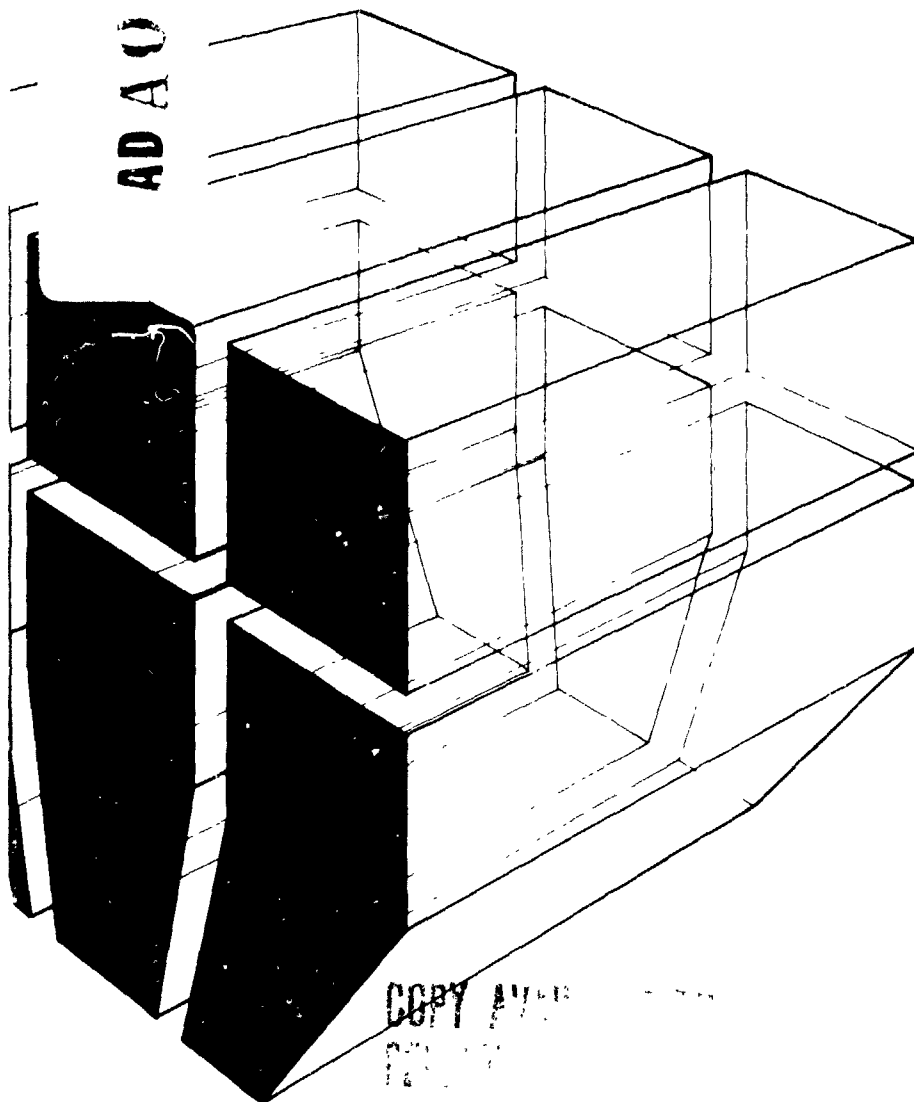


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October 1976
Multi-Purpose Structural Components

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FIELD EXPERIMENT ON A PREFABRICATED
EXPANDABLE FOAM/WOOD STRUCTURE



by
R. L. Trent
T. M. Whiteside
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report, the third in a series of reports covering development of multi-purpose structural components,* documents the findings, results, and conclusions of a field experiment to fabricate and erect the components of a prefabricated foam/wood theater of operations (TO) structure. The floor, wall, and roof panels were fabricated off-site and shipped without damage to the erection site; the foundation bents and roof trusses were fabricated on-site. These multi-purpose structural components were		

then assembled and erected on a building site at Fort Belvoir, VA. Interior finishing and services were provided to enable the completed structure to be used as a classroom, as well as a demonstration facility.

* R. L. Trent and T. M. Whiteside, *Multi-Purpose Structural Components (Prefabricated, Expandable Foam/Wood Structure for the Theater of Operations)*, Technical Report C-45 (U.S. Army Construction Engineering Research Laboratory [CERL], 1975); and R. L. Trent, T. M. Whiteside, and J. Robertus, *Erection Procedures for Prefabricated Expandable Foam/Wood Structure*, Technical Report C-52/ADA027382 (CERL, 1976).

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FOREWORD

This field experiment was performed cooperatively by the Military and Base Engineering Branch, Facility Operations Division of the U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL; and the Department of Engineering Sciences (D-E/S) of the U.S. Army Engineering School (USAES), Fort Belvoir, VA. CPT John Robertus, USMC, of D-E/S was the Project Officer at USAES.

This work was funded by the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), under Project 4A764717DT34, "Development for Engineering Support to the Field Army"; Task 04, "Base Development"; Work Unit 003, "Multi-Purpose Structural Components." The QCR number is 1.01.001(4). The OCE Technical Monitor is Mr. R. Barnard; the CERL Principal Investigator is Dr. A. Kao. The Principal Investigator during the field experiment was Mr. R. L. Trent.

Appreciation is extended to Mr. A. Smith of CERL for technical advice concerning polyurethane foam during the development of the field experiment and to Mr. H. Barrett of CERL for assistance in fabricating the floor, wall, and roof panels.

Dr. E. L. Marvin is Chief of the Military and Base Engineering Branch and Mr. R. Blackmon is Chief of the Facility Operations Division. COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Deputy Director.

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FIELD EXPERIMENT ON A PREFABRICATED EXPANDABLE FOAM/WOOD STRUCTURE

1 INTRODUCTION

Background

The Corps of Engineers (CE) has recognized the need for new and improved construction techniques and materials to support the Army in future theaters of operations (TO) by placing increased emphasis on developing more timely and responsive construction support efforts for new and revised tactical scenarios. This report documents part of an effort to provide construction materials, fabrication techniques, and erection procedures that a CE officer in the TO can use to field-fabricate many of the needed facilities.

During FY 74 and FY 75, the U.S. Army Construction Engineering Research Laboratory (CERL) developed and refined a building system suitable for TO use; this system used the complementary properties of spray-applied polyurethane expanded foam and dimensioned lumber. Much of this work was performed in cooperation with the U.S. Army Engineering School (USAES) to provide CERL with a background of experience for TO construction, and to insure interaction and recognition of the military user's requirements in the TO.

Multi-purpose structural components of various designs and proportions of foam and wood were fabricated at CERL and USAES and used to erect several partial and complete structures. The components were tested and evaluated to improve and refine their assembly and erection. On the basis of this work, an optimal family of structural components was selected for further refinement. The optimal foam/wood building system is characterized by a set of floor, wall, and roof panels and foundation bents and trusses--all of which can be prefabricated in the TO. The building system is 24 ft (7.2 m) wide; its length can be expanded in 8-ft (2.4 m) increments.

Computerized evaluations¹ of the components, based on material and labor cost estimates from the test buildings, indicated that the building system possesses several advantages over competing building systems proposed for TO use. To verify this analysis, two field experiments were planned for FY 76. This report documents the results of the first field experiment conducted at USAES, Fort Belvoir, VA. The second experiment was conducted in early 1976 at a U.S. Army Training and Doctrine Command (TRADOC) installation (Fort Rucker, AL).

¹T. C. Ryan and L. C. Tietz, *Evaluation System for Proposed Theater of Operations Structures (TOBSEP)*, Technical Report C-14, Vols I-ADAO06014, II-ADAO06495, III-ADAO06145 (U.S. Army Construction Engineering Research Laboratory [CERL], 1975).

Purpose

The purposes of this field experiment were:

- a. To insure that the CE troops in a field environment could construct and handle the foundation bents and trusses.
- b. To determine whether the panels could be prefabricated and shipped with minimal damage.
- c. To verify that new erection procedures for the foundation bent and floor panels would ease and speed up erection of the building system.
- d. To determine actual time and cost for the fabrication and erection of the building system by CE troops.

Approach

The floor, wall, and roof panels required for the structure were prefabricated and sprayed with urethane foam at CERL, then shipped to USAES. The bents and trusses were prefabricated at USAES. The system at USAES was erected in three phases: (1) fabrication of bents and trusses, (2) structural erection, and (3) interior and exterior finishing procedures. The labor and material costs were compared to those of three respective Army Facilities Components System (AFCS) facilities, and the foam/wood system was evaluated based on the design criteria presented in Chapter 2.

Mode of Technology Transfer

It is anticipated that this study will have an impact on TM 5-301, 5-302, and 5-303.² The technology transfer will be through field demonstrations, reports, and the Army Training Literature Program.

²*Army Facilities Components System-Planning, TM 5-301; Army Facilities Components System-Designs, TM 5-302; Army Facilities Components System-Logistic Data and Bills of Materials, TM 5-303 (Department of the Army, 1973).*

2 BUILDING DESIGN CRITERIA

Design Criteria

The primary concern during development of this building system has been that it be capable of field-fabrication in the T0. The building system must be easy to fabricate and erect in the field, and must be easily modifiable to meet tactical, climatic, or other T0 demands.

The building system capable of being field-fabricated is a viable alternative to the prefabricated/pre-engineered metal folding frame or panelized building systems envisioned for future inclusion in the AFCS. While such prefabricated/pre-engineered systems will provide rapid development and erection in a T0, they do have the following drawbacks:

- a. Prefabricated/pre-engineered buildings shipped to the T0 in erected, collapsed, or panelized modes create transportation problems because they are voluminous, heavy, cumbersome, and have poor weight/volume ratios.
- b. Erection of many of the prefabricated metal collapsible or panel structures requires heavy equipment such as cranes, and some experience in steel construction.
- c. The prefabricated/pre-engineered building systems generally have high initial cost. To be economically feasible, these systems require a certain number of relocations; whether these building systems will be reused as intended is not known.
- d. Most of the available prefabricated building systems were designed for commercial/industrial use in this country; little applicability for specific military needs in the T0 is evident.

Because of these drawbacks, prefabricated/pre-engineered building systems, particularly metal ones, may not be optimal in all circumstances. A more detailed analysis of various building systems for military use in the T0 can be found in two Army documents.^{3,4}

Design of the CERL foam/wood building was based on the principles of T0 construction, including:

- a. Speed of construction. The building design, fabrication, and erection methods are standardized to increase working efficiency.

³*Pre-Engineered Logistic and Administrative Structures (PLAST)* (U.S. Army Engineering School, 1973).

⁴R. D. Reynolds and T. Whiteside, *Base Development, Vol VI, Vertical Construction (VERCON)*, ACN 20583 (U.S. Army Training and Doctrine Command [TRADOC], 1975).

Construction activities are simplified, austerity is enforced, and phased construction is relied on to insure earliest maximum usage.

b. Economy. It is essential to conserve manpower and materials and to accomplish construction with a minimum of shipped-in tonnage and volume.

c. Flexibility. Construction must be adaptable to various conditions without major modification.

Specific design criteria were derived from these principles of construction:

a. Maximum rapidity of fabrication and erection of components.

b. Maximum simplicity of fabrication and erection of components.

c. Expandability.

d. Reductions in logistics, supply, and transport requirements including weight/volume ratio.

e. Minimal additional training requirements for fabrication and erection of the building system.

f. Reduction in building system costs.

g. Reduction in operation, maintenance, and repair costs.

h. Relocatability.

i. Maintenance of a high degree of flexibility for commanders and military planners.

Description of Building System

The foam/wood building system is essentially modular, panelized, and erected on a raised floor system supported by foundation bents. Figure 1 shows the basic characteristics and dimensions of the system. The module is 4 by 8 ft (1.2 by 2.4 m) based on the dimensions of a standard plywood sheet. This module controls the building width, expansion length, and interior clear ceiling height. The building system is composed of five major components.

a. Foundation bent. The bent is essentially a built-up "I" beam of plywood and 2- by 4-in. (3.8 by 8.9 cm) lumber supported by two legs. The bent provides an elevated base above ground level for the floor system. It is 24 ft (7.2 m) long and is spaced on 8 ft (2.4 m) centers.

