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# ENGINEERING AND ECONOMIC STUDY ON TENT DECKS AND FRAMES

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

# ENGINEERING AND ECONOMIC STUDY ON TENT DECKS AND FRAMES

MCS-58-00-10

Type B Final Report

by

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## OBJECT OF TASK

To determine the economic and engineering feasibility of fabricating a tent deck and frame from corrosion-and-fire-resistant materials for Tent, Medium, General Purpose (MIL-T-00172 QMC).

## ABSTRACT

Three materials, magnesium, plastics, and aluminum, were investigated for use in frame fabrication. Four materials, plastics, concrete, stabilized soils, and corrosion-resistant metals, were studied for deck use. Procedures stemming from the U. S. Marine Corps requirements resulted in the design and fabrication of an aluminum tent frame and in the procurement and test of two types of aluminum decks.

## INTRODUCTION

In certain circumstances, the U. S. Marine Corps prefers to house trainees in tents in order to familiarize them with the field living conditions they may expect to encounter during Marine Corps service.

NCEL was assigned the task of conducting a study on the engineering and economic feasibility of fabricating tent decks and frames to meet Marine Corps requirements.

## DESIGN CRITERIA

The following criteria, based on existing requirements and information received from the U. S. Marine Corps via BUDOCKS, were developed for the design of the tent deck and/or frame:

1. Tent deck and frame must:
   a. Be compatible with Tent, Medium, General Purpose (MIL-T-00172 QMC).
   b. Be fabricated of lightweight corrosion-resistant and fire-resistant material.
   c. Have a minimum service-life of five years.
   d. Have parts and assemblies capable of being manhandled.
   e. Be easily fabricated by large or small shops.
   f. Be economically feasible.

2. Tent frame should:
   a. Be of knockdown, prefabricated construction.
   b. Be structurally adequate to withstand a 40-knot wind normal to the long axis.
   c. Be capable of manual erection a minimum of four times.
   d. Be suitable for erection under most soil and weather conditions.

## TENT DECK TEST REQUIREMENTS

1. Eighty percent of the decks would be subjected to a floor loading of 40 psf.

2. Sixteen percent of the decks would be subjected to a floor loading of 100 psf.

3. Four percent of the decks would be subjected to a floor loading of 200 psf. (However, the Marine Corps stipulated that this need not be a requirement of this study.)

## TENT FRAME DEVELOPMENT

### Material Investigation

The criteria governing the design of the frame restricted the field of investigation to three materials: (1) magnesium, (2) plastics, and (3) aluminum.

The investigation of r. --sium and fibrous-glass-reinforced plastics indicated that although a satisfactory frame may be fabricated from these materials, it would be considerably more expensive than aluminum.

Aluminum satisfies all requirements of the design criteria, as being corrosion and fire-resistant, lightweight, structurally adequate, readily available, and comparatively inexpensive.

### Description

The frame, Figure 1, conforms to the tent size and has a base 16 feet wide by 32 feet long and is 10 feet high at the ridge. The eave line is 5 feet 2 inches above the base and an entrance of 5 feet 6 inches high by 3 feet wide is provided at each end. The structure is a rigid-frame gabled-roof design of aluminum tubing prefabricated for knockdown construction. The eave bents, corners, and ridge connectors, as shown in Figures 2 through 5, are prefabricated from 2-inch-O.D. 6061-T6 aluminum tubing with 1/4-inch 6061-T6 aluminum-plate gussets. The framing members, fabricated from 1-1/4-inch 6061-T6 aluminum pipe, are pre-cut to length with the ends drilled and/or slotted for assembly. The frame weighs approximately 400 pounds. Detailed drawings for the frame are contained in the Appendix.

Figure 1. Aluminum tent frame.

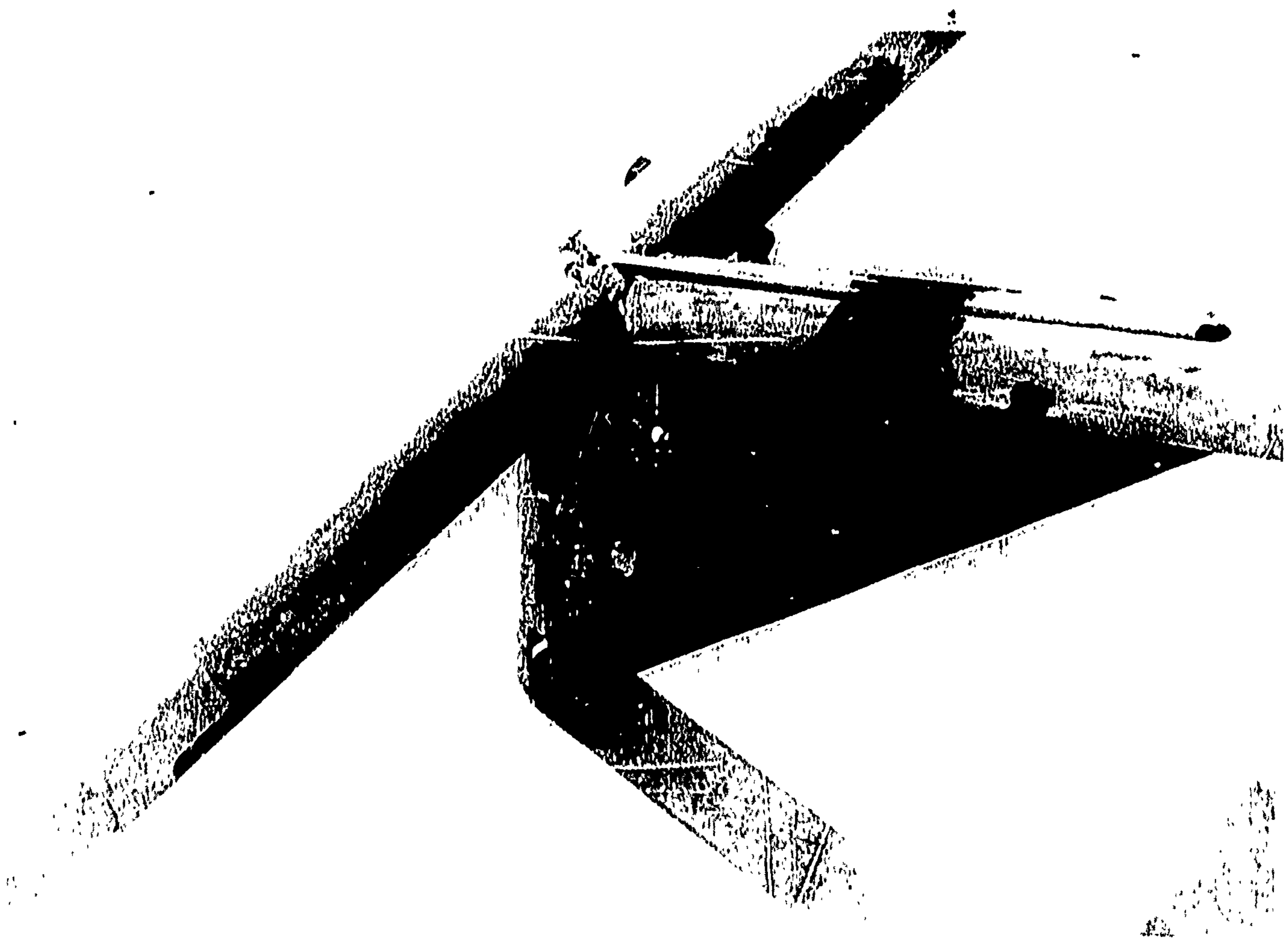


Figure 2. Typical eave bent connection.

Figure 3. Typical corner connection.

