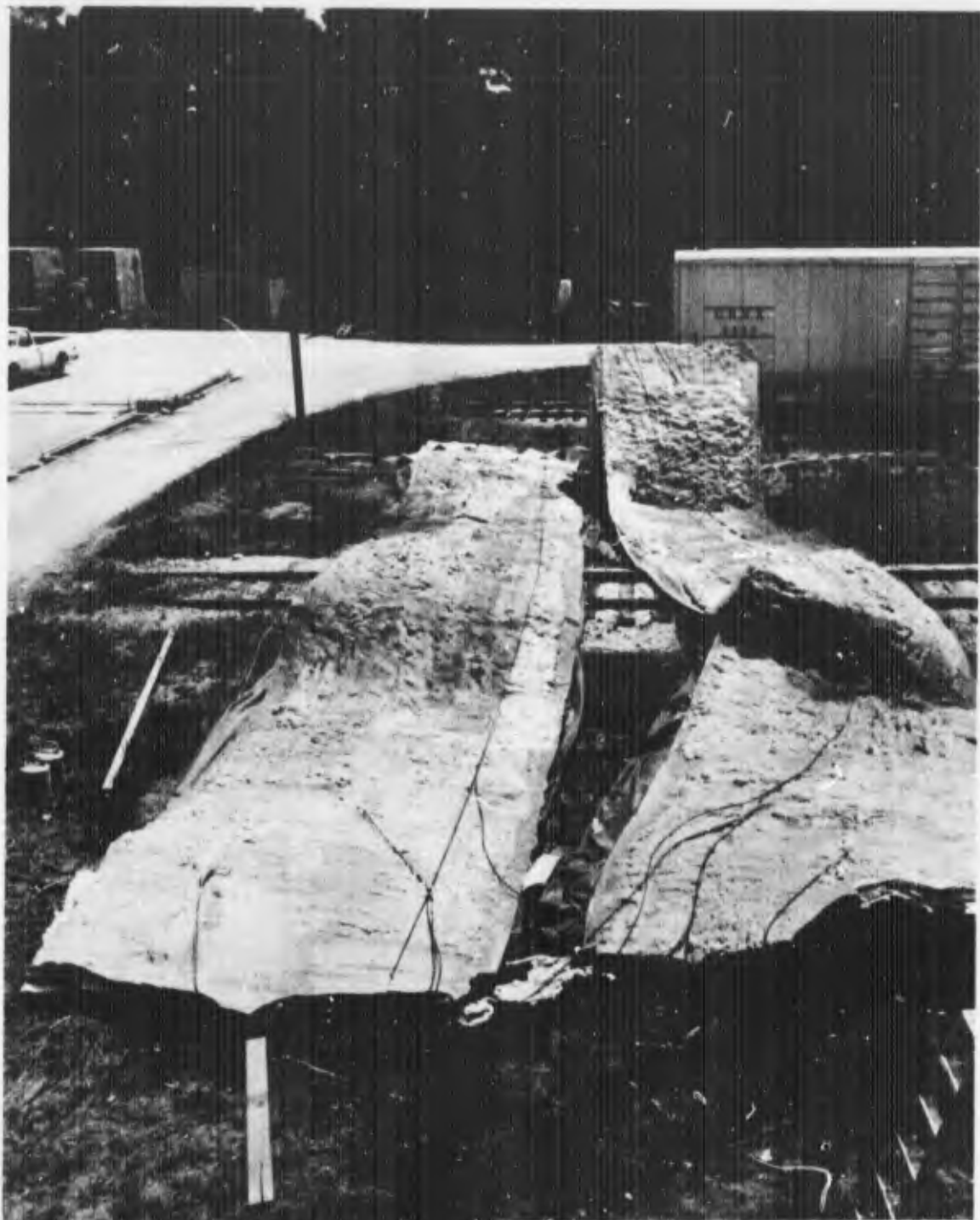
PHOTOGRAPH 15

FOAM TRIED TO MAINTAIN ARCH WITHOUT
SUPPORT - NOT STRONG ENOUGH AT THIS STAGE



PHOTOGRAPH 16
BOTH SECTIONS DOWN

24-h



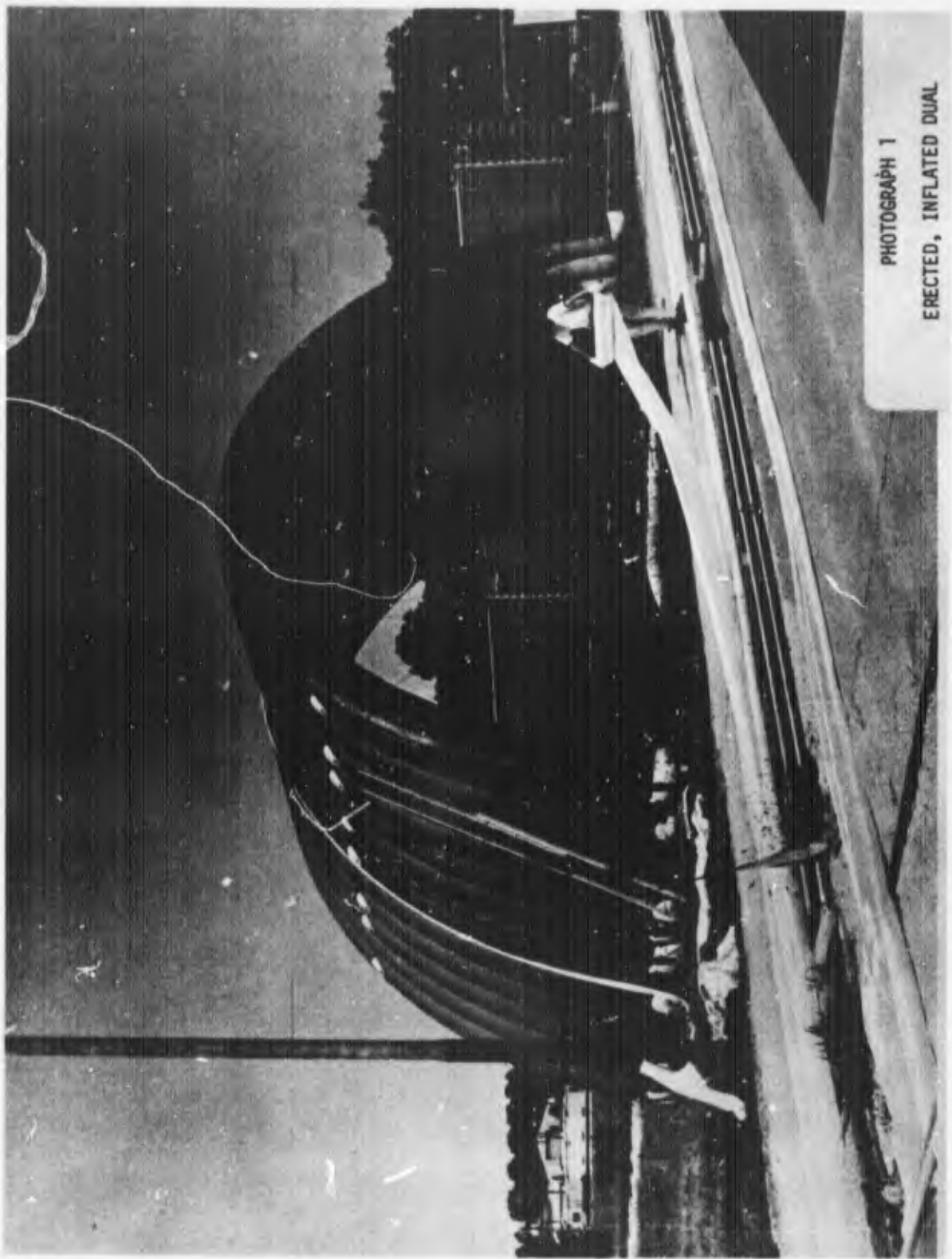
PHOTOGRAPH 17
END VIEW BOTH SECTIONS DOWN

24-i

CONCLUSIONS AND RECOMMENDATIONS

Based on the studies completed, it is concluded that this method of forming a general purpose arch structure is feasible and practical. In the phase of the study involving actual fabrication of a portion of the foam shell on inflated sections, numerous problems were identified and solutions found. In the partial erection of a structure in the feasibility study, invaluable information was gained which lead to the positive conclusion. the positive conclusion.