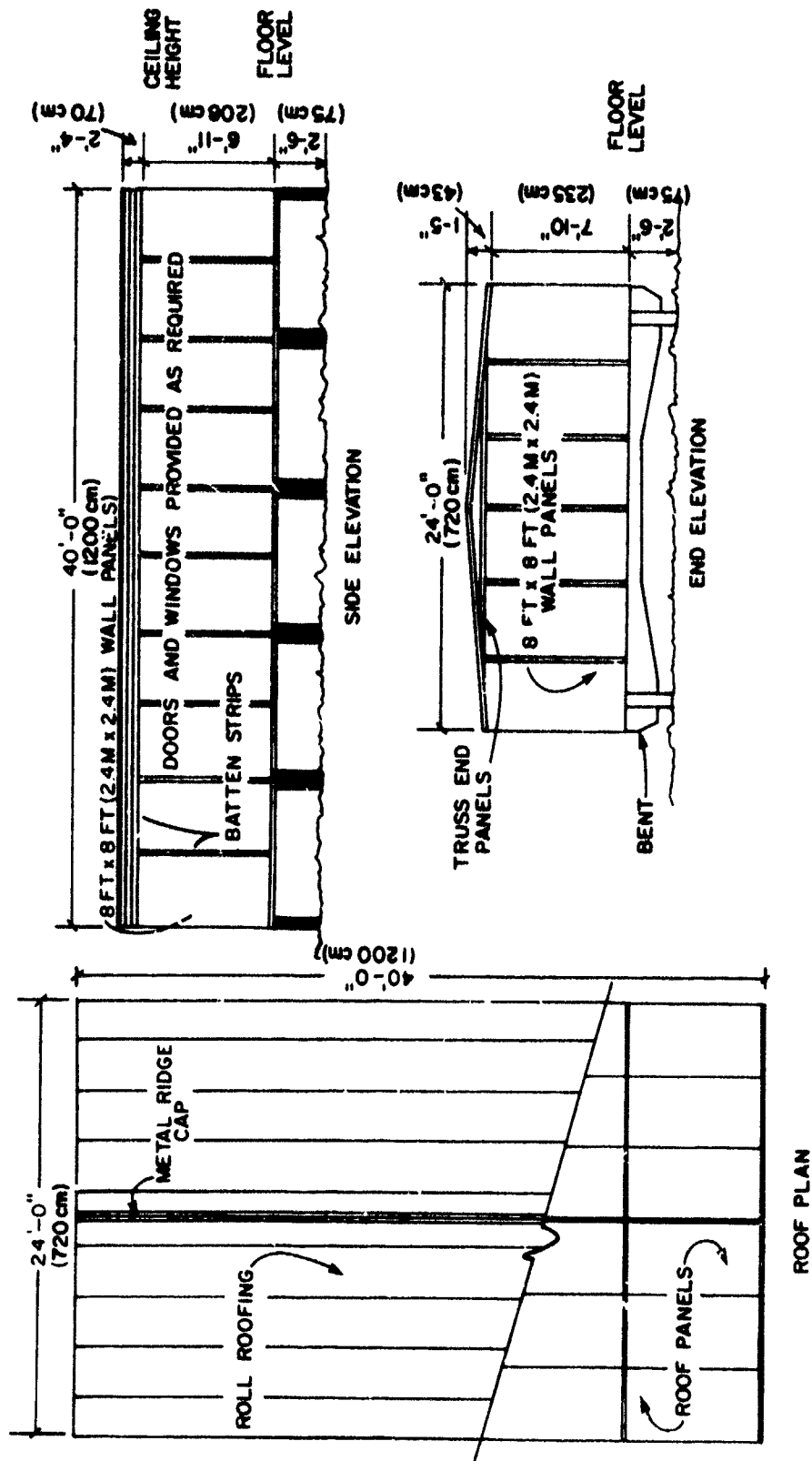


Figure 1. Foam/wood prefabricated expandable building system--USAES experiment.

b. Floor system. The floor system is composed of panels constructed from 1/2-in. (1.27 cm) plywood over a 2- by 4-in. (3.8 by 8.9 cm) lumber frame. These panels fit between and bear on the bents.

c. Wall system. The wall panels are 8 by 8 ft (2.4 by 2.4 m) and fabricated from 1/4-in. (0.63 cm) plywood and 2- by 4-in. (3.8 by 8.9 cm) lumber. The plywood serves as an exterior surface, and provides connections between floor, roof, and adjacent wall panels.

d. Roof truss. The truss is similar to the bent in that it is a tapered "I" beam fabricated from plywood and 2- by 4-in. (3.8 by 8.9 cm) lumber. The trusses provide a 24-ft (7.2 m) span spaced on 8-ft (2.4 m) centers.

e. Roof panels. The 4- by 8-ft (1.2 by 2.4 m) roof panels are fabricated similarly to the floor panels except that the 2- by 4-in. (3.8 by 8.9 cm) lumber is on 24-in. (60 cm) centers rather than 16-in. (40 cm) centers. The roof panels fit between and bear on the truss.

Urethane foam sprayed on the floor, wall, and roof panels as an insulation envelope also serves as additional structural support during and following erection of the building system. Site preparation consists of minimal clearing, laying the building out on-site, and augering and concreting holes for the foundation bent. Appendix A contains working drawings for the system.

3 FIELD EXPERIMENT AT USAES

User Requirements

The experimental structure was required to be an all-weather facility for classroom use. Since it was intended to perform a long-term function and be provided with adequate lighting levels, heating, ventilation, and air conditioning, it was also required to meet CONUS building codes, including fire-proofing. Therefore, while the wall and roof panels may be acceptable with exposed foam interior surfaces for TO applications, for this experiment they were provided with 3/8-in. (0.95 cm) gypsum wallboard facings after installation of the utility services. The building dimensions were 24 by 40 ft (7.2 by 12 m).

Description of Activities

Panel Fabrication

The 76 floor, wall, and roof panels required for the structure were prefabricated and sprayed with urethane foam at CERL and shipped to USAES. The panels were shipped without damage from normal handling and all were acceptable for use in the structure.

Foundation Bents and Roof Truss Fabrication

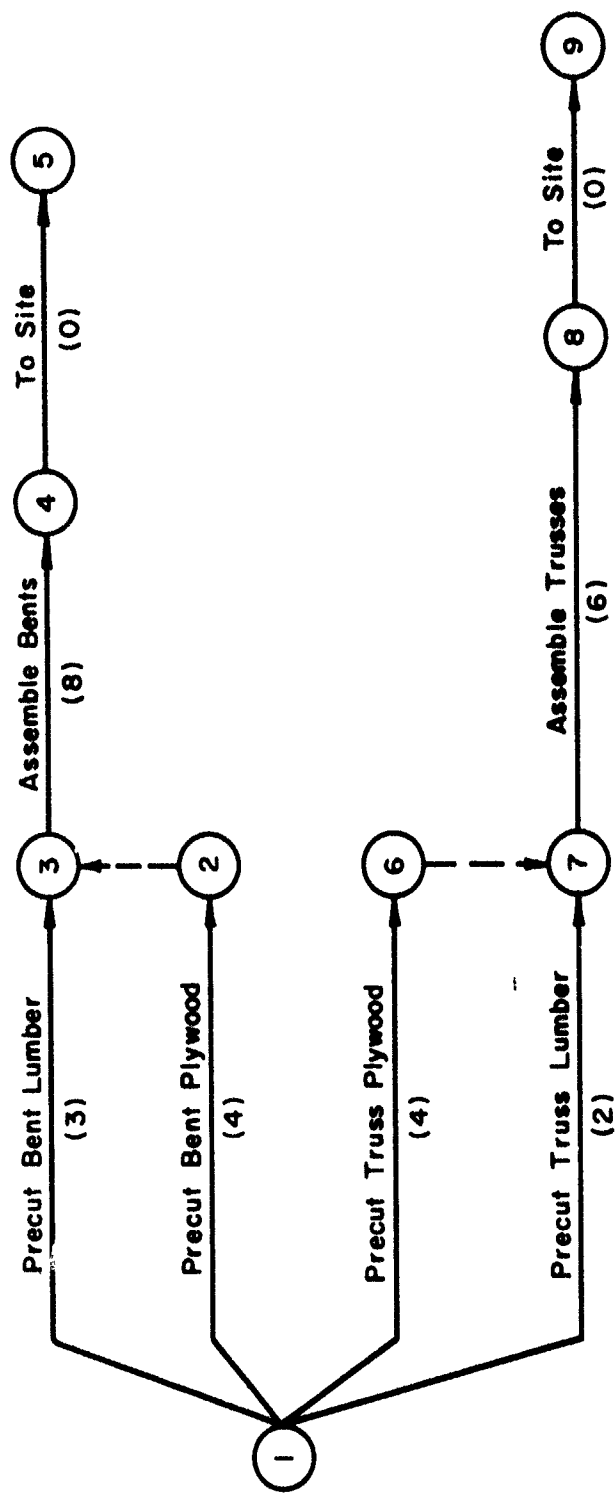
The bents and trusses were prefabricated at USAES in accordance with the design drawings included in Appendix A.

Building Erection

The building system was erected in three phases: Phase I--Fabrication of Foundation Bents and Roof Trusses (Figure 2); Phase II--Structural Erection Procedures (Figure 3); and Phase III--Interior/Exterior Finishing Procedures (Figure 4). Appendix B details particular activities in each phase.

The activities shown in these figures are fairly self-explanatory. However, because of problems in providing permanent ground anchorages for the bent encountered in earlier tests, one of the major objectives of this experiment was to verify a new erection procedure for the bent and floor panels. The specific problems experienced were controlling the dimensional tolerances between the bents and leveling the floor system while concrete was being poured in the augered holes around the bent legs. An alternate set of erection procedures which was developed to overcome these deficiencies was tested at Fort Belvoir. The modified procedure, as incorporated in Figure 3, consists of the following steps:

a. The building site is laid out (e.g., with batten boards), and the locations for the augered holes are determined. The bent legs are prefabricated using dimensions based on the terrain elevation differences on the site.



- Notes :
1. Numbers in () Indicate Actual Man-hours
 2. Phase I USAES Total Man-hours -- 27

Figure 2. CERL/USAES experimental building, activity network phase I - fabrication of foundation bents and roof trusses.

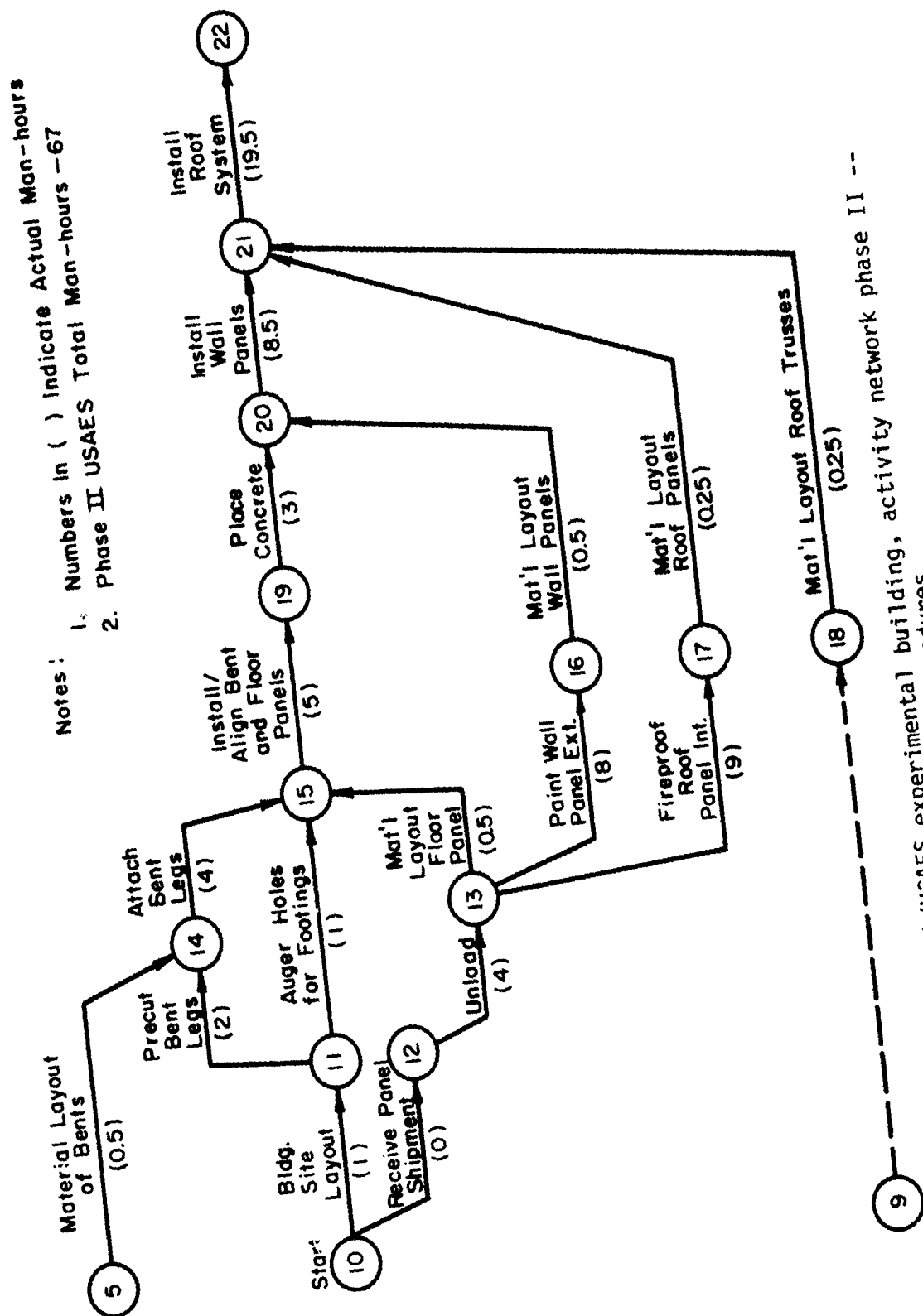
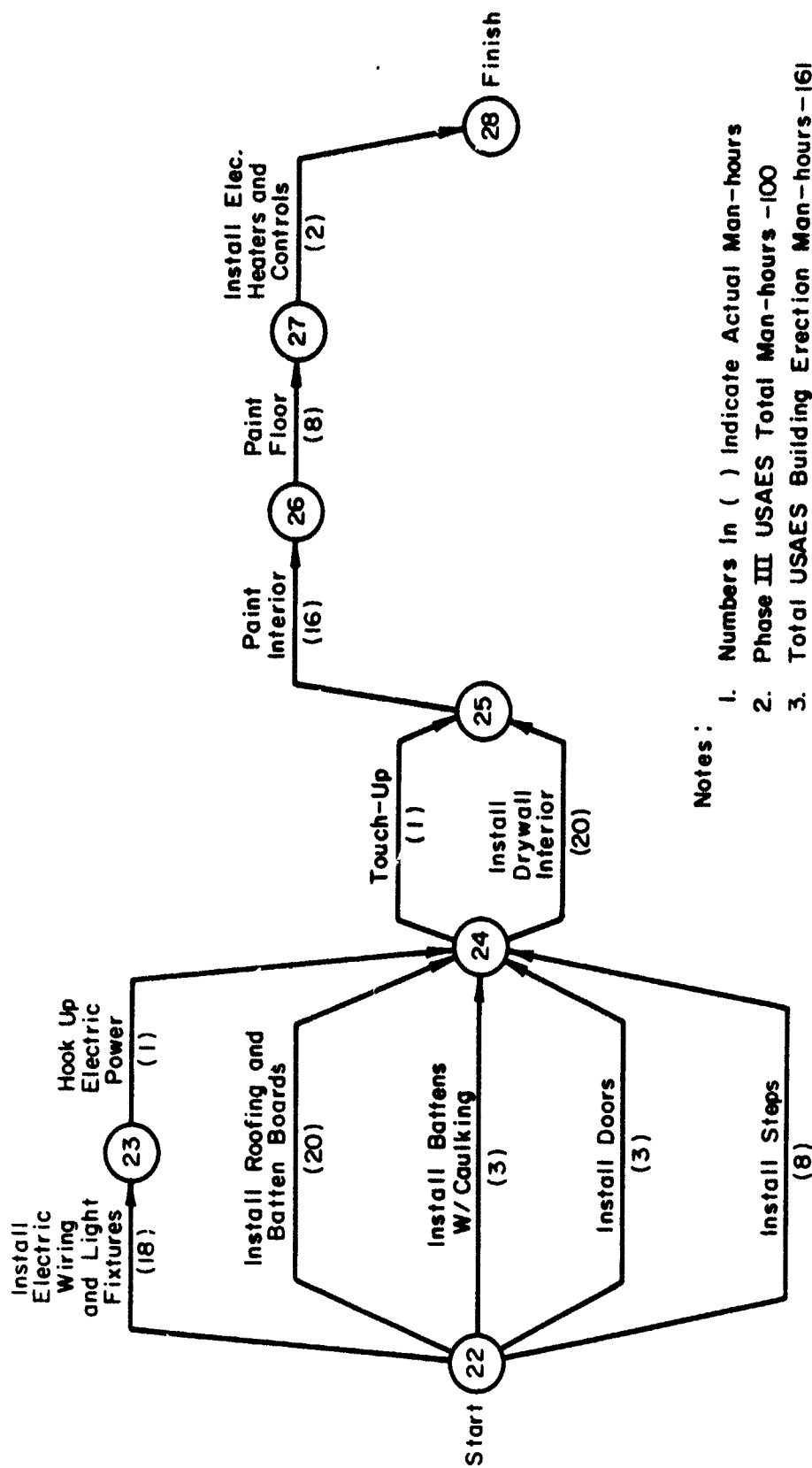