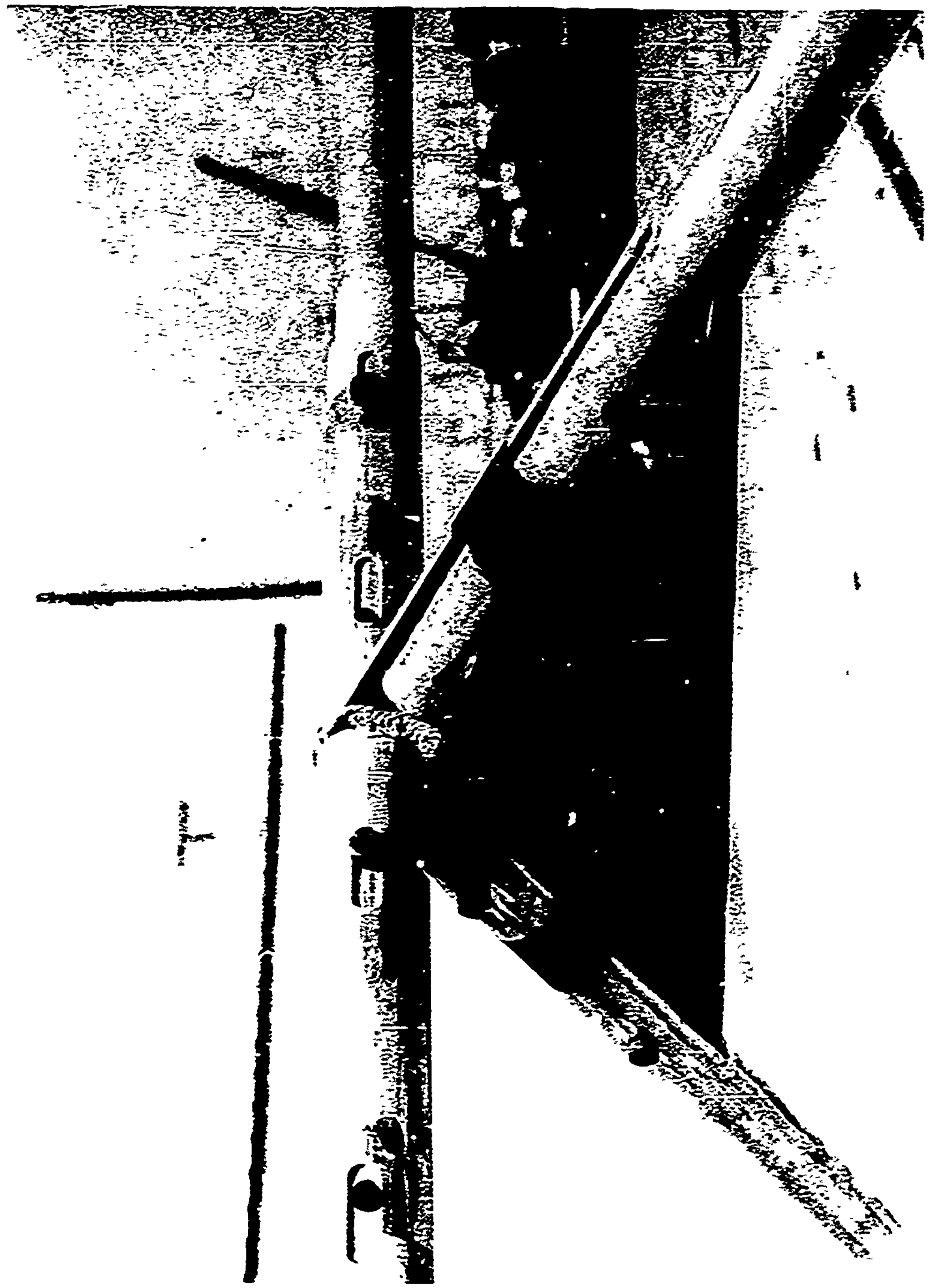


Figure 4. Middle ridge connection.

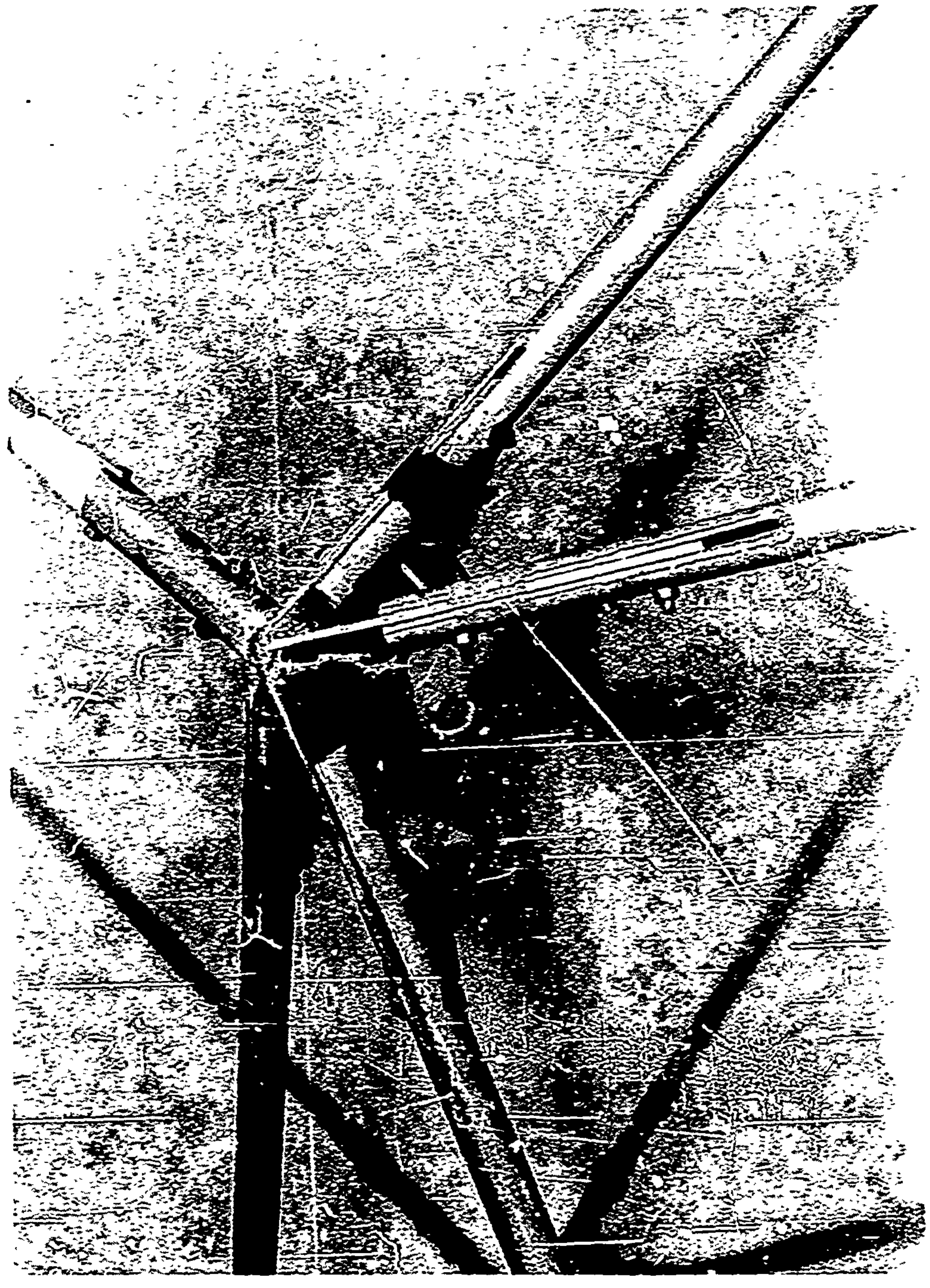


Figure 5. Typical end ridge connection.

## TENT FRAME TEST PROCEDURE

### Erection Tests

Four erection tests were made to determine the suitability of the frame for assembly under advance-base conditions. To simulate these conditions, a crew of civilian personnel of varied skills was used for all erections.

The purpose of the first test was to determine the ease of erection with personnel unfamiliar with the frame and to record the manhours required for assembly and erection. The second, third, and fourth erections were made to determine the suitability of the design for repeated assembly and to record the manhours required for assembly and erection. At least one man, familiar with the frame, was on the crew except in the first erection test.

### Erection Sequence

The erection sequence for the tests was as follows:

1. The roof frame was assembled, as shown in Figure 6, with the assembly bolts finger-tight.

2. The assembly bolts were then wrench-tightened until a firm joint was obtained. The completed roof frame is shown in Figure 7.

3. The canvas was placed over the roof frame and secured with the existing tie-down cords, as shown in Figure 8.

4. The frame was raised and the struts were inserted and connected as shown in Figures 9 and 10.

5. The frame was squared and staked to the ground through the plates provided at the base of each strut.

### Results and Discussion

A summary of the manhours required to assemble and erect the tent frame, in each of the four tests, is given in Table 1 on page 14.

