U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A026 191

A MODULAR FLOOR SYSTEM FOR USE WITH RELOCATABLE BUILDINGS

Civil Engineering Laboratory (Navy)

April 1976

Technical Report

R 841

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

April 1976

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California 93043

A MODULAR FLOOR SYSTEM FOR USE WITH RELOCATABLE BUILDINGS

by J. M. Ferritto and P. Springston

Approved for public release; distribution unlimited.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-341	2. GOVT ACCESSION NO. DN587035	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A MODULAR FLOOR SYSTEM FOR USE WITH RELOCATABLE BUILDINGS		5. TYPE OF REPORT & PERIOD COVERED Final; Oct 1974 to Oct 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. M. Ferritto and P. Springston		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Civil Engineering Laboratory Naval Construction Battalion Center Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62760N, YF53.356.006.01.020
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, Virginia 22332		12. REPORT DATE April 1976
		13. NUMBER OF PAGES 65
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Relocatable floor system, prefabricated building panels, joists, flooring.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Navy Advanced Base Functional Component Program utilizes many prefabricated buildings intended to be quickly emplaced and relocated. These buildings have usually had concrete slabs for floors; however, this requires skilled craftsmen and concrete batching facilities and results in floors which are not relocatable. This report describes the development of two modular relocatable floor systems – a system on-grade for heavy warehouse loads and continued		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Continued

a raised floor system for administrative buildings. The relocatable floor systems are generally less expensive per application, do not require highly skilled craftsmen, and are erected in less time than conventional concrete slabs.

Library Card

Civil Engineering Laboratory
A MODULAR FLOOR SYSTEM FOR USE WITH RELOCATABLE BUILDINGS(Final), by J. M. Ferritto and P. Springston
TR-841 53 pp illus April 1976 Unclassified

1. Relocatable floors 2. Prefabricated buildings I. YF53.536.006.01.020

The Navy Advanced Base Functional Component Program utilizes many prefabricated buildings intended to be quickly emplaced and relocated. These buildings have usually had concrete slabs for floors; however, this requires skilled craftsmen and concrete batching facilities and results in floors which are not relocatable. This report describes the development of two modular relocatable floor systems – a system on-grade for heavy warehouse loads and a raised floor system for administrative buildings. The relocatable floor systems are generally less expensive per application, do not require highly skilled craftsmen, and are erected in less time than conventional concrete slabs.

CONTENTS

LIST OF ILLUSTRATIONS

(Pages iii and iv blank)

LIST OF TABLES

INTRODUCTION

The Navy Advanced Base Functional Component Program utilizes many prefabricated buildings intended to satisfy the requirements for quickly emplaced and recoverable buildings in forward areas to provide efficient and economical operations of military field forces. Most of these buildings do not come equipped with flooring; rather, they were planned for use with conventional poured-in-place reinforced concrete. The requirement for large areas of concrete slabs places severe restrictions on the quick-erection requirements, requires additional skilled construction forces, may necessitate a logistics problem when concrete is not locally available, and results in floors which are not relocatable. The Naval Facilities Engineering Command sponsored this work unit to investigate the use of modular floor systems in Advanced Base Functional Component Shelters which do not have integral floors. A general discussion of the shelters in use which could be used with expeditionary floors is presented in Appendix A.

SYSTEM REQUIREMENTS

This specification provides an outline for the development of modular flooring systems which may be placed directly on prepared ground or used in conjunction with supporting beams to form raised floors. The system placed directly on the ground is intended for use in heavy warehouses. The raised floor system is intended for such uses as battalion and regimental headquarters, communications facilities, hospitals, operations buildings, Aerial Surveillance and Target Acquisition (ASTAC) and Antisubmarine Warfare (ASW) facilities, administrative offices, berthing, and messing facilities. The raised floor surface must be capable of modification to meet Bureau of Medicine and Surgery (BUMED) sanitary requirements for field hospitals and galleys. The floor system may be reusable, in which case the flooring system would be recovered, or disposable, in which case the floor systems would be abandoned in place.

The following specifications for a reusable flooring system are described below.

Life	Major components shall be capable of a minimum of 5 years continuous service with three relocations or 20 years of covered storage with less than 10% replacement.
Cost	The cost goal based on initial procurement cost shall be 5% of the structure cost per application (15% of the structure cost, considering the minimum of three relocations).
Modular	The system should be modular to provide flexibility in combining components to form floors of various sizes. Modules should be standardized and sized to fit within standard containers or on pallets.
Relocatable	Strike-down times and set-up times shall be minimized. Erection packing, dismantling, and removal time shall be considered.

Specifications for a disposable system (single usage) follow:

Life	Major components shall be capable of 2 years of continuous service with less than 10% replacement.
Cost	The cost goal, based on initial procurement, shall be 5% of the structure cost.

General specifications for both reusable and disposable systems are as follows:

Site Selection	The range of sites to be considered shall include all soils with an allowable bearing strength of 2,500 pounds per square foot or greater (see Appendix B). Special requirements for insulation associated with permafrost at arctic conditions will not be required.
Site Preparation	The site area shall be graded level and be free of trees, stumps, rock outcrops, cobbles, and brush. The area shall be graded to drain away from the structure and compacted to provide a firm bearing surface.
Floor Load Capacity	Raised floor load capacity shall be capable of resisting a distributed load of 100 pounds per square foot with an elastic deflection of less than L/240 where L is the clear span between supports. Floor systems on the ground shall resist 300 pounds per square foot.
Moisture Penetration	Appropriate means shall be provided to prevent moisture penetration. Reusable floor material will not be susceptible to corrosion or other deterioration while in the presence of water.
Floor Surface	The raised floor's surface shall be smooth, hard, and grease resistant and be capable of being cleaned and waxed. Joints between panels will be tight to prevent rodent and insect penetration. The floor surface shall be self-extinguishing to fire by ASTM Test D636-68, and have a flame spread rating of less than 100 as determined by ASTM Test E84.
Climate	The system shall be applicable for use or for storage in all normal climates. The floor materials shall not be adversely affected by temperatures from -30° to 120°F.
Installation	The floor system shall be capable of installation at the rates of 4,000 sq ft/day — on grade 1,000 sq ft/day — raised floor utilizing standard table of allowance tool kits and eight men, not including site preparation.

This specification is written to be compatible with military specification MIL B 28658A (YD) 17 August 1973, Building Components, Panelized, Prefabricated, Ready-Cut, Relocatable and Building Extension Kits. Specifically, the building is designed to withstand at least a 5-year life under all normal weather conditions encountered in ambient temperature zones of -30°F to 120°F. Soil bearing is assumed to be 2,500 psf. All components shall be sized for shipment in standard 8 by 8 by 20-foot International Standards Organization (ISO) shipping containers. No box or crate shall exceed 3,000 pounds or 19 feet 3 inches long by 7 feet 2 inches wide by 7 feet 3 inches high.