Figure 3. CERL/USAES experimental building, activity network phase II -- structural erection procedures.



- Notes:
1. Numbers in () Indicate Actual Man-hours
 2. Phase III USAES Total Man-hours -100
 3. Total USAES Building Erection Man-hours-161

Figure 4. CERL/USAES experimental building, activity network phase III - interior/external finishing procedures.

b. The holes for the bent legs are augered to the proper depth.

c. The legs are connected to the foundation bents on-site and each bent is placed in its respective hole. The bents are supported over the hole in approximate position by temporary timber cradles or supports adjacent to the legs (Figure 5).

d. The floor panels are placed in a row between the bents. The entire row of panels and the two bents are then plumbed and leveled with shims at the temporary cradles.

e. When the complete floor system has been installed and leveled, concrete is poured around the legs in the augered holes.

f. The temporary cradles are left in place as erection of the wall and roof systems continues and the concrete cures.

This procedure permits erection of the building above the floor system without waiting for the concrete foundation to cure. In addition, the floor panels serve as the spaces to keep the bents in the proper locations. Adjustments can be accomplished more easily when the entire floor/foundation system is supported over the holes prior to concrete placement.

Finishing operations usually involve weatherproofing the building and installing utilities such as power, heat, and light. In the experimental building, fluorescent lamps and electric radiant heaters were installed with temporary electrical power; permanent power is currently being installed.

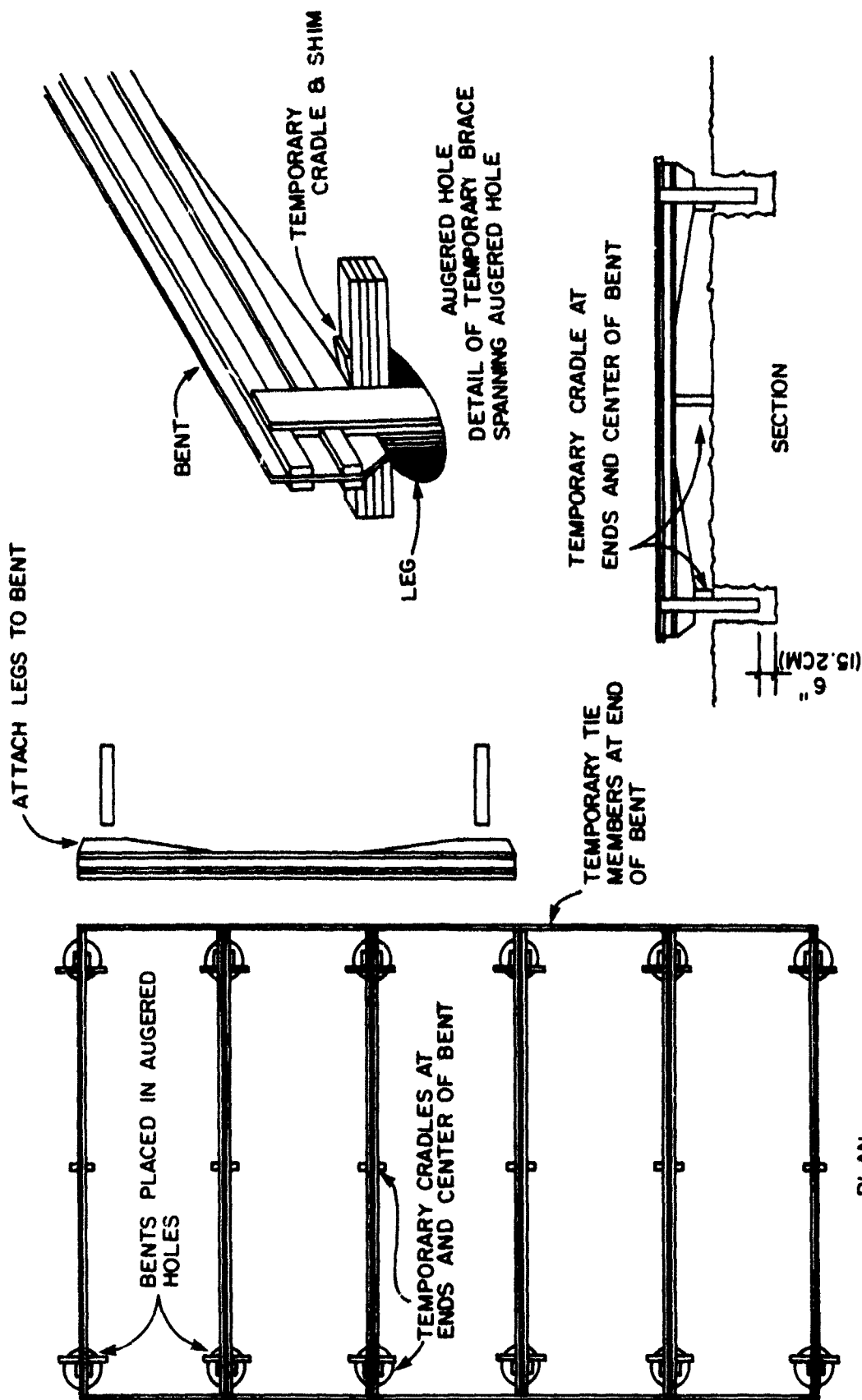


Figure 5. Foundation bent erection details.

4 COST COMPARISON WITH AFCS BUILDING DESIGNS

The AFCS was chosen for a cost comparison with the foam/wood system because both represent similar anticipated usage--i.e., actual fabrication in a TO. However, because of inconsistencies in data, the cost comparisons are approximate and should not be used as the sole basis for selecting a system; other cost elements such as service life, equipment, and skill requirements should also be considered.

Cost Calculations

The labor figures for the experiment are based on actual man-hours to fabricate and erect the completed building. Material costs for the experiment are also based on actual costs. The material cost and labor requirement of selected AFCS designs were taken from TM 5-303. For both the AFCS and foam/wood designs, an arbitrary rate of \$3/hr was set for labor cost. The construction machine cost was not considered.

Foam/Wood Building System - USAES Experiment

Table 1 summarizes the material and labor costs for fabrication and erection of the system; Appendix C provides a more detailed breakdown of the material and labor requirements. Excluding construction machine costs, the total cost of the experimental building at Fort Belvoir was \$5,301, at a labor rate of \$3/hr. Cost of the building itself, excluding painting and utility installation, was \$4,695. This figure is more appropriate for comparison with AFCS designs, since no AFCS facility has similar utility features or includes painting.

Table 1

Summary of Material and Labor Requirements of
Experimental Building at Fort Belvoir

	<u>Material</u>	<u>Labor</u>		<u>Total</u>
		<u>MH</u>	<u>Cost</u>	
Building only	\$3,927	256	\$768	\$4,695
Miscellaneous (painting, utility)	<u>468</u>	<u>46</u>	<u>138</u>	<u>606</u>
TOTAL	\$4,395	302	\$906	\$5,301

AFCS Designs

Three facilities were chosen from the AFCS inventory using TM 5-302 and TM 5-303. These facilities were chosen as representative of AFCS field-fabricated lumber-framed building designs. Two general-purpose facilities--340512 and 340514 (Figures 6 and 7)--were chosen as more recent additions to the inventory and for their concrete and wood floor systems. Facility 340321 (Figure 8), a basic barracks building, was chosen for its raised floor system.

Facility 340512 is supported by a concrete floor slab with an integral foundation. Facility 340514 is raised above ground level over a crawl space, with a foundation wall supporting the floor system. The walls of both facilities are site-fabricated of 2- by 4-in. (3.8 by 8.9 cm) lumber, spaced on 24-in. (61 cm) centers. The roof system uses 2- by 8-in. (3.8 by 18.75 cm) lumber to provide "W" trusses, with 2- by 8-in. (3.8 by 18.75 cm) purlins on 24-in. (61 cm) centers. The roof covering materials are insulation board and corrugated metal. The external wall coverings are insulation board and plywood. Insulation provided in walls and ceilings is 2-in. (5.08 cm) fiberglass batts.

Facility 340321 is the basic 20- by 20-ft (6 by 6 m) building block for earlier AFCS barracks. Additional facility members are required, such as 340322 to form a building with dimensions of 20 by 40 ft (6 by 12 m); 340361 for exterior cladding; 340374 for an elevated floor system*; and 340391 for an interior liner. Walls can be "stick-built" or built as panels; both have 2- by 4-in. (3.8 by 8.9 cm) lumber on 48-in. (121.9 cm) centers. The roof covering is asphalt roofing felt. Exterior cladding is 1-in. (2.5 cm) boards. Insulation is 3/4-in. (1.9 cm) insulation board.

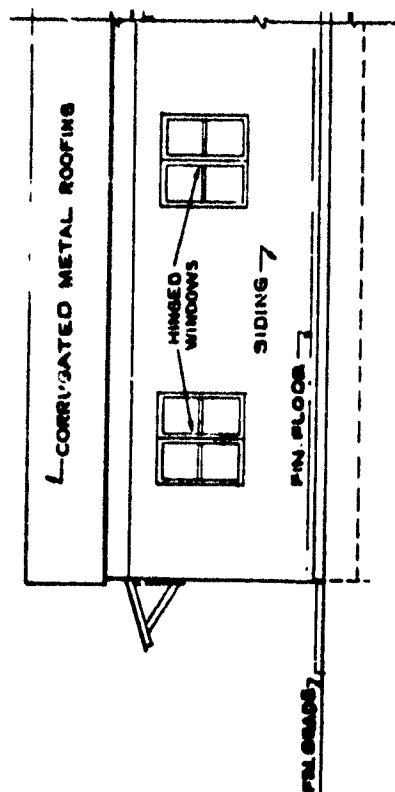
Table 2 summarizes the material and labor requirements of these AFCS facilities based on the data from TM 5-303.

Cost Comparisons

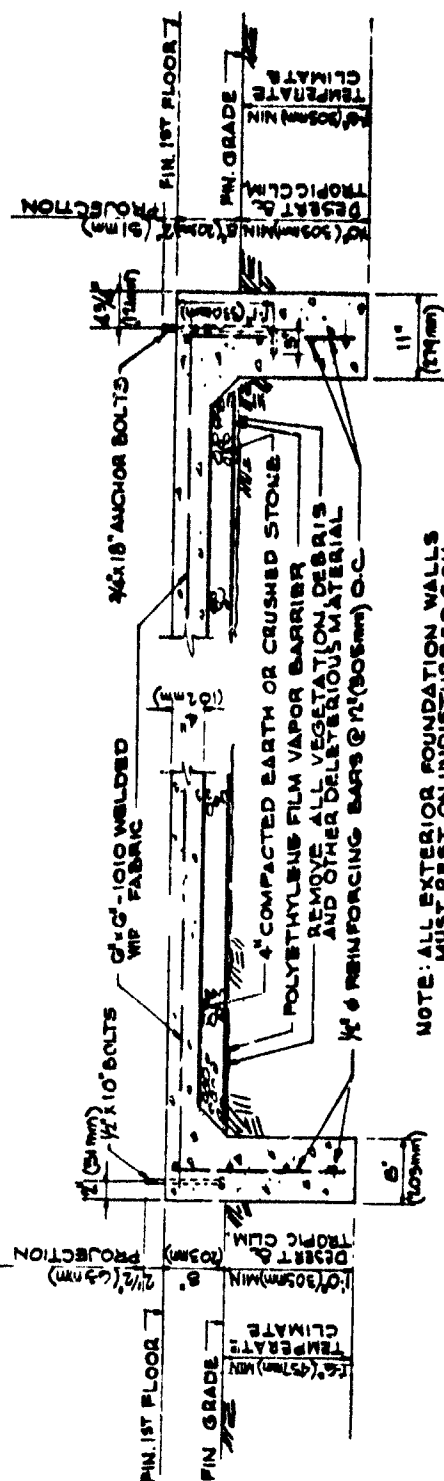
Table 3 compares the costs of the AFCS facilities and the foam/wood system. The total cost of the foam/wood system is 29 percent and 41 percent less than that of facilities 340512 and 340514, respectively. Facility 340321 (including supplemental facilities 340322, 340361, 340374, and 340391) is approximately 5 percent less expensive than the foam/wood system.