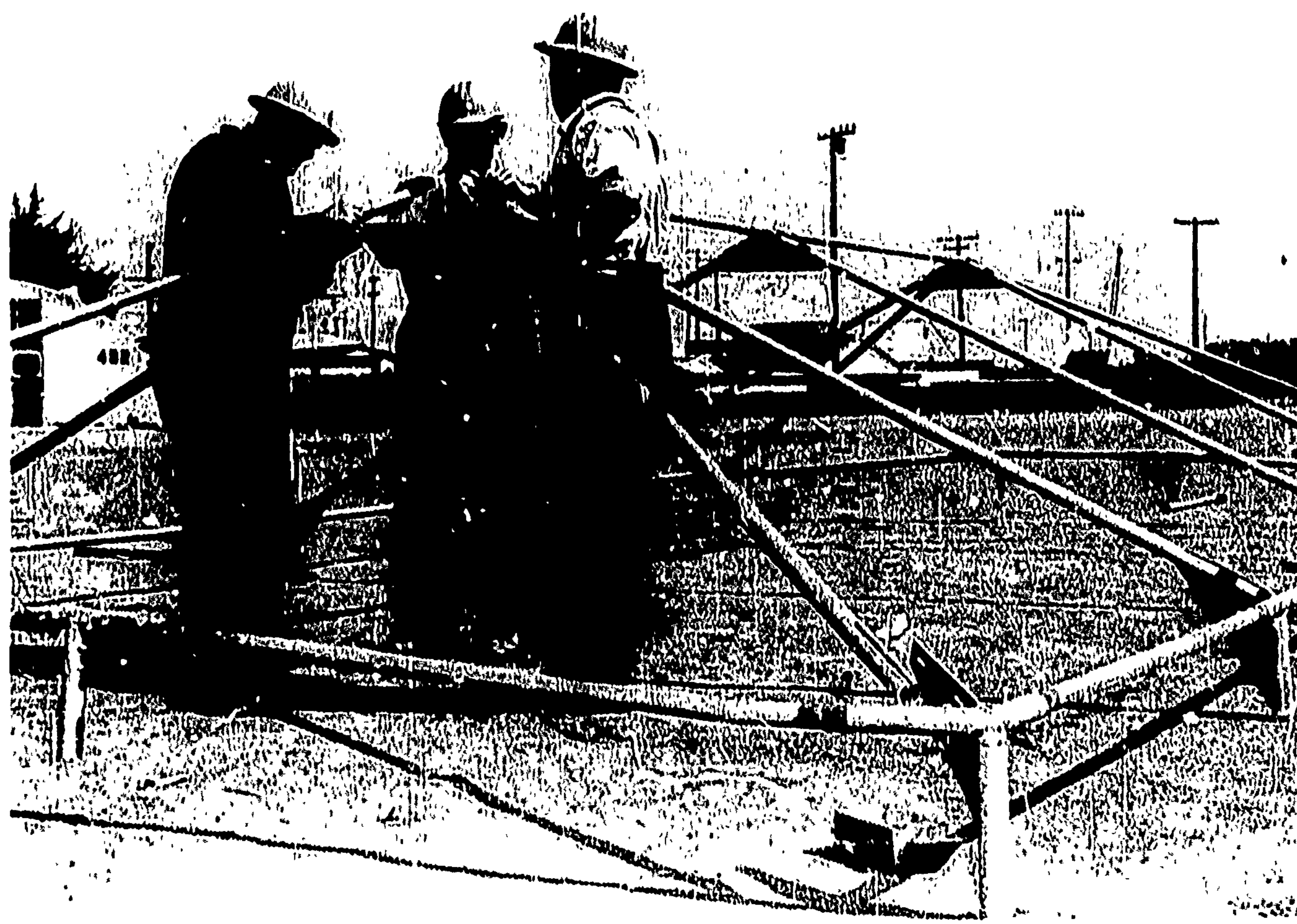


Figure 6. Roof frame being assembled.

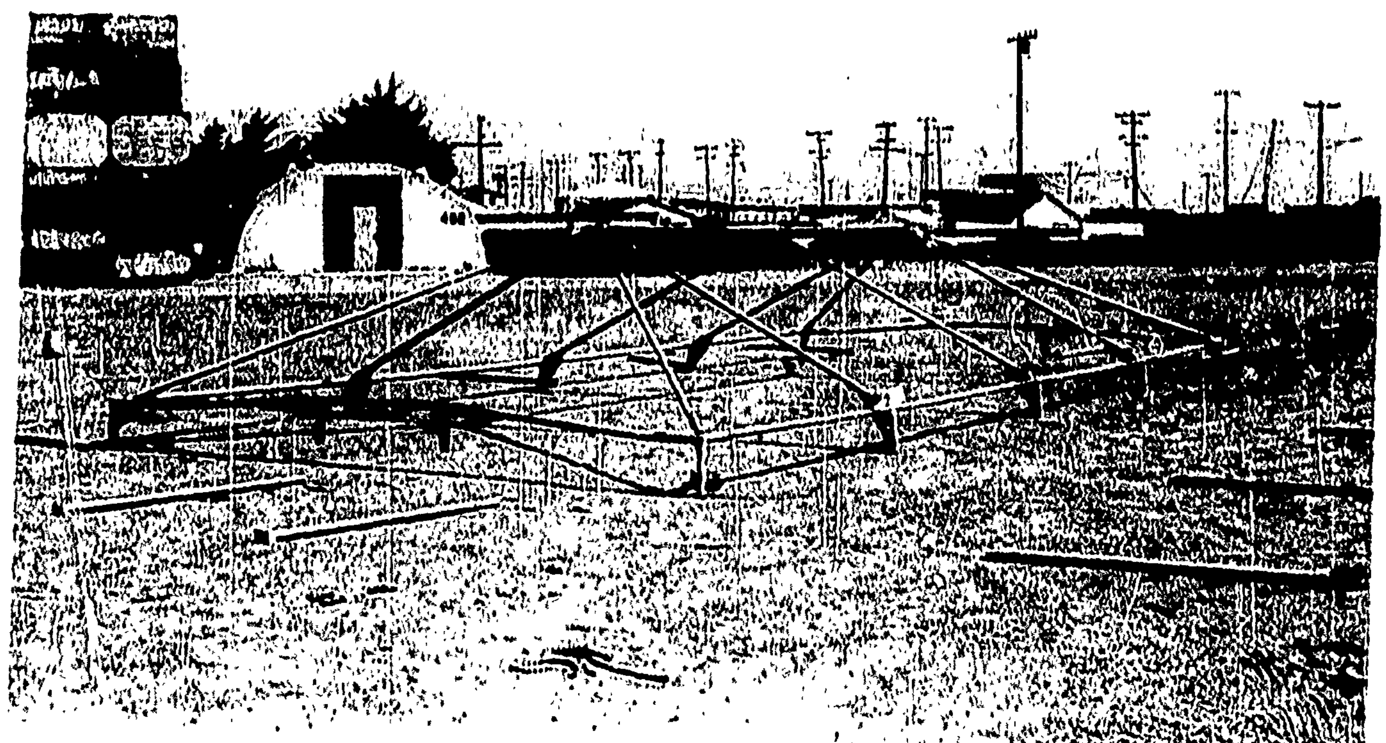


Figure 7. Completed roof frame.

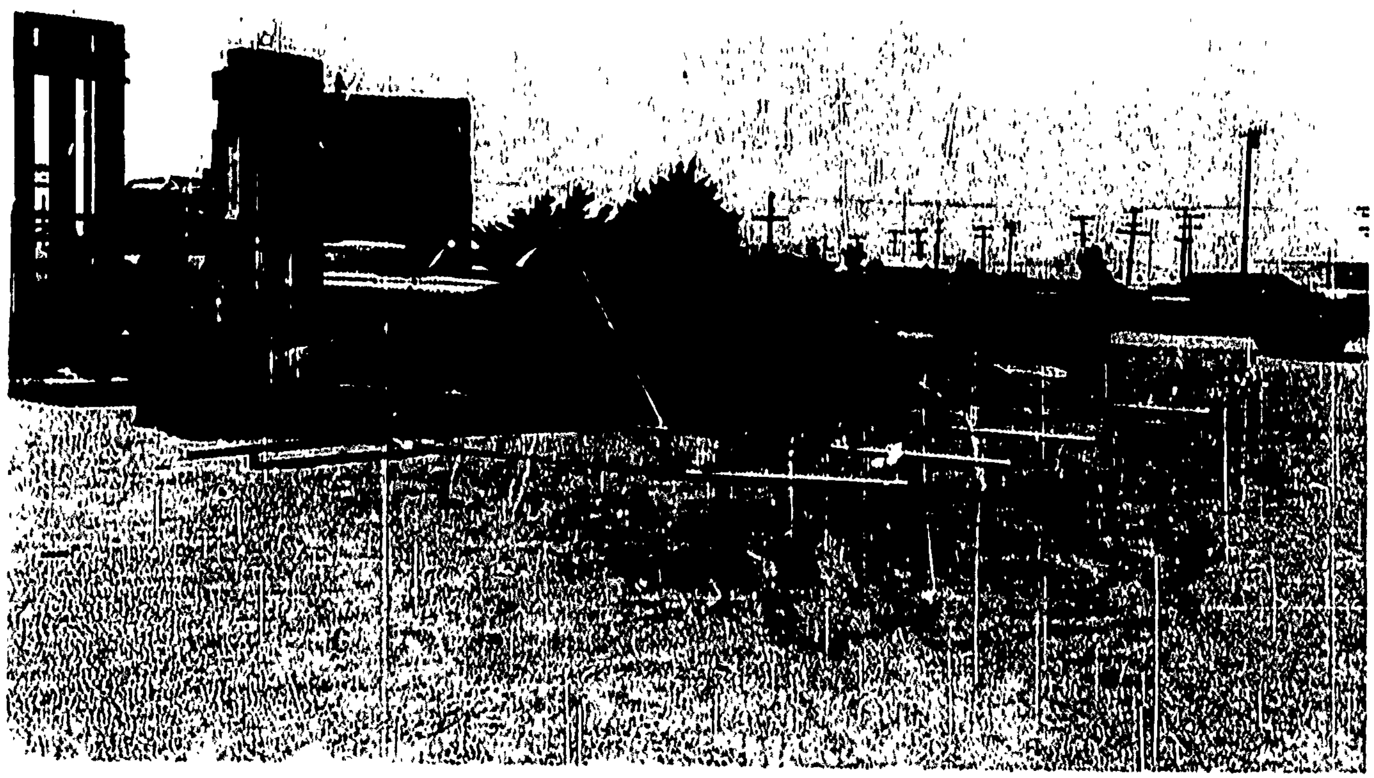


Figure 8. Placing canvas over roof frame.

Figure 9. Frame with canvas being raised.