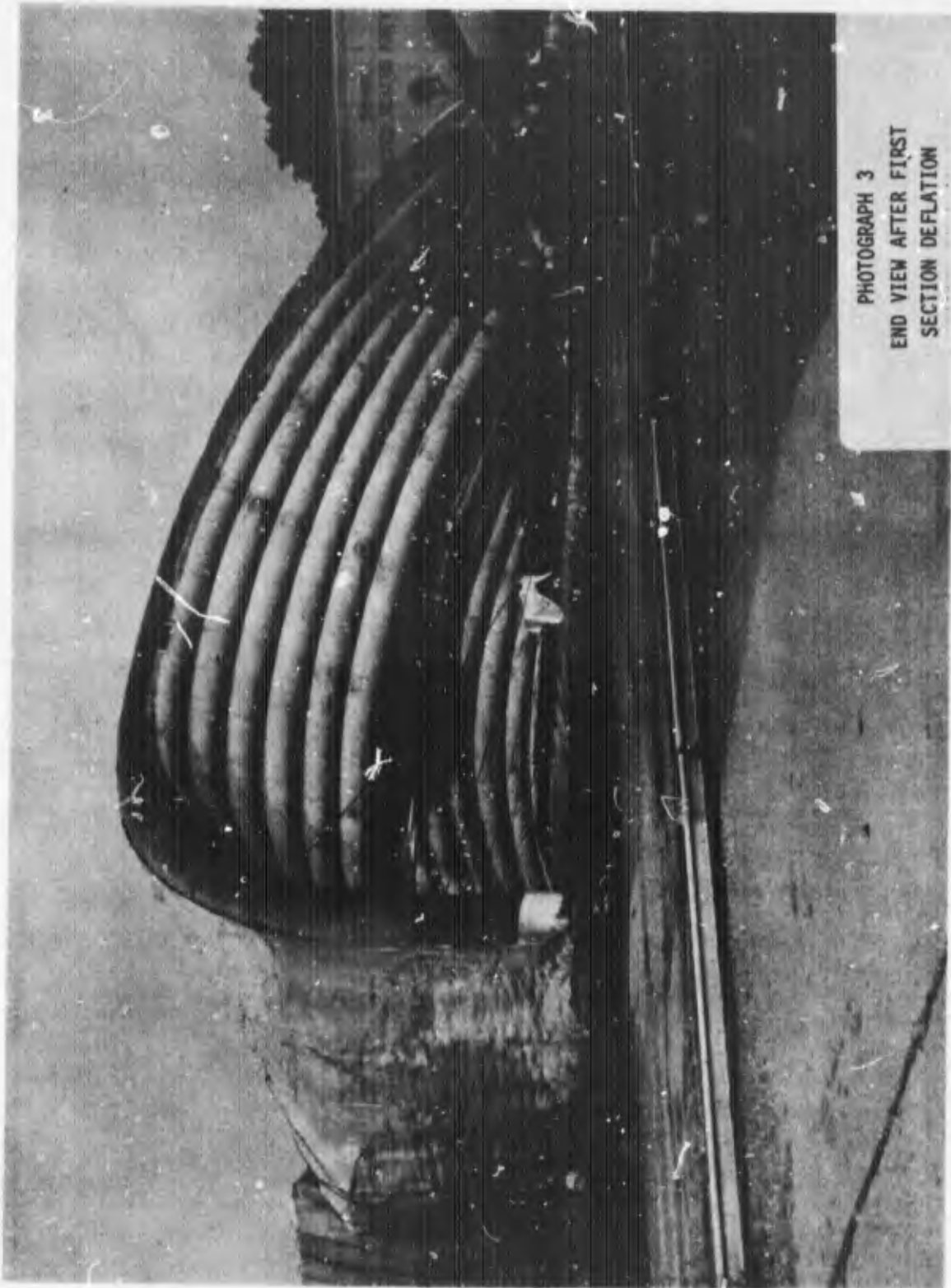
It is recommended by the authors that the study be continued by erection of a minimum of two sections at a selected site and that measurements of strength and durability be made.