The AFCS designs were developed to meet a 5-year design life, but have been capable of much longer use. The foam/wood system is designed

*Facility 340321 can be supported by concrete perimeter walls or by an elevated wood floor system (Figure 8). The latter method was chosen for this comparison.



TEMPERATE CLIMATE
SIDE ELEVATION
SCALE NO. 2



NOTE: ALL EXTERIOR FOUNDATION WALLS
MUST REST ON UNDISTURBED SOIL
REGARDLESS OF CLIMATE.
IN COLD CLIMATES, FOUNDATION DEPTH
TO BE CARRIED TO BELOW FROST LINE

SECTION 2-2
SCALE NO. 6

Figure 6. AFCS Facility 340512.

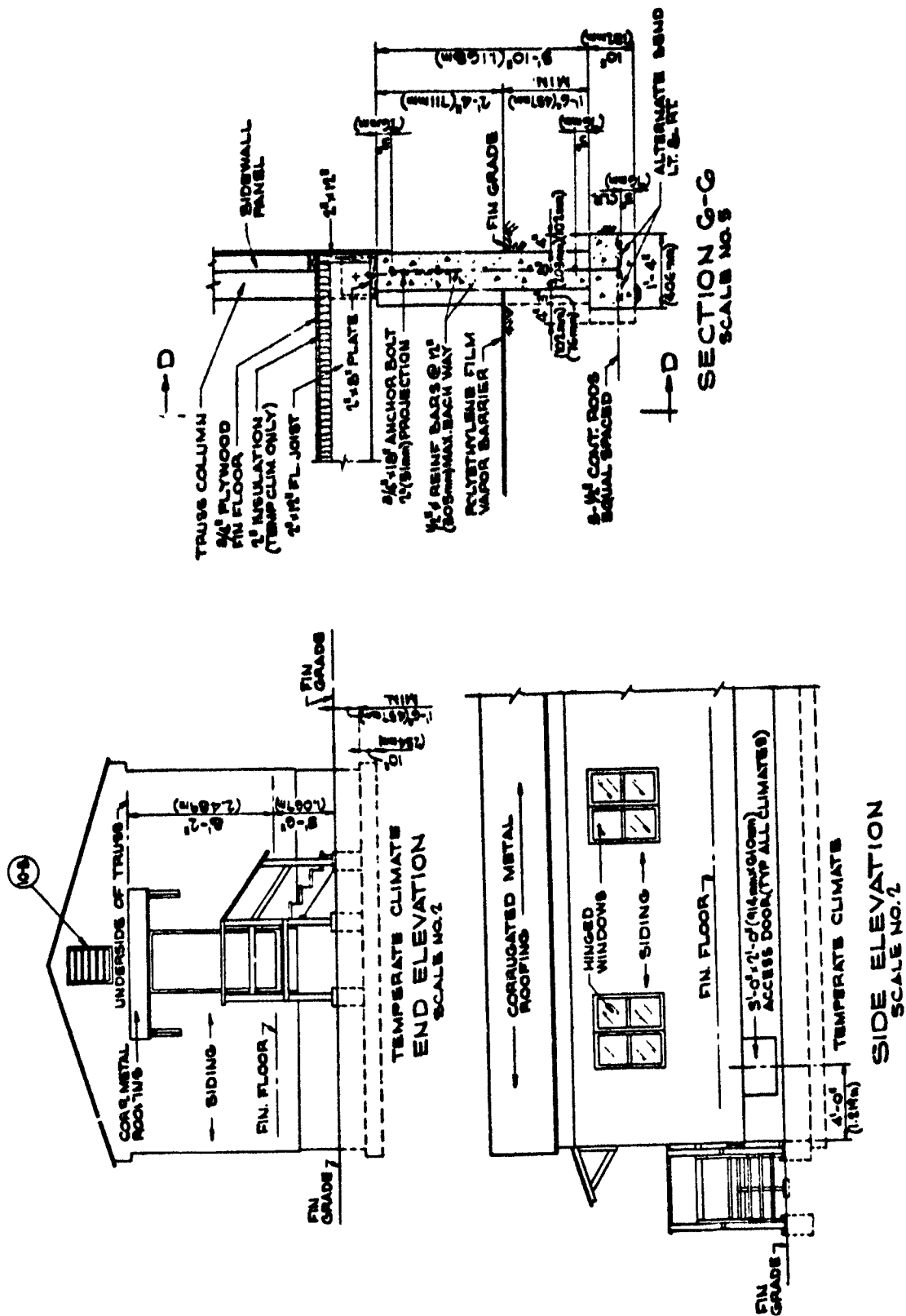


Figure 7. AFCS Facility 340514.

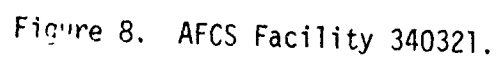
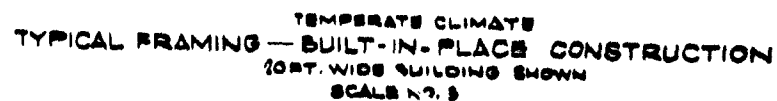


Table 2

Summary of Material and Labor Costs for Selected AFCS Designs

Facility	Description	Material Cost	Total Labor		Estimated Total Cost
			MH	Cost	
340512	20 x 40 ft (6 x 12 m) general-purpose, basic building; wood frame with corrugated metal roof and plywood siding; insulated for temperate climate; concrete floor and foundation	\$3,127	1,150	\$3,450	\$6,577
340514	Same as above, except for concrete footing and wood floor system	\$3,956	1,323	\$3,956	\$7,925
340321	20 x 20 ft (6 x 6 m) wood frame, basic barracks building; supplemented by following: 340322 - Additional 10 ft (3 m) wide bay 340361 - Wood and felt cladding 340374 - Wood flooring 340391 - Insulation for wood frame building	\$2,508*	651*	\$1,953	\$4,461

* Adjusted to 960 sq ft (89 m²) building.

Table 3
Comparison of Material and Labor Costs

Facility	Material Cost	Labor		Total Cost
		MH	Cost	
340512 (AFCS)	\$3,127	1,150	\$3,450	\$6,577
340514 (AFCS)	3,956	1,323	3,969	7,925
340321, 22, 61, 74, 91 (AFCS)	2,508	651	1,953	4,461
Foam/Wood*	3,927	256	768	4,695

*Does not include painting and utility installation costs.

to meet the 5-year requirement by reducing material without lessening the building's usefulness for human occupancy. This highlights the usefulness of foam, which can be easily shipped to the TO, expands to approximately 30 times its original volume, and serves the dual purposes of structure and insulation.

More than 20 percent of the \$4,695 total cost of the USAES experimental building was for the foam materials (\$1,024). However, the building system can be erected as a very basic structure without the foam. Recent structural investigations on which the system design is based have not included the effects of the foam. Portions of a test building erected at CERL in May 1975--which did not include foam--have not lost their structural integrity. However, the foam does make the panels noticeably more rigid, which is useful during handling and erection. The foam also permits a complete panel (including insulation) to be prefabricated off the building site. It is anticipated that operation and maintenance costs will be lower when foam is used.

Another consideration is the foundation system. The foundation bent was designed as an improvement over the two AFCS floor systems: (1) the concrete floor slab, concrete foundation wall, and raised floor system, and (2) the wood post/laminated-girder raised floor system of the three AFCS facilities chosen for comparison. Table 4 summarizes the costs of these four foundation designs. The bent and its erection procedure reduce labor, time required for site preparation, amount of concrete required, and the construction delay required for concrete to cure; the bent system is also less material- and labor-intensive than the post and laminated-girder design. It results in a more quickly erected floor system over which the rest of the building can be erected without delay.

Table 4

Foundation Costs for 960 Sq Ft (86 m²) Building

Foundation System	Material Cost	Labor		Total Cost
		MH	Cost	
Foundation Bent (Foam/Wood System)	\$227	21	\$ 63	\$290
Concrete Slab with Integral Foundation (AFCS)*	275	126	378	653
Foundation Wall (AFCS)*	500	69	207	707
Wood Post with Laminated Girder (AFCS)*	678	101	303	981

* Data for the three AFCS foundations were taken from TM 5-302.

5 EVALUATION OF FIELD TEST RESULTS

Results of the USAES experiment were compared to the design criteria outlined in Chapter 2.

Maximum Rapidity of Fabrication and Erection of Components

The system components were fabricated and erected in a total of 302 man-hours. This compares favorably to the range of 651 to 1,323 man-hours for the AFCS facilities. Repetition of operations in a prefabrication shop can be expected to further reduce the component fabrication time. An air-powered staple gun was used to fabricate panels for the TRADOC experiment; it is estimated that this equipment, which may be useful in a TO, has resulted in a 5 percent time savings for prefabricating the 8- by 8-ft (2.4 by 2.4 m) wall panels.

Maximum Simplicity of Fabrication and Erection of Components

The foam/wood building system is designed to permit fabrication and erection in a field environment. Civilian personnel experienced in wood construction have prefabricated the panels at CERL without problems. The bents and trusses for this experiment were prefabricated at USAES in an exterior, covered work area; CE troops assigned to the school constructed these components without problem. As can be seen by the labor summary (Figures 3, 4, and 5), slightly less than two percent of the total time was spent erecting the building. Most of the time (250 man-hours) was spent fabricating the components and performing finish work on the basic shell, indicating that most of the labor required can be performed in a sheltered environment (either prefab shop or the building itself) with a minimum of time required outside the building on-site.

Erection of the building calls for minimal equipment. Augers and a concrete mixer are required for the foundation, and trucks may be needed to transport components to the building site; however, once the foundation is placed, the building shell is erected with hammers, nails, one or two stepladders, and a crowbar to align the panels.

Panel fabrication is speeded up and simplified by use of standard 4- by 8-ft (1.2 by 2.4 m) plywood sheets. The plywood acts as a built-in square for the panels and is the only template required to insure their dimensional integrity.

Expandability

The building system can be expanded by removing one end of the building and adding additional components lineally to the required length in multiples of 8 ft (24 m).

Reductions in Logistics, Supply, and Transport Requirements

Shipment of the lumber, foam, and finish materials for the 24- by 40-ft (7.2 by 12 m) USAES experiment is estimated to take up 8 STON (7.2 metric tons) and 10 MTON (11.4 m³), compared with between 14 to 19 STON (12.7 to 17.2 metric tons) and 22 to 48 MTON (25.1 to 54.9 m³) for the AFCS designs. Once fabricated, the panels are bulky, but can be moved by two persons. Trusses and bents can also be moved by two persons, although bents with legs attached should be moved by at least three persons. Lumber for the basic components is in even lengths of 2 by 4 in. (3.8 by 8.9 cm), with most being 8 ft (2.4 m) long; 2- by 8-in. (3.8 by 18.75 cm) lumber is used for the bent legs. (The legs for the bent at USAES were prefabricated from 2- by 4-in. (3.8 by 8.9 cm) lumber because it was available in pressure-treated form.)

Minimum Additional Training Requirements for Fabrication and Erection of the Building System

No military occupational specialty (MOS) exists for operation of the foam spray apparatus. However, in a 2-week experiment at Fort Belvoir in November 1974, CERL personnel were able to give one CE enlisted man enough on-the-job training to operate and maintain the equipment satisfactorily. Civilian industry offers two 8-hour blocks of instruction in use of the equipment. Other fabrication and erection skills are within present MOS capabilities.

Reduction in Building System Costs

The cost of a completed foam/wood building is less than two of the AFCS designs and slightly more expensive than the third, as discussed in Chapter 4.

Reduction in Operation, Maintenance, and Repair Costs

These costs will be evaluated based on information gathered from Fort Belvoir and the TRADOC installation. It is expected that the foam insulation will reduce heating and air conditioning loads appreciably, because the entire structure is furnished with an equivalent of 4 in. (10.2 cm) of fiberglass insulation.

Relocatability

No effective test of the relocatability of this building system has been conducted. It is assumed that all of the major components will be capable of reuse with some minor repair and restocking of expendable items such as nails, roofing felt, batten boards, and caulking.

Maintenance of a High Degree of Flexibility for Commanders and Military Planners

Flexibility is one of the more attractive features of the foam/wood building system. The system has been designed to provide a shelter which can be erected in a T0 by troops without unusual equipment or excessive manpower. Structures using the system can be erected individually as required by non-CE unit commanders, or in large numbers by CE troops in a pre-fab shop during base development.

The building system can be fabricated and erected from locally acquired materials or from materials shipped to the T0. The commander can determine the level of austerity to be supplied by the system. For example, foam may not be needed as insulation. Windows and doors built with commercial frames or field-fabricated can be located as required.

Site preparation is minimal. Terrain can slope as much as 3 ft (0.9 m) between bent legs, given suitable frost conditions. The legs can be prefabricated true foam-filled sandwich panels with two 1/4-in. (0.6 cm) plywood faces. A simple press was used to prevent foam expansion from forcing the panel apart. This modified operation gave a neater and much stronger panel and showed that this type of panel can be field-fabricated. The press consisted of two built-up panels with twin layers of 3/4-in. (1.9 cm) plywood and 2- by 6-in. (5.1 by 15.2 cm) lumber bracings. Six pipe clamps were used to hold the panels during the forming operation.

In earlier experiments at CERL, a waterproof paper was used as an exterior skin and stapled to a 2- by 4-in. (5.1 by 10.2 cm) lumber frame. Foam was then sprayed on the panel interior. These panels were erected and have performed adequately, indicating that materials such as corrugated metal and roofing felt can be used as cladding for the panels without significantly altering the erection and fabrication procedures.