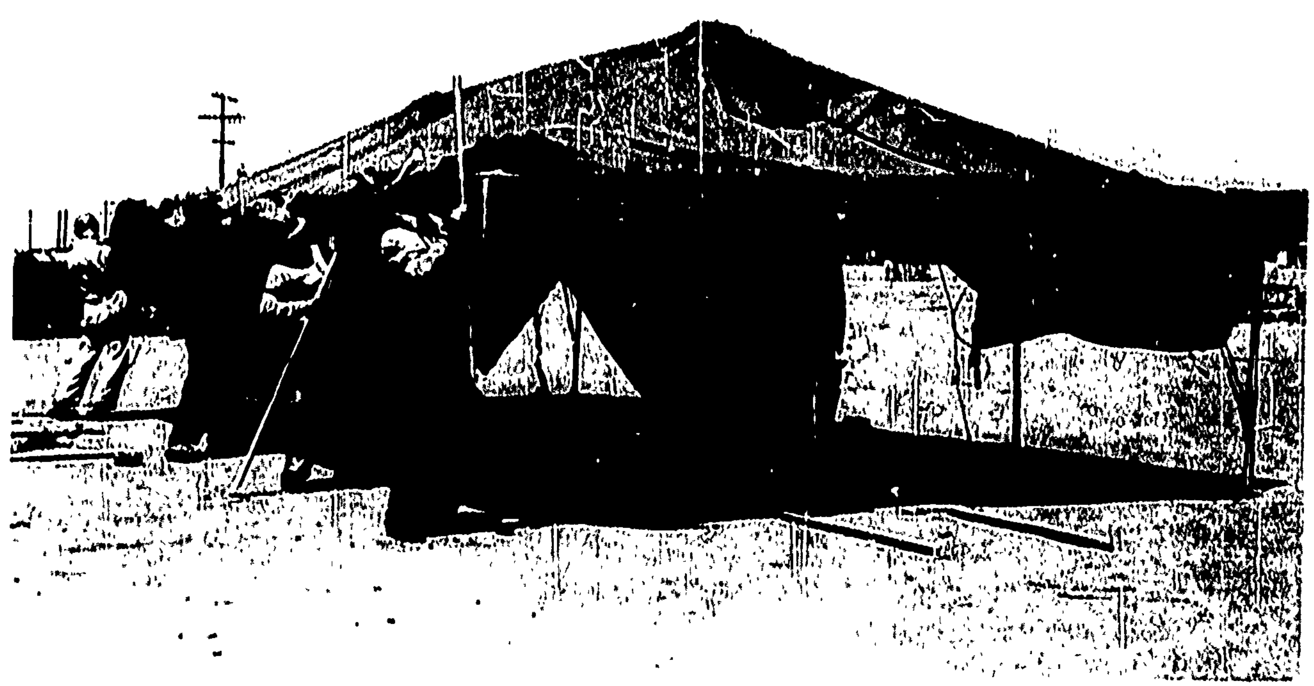


Figure 10. Frame raising being completed.

Table 1. Summary of Manhours Required for Erection

| Test | Personnel | Sequence | Manhours |
|---|---|---|---|
| *1 | 4 riggers | Erect frame<br>Square & anchor frame | 2.00<br>0.40<br>2.40 |
| 2 | 2 carpenters<br>1 rigger | Erect frame<br>Place canvas<br>Square & anchor frame | 1.30<br>0.15<br>1.00<br>2.45 |
| 3 | 2 carpenters<br>1 rigger | Erect frame<br>Place canvas<br>Square & anchor frame | 1.45<br>0.15<br>1.00<br>2.60 |
| 4 | 2 carpenters<br>1 rigger | Erect frame<br>Place canvas<br>Square & anchor frame | 1.15<br>0.15<br>0.45<br>1.75 |

* Canvas tent was not used for this test.

Several techniques were tried to determine one which would provide the simplest and fastest method of erection. One erection was made using only a schematic drawing of the completed frame. Some confusion in the distinguishing of the various framing members prompted the establishment of a color code to aid in the indentification of the members. For the second test all joints were striped with an identifying color, with framing members to the joints similarly marked. Subsequent tests indicated that the color coding aided greatly in assembly of the frame.

One test was made where the component members of the frame were laid out prior to assembly, as shown in Figure 11. This technique, although simplifying the procedure, did not reduce the time required for assembly and erection.

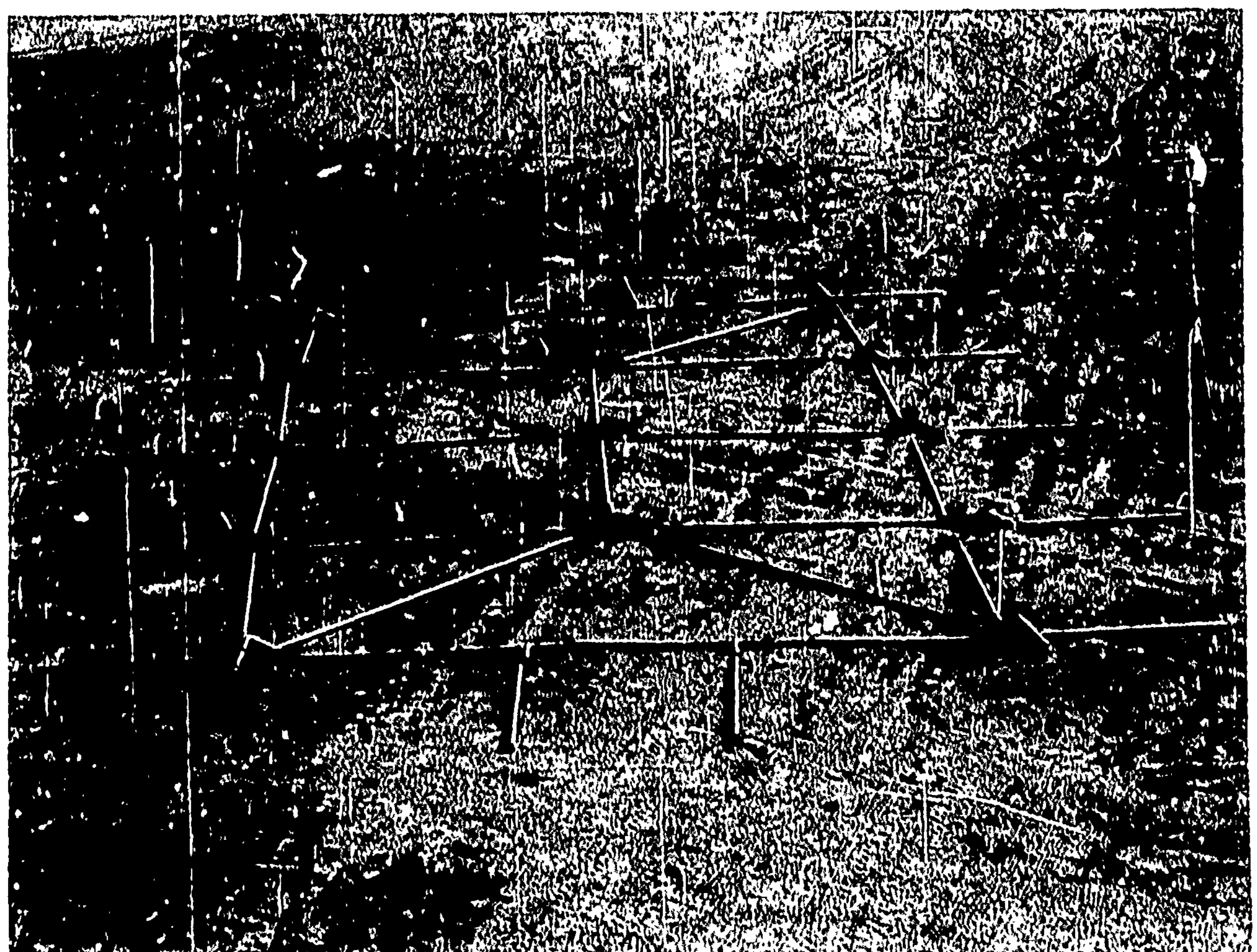


Figure 11. Frame lay-out prior to erection.

It was determined from these tests that four men provided the optimum crew size for the assembly and erection of the frame. The tools required consisted of an adjustable end-wrench for each man and a 10-pound sledge hammer for staking the tent.

### Wind Load Tests

Simulated wind load tests were conducted to determine the structural adequacy of the frame under a 40-knot wind normal to the long axis. The frame was erected and staked to the ground without the use of side tie-downs and the load applied at the eave line, as shown in Figures 12 and 13, to give a maximum equivalent wind loading of 6.45 psf.

### Results and Discussion

The maximum deflection recorded for the two wind load tests was 5-1/2 inches with a maximum residual deflection of 1-1/4 inches. The recorded deflections are summarized in Table II on page 20.

During the first test, a weld defect in the nature of a crack, Figure 14, was noted at corner connector "E" (see Table II). After inspection, it was concluded that the crack was not serious enough to warrant discontinuing the tests. Inspection following the second test revealed that the weld crack had not progressed with repeated load applications.

As a result of these tests, and considering the weld defect as local in nature, the frame was considered structurally adequate.

## TENT DECK DEVELOPMENT

### Material Investigation

An Investigation was made to determine the material best suited for the deck. The factors considered in the determination were as follows:

1. Design criteria

2. Number of units to be fabricated

3. Length of time the units would be in use

4. Personnel and equipment available for installation

5. Erection-time limitations

6. Logistics

7. Cost

Each of the factors in turn determine, limit and/or eliminate a particular material.

Four types of materials were investigated: plastics, stabilized soils, concrete, and corrosion-resistant metals.