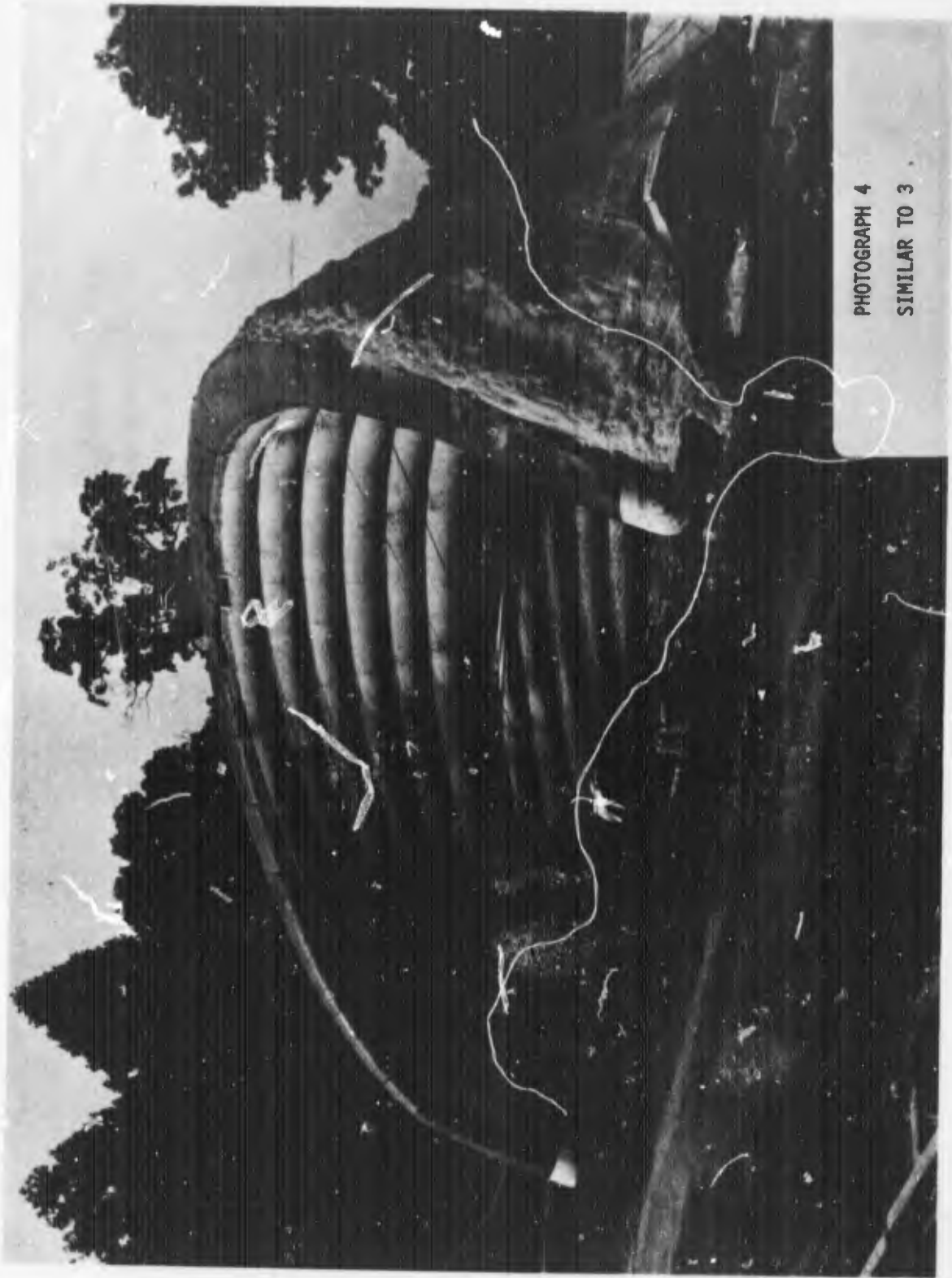
PHOTOGRAPH 1
ERECTED, INFLATED DUAL



PHOTOGRAPH 2
SIDE VIEW AFTER FIRST
SECTION DEFLATION



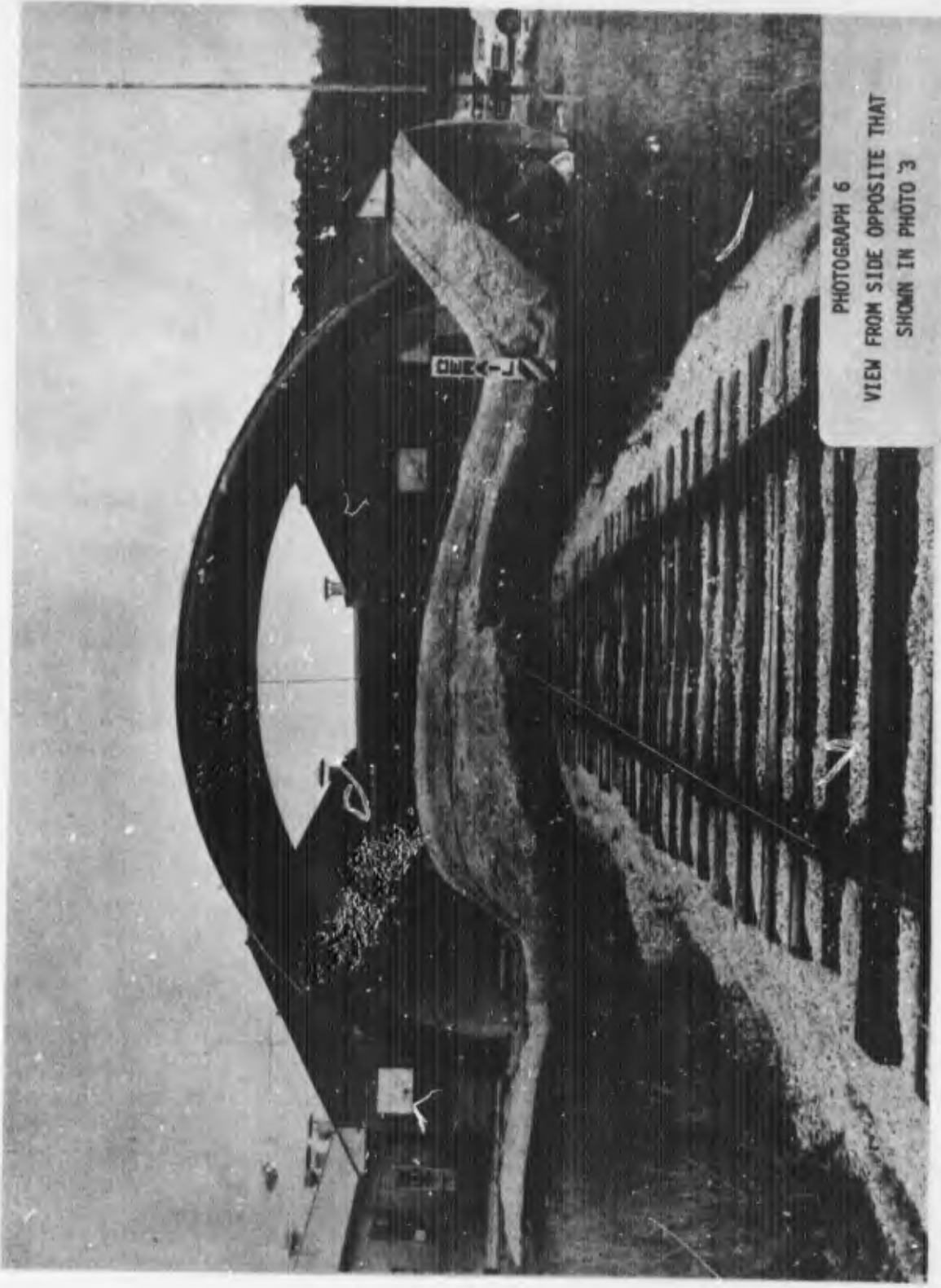
PHOTOGRAPH 3
END VIEW AFTER FIRST
SECTION DEFLATION



PHOTOGRAPH 4
SIMILAR TO 3



PHOTOGRAPH 5
CRACK OF FOAM MATERIAL
SHOWING THICKNESS



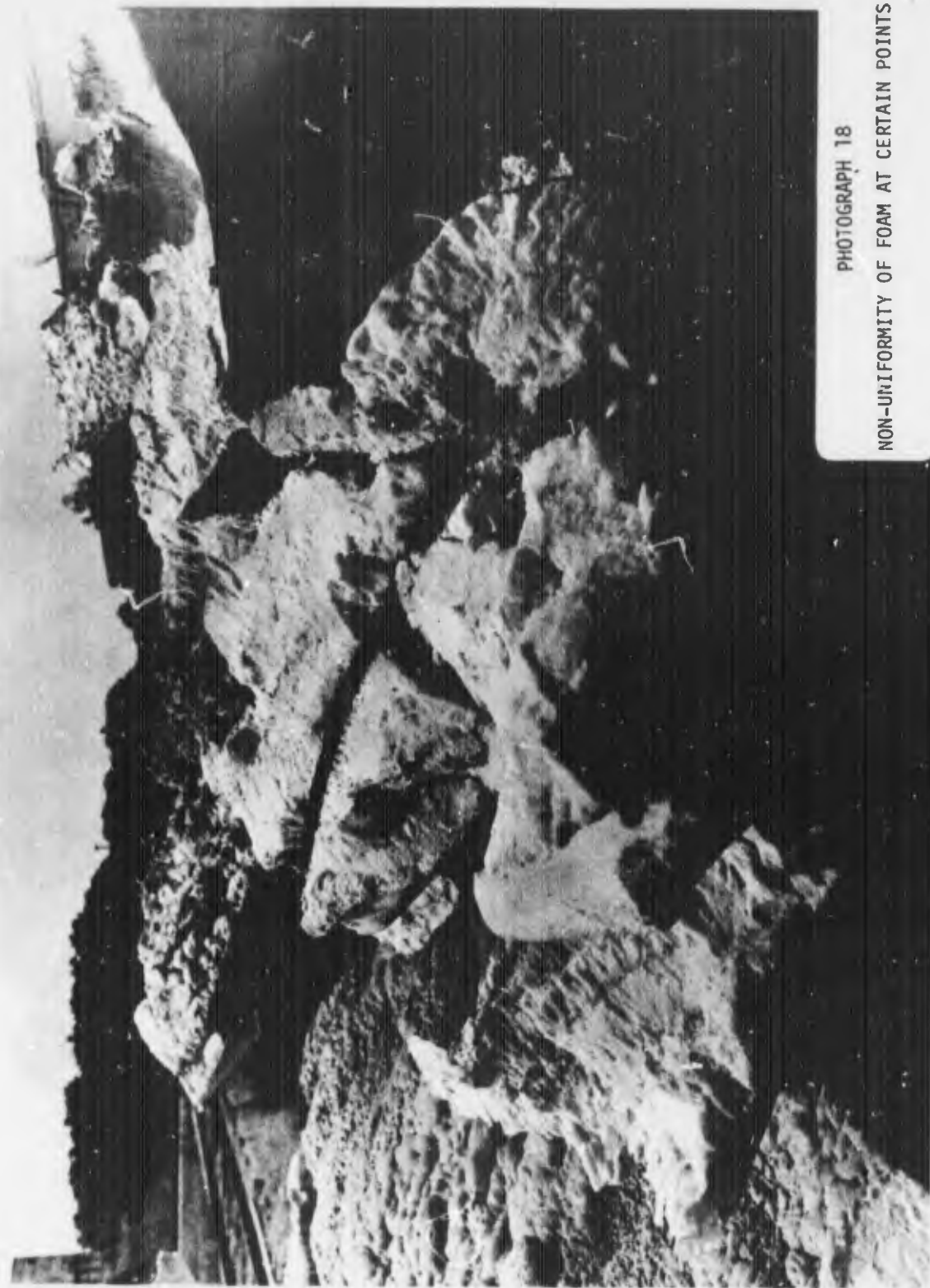
PHOTOGRAPH 6
VIEW FROM SIDE OPPOSITE THAT
SHOWN IN PHOTO '3



PHOTOGRAPH 7
FOAM CRACK AND SEPARATION



PHOTOGRAPH 8
CLOSER VIEW OF END OF
DAMAGED STRUCTURE



PHOTOGRAPH 18

NON-UNIFORMITY OF FOAM AT CERTAIN POINTS



PHOTOGRAPH 19
LINES INDICATE LAYER BUILD-UP



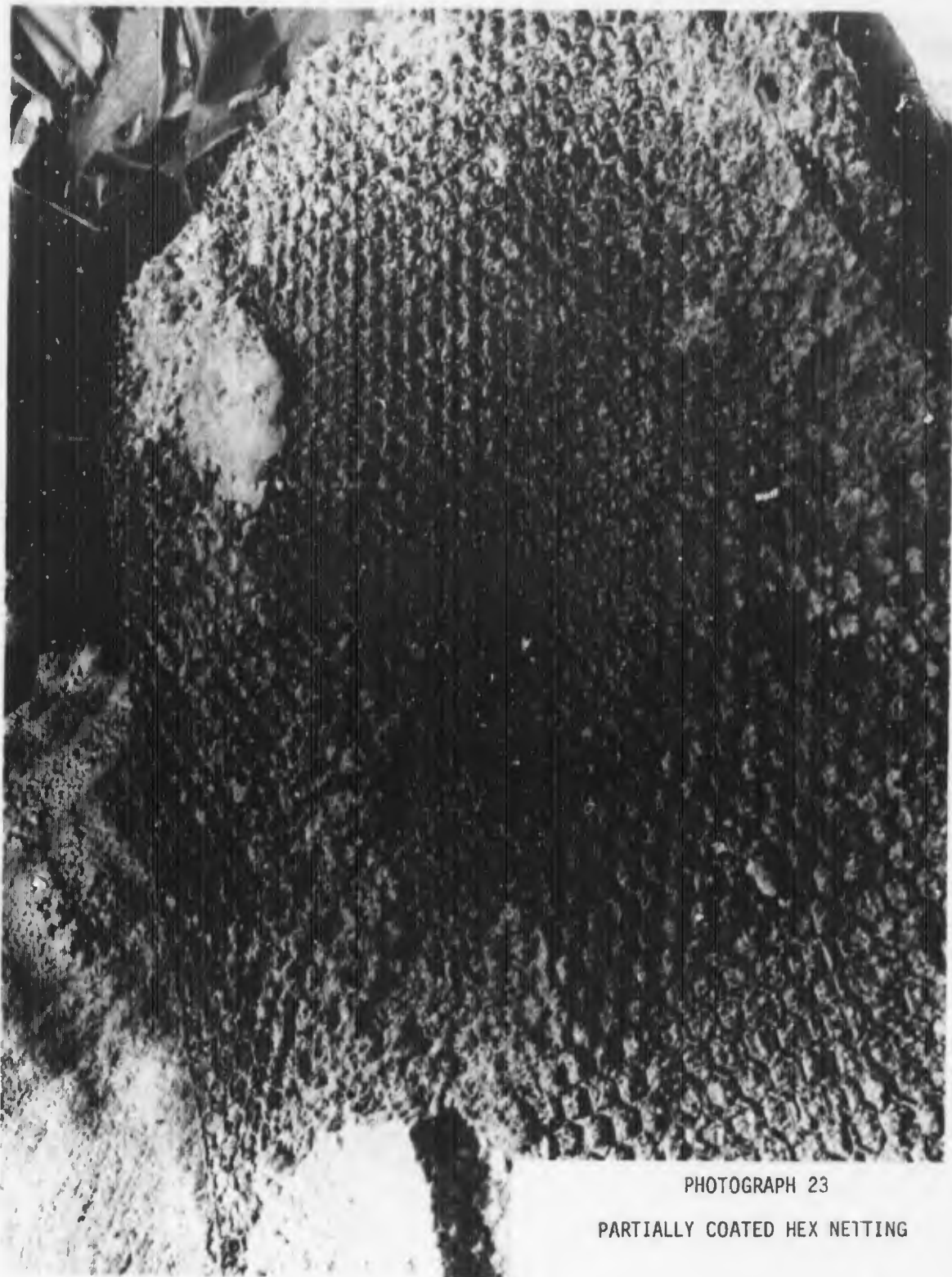
PHOTOGRAPH 20
PARTIALLY COATED HEXAGONAL
(CHICKEN) NETTING



PHOTOGRAPH 21
EXTERNAL ROUGHNESS OR "PROFILE"
OF SPRAYED FOAM

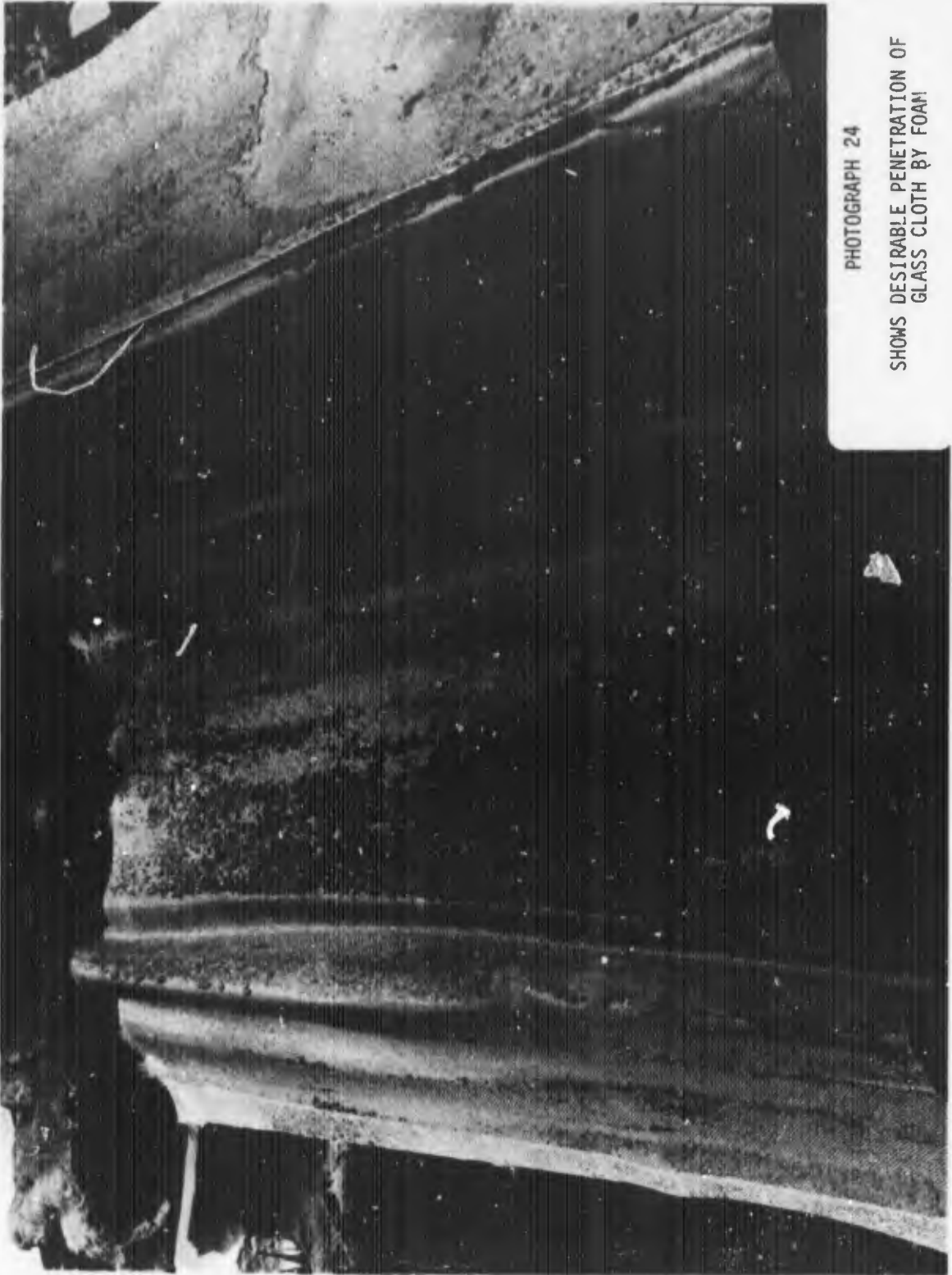


PHOTOGRAPH 22
MOLD RELEASE WORKS



PHOTOGRAPH 23

PARTIALLY COATED HEX NETTING



PHOTOGRAPH 24