6 CONCLUSION

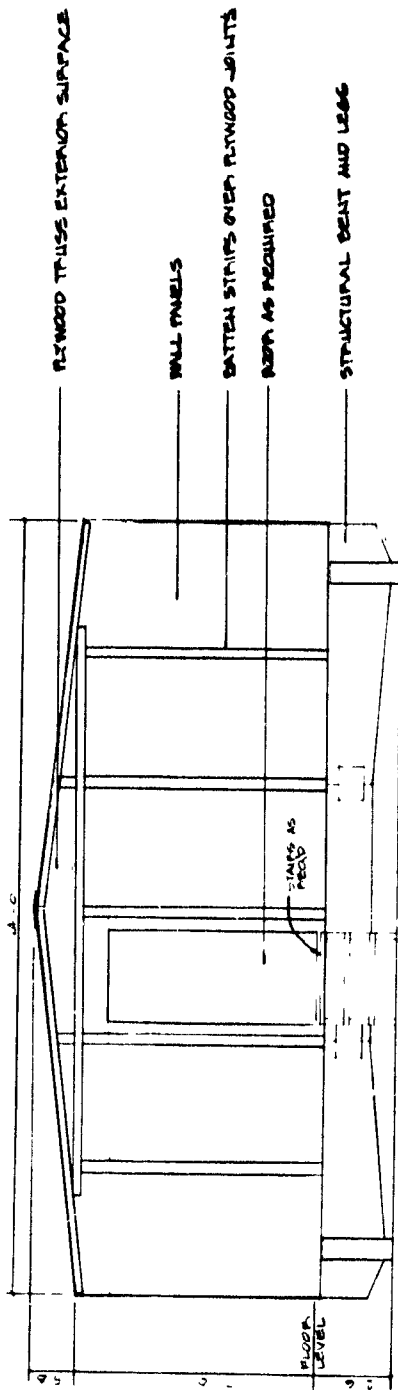
The Fort Belvoir experiment has provided initial validation of earlier assumptions and computerized evaluations of the foam/wood prefabricated expandable building system. The fabrication methods for the panel components are now well established, and the trusses and bents can be fabricated by CE troops in the field. None of the panels shipped from CERL to USAES required repair or rebuilding, indicating that the panels can be shipped with minimal damage. Improved erection procedures for the bents and floor system speeded up and simplified erection. Labor and material costs compare favorably with present AFCS designs. Operation and maintenance costs will be evaluated as the building is used at Fort Belvoir.

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- Army Facilities Components System-Designs*, TM 5-302 (Department of the Army, 1973).
- Army Facilities Components System - Logistic Data and Bills of Materials*, TM 5-303 (Department of the Army, 1973).
- Army Facilities Components System - Planning*, TM 5-301 (Department of the Army, 1973).
- Pre-Engineered Logistic and Administrative Structures (PLAST)* (U.S. Army Engineering School, 1973).
- Reynolds, R. D. and T. Whiteside, *Base Development, Vol VI, Vertical Construction (VERCON)*, ACN 20383 (U.S. Army Training and Doctrine Command, 1975).
- Ryan, T. C. and L. C. Tietz, *Evaluation System for Proposed Theater of Operations Structures (TOBSEP)*, Technical Report C-14, Vols I-ADA006014, II-ADA006495, III-ADA006145, and IV (U.S. Army Construction Engineering Research Laboratory [CERL], 1975).
- Trent, R. L. and T. Whiteside, *Multi-Purpose Structural Components (Prefabricated, Expandable Foam/Wood Structure for the Theater of Operations)*, Technical Report C-45 (CERL, 1975).
- Trent, R. L., T. M. Whiteside, and J. Robertus, *Erection Procedures for Prefabricated Expandable Foam/Wood Structures*, Technical Report C-52/ADA027382 (CERL, 1976).

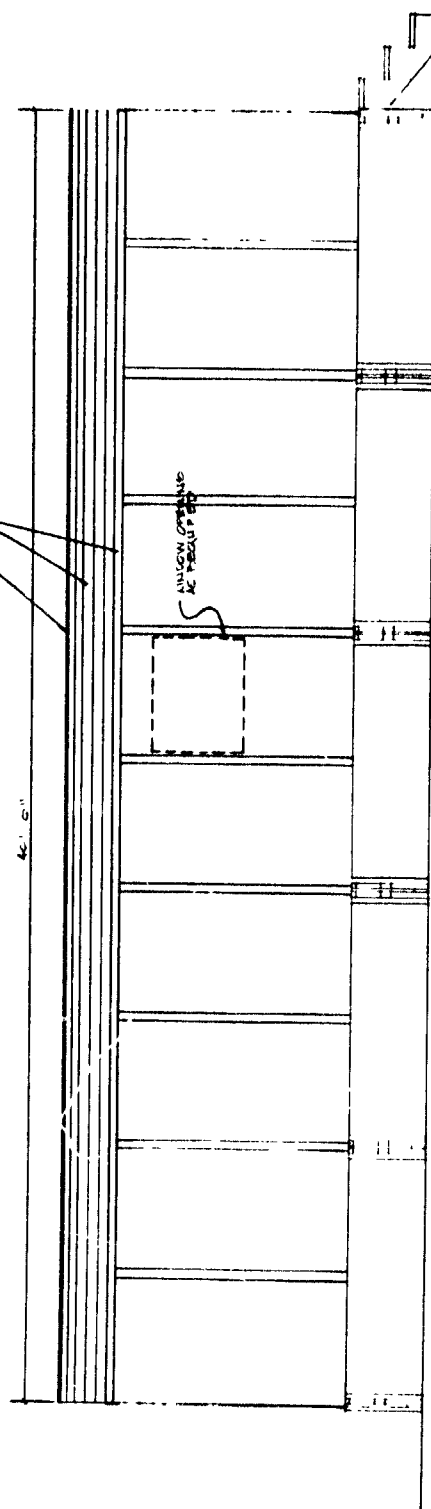
APPENDIX A:

**FABRICATION DRAWINGS FOR FOAM/WOOD PREFABRICATED
EXPANDABLE STRUCTURAL COMPONENTS**



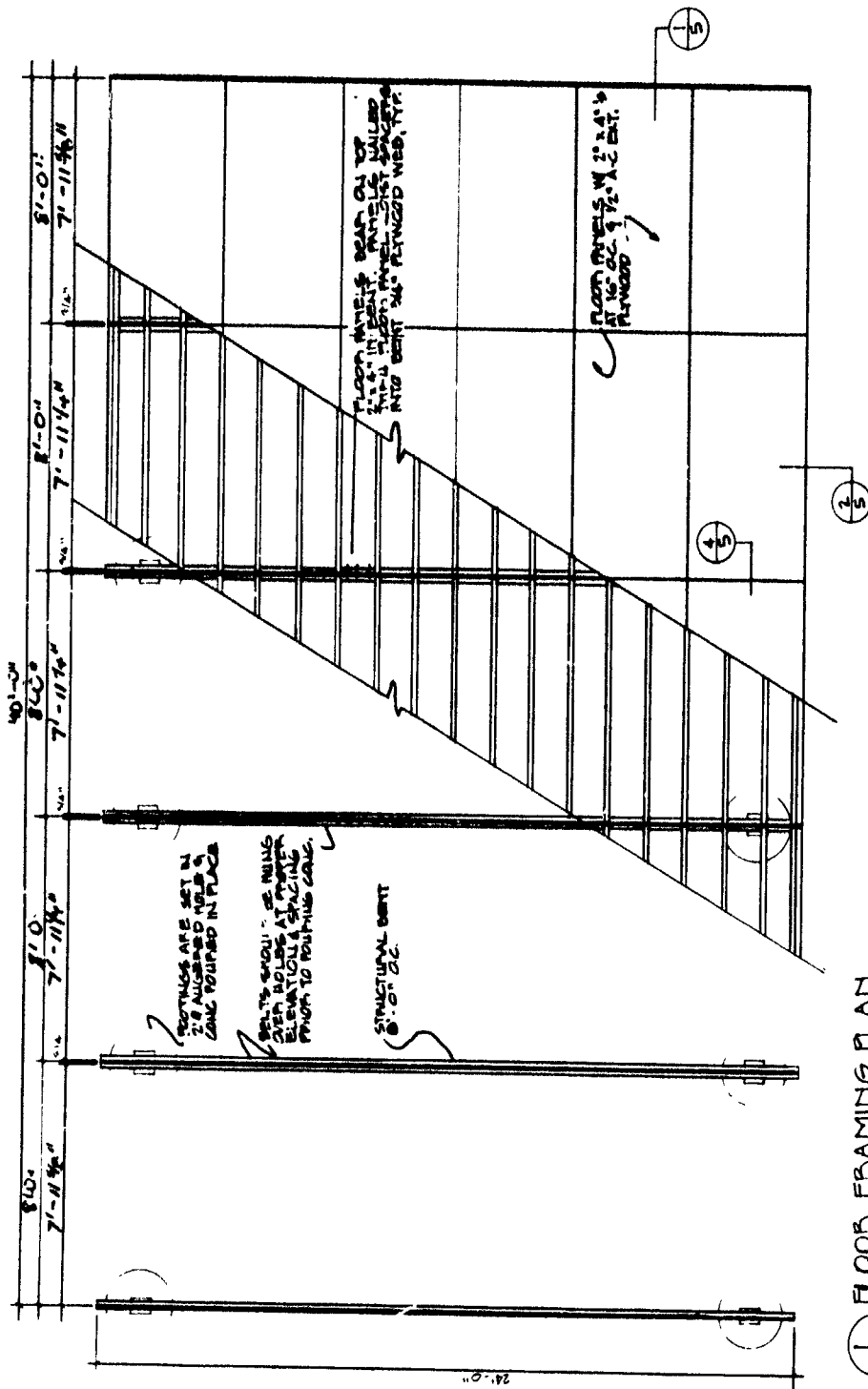
1 ELEVATION
3/8" = 1'-0"

ROOFING FELT NAILED TO ROOF RAFTERS
AND TURNED DOWN OVER WALL PANELS

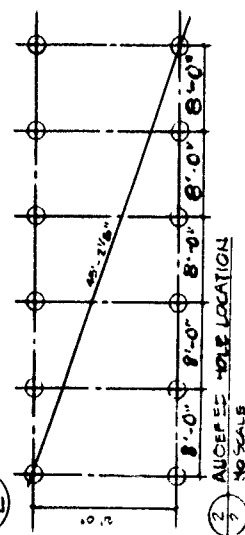


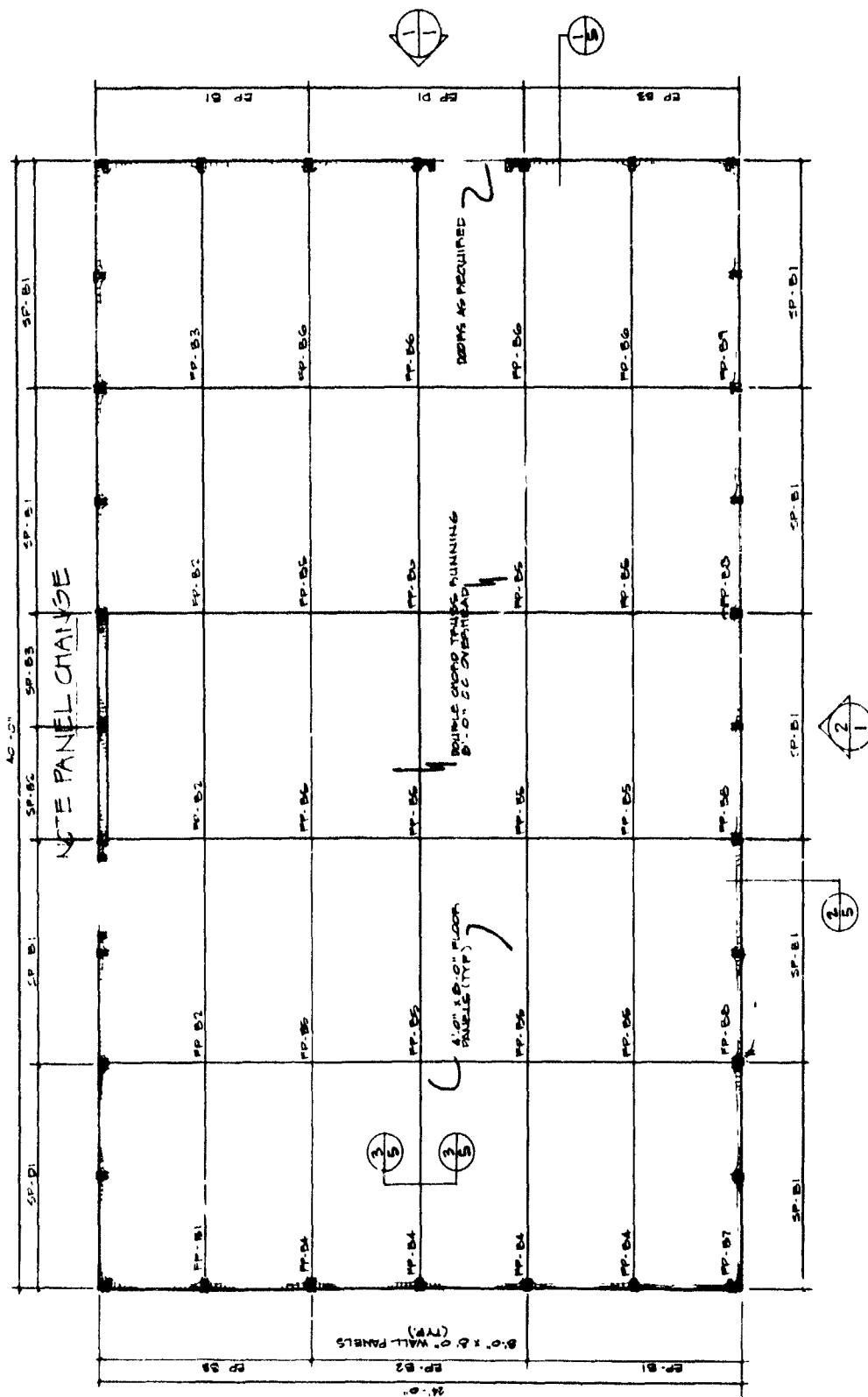
2 ELEVATION
3/8" = 1'-0"