Plastics. Investigations into the use of plastics as a soil stabilizer or as a fabricated deck indicated that limited availability and high cost would not make such a deck practicable at the present time. However, developmental work in the plastics field may provide an economically suitable material in future years.

Stabilized Soils. The use of soils stabilized with chemicals (sodium silicate, chrome lignin, and analine furfural), cement, and bitumuls was investigated.

Several objections to the use of chemically stabilized soil were found: (1) high cost; (2) specialized equipment required; (3) possible toxic effect of the chemical used; (4) number of personnel required for installation; (5) specialized training of personnel required in the use and handling of the chemicals; (6) curing time; and (7) the question of stabilizing effectiveness of the chemical in all types of soil.

Where soil conditions are satisfactory, soil cement would provide an adequate deck material. The primary advantage of soil cement is derived from the fact that the bulk of the material required for the deck is located at the site. However, the specific soil conditions for a satisfactory mixture coupled with the necessity for specialized equipment and training of personnel in the placement of soil-cement surfaces tend to limit its use.

The use of soils stabilized with bitumuls offered the objection of possible unpleasant odors produced by the stabilizing agent.

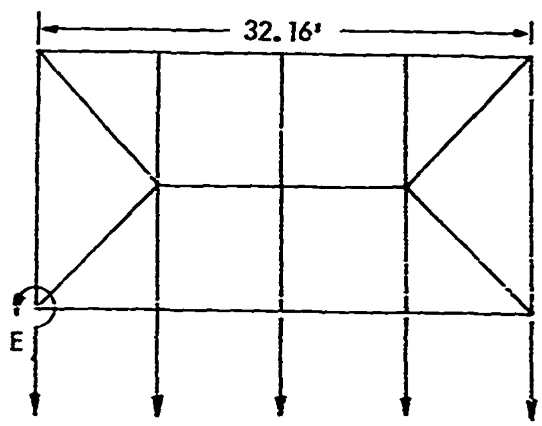
Figure 12. Frame being subjected to simulated wind load.

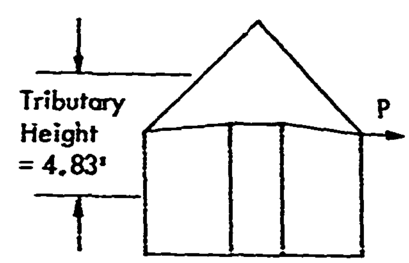
Figure 13. Wind load test - frame.

Table II. Wind Load Test

Lateral Eave Line Deflections

| Total Load (lb) | Deflection - inches | | | | |
|---|---|---|---|---|---|
| | Point A | Point B | Point C | Point D | Point E |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 375 | 2.75 | - | - | - | 2.25 |
| 500 | - | 3.0 | 3.0 | 2.25 | - |
| 750 | 4.25 | - | - | - | 4.675 |
| 1000 | - | 5.5 | 5.5 | 4.75 | - |
| 0 (Residual) | 0.75 | 1.0 | 1.2 | 1.0 | 1.0 |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 375 | 2.375 | - | - | - | 1.125 |
| 500 | - | 2.25 | 2.25 | 1.5 | - |
| 750 | 4.0 | - | - | - | 3.675 |
| 1000 | - | 4.75 | 5.0 | 4.0 | - |
| 0 (Residual) | 0.5 | 0.25 | 0.5 | 0.25 | 0.0 |




Note: Defective weld at corner "E"

Loading —

Area = 4.83 x 32.16
Area = 155 sq ft
Wind load = 1000/155
Wind load = 6.45 psf

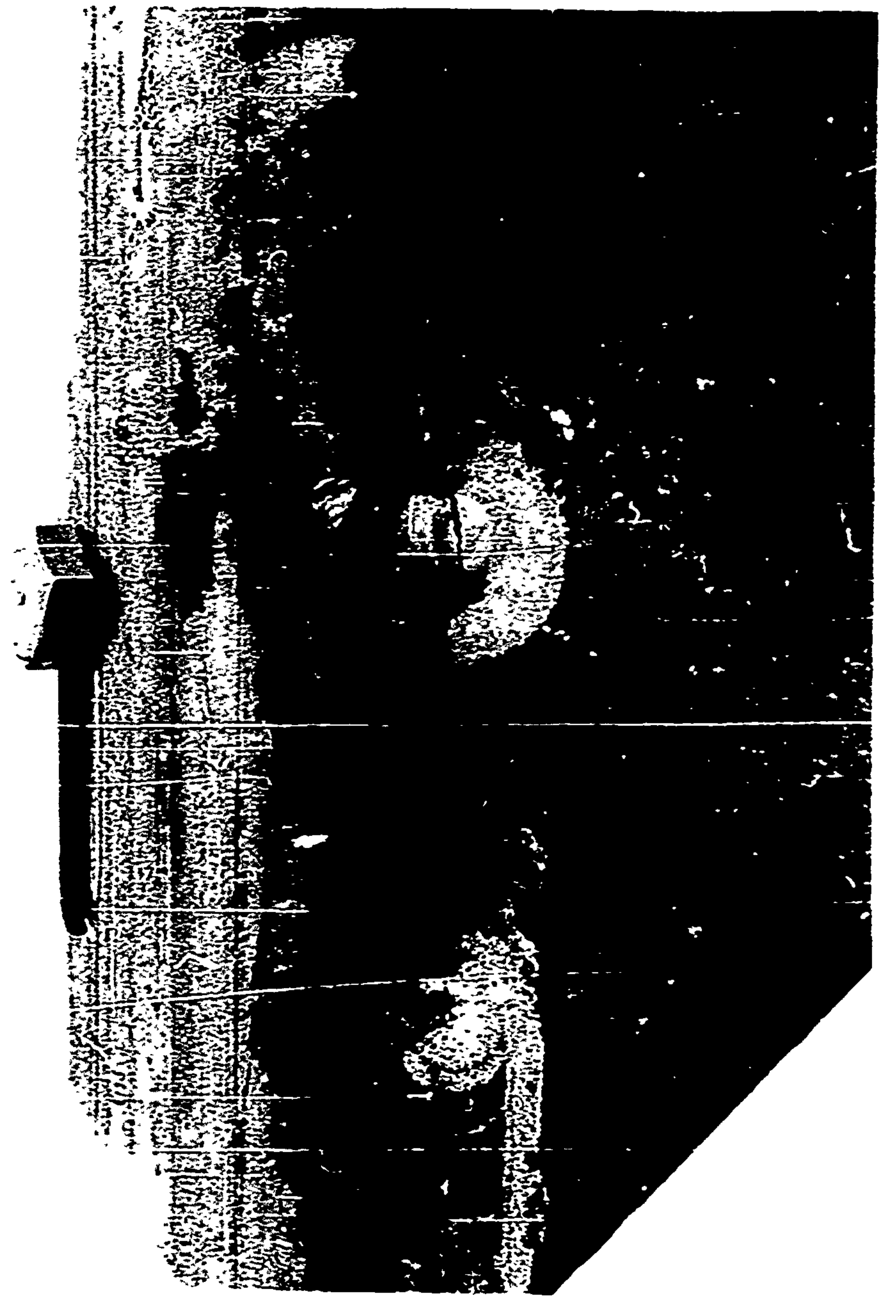


Figure 14. Corner-connector-weld failure.

Concrete. Concrete offered the advantage of an economical, long-wearing material. Two forms of concrete deck were investigated: pre-cast panels and a cast-in-place slab or deck.

Pre-cast panels, either prestressed or reinforced-concrete, offered the promise of a suitable deck. However, the fact that the deck panels would be used a number of times presented handling problems, as concrete does not lend itself well to repeated handling. Cracking, chipping, and complete failure may result from the handling required of a portable deck.

A cast-in-place reinforced-concrete deck would provide a long-wearing, smooth, sanitary, and relatively inexpensive deck ideally suited for permanent camp-sites. The reinforcement required for the slab would depend on the particular soil conditions at the selected site.

The approximate dimensions of the deck required are 16 feet 3 inches by 32 feet 3 inches by 3 inches thick. Anchor bolts set into the concrete to coincide with the frame struts would be used to anchor the frame to the deck.

Metals. Two metals were considered for use in the deck: magnesium and aluminum. An investigation into the use of these two metals indicated that:

1. Magnesium and aluminum are of approximately equal strength, although some aluminum alloys are stronger.

2. Magnesium is approximately one-third lighter than aluminum.

3. Magnesium costs approximately twice as much as aluminum.

It was felt that the higher cost of magnesium was not justified by the weight savings and, therefore, it was decided to use aluminum for the deck material.

Description of Tent Decks

Two types of deck construction were investigated: an interlocking extruded 6063-T6 aluminum section and a section consisting of a honeycomb core with 6061-T6 aluminum facing both top and bottom.

Interlocking Section. A sufficient number of interlocking extruded aluminum sections (Reynolds Metals Company Section Number 20133B) was obtained for the fabrication of four test panels. The extruded section has an interlocking joint which utilizes a pivoting wedge action as shown in Figure 15. The joint assures a self-aligning tight fit without the need of rivets, screws, or bolts.