To assist in the evaluation a list of system attributes and relative weights was developed in conjunction with the Civil Engineering Support Office, as follows:

Attribute	Definition	Weight
Effectiveness	Degree to which the system provides the total requirements of strength, waterproofing, appearance, and fire protection	25
Erection Time	Speed with which the system can be emplaced after site preparation is completed	19
Durability	Degree to which the system meets the service-life requirements based on initial longevity and on repairability	16
Simplicity	The level of expertise and the sophistication of tools required from field construction forces for proper placement	13
Retrievability	The extent to which the components of the in-place system may be retrieved	12

continued

Attribute	Definition	Weight
Logistics	A measure of shipping economy as determined by system weight, cubage, and storage requirements	9
Versatility and Modularity	The potential the system offers for easy adaptation from the principal set of design functions and loads to another.	6

ON-GRADE FLOORING SYSTEM

Various concepts were formulated to provide a flooring system which could be placed directly on a prepared ground surface and yet resist moisture and deterioration. The following general categories were considered:

1. Wood products (such as plywood, hardboard, builtup plywood).

2. Composite sandwich (such as composites with skins of aluminum; fiber-reinforced plastic; or steel in conjunction with cores of aluminum, honeycomb, balsa, paper honeycomb, foam, or plywood).

3. Metal extrusions.

4. Nonmetallic membranes (such as T17 or WX 18 which are rubber-cloth membranes).

5. Airfield mats (such as AM2, XM19, AM6, T12, T13, MOMAT).

6. Spray-on surfaces (such as Onfast).

Details on each item, except item 6, are presented in Appendix C. Spray-on surfaces, generally complex to use, are not yet available within the military system.

A qualitative cost-effectiveness study was made of the various alternatives. Judged solely by performance, lightweight surfacing with load-distributing capability is applicable over the broadest range of soil types and is the most advantageous. This concept eliminates a flexible membrane as a candidate since flexible membranes do not distribute loads, are restricted to firm soil surfaces, and do not exhibit good wear characteristics under traffic. Airfield mats are costly and overdesigned for adaptation solely for flooring. Composite constructions and metal extrusions are not considered cost effective. The use of sheets of plywood in two layers with joints overlapped appears to be the most cost-effective solution. MOMAT [2], a fiberglass-reinforced plastic molded into a waffle-like configuration and available through the military supply system, is the second most cost-effective solution, although it is approximately four times more costly than the proposed plywood flooring system.

A concept was developed utilizing sheets of standard exterior plywood to form a floor on-grade. A sheet of thin film plastic (6-mil polyethylene) is laid down. Single sheets of plywood are laid out as shown in Figure 1. Underlayment glue is applied to the first layer of plywood, and a second layer of plywood is laid over the first layer in the opposite direction. Note in Figure 1 that the joints and panels are staggered to provide maximum strength. Number 14 self-drilling screws, driven by a screw gun, are used at 12-inch spacing to hold the sheets together to provide contact until the glue dries. Figure 2 shows installation of a test section. Appendix D gives traffic test results of a typical flooring application for a soil subgrade with a CBR of 13 using 3/4-inch plywood sheets. The results indicate that the coverage expected (over 10,000) is satisfactory and can be predicted by using Appendix B.

This concept was analyzed using a finite element computer program (SLIP) developed at CEL [3]. The program gave the stress state in the plywood and the deflection of the system. Various soil California Bearing Ratio (CBR) values were used to develop the design curve given in Figure 3 for two typical forklifts with different loadings.

Type CD one side plugged and touch sanded underlayment grade exterior plywood should be used. For a 10,000-pound load and soil CBR of 15, 5/8-inch plywood would be required (Figure 3). The cost of this 5/8-inch-thick plywood in quantity from commercial plywood producers is about $0.24 a square foot. The cost of the floor system based on the unit cost would be about $0.55 a square foot. A surface of 4,000 ft^2 (building 40 x 100 feet) could be installed based on CEL tests in less than 25 man-hours. The life expectancy of the system would be between 6 months and 2 years depending on the soil conditions.

To extend the life of the system, pressure-treated plywood can be used. Either water-base or gas commercial treatments are in use and have been shown to

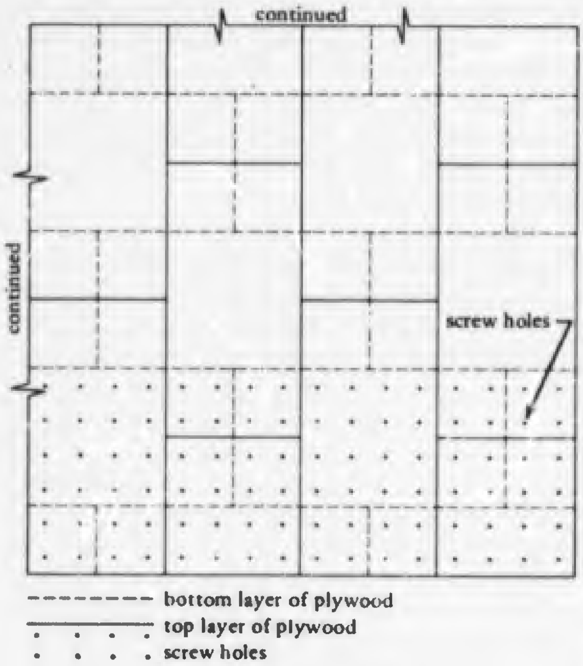


Figure 1. On-grade slab.

provide a useful life well in excess of 15 years The cost of the treatment approximately doubles the cost of the plywood. Rather it is suggested that a wood preservative, such as copper napthenate or pentachlorophenol mixture, be applied to the bottom side of the plywood. Both of these are available through the General Services Administration Federal Supply Service in 55-gallon drums for about $60.00 per drum. These can control shrinking, swelling, insects, fungi, and decay. One drum should cover 4,000 ft^2.

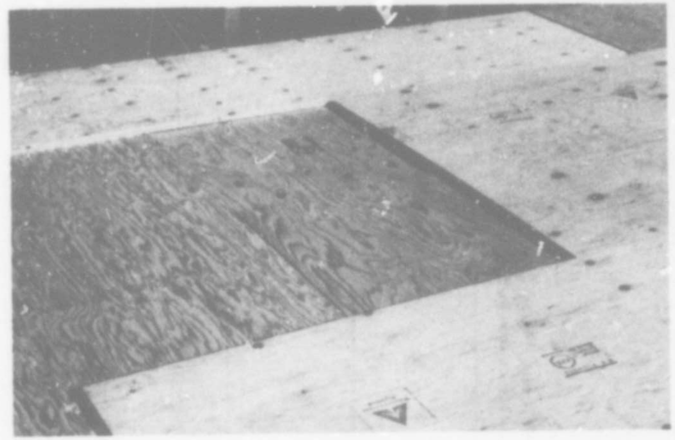
RAISED-FLOORING SYSTEM

The raised floor system is composed of three parts: (1) the framing members and supports, (2) the floor panels, and (3) the floor wear surface material.

Various concepts of supporting the floor panels were considered. Framing systems evaluated included structural steel sections, steel bar joists, open web punched steel joists, hollow structural sections and light-gage, cold-rolled steel joists. Various framing plans were considered through varying joist span and spacing to achieve a minimum total system cost (including the panel cost). The most cost-effective system found utilizes a channel section identical to United States Steel (USS) Super-C joists [4] on screw jack supports. These joists are available in different lengths and gages. However, to minimize the number of different sizes and lengths of joists required, the system was designed utilizing only one member. This member, designated SC 10J-14 (USS), is made from 14-gage galvanized steel and is 9-1/4 inches high, 2 inches wide, and 12 feet long. Use of only one member imposes an additional cost of $0.05 a square foot over the optimum configuration. However, it allows for total flexibility in assembly.