PLYWOOD
BATTEN

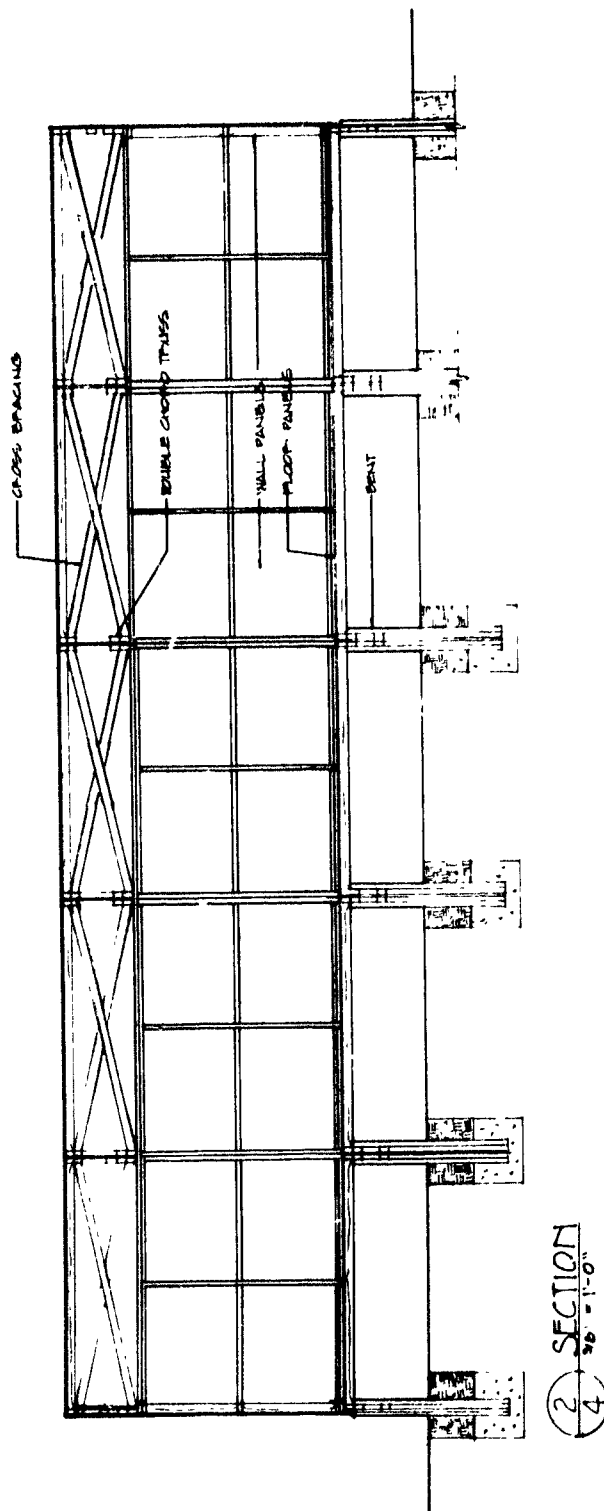
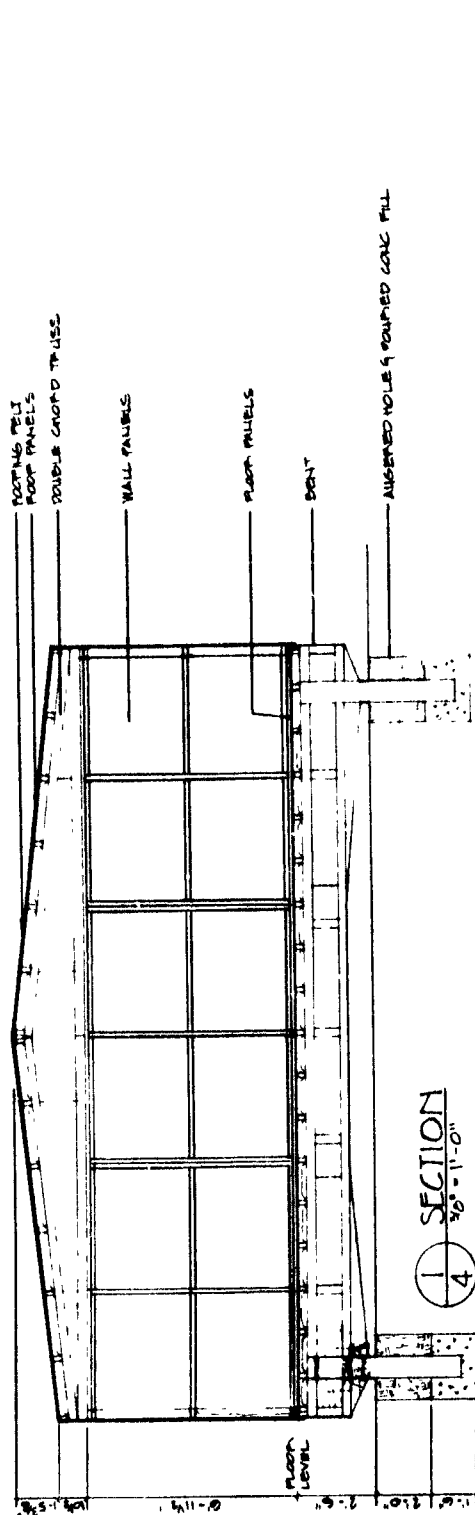


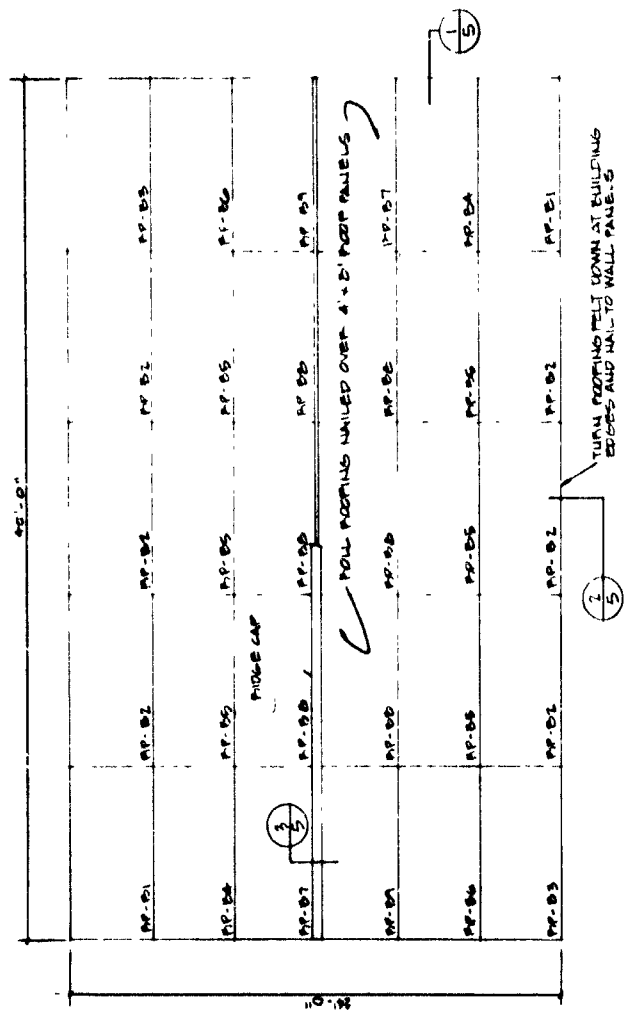
1 FLOOR FRAMING PLAN
2 3/8" = 1'-0"



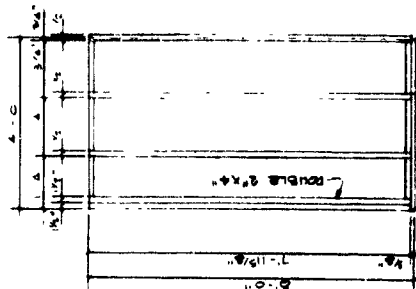


1 FLOOR PLAN
3 3/8" = 1'-0"

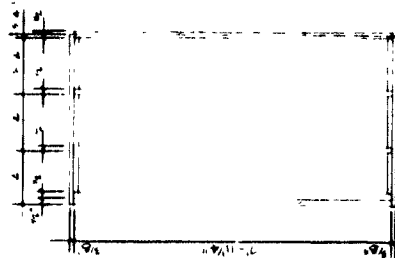




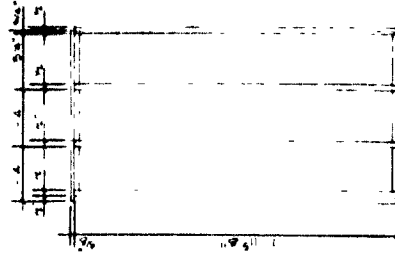
1 ROOF PLAN
6 1/8" = 1'-0"



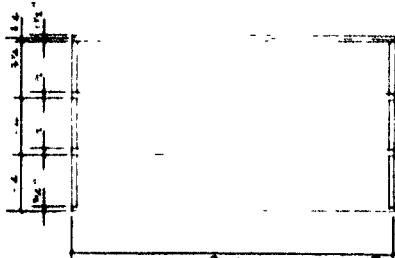
FP-D1: 1 REQD.



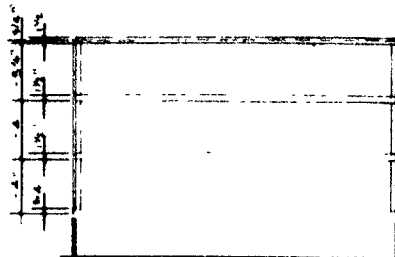
FP-D2: 3 REQD.



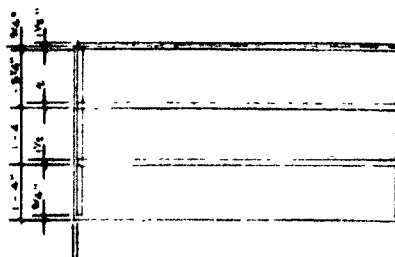
FP-D3: 1 REQD.



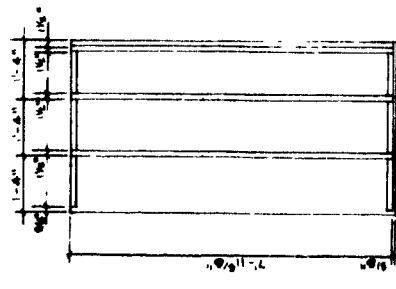
FP-D4: 4 REQD.



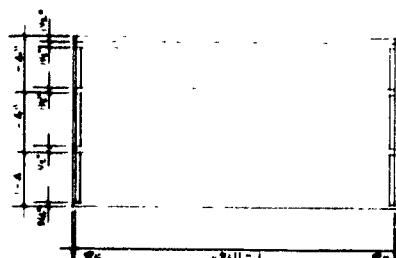
FP-D5: 12 REQD.



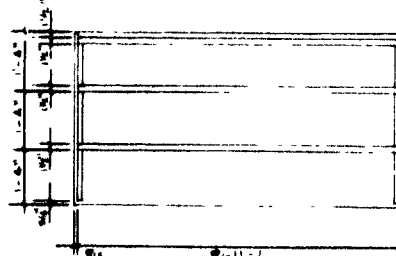
FP-D6: 4 REQD.



FP-D7: 1 REQD.

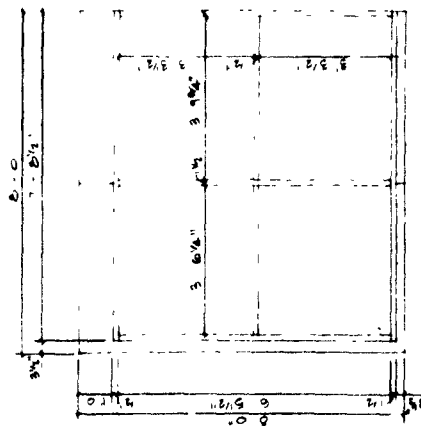


FP-D8: 3 REQD.

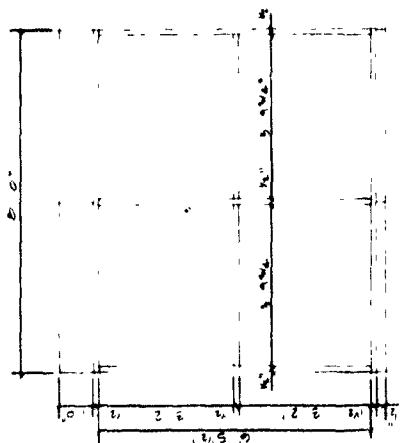


FP-D9: 1 REQD.