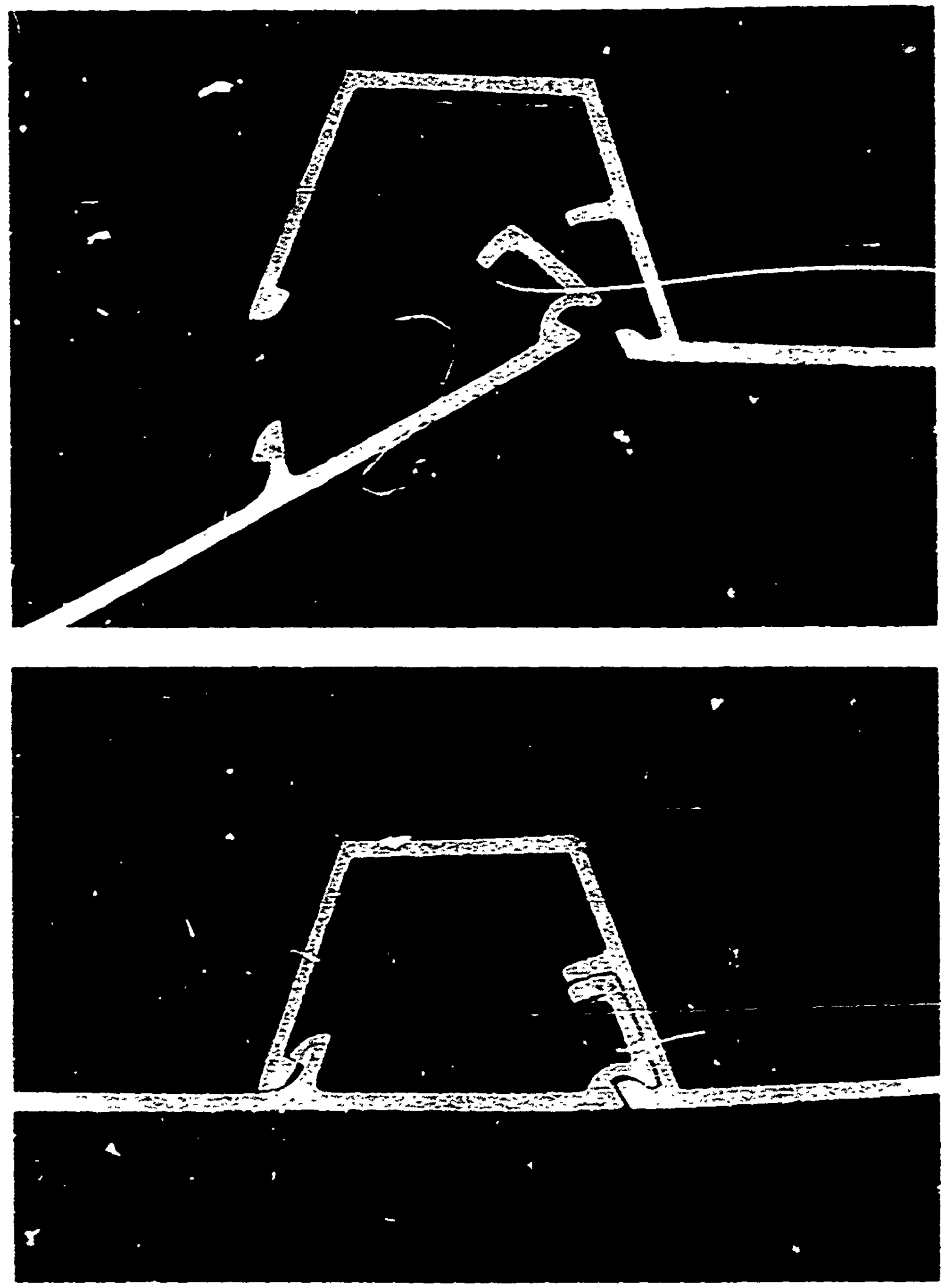


Figure 15. Extruded-aluminum section.

For test purposes, four 3-foot 8-inch by 8-foot panels were fabricated by snapping seven of the 6-inch-wide interlocking sections together and framing with an aluminum channel section. The completed panel is shown in Figure 16. In lieu of procuring special extruded sections, the sides of the deck panel were formed by cutting off the locking portion of a section and snapping it into place on the opposite side, thus forming a closed side. For large-quantity production, special extruded sections, to form the two sides of the deck panel and provide a 4-foot-wide panel, could be procured at a nominal cost. A complete 4-foot by 8-foot deck panel would weigh approximately 80 pounds and cost approximately $50.00.

Sandwich Constructed Panel. Four AIRCOMB panels, developed by the Douglas Aircraft Company for building construction, were obtained for test. The 4-foot by 8-foot by 1.876-inch panels consisted of a 1.75-inch Style 125-35 Type-20 AIRCOMB core, 063 6061T6 aluminum facing both top and bottom and an aluminum channel edge. The panel weighed 88 pounds and the cost was approximately $125.00.

## TENT DECK TEST PROCEDURE

### Load Test

The design criteria stipulated that 80 percent of the decks would be subjected to a floor loading of 40 psf, and 16 percent of the decks would be subjected to a floor loading of 100 psf. In lieu of two decks, it was decided that a deck capable of withstanding both loadings would be more economical. To obtain the most severe condition, the panels were tested as simply supported beams. The deflections recorded during the tests are summarized in Table III on page 26.

### Test Results and Discussion

The maximum deflection recorded for the AIRCOMB panel under a 100 psf loading was 0.62 inches, while the maximum deflection for the extruded-aluminum panel was 3 inches.

The channel framing around the extruded-aluminum deck panel failed at mid-span with a loading of 75 psf as shown in the insert in Figure 17. An additional panel was fabricated, eliminating the weld at mid-span, and tested to a loading of 100 psf without failure.

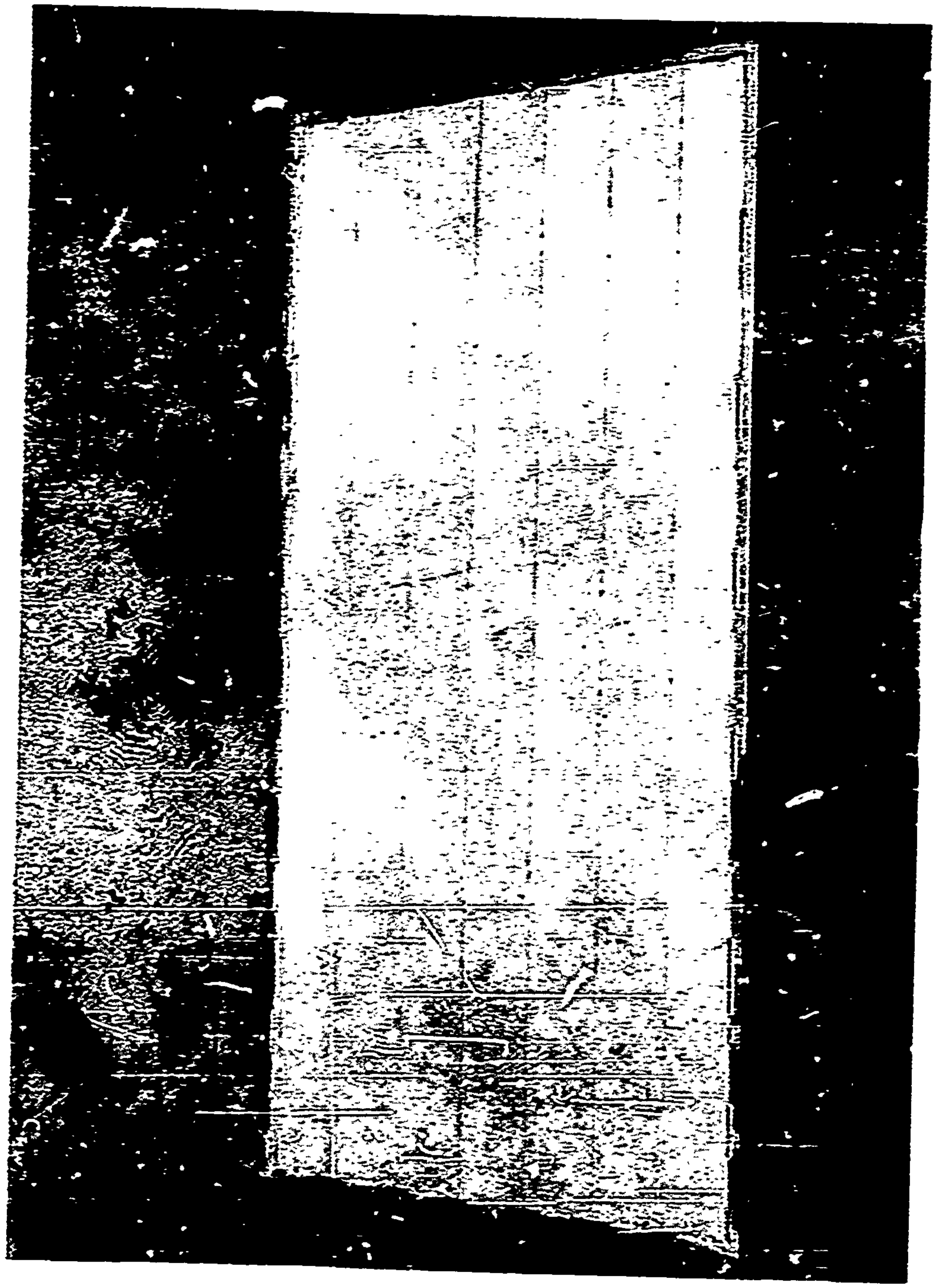


Figure 16. Completed extruded-aluminum deck panel.