SHOWS DESIRABLE PENETRATION OF
GLASS CLOTH BY FOAM

APPENDIX A
STATEMENT OF WORK

1.0 SCOPE

1.1 OBJECTIVE

The purpose of the effort described in this Statement of Work is to demonstrate the feasibility of using dual wall shelter sections as forms for using foam-in-place techniques to form a rigid foam arched general purpose shelter. The NAD will be required to demonstrate this feasibility by preparing test panels of different foams and reinforcing materials and performing laboratory tests to determine their relative structural characteristics.

1.2 APPROACH

This program shall use commercially available foam formulations and commercially available equipment.

It is intended that foam will eventually be applied to the exterior of the air inflatable shelter sections at Tyndall AFB by AFCEC personnel. After the foaming is completed and cured, the air inflatable shelter sections will be removed.

If required, a section of an air inflatable shelter will be provided for testing purposes at NAD.

The following areas will be investigated by NAD and integrated into a report, which will discuss the current state-of-the-art of foam in place technology, results of laboratory testing, and recommendations on how to foam a shelter using the dual wall air inflatable shelter sections.

- a. Methods of preventing the foam from sticking to the shelter sections.
- b. The actual structural characteristics of various methods will be determined by laboratory testing.
- c. Methods of anchoring foam shelter to ground.
- d. Methods of removing air inflatable shelter sections after foaming.
- e. Methods of coating the foam to prevent deterioration.
- f. Physical properties of the cured foam between -50°F to 230°F .
- g. "Optimum" design considerations, based on test data and AFCEC structural consultation.