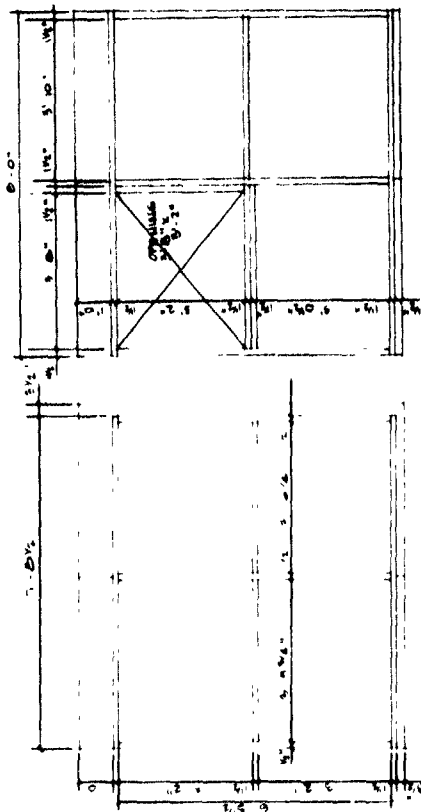
1/2" A-C EXT PLYWOOD ON ALL PANELS, A SIDE UP
2" x 4" x 1/2" USED THROUGHOUT
PANELS NAILED THRU PLYWOOD
MARK PANEL TYPE ON SIDE 2" x 4"
PANEL PANELS AT 2" DEEP



EP-B1: 2 REQUIRED

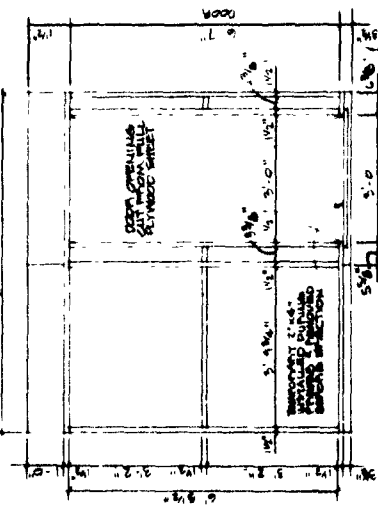


EP-B2: 1 REQUIRED
SP-B1: 9 REQUIRED



EP-B3: 2 REQUIRED

WIDOW PANEL, SP-W1: AS REQ'D

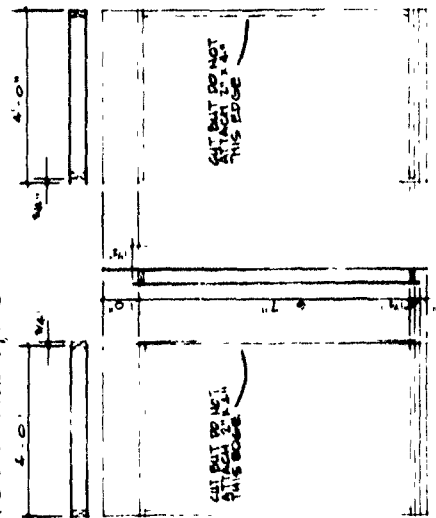


EP-D1: 1 REQUIRED
SP-D1: 1 REQUIRED

PANELS TO BE INDICATED WITH 2 SHEETS 1/4" A-C EXT PLYWOOD, A SIDE OUT 2" X 4" STUDS USED THROUGHOUT URETHANE FOAM APPLIED TO APP DEPTH OF 2" W/ 1/4" PANEL W/ 1/4" ON SIDE 2" X 4"

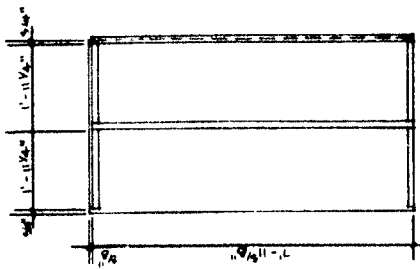
ALTERNATE PANELS FLOOR W/ 2" X 4" A-C EXT PLYWOOD SHEETS & FOAM APPLIED TO FULL CAVITY

DURING BLOCK ERECTION THESE PANELS SET OVER 2" X 4" S NAILED TO FLOOR PANELS

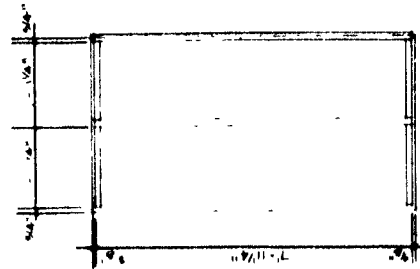


EP-D2: 1 REQ'D

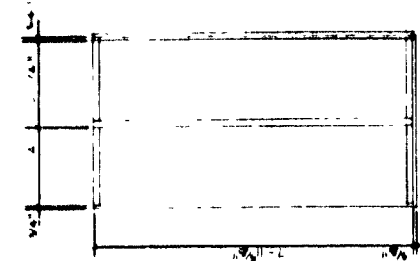
SP-B3: 1 REQ'D



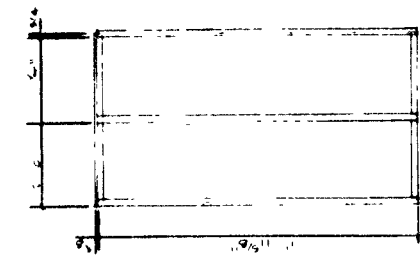
RP-D6: 2 RECD



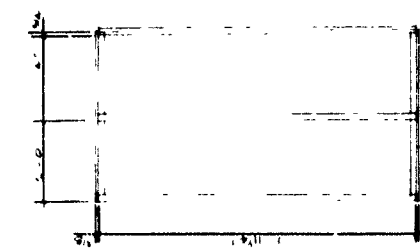
RP-D5: 6 RECD



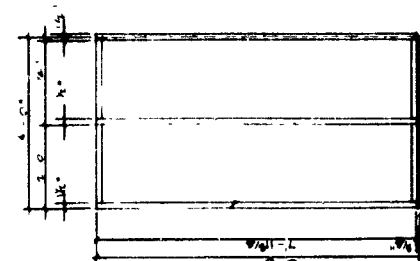
RP-D4: 2 RECD



RP-D3: 2 RECD

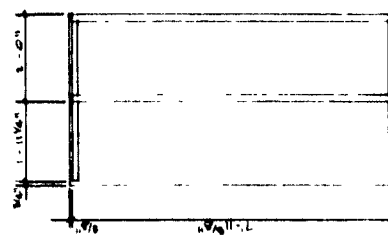


RP-D2: 6 RECD

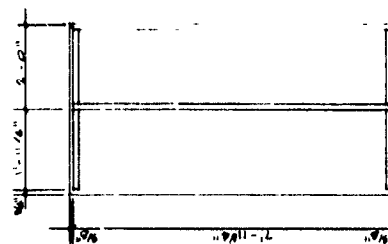


RP-D1: 2 RECD

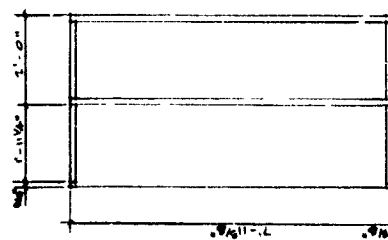
PANELS FABR. FROM 1/2" A-C EXT. WOOD
A FACE TO OUTSIDE
2" X 4" USED THROUGHOUT
FOAM APP. 2" DEEP
WITH PANEL TYPE ON SIDE 2" X 4"



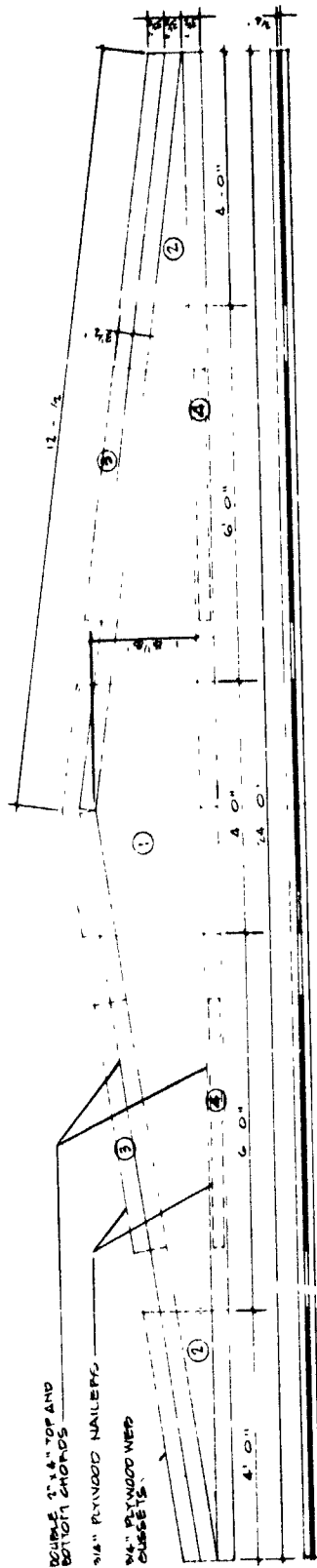
RP-D7: 2 RECD



RP-D8: 6 RECD

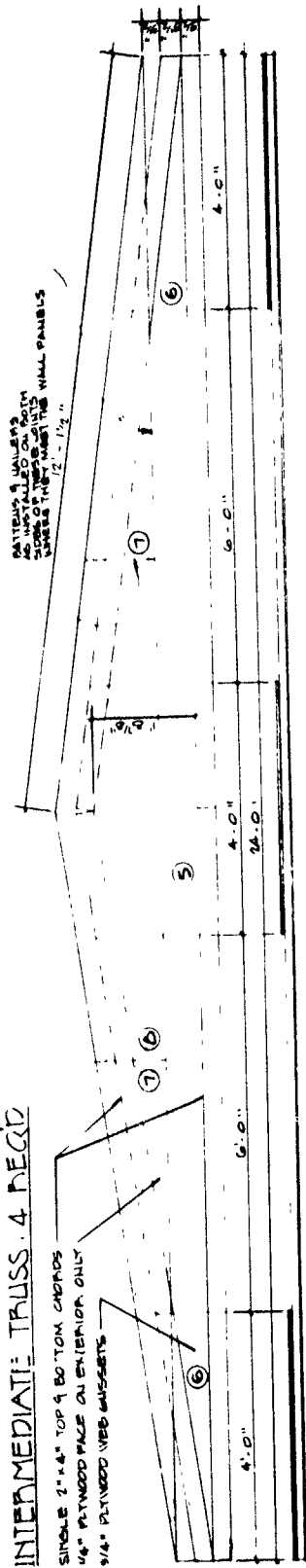


RP-D7: 2 RECD



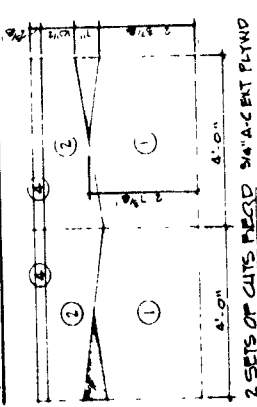
INTERMEDIATE TRUSS - 4 REQ'D

SINGLE 2"x4" TOP & BOTTOM CHORDS
1/4" PLYWOOD FACE ON EXTERIOR ONLY
1/4" PLYWOOD WEB GUSSETS

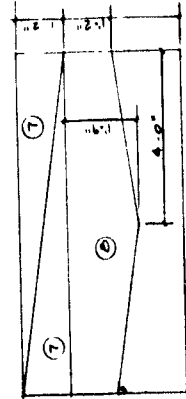


PATIENTS & VALUERS
AS INSTALLED ON BOTH
SIDES OF TRUSS WITH THE
SHEETS THAT MAKE THE WALL PANELS
12' - 1 1/2"