Table III. Load Test - Deck Panels

| Load (psf) | Deflection - inches | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | AIRCOMB Panel | | Extruded Aluminum Panel | | | | | | | |
| | A | B | A | B | A | B | C | A | B | C |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 0.0 | 0.06 | 0.38 | 0.31 | - | - | - | - | - | - |
| 20 | 0.125 | 0.125 | 0.50 | 0.44 | - | - | - | - | - | - |
| 30 | 0.25 | 0.25 | 0.63 | 0.63 | 0.25 | 0.25 | 0.625 | - | - | - |
| 40 | 0.31 | 0.31 | 0.81 | 0.75 | - | - | - | 0.563 | 1.5 | 0.5 |
| 50 | 0.38 | 0.38 | 1.38 | 1.13 | 1.00 | 0.75 | 1.50 | - | - | - |
| 75 | 0.56 | 0.50 | Weld failure* | | Weld failure* | | | 1.5 | 2.38 | 1.5 |
| 100 | 0.62 | 0.62 | Weld failure* | | Weld failure* | | | 2.5 | 3.0 | 2.0 |

* See insert, Figure 17

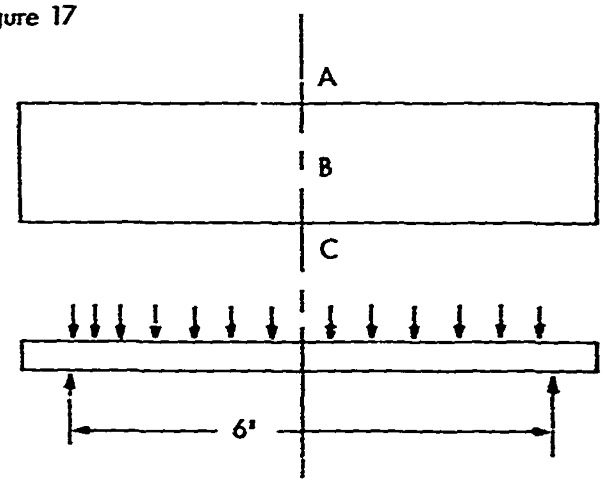


Figure 17. Extruded-aluminum deck panel being load tested (Insert shows weld failure of framing).

The results of the tests indicate that, while both types of deck are structurally adequate, the AIRCOMB deck is considerably more rigid. However, since the panels were tested as simply supported beams, a condition not expected under normal installation, the larger deflection of the extruded-aluminum panel is not considered detrimental.

Deck Assembly

No deck assembly tests were conducted. However, assembly of the 16-foot by 32-foot deck should offer no difficulty. The 4-foot by 8-foot panels can be laid directly on the ground or if necessary on dunnage. The panels can be tied together with connector plates which are secured to the panels with self-tapping metal screws.

A smooth level area should be provided for the bed of the deck. This will assure a flat deck surface and keep the loading of the connector plates to a minimum.

Since the deck was designed to be independent of the frame, no facility for securing the frame to the deck is provided. The deck is laid out inside the frame structure, and the frame is staked or tied down.

## PACKAGING STUDIES

A summary of the packaging and crating study is shown in Table IV. The frame has a packaged weight of 430 pounds and a shipping cube of approximately 28 cubic feet. A complete extruded-aluminum deck, sixteen 4-foot by 8-foot panels, weighs 1,280 pounds and has a shipping cube of 80 cubic feet. A complete AIRCOMB deck, sixteen 4-foot by 8-foot panels, has a packaged weight of 1,400 pounds and has a shipping cube of 80 cubic feet.

## COST COMPARISON

A comparison of cost between the tent frames utilizing the AIRCOMB, extruded-aluminum, and cast-in-place concrete decks is given on the following page.

| Item | Estimated Cost | Total Shipping Weight (lbs) |
|---|---|---|
| Frame w/AIRCOMB deck | $3700 | 1,830 |
| Frame w/extruded-aluminum deck | 1600 | 1,710 |
| Frame w/cast-in-place 3-inch-thick concrete deck | 1180 | 430* |
| Frame w/o deck | 430 | 430 |

* It is assumed that the material required for the concrete deck would be on hand for other construction work. Otherwise, add 3,600 pounds for cement based on a six-bag mix.

Table IV. Summary of Weights and Cubes – Tent Frame and Decks

| Item | Number of Packages | Packaged Weight (lbs) | Total Cube (cu ft) |
|---|---|---|---|
| Tent Frame | | | |
| Connectors, bolts and nuts, misc. tools | 1 | 200 | 20.0 |
| Framing members | 3 | 230 | 8.0 |
| Total | 4 | 430 | 28.0 |
| Deck | | | |
| AIRCOMB panels | 4 | 1,400 | 80.0 |
| Extruded-aluminum panels | 4 | 1,280 | 80.0 |

## CONCLUSIONS

### Frame

1. The frame, as designed, is suitable for use with Tent, Medium, General Purpose (MIL-T-00172 QMC).

2. The frame is capable of being assembled and disassembled a minimum of four times.

3. The frame can be easily erected with a crew of four men in approximately thirty minutes.

4. Color coding of the connectors and framing members aided in the assembly of the frame.

### Deck

1. The extruded-aluminum deck is structurally adequate.

2. The AIRCOMB deck is structurally adequate.

3. Cast-in-place concrete decks appear to be the best-suited for permanent camp sites.

## RECOMMENDATIONS

1. That cast-in-place concrete decks, with stud bolts set in the concrete to anchor the frame, be used for permanent camp sites.

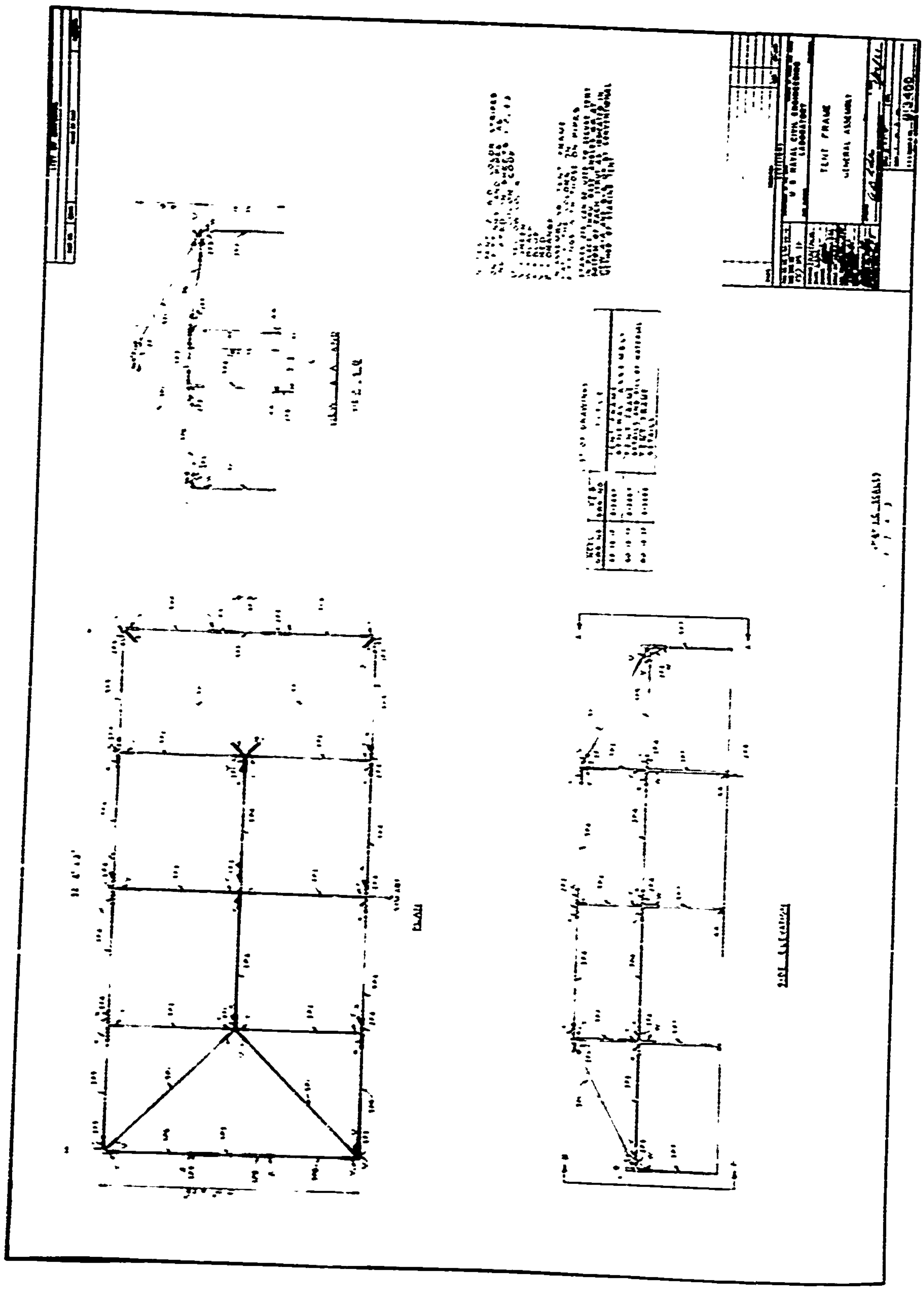
2. That for semi-permanent sites, the extruded-aluminum deck panel be used.