The Air Force Civil Engineering Center (AFCEC) will act as a structural consultant to NAD during determination of preliminary design criteria and structural analysis.

2.0 SUMMARY OF PRESENT DESIGN

Attachment 1 is an excerpt from the erection manual for these air inflatable shelter sections. Attachments 2 through 4 are sketches that show the overall configuration of the shelter sections.

3.0 REQUIREMENTS

3.1 RESISTANCE TO ELEMENTS

The overall structure must be water tight and allow no wind driven rain to enter structure through joints.

The foam should be closed cell with low moisture absorption. An evaluation should also be conducted on the resistance of the foam to the elements during the foaming operation.

3.2 EQUIPMENT REQUIRED

The recommended equipment for foaming the shelter sections will be commercially available.

NAD will furnish a list and description of all tools and equipment required to foam the shelter sections.

3.3 FOAM MATERIALS

The foam materials used to foam the shelter shall be commercially available through several sources.

4.0 QUALITY ASSURANCE

4.1 PROGRESS REPORTS

NAD shall prepare a program milestone activity plan. The milestone plan will include, but not be limited to, structural analysis, laboratory testing, design review, final report, etc. This activity plan shall be submitted at the beginning of project and will be used to monitor progress. Monthly progress reports shall be furnished in sufficient detail to keep the program milestone project activity plan updated. The reports shall give the title of the project, describe in detail the project progress for the reporting period, and describe the planned progress for the next reporting period. Monthly progress reports shall be submitted within 10 days following each 30 calendar day reporting period. The first calendar day of the first reporting period shall commence on the first day of the month after contract award.