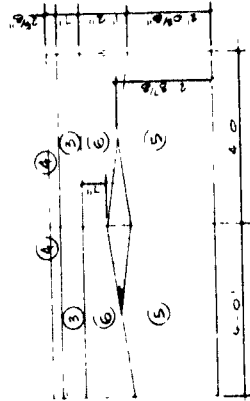
PERIMETER TRUSS - 2 REQ'D



2 SETS OF CUTS REQ'D 3/8\"/>

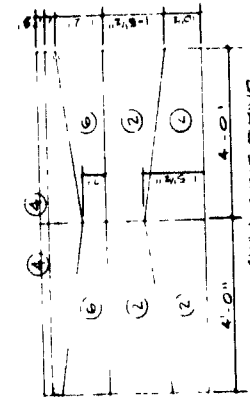


2 SHEETS 1/8\"/>

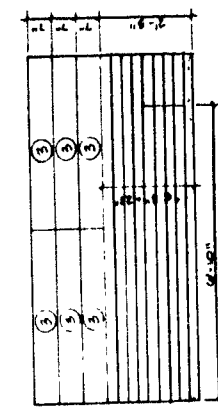


ONE SHEET 3/4\"/>

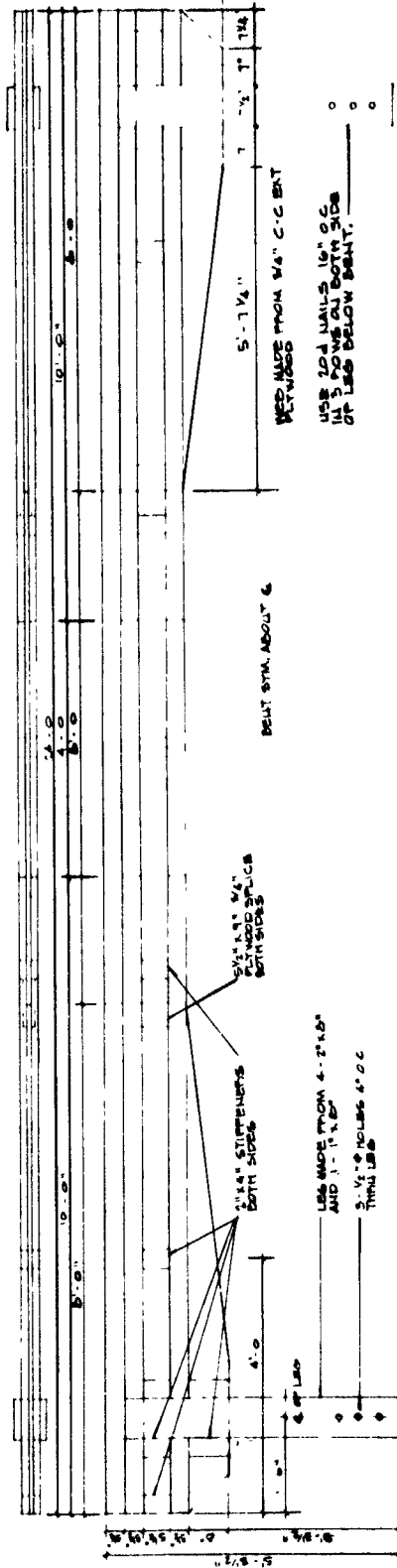
NAILING SCHEDULE:
USE 8D NAILS 4\"/>



ONE SHEET 3/4\"/>

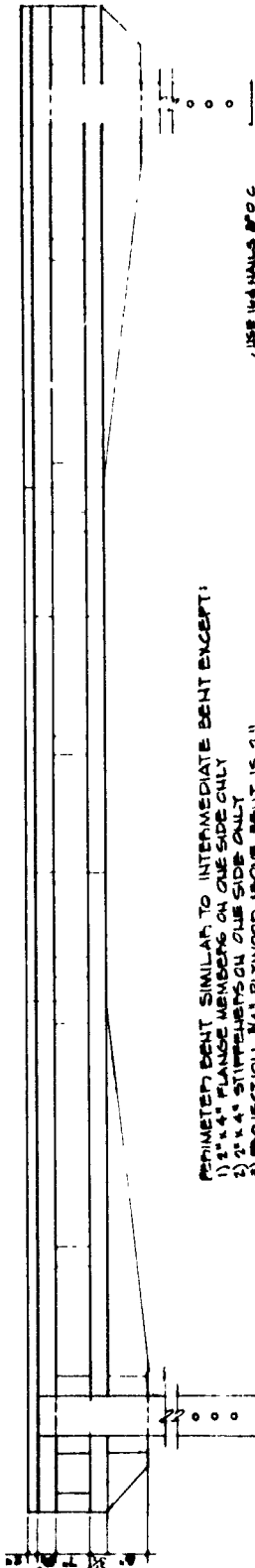


ONE-HALF SHEET 3/4\"/>



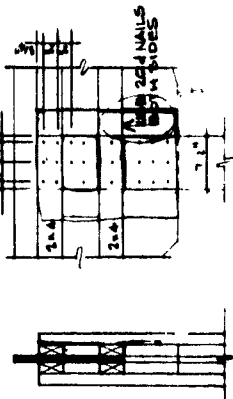
INTERMEDIATE BENT : 4 REQUIRED

NOTE:
DIMENSIONS FOR LEGS SHOULD BE VERIFIED ON-SITE BEFORE FABRICATION

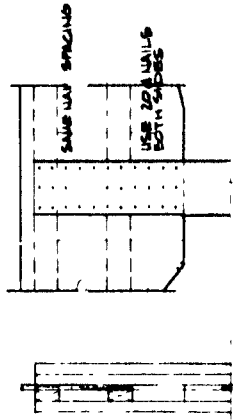


PERIMETER BENT SIMILAR TO INTERMEDIATE BENT EXCEPT:
1) 2x4 PLANKS MEMBERS ON ONE SIDE ONLY
2) 2x4 STIFFENERS ON ONE SIDE ONLY
3) PROJECTION 1/4" PLYWOOD ABOVE BENT IS 2"
4) 1/4" PLYWOOD SPLICE IS 7"x4", ON BOTH SIDES OF BENT.

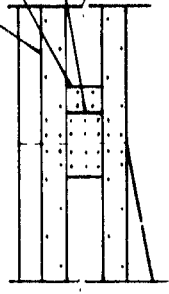
PERIMETER BENT : 2 REQUIRED



INTERMEDIATE BENT DETAIL



PERIMETER BENT DETAIL



SPLICE DETAIL

ALTERNATE CONNECTION
12 3/8" Ø BOLTS, 5' APART

APPENDIX B:

FOAM/WOOD PREFABRICATED EXPANDABLE BUILDING SYSTEM FABRICATION AND ERECTION ACTIVITIES

The following task list provides (1) the number of enlisted men (EM) and noncommissioned officers (NCO) required to perform the task, (2) the equipment required, and (3) a description of the task.

1-2 Precut Bent Plywood

1. Crew size: 2 EM
2. Electric circular handsaw
3. Mark off cuts on full plywood sheets and cut as desired with electric saw. Identify and label each piece and stack for assembly.

1-3 Precut Bent Lumber

1. Crew size: 2 EM
2. Electric circular handsaw
3. Mark off lengths of 2 x 4 required, then cut, identify, label, and stack for assembly.

1-6 Precut Truss Plywood

1. Crew size: 2 EM
2. Same as 1-2
3. Same as 1-2

1-7 Precut Truss Lumber

1. Same as 1-3
2. Same as 1-3
3. Same as 1-3

3-4 Assemble Bents

1. Crew size: 1 NCO, 3 EM
2. Requires 24 ft (7.3 m) long area
3. Layout materials for bent. Nail 2 x 4 to plywood from one side, then turn over using three men, and repeat nailing

2 x 4 on back side. Inspect and carry to site. Carry so plane of plywood is kept in vertical orientation.

7-8 Assemble Trusses

1. Same as 3-4
2. Same as 3-4
3. Same as 3-4

10-11 Building Site Layout

1. Crew size: 1 NCO, 1 EM
2. Two 50-ft (15.2 m) tapes, string, line
3. Lay out two parallel lines on ground, establish a corner and right angle, mark off 8 ft, 0 in. (2.4 m) on center (O.C.) post location and deposit lime to locate auger position at diameter holes.

10-12 Receive Panel Shipment

1. Crew size: 4 EM, 1 NCO
2. N/A
3. Remove panels from truck and stack for assembly or further preparation (i.e., painting, inspection).

11-14 Precut Bent Legs

1. Crew size: 2 EM
2. Electric handsaw
3. Mark off and cut lengths of creosoted 2 x 4 material. Stack for assembly.

14-15 Attach Bent Legs to Bent

1. Crew size: 1 NCO, 3 EM
2. Requires 20-oz (0.6 kg) or heavier hammers
3. Layout and nail 2 in. (5.1 cm) thick post material to bents. Insure nail size and pattern are correct. This should be done at the site since bents with posts installed are quite heavy. A four-man crew can place bents in position without difficulty.

11-15 Auger Holes for Footings

1. Crew size: 1 NCO, 1 EM
2. Truck-mounted earth auger (type used for pole excavation by Signal Corps)
3. Align truck over diameter of row of holes to be dug. Center auger bit on each lime marker, then auger to proper depth. Depth should be a minimum of 2 ft (0.6 m) but must be at least as deep as post length. A dumpy level is the best device to insure uniform, effective depth.

13-16 Paint Wall Panel Exterior

1. Crew size: 1 NCO, 4 EM
2. Paint, rollers, and roller pans
3. Position wall panels with plywood side up on floor or ground. Then apply paint to exterior surface with roller or wide brushes. Painting could also be done when panels are assembled or with spray gun at any time prior to installation. A latex base, fast-drying paint is best.

13-17 Fireproof Roof Panels

1. Crew size: 2 EM
2. Fireproofing--3/8 in. (9.5 mm) gypsum sheetrock
3. Cut sheetrock to fit and nail to panels.

15-19 Install/Align Bents and Floor Panels

1. Crew size: 1 NCO, 3 EM
2. Dumpy level or sighting level (handheld), heavy prybar (60 in. [1.5 m] wrecking bar), assorted timber dunnage such as 2 x 4, 1 x 4, 6 x 6 blocks.
3. Place bents in holes; starting from one end of the building, level off the first bent and block and brace in place. Then measure off 8 ft, 0 in. (2.4 m) to second bent and nail a brace to maintain space. Install the floor panels between the first and second bent, then lift the second bent and level all panels simultaneously until all panels between the bents are level. Block and brace second bent. Plumb posts and insure posts are suspended in plumb. Place a temporary support at the bent midpoint by inserting a block between bent and ground. Proceed to next bent and repeat. When

all bents and floor panels are installed, recheck alignments and adjust elevation or horizontal placement to insure floor is level and straight.

19-20 Place Concrete

1. Crew size: 1 NCO, 2 EM
2. Concrete mobile or concrete transit truck
3. Back vehicle up to hole and deposit concrete around post. Mix should be workable to allow concrete to fill hole and surround post without voids. Concrete should be vibrated or compacted by hand around posts. Do not remove blocking and bracing on bents for 3 days after concrete has been placed.

20-21 Install Wall Panels

1. Crew size: 1 NCO, 3 EM
2. N/A
3. After paint has dried, lift wall panels in place and nail together. Install temporary brace at each panel connection by nailing a 1 x 6 to floor and then to panel girt. Plumb each panel and the nail brace. Maintain 8 ft, 0 in. (2.4 m) spacing by checking joints at floor panels.

21-22 Install Roof System

1. Crew size: 1 NCO, 3 EM
2. N/A
3. Place trusses in position, rotate upright, and nail in place. Insert roof panels and nail. Check alignment and squareness of first row of panels between gable and first truss; then proceed to next truss and row of roof panels. Be sure to nail each roof panel as it is inserted and insure that plywood flange overlaps as required to facilitate supported joint at panel-to-panel connection.

22-23 Install Electrical Wire and Fixtures

1. Crew size: 1 NCO, 1 electrician EM
2. Electric drill with 3/4 in. (1.9 cm) wood bit
3. Install wiring as required by project specifications and National Electrical Code. Wiring includes junction

boxes, wires, switches, receptacles, light fixtures, and main breaker/panel unit with weather head service device.

22-24 Install Two Sets of Stairs with Porches and Railings

1. Crew size: 1 NCO, 2 EM
2. Electric handsaw
3. Stairs and porch should be precut and preassembled in standard size of 7 in. (17.8 cm) rise and 10 in. (25.4 cm) tread. The first step can be adjusted by placing mud sill at appropriate height. Insure that drainage around stairway does not cause ponding. Railing should be in accordance with TM 5-302* (detail 1-Z, sheet 1 of drawing 99-98) or TM 5-551B** (Section 7-22).

22-24 Install Battens With Caulking

1. Crew size: 2 EM
2. Caulking gun with caulking (bulk or cartridge)
3. Fill wall joints with caulking, then nail batten with 8d nails. See paragraph 7-14C, TM 5-551B. Battens may be prepainted.

22-24 Install Doors

1. Crew size: 1 NCO, 1 EM
2. Tools to install lockset. See TM 5-551B (Section 1, Chapter 9).
3. See TM 5-551B. For panel door, install three hinges and locking device. Weather stripping and door stop material should also be installed.

22-24 Install Roofing and Batten Boards

1. Crew size: 1 NCO, 3 EM
2. N/A

**Army Facilities Components System-Designs, TM 5-302 (Department of the Army, 1973).*

***Carpenter, TM 5-551B (Department of the Army, 1971).*

3. Lift roll roofing onto roof and start on gable ends. Cover gables with one layer lapping edge of roof rake. Then start with eave and roll out successive layers with a 6 to 8 in. (15.2 to 20.3 cm) lap until reaching the ridge. Place three layers on ridge to act as cap. Nail all edges at 4 in. (10.2 cm) O.C. with roofing nail. Overlap felt on eaves and gables about 6 in. (15.2 cm) down wall and fasten with batten strip. Gable-end plywood should be backed with 2 x 4 backs to allow felt to be nailed to plywood.

23-24 Hook up Electric Power

1. Crew size: 1 NCO, 2 electricians
2. N/A
3. Install service drop to building and connect power.

24-25 Install Drywall Interior

1. Crew size: 1 NCO, 3 EM
2. Drywall joint compound and tape
3. Install drywall to fit, tape joints, and apply joint compound. Nail with sheetrock nails at 6 in. (15.2 cm) O.C. Use procedure outlined in TM 5-551B (paragraph 7-15).

24-25 Touch-up Paint

1. Crew size: 1 NCO, 1 EM
2. Same as 13-16
3. Touch up mars and unpainted portions of exterior/interior of building.

25-26 Paint Interior

1. Crew size: 1 NCO, 3 EM
2. Same as 13-16
3. Paint interior walls.

26-27 Paint Floor

1. Crew size: 1 NCO, 1 EM
2. Paint rollers and pans, same as 13-16
3. Apply deck paint with rollers. Clean floor with broom and mop, then allow to dry. Apply paint in two medium coats. Caulk floor joints if required.

APPENDIX C:

DETAILED BREAKDOWN OF MATERIAL AND LABOR REQUIREMENTS FOR FOAM/WOOD BUILDING

Table C1

Phase I - Component Prefabrication Costs

<u>Activity</u>	<u>Material Cost</u>	<u>Labor</u>	<u>Labor Cost</u>
Fabrication of wall, roof, and floor panels			
Materials: lumber, plywood, nails	\$2,093		
foam components	\$1,024		
Labor: Carpenter		61 MH	\$183
Helper		16 MH	\$ 48
Sprayer		16 MH	\$ 48
Helper		42 MH	\$126
Fabrication of bents and trusses			
Materials: lumber, plywood, nails	\$ 308		
Labor: Carpenter		<u>33 MH</u>	<u>\$ 99</u>
Subtotal for Phase I	\$3,425	168 MH	\$504
Total Cost for Phase I	\$3,929		

Table C2
Phase II - Structural Erection Costs

<u>Activity</u>	<u>Material Cost</u>	<u>Labor</u>	<u>Labor Cost</u>
Materials: paint, exterior, concrete, nails	\$ 70		
Labor: Construction Surveyor		1 MH	\$ 3
Concrete Paving Equipment Operator		3 MH	\$ 9
Carpenter		5 MH	\$ 15
Forklift Operator		5 MH	\$ 15
Construction Foreman		8 MH	\$ 24
Construction and Utility Worker	_____	<u>30 MH</u>	<u>\$ 90</u>
Subtotal for Phase II	\$ 70	52 MH	\$156
Total Cost for Phase II	\$226		

Table C3

Phase III - Interior/Exterior Finishing Costs

<u>Activity</u>	<u>Material Cost</u>	<u>Labor</u>	<u>Labor Cost</u>
Basic Building			
Materials	\$ 378		
Labor: Carpenter		11 MH	\$ 33
Construction Foreman		8 MH	\$ 24
Construction Worker		35 MH	\$105
Utility Installation and Painting			
Materials	\$ 468		
Labor: Electrician		19 MH	\$ 57
Utilities Foreman		2 MH	\$ 6
Construction Worker		<u>25 MH</u>	<u>\$ 75</u>
Subtotal for Phase III	\$ 846	100 MH	\$300
Total for Phase III	\$1,146		

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