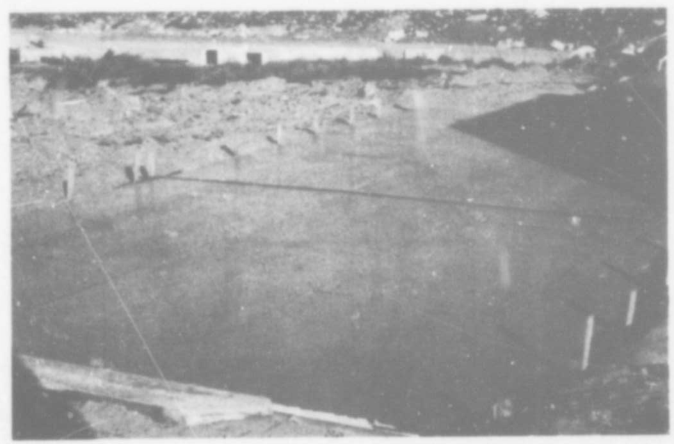
The C-section is made with one flange larger than the other so the sections may be nestled together reducing shipping volume and damage. This nesting concept is utilized to form a girder section of higher moment capacity. The framing plan utilizes 12-foot long joists spaced 32 inches apart which frame into girders formed of two nestled C-sections. The girders are supported on jacks spaced 6 feet apart. Analysis proved this to be the optimum spacing. The joists attach to the girder by use of support straps attached by self-tapping 1/4-14 x 3/4 inch hex-head, washer-head, zinc-coated screws. These screws are installed with the 1/2-inch drive electrical driver shown in the Naval Mobile Construction Battalion Table of Allowance listing for a Kit 29 Erection Tool Kit for 40 x 100 pre-engineered buildings. There are two such drivers in the Kit 29 and none in the Kit 30 Erection Tool Kit for 20 x 48 pre-engineered buildings. Additional drivers may have to be added to these kits or the central tool room items to accommodate instances where floor installation and building sheeting are proceeding simultaneously. Figures 4 and 5 give details of the framing plan. The cost of the framing system [4] is $0.80 a square foot of floor surface, including jacks. The cost of the joist is $0.89 per linear foot, and the cost of each joist hangar is $1.31. Purchase of 20,000 linear feet or more from a fabricator directly should result in a one-third cost reduction. Perimeter and interior splice jacks cost about $9.20 each. Corner jacks cost about $11.70 each.

(a) Placement of first sheet of plywood over plastic.



(b) Second sheet of plywood layed over first sheet.

(c) Installation of fasteners in plywood.



(d) Completed plywood slab.

Figure 2. Installation of floor system on-grade.

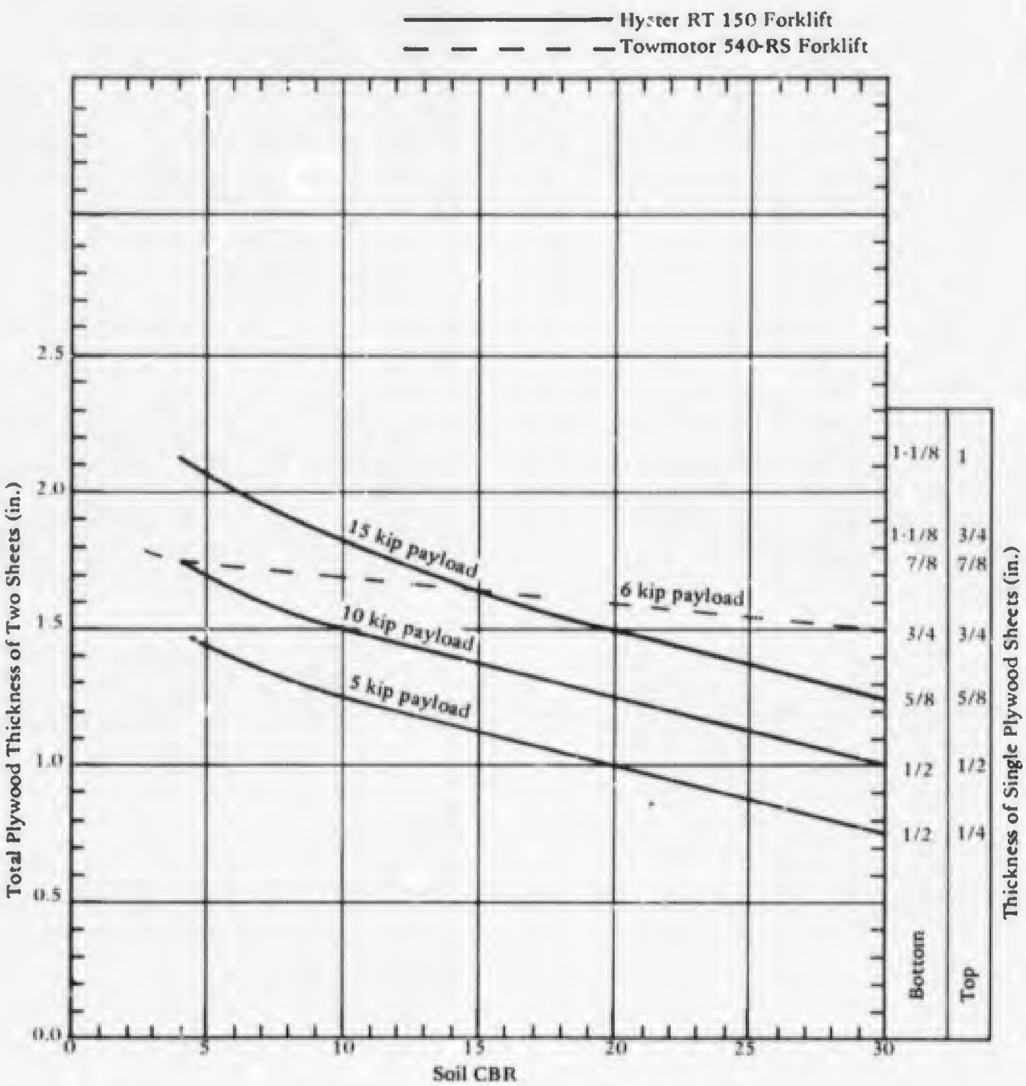
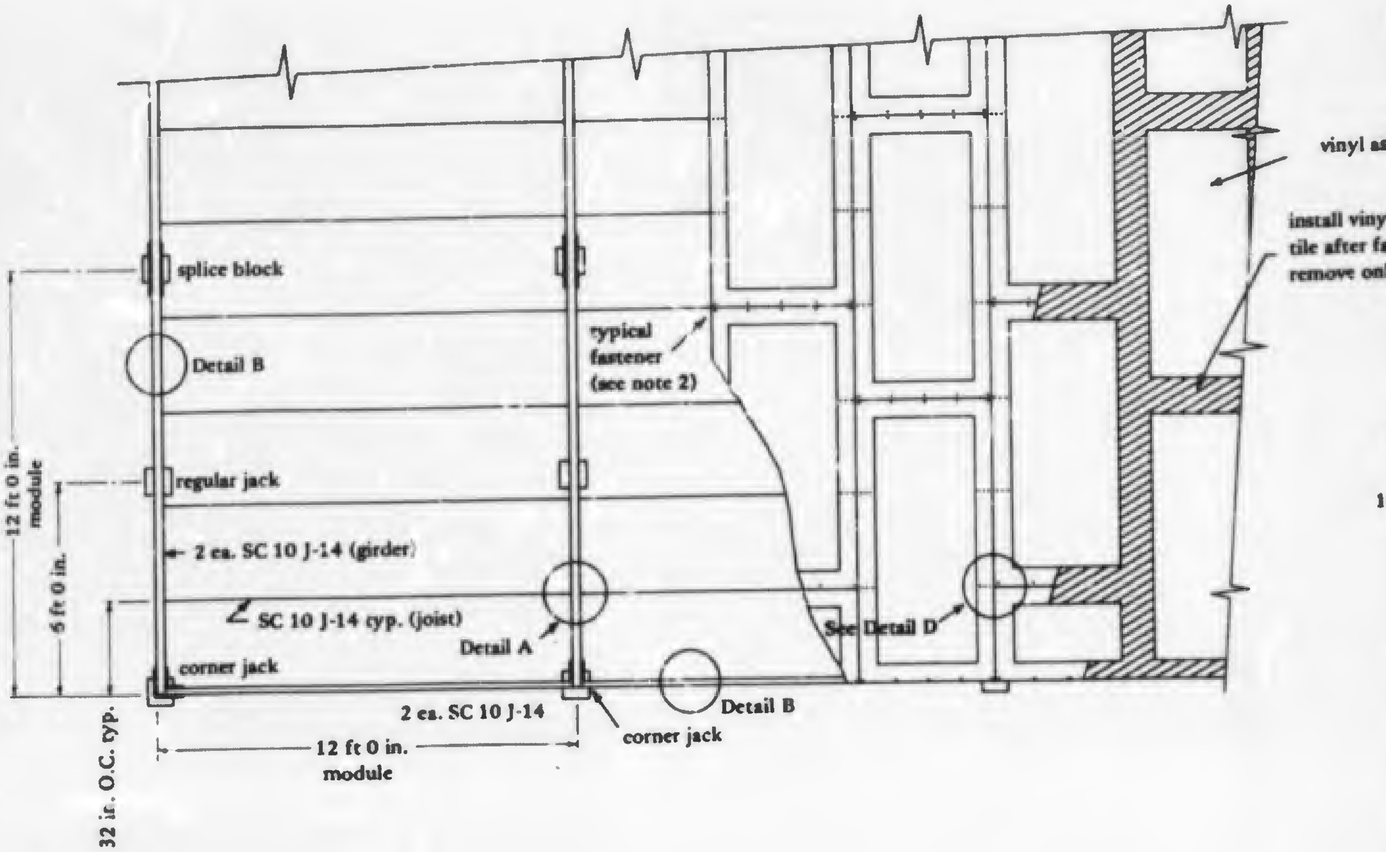
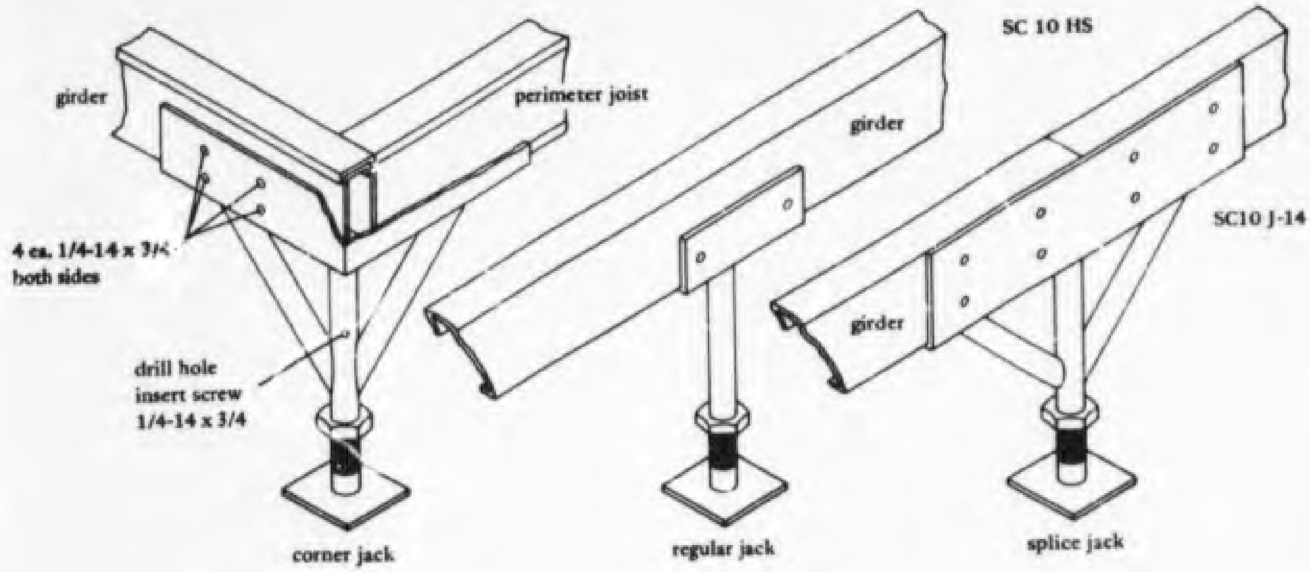