4.2 DESIGN REVIEW

The NAD shall conduct a design review within 90 days after acceptance of this project. The design review will be held at NAD facilities and will involve review of engineering documentation which defines the design of the contract end item. NAD shall notify AFCEC in writing, fifteen days prior to the design review, of the review date. Minutes will be due 15 days after the design review.

4.3 FINAL REPORT

NAD shall develop a final report which documents and summarizes the results of the entire effort performed under this contract. This report shall also include step-by-step description of how to foam the shelter sections, equipment, and tool list, drawings, photographs and specifications in sufficient detail to provide AFCEC with complete data required to procure the foaming of shelter sections. This report will be due 30 days after the design review.

5.0 ADDITIVE ALTERNATES

5.1 DEMONSTRATION (Alternate #1)

If the program confirms the feasibility of foaming a shelter in place, NAD may be required to demonstrate this at Tyndall AFB. NAD will furnish all equipment, materials and personnel required to foam two shelter sections for this demonstration.

5.2 TRAINING (Alternate #2)

NAD may be required to provide on-the-job-training for two AFCEC personnel at NAD. Equipment and materials will be furnished by NAD.

TIME TABLE

23 April 1973
7 May 1973
14 May 1973
* 21 May 1973
4 June 1973
11 June 1973
* 18 June 1973
25 June 1973
9 July 1973
* 16 July 1973
30 July 1973

MILESTONE

Conduct Structural Analysis
Discuss Design Criteria with AFCEC
Design Lab Analysis
Prepare Samples
Start Lab Test
Complete Lab Tests
Start Evaluate Data
Complete Evaluate Data
Select Design with CEC
Erect Two Shelter Sections
Apply Foam
Paint Exterior
Remove Inflatable Sections
Final Report

*Periodic Reports of Progress to AFCEC

APPENDIX 3

EQUIPMENT

The equipment used at NAD Crane was designed and built by Gusmer Corporation, 414 Rt. 18 and Spring Valley Road, Old Bridge, New Jersey, 08857. The proportion pump was a Model FF with a seven pound per minute output.

Other equipment may be used. Several manufacturers are listed below:

**Binks Manufacturing Co.
Plastic and Resin Equipment Division
9201 West Belmont Avenue
Franklin Park, Illinois 60131**

312-671-3000

**Glas-Craft of California
9145 Glen Oaks Boulevard
Sun Valley, California 91352**

213-855-2203

**Graco Inc.
60 Eleventh Street, N.E.
Minneapolis, Minnesota 55441**

612-332-2262

**The Martin Sweets Co., Inc.
3131 W. Market Street
Louisville, Kentucky 40212**

502-774-5786

APPENDIX 4

FOAM SYSTEMS SUPPLIERS

The foam selected for trial use at NAD Crane was CPR 385 or 485 made by CPR Division, The Upjohn Co., 555 Alaska Avenue, Torrance, California, 90503, 213-320-3550. Other systems are available. Care must be exercised in matching foam systems and equipment to be used in spraying it. If fire retardant systems are required, this also must be indicated. Other suppliers:

Cook Paint and Varnish Co.
1412 Knox Street
P. O. Box 389
Kansas City, Missouri 64141

816-471-4800

Durez Division
Hooker Chemical Corporation
2031 Walck Road
North Tonawanda, New York 14120

716-695-1600

The Flintkote Co.
Sealzit Division
3640 Chicago Avenue
Riverside, California 92507

714-684-8333

Freeman Chemical Corporation
P. O. Box 247
Port Washington, Wisconsin 53074

414-284-5541

**Mol-Rez Resins Division
Whittaker Corp.
3134 California Street, N. E.
Minneapolis, Minnesota 55418**

612-781-4833

**PPG Industries
No. 1 Gateway Center
Pittsburgh, Pennsylvania 15222**

**Other manufacturers and compounders exist. The above constitutes a
spectrum of known suppliers.**

APPENDIX 5

OTHER MATERIALS

Glass Cloth: The glass cloth, 7.5 oz. per yard, was supplied by Cadillac Plastics, Indianapolis. A second source is Meyer Materials, 5101 East 65th Street, Indianapolis. Many other sources are available. One near the point of procurement should be selected to enhance service and delivery.

Mold Release: The mold release used was Permamold SP-169 by Brulin and Co., 2920 Martindale Avenue, Indianapolis, Indiana, 46205, 317-923-3211. Suitable releases may be available also from:

Chem-Trend Inc.
3205 East Grand River
Howell, Michigan 48843

517-546-4520

CPR Division
The Upjohn Co.
555 Alaska Avenue
Torrance, California 90503

The type of use should be described so that compatibility can be established.

Hardware: Cable, connectors, hand tools, etc., were purchased from general supply sources.

Coatings: Standard roof coatings provide adequate sealing and protection to the foam. Aluminized asphalt base coatings work well and are economical. Specialized coatings based on rubbers and elastomers are available but are very expensive. Exterior latex paints are adequate and inexpensive.