3. That for high portability, no deck be used with the frame.

4. That several of the frames and extruded aluminum decks be procured for in-service tests by the Marine Corps.

Appendix

TENT FRAME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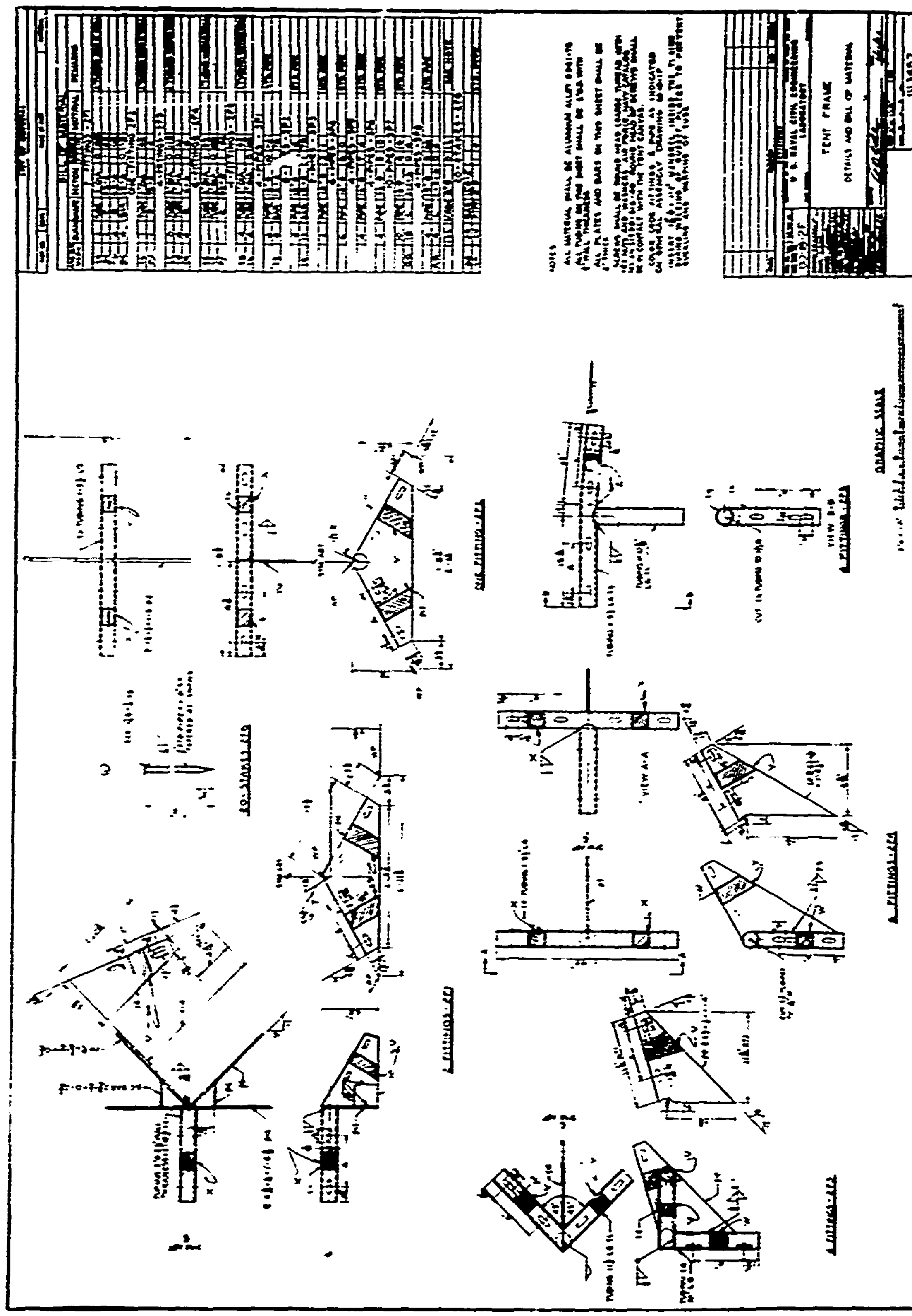
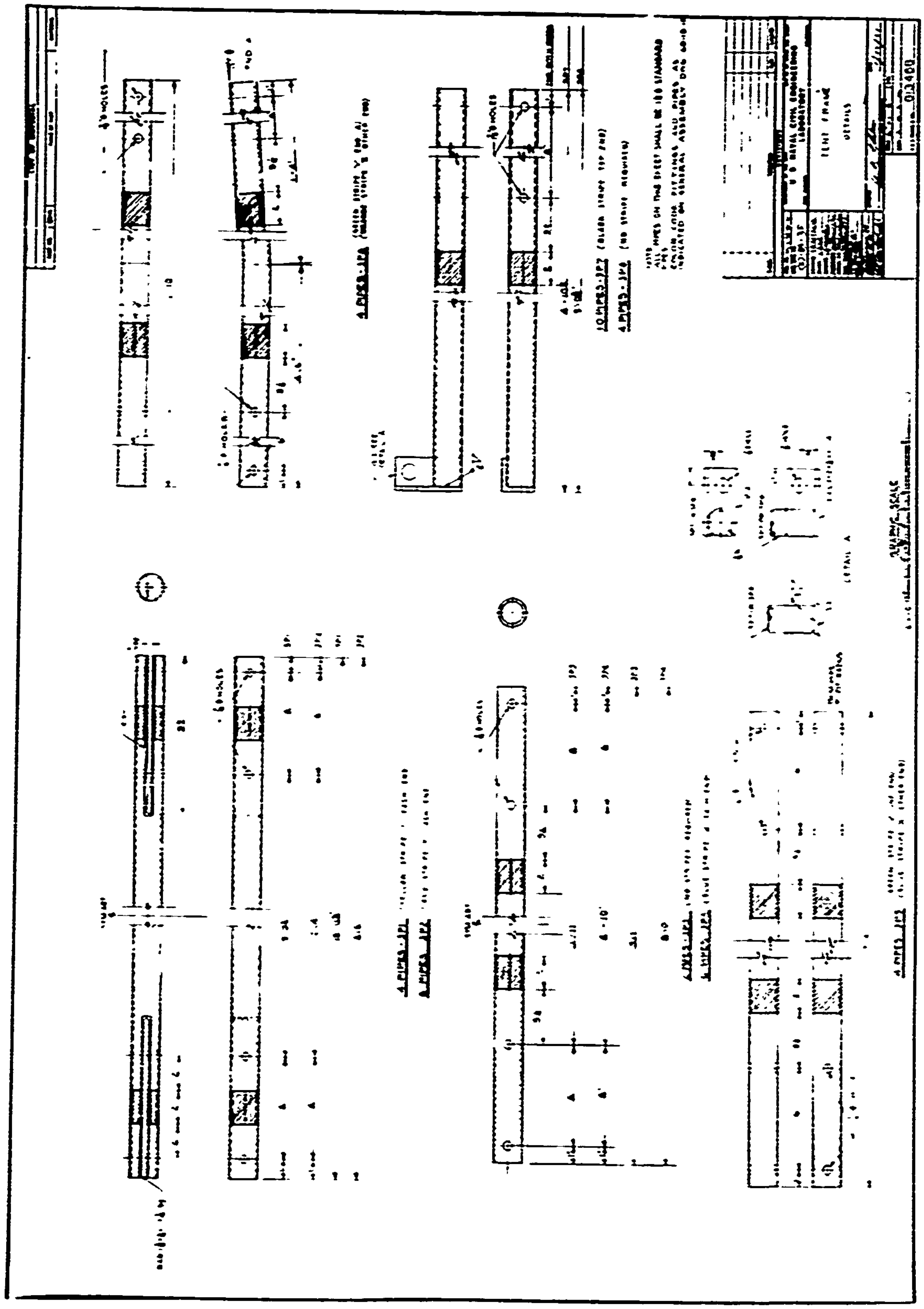
GENERAL ASSEMBLY





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| 7 | N5 | Construction Battalion Center |
| 5 | N6 | Construction Officer-in-Charge |
| 1 | N7 | Construction Resident-Officer-in-Charge |
| 12 | N9 | Public Works Center |
| 1 | N14 | Housing Activity |
| 2 | R2 | Recruit Depots |
| 2 | R10 | Supply Installations (Albany and Barstow only) |
| 1 | R20 | Marine Corps Schools, Quantico |
| 3 | R64 | Marine Corps Base |
| 1 | R66 | Marine Corps Camp Detachment (Tengan only) |
| 7 | W1A1 | Air Station |
| 35 | W1A2 | Air Station |
| 9 | W1B | Air Station Auxiliary |
| 5 | W1C | Air Facility (Phoenix; Monterey; Oppama; Naha; and Naples only) |
| 3 | W1E | Marine Corps Air Station (Except Quantico) |
| 1 | W1F | Marine Corps Auxiliary Air Station |
| 8 | W1H | Station - BuWeps (Except Rota) |