Figure 3. Total plywood thickness required for varying soil CBR values and forklift loads.





1. Use

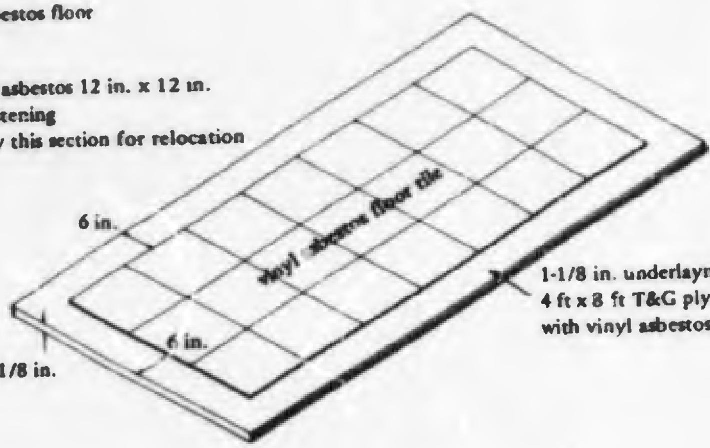
2. Use
Sel
fast
Det

3. Use
pla

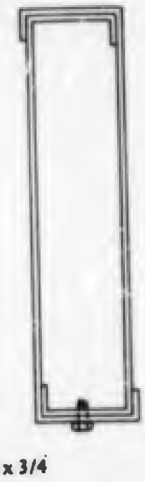
4. Ins
to
the

Figure 4. Modular relocatab

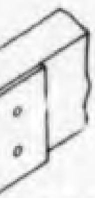
A

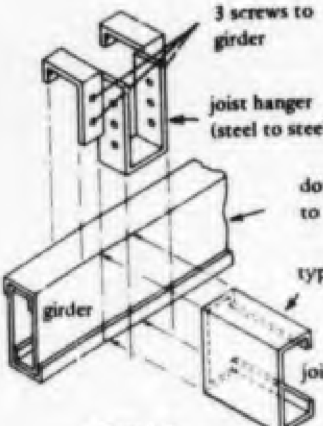


Detail C

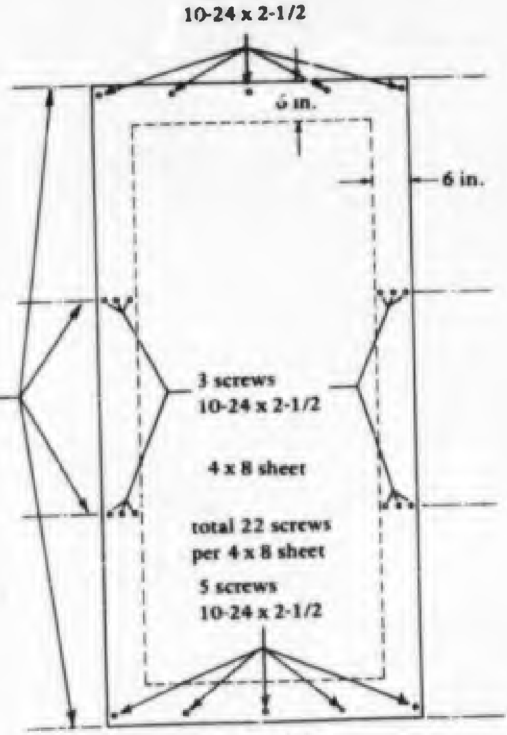


Detail B





Detail A



Detail D

1. Use double joist for all perimeter sections.
2. Use 10-24 x 2-1/2 Phillips flat head with pilot point. Self drilling screw zinc plated or cadmium plated for fastening plywood to joist. Screw spacing (see Detail D).
3. Use 1/4 in.-14 x 3/4 hex washer head zinc or cadmium. plated for fastening joists to hanger.
4. Install tile on panel (Detail C). This will allow screws to be removed for relocation without removal of all the tile.

4. Modular relocatable floor system.

b

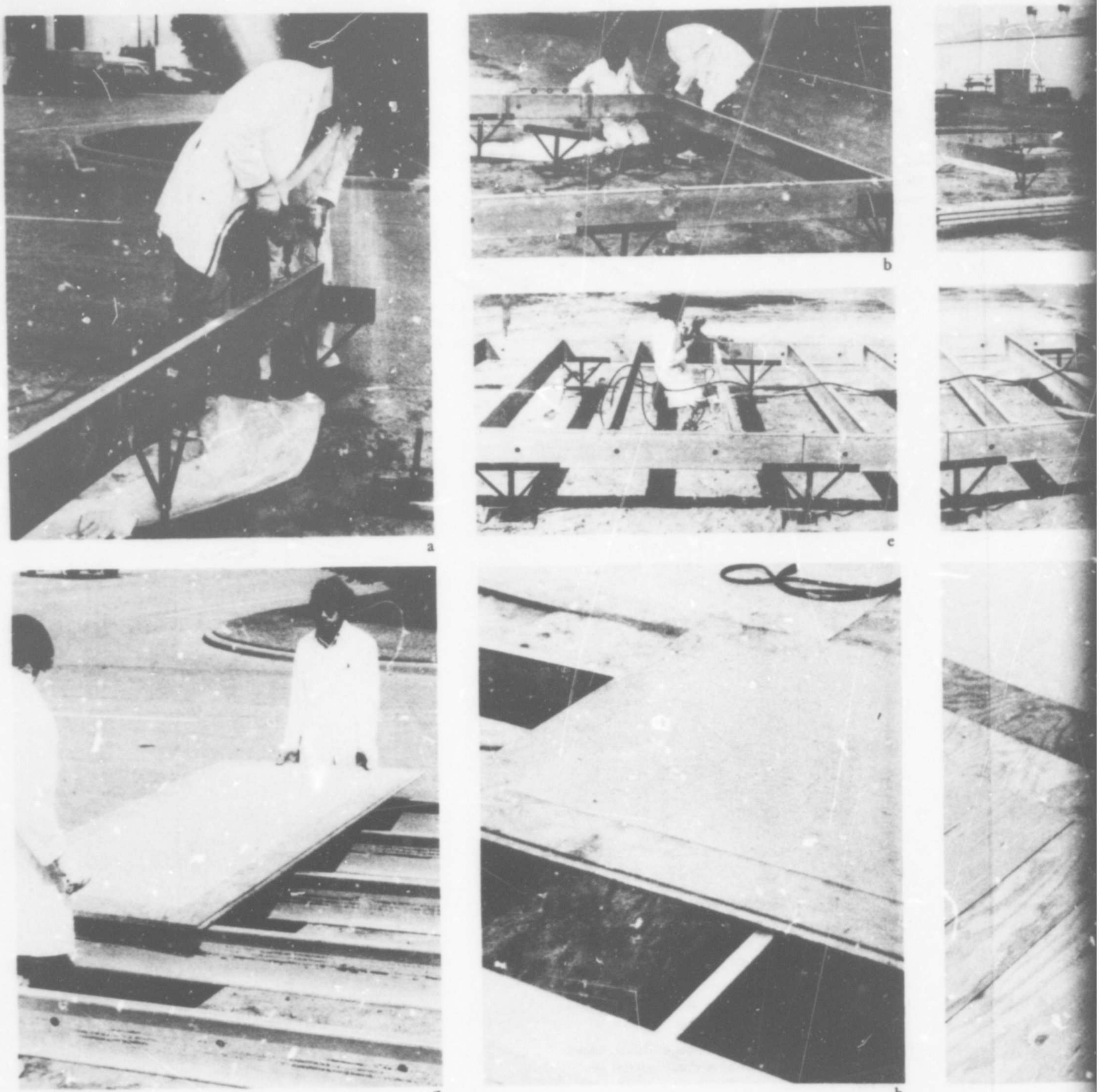
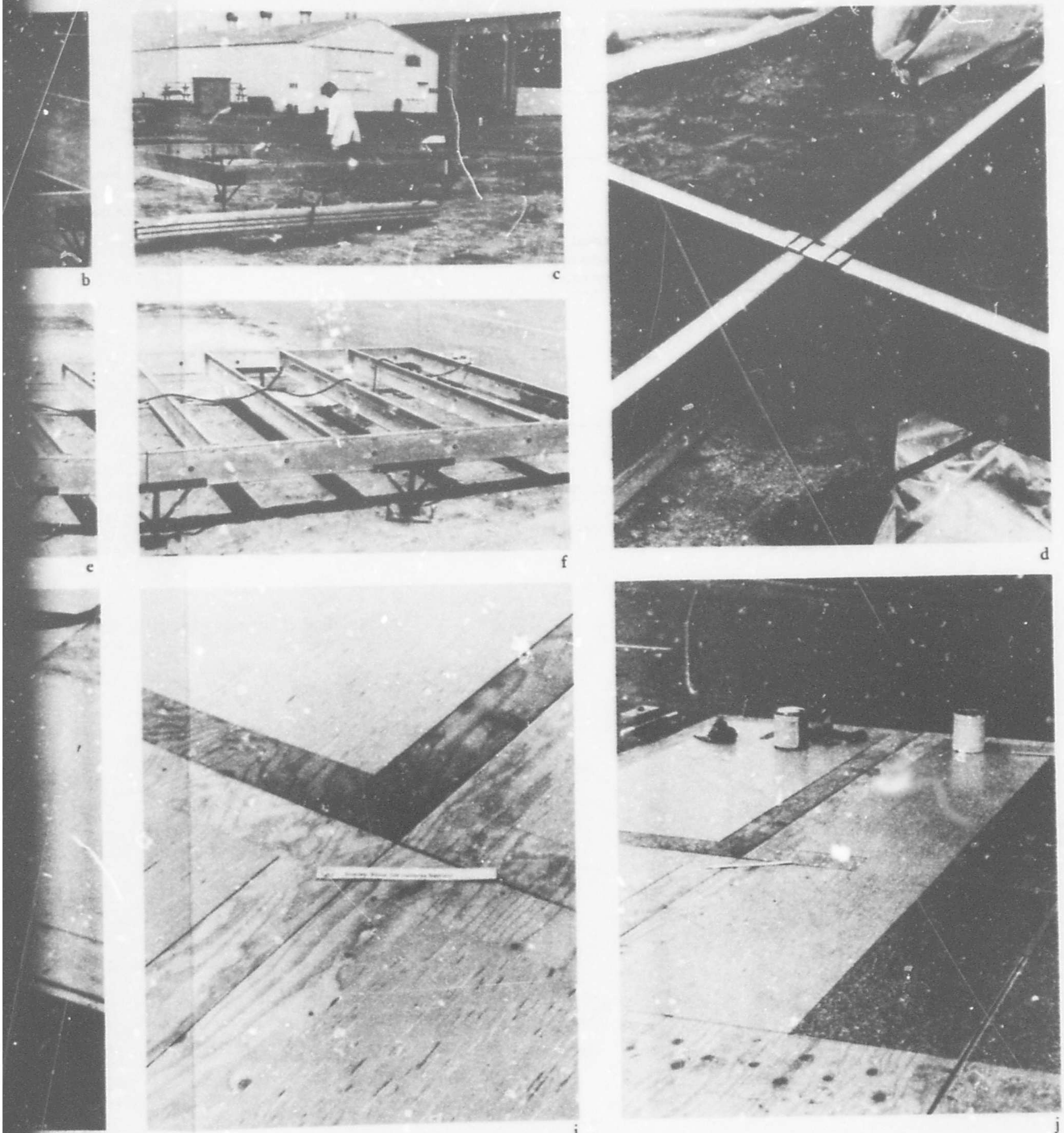


Figure 5. Construction sequence of raised floor.



Construction sequence of raised floor.

B

Numerous floor panels were considered, including those mentioned for the slab on-grade system. The seven specific designs compared included:

1. plywood
2. aluminum skin and honeycomb core
3. fiber reinforced plastic skin and aluminum honeycomb core
4. aluminum skin and balsa core
5. fiberglass reinforced plastic and balsa core
6. fiberglass reinforced plastic and plywood core
7. aluminum or steel skins and plywood core

Of all systems considered, the most cost-effective concept was tongue and groove plywood. The final panel design for the raised floor system uses 2-4-1 CD underlayment-grade, tongue-and-groove plywood with exterior glue. The plywood is attached to the steel joists using 10-24 x 2-1/4-inch Phillips-head, self-drilling, self-tapping screws (24 screws per panel). The panel fasteners are installed with the same electrical driver used for the steel framing fasteners.

Various types of floor coverings were considered, including:

1. Vinyl asbestos floor tile
2. Sheet vinyl of various grades
3. Spray-on vinyl
4. Trowel-on epoxy coatings
5. Trowel-on polyurethane coatings

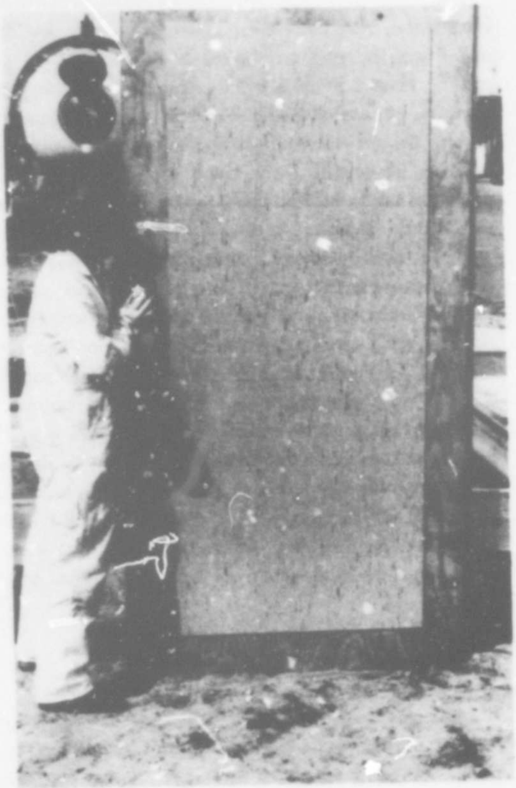
Figure 6 shows floor panels with vinyl asbestos tile and with sheet vinyl covering. Factory-installed floor finishes were considered; however, this was not cost effective. The most cost-effective system was field-installed, conventional, 12-inch-square, vinyl asbestos floor tile. This material is available through the Government Services Administration and consequently is very inexpensive compared with other alternatives. The wear characteristics are excellent and surpass all.

To eliminate the need for removal of the floor tiles for relocation of the floor system, the panel screws are located within a 6-inch area around the 4 edges of the panel. All of the plywood panels can be installed at the same time. Then vinyl tile would be laid using the pattern shown in Figure 7. This procedure results in tiles evenly spaced over the joints between plywood sheets. For relocation of the floor system only the rows over the joints in the plywood need be removed. Once these are removed all the panel fasteners will be visible. The 3 by 7 foot center of tile can remain.

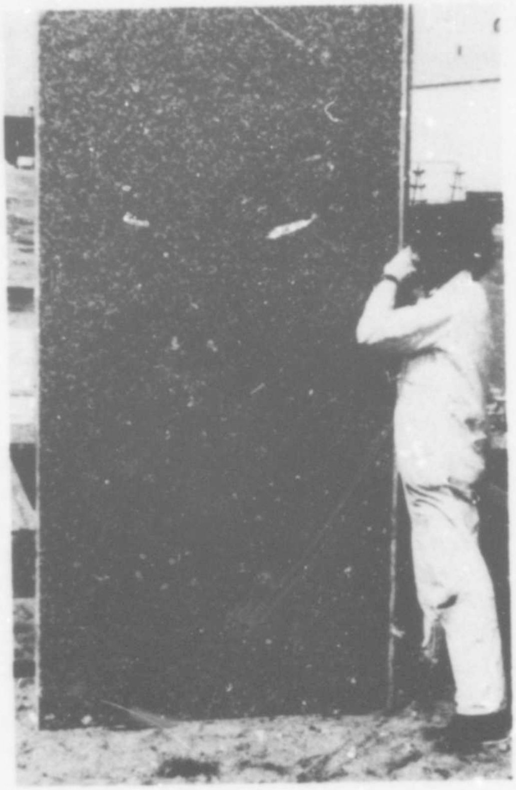
The total disassembled weight of the floor system is 5.73 pounds per square foot of floor area, and the total disassembled volume is 0.17 ft^3 per square foot of floor area. The erection time is 0.05 man-hours/ft^2 floor. The disassembly time is 0.01 man-hours/ft^2 floor. This system meets or exceeds all of the system requirements mentioned above. If plywood is available in the theater of operation, it need not be shipped with the building. Note that 3/4-inch plywood may be used with a reduced joist spacing from 32 inches to 24 inches; however, additional joists and shorter screws are required. The load capacity remains at 100 lb/ft^2.

Load Tests

The girder formed by nesting two 12-foot-long C joists together was load tested. The girder was supported on jacks spaced 8 feet apart, and two concentrated vertical loads were applied 32 inches from the supports. The girder was laterally braced at the load points to simulate the framing of joists in the actual floor system. The load-deflection curve is given in Figure 8. Strain gages were used to determine the stress in the member; 3 Ames dial gages were used to measure deflections. At the service load of 100 lb/ft^2 (3,200 pounds on each load point), the deflection of the center of the girder was 0.16 inch. At twice the service load the deflection at the center of the girder was 0.35 inch. The maximum allowable deflection for this test case (L/240) is 0.40 inch. The nominal minimum yield point is stated by the manufacturer to be 40,000 psi; the loading of twice the service load produced some inelastic behavior with a permanent deflection of 0.07 inch. Twice the service load represents the threshold of inelastic behavior. The raised floor shown in Figures 4 and 5 was load-tested by placing bags of sand on the floor to achieve the service load level of 100 lb/ft^2 (Figure 9). The deflection of the floor system was 0.31 inch at mid-span of



(a) Vinyl asbestos tile.



(b) Sheet vinyl.

Figure 6. Raised floor panels.

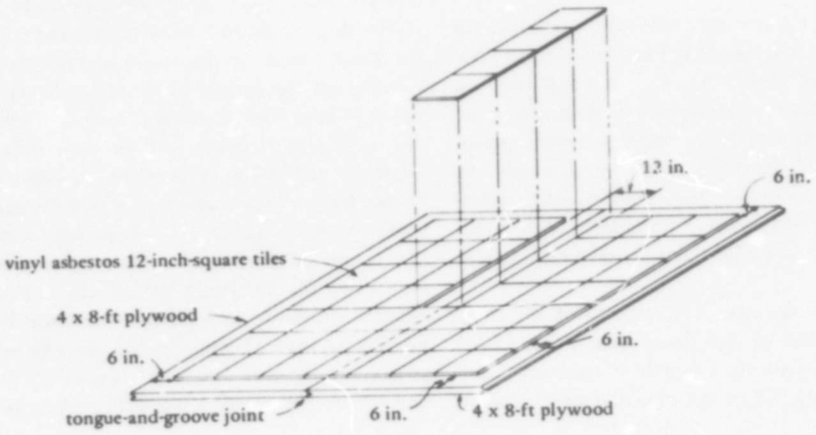


Figure 7. Typical section of floor, showing removal of tiles over joint in plywood.

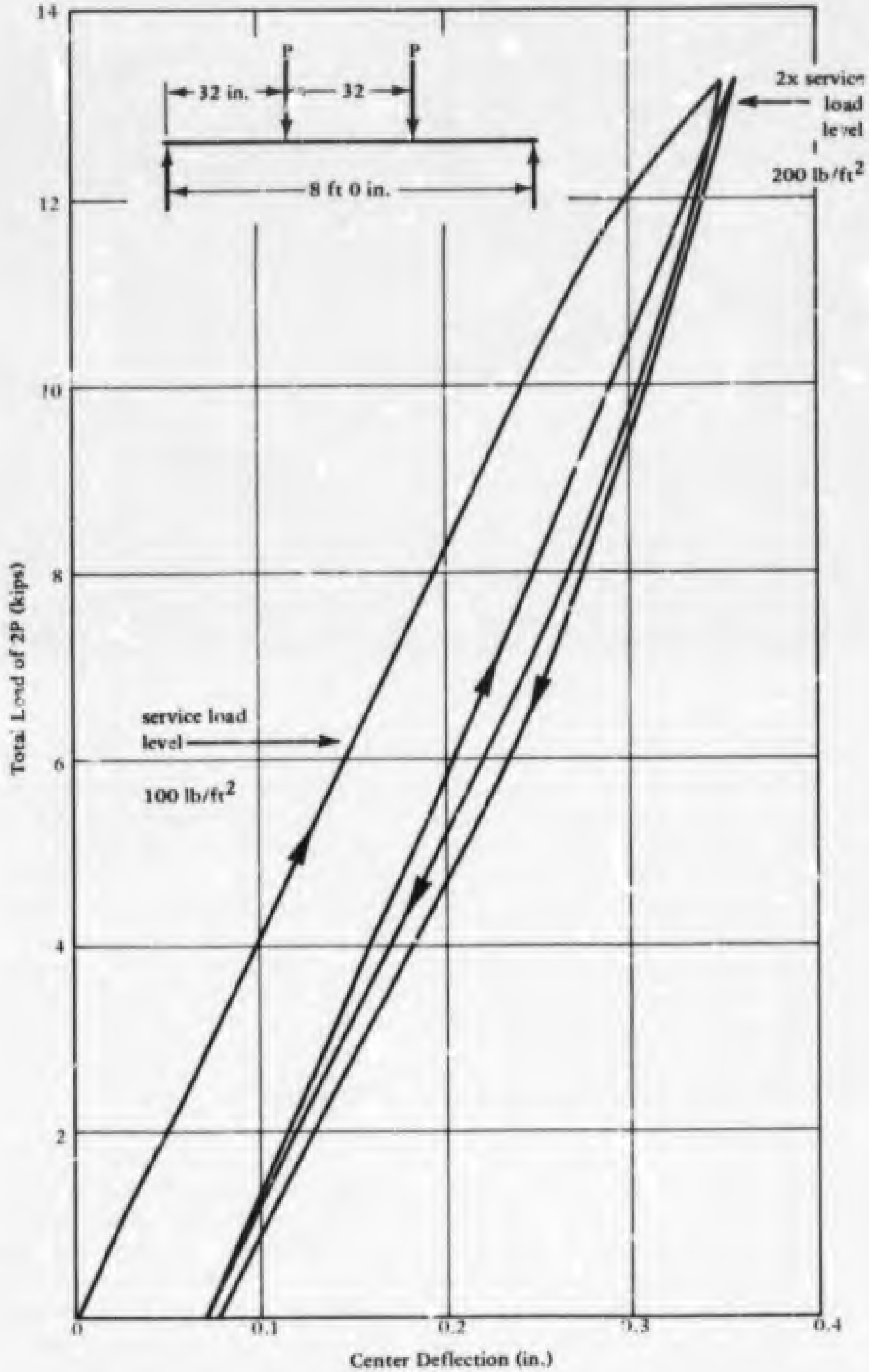


Figure 8. Load deflection curve for girder section formed by two nested joists.

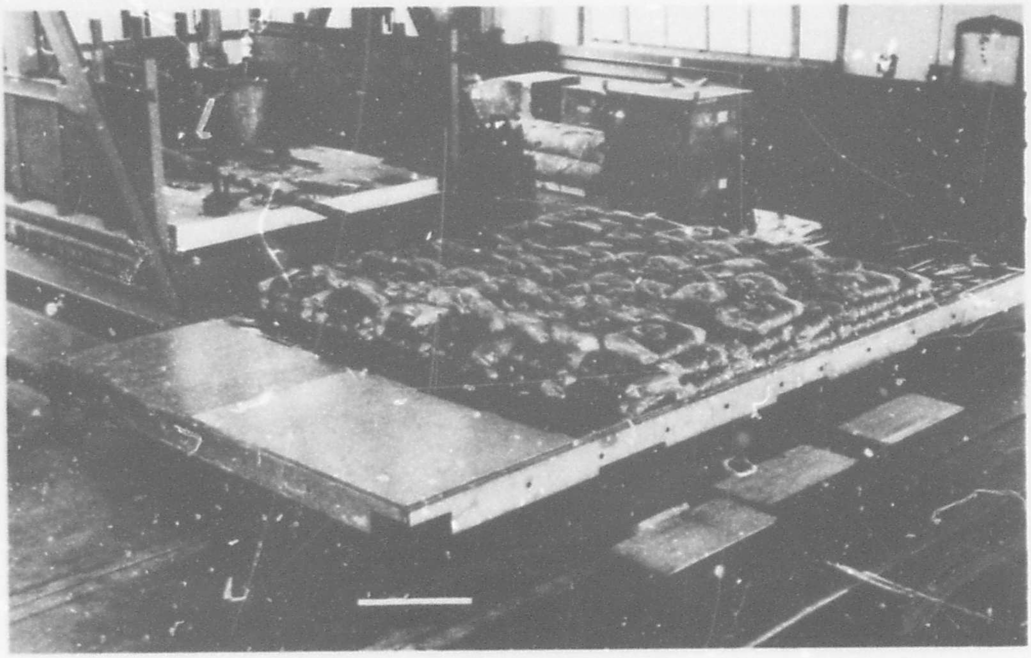


Figure 9. Load testing of floor system.

the joist; the allowable deflection (L/240) was 0.6 inch. The initial loading produced composite action in which the plywood deck worked with the joists to carry load because the fasteners joined the plywood to the joists tightly. The load was removed and reapplied. The second application of load (100 lb/ft^2) did not produce composite action; the deflection was 0.58 inch, less than the allowable deflection of 0.6 inch. The stress in the joists was measured at 24,200 psi. The nominal yield of the joists is 40,000 psi with an allowable of 24,000 psi. The measured stress is less than 1% higher than the allowable and is judged satisfactory.

Field Evaluation

A 40 x 100-foot prefabricated building was planned for the Naval Construction Battalion Center. When this building was erected, the raised floor system was installed in the building utilizing Seabee labor and supervision. Appendix E contains Civil Engineer Support Office (CESO) design drawings for the floor system. CEL monitored the installation of the floor system. No major problems were encountered. The speed of erection and volume of material per square foot of floor were verified. Figure 10 shows photographs of the installation. The building columns were bolted to a concrete grade beam running along the perimeter of the building. The floor system was independent of the building frame. Since this was a permanent facility the joists were ordered cut to specific lengths to eliminate the need for any field cutting.

DISCUSSION

A conventional 6-inch-thick concrete slab presently employed with relocatable buildings, based on standard construction data [5], has a material cost of \$0.52/ft^2 and requires 0.09 man-hours/ft^2 for construction. When floor tile is added, the cost increases to \$0.67/ft^2 and the time to 0.10 man-hours/ft^2. Thus, for a 40 x 100-foot building, the material cost would be \$2,080 for concrete and \$600 for floor tile for a total of \$2,680. The man-hours required would be 360 for the concrete and 52 for the tile laying for a total of 412 man-hours. At the time of relocation none of the floor system can be relocated.

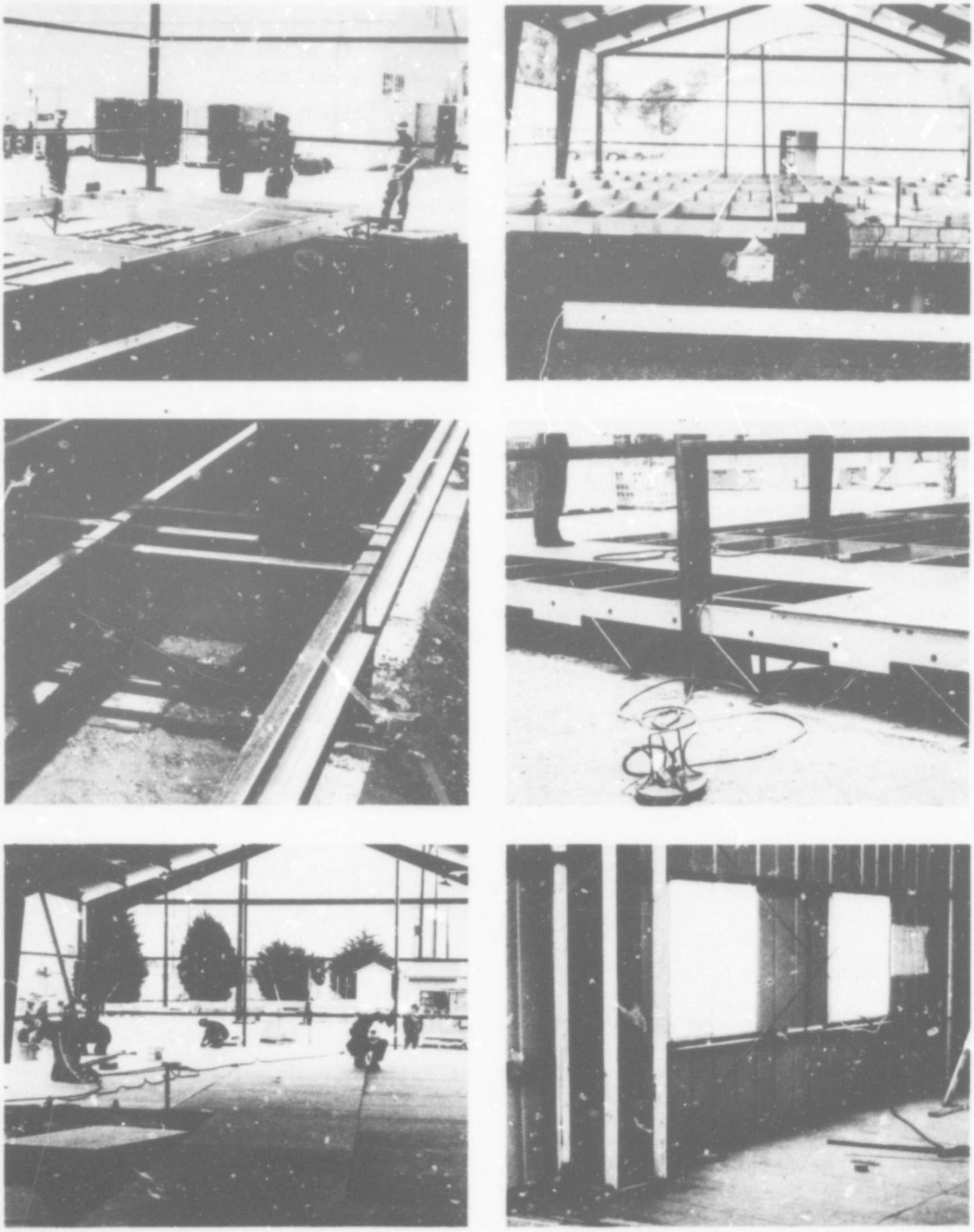


Figure 10. Construction of 40 x 100-foot building.

The raised floor system developed in this study is capable of carrying a 100 lb/ft^2 live load and of having three relocations with a total cost of $1,800 per application including tile. The raised floor system could be installed in 250 man-hours by a typical crew of steelworkers or builders. With reasonable care the system should be usable for more than three relocations, further reducing the cost; however, an assumption of three relocations is used for planning purposes.

The plywood slab on grade concept for heavy warehouse loads could be installed in a 40 by 100-foot building in 40 man-hours at a cost of about $2,000 per location. This is about the same cost as a concrete slab, but the installation time is one-ninth that of a concrete slab; however, the life of the plywood system is obviously less. The floor systems developed result in a cost savings and a reduction in the need for skilled labor.

One of the interesting trade-offs considered was the application of the floor covering in the "factory" as opposed to the field. The labor cost for factory installation of the vinyl floor tile would be about 4 times that of field installation and would add about $0.50/ft^2 to the raised floor system cost. This would reduce field erection time; however, it would also increase the plywood weight. The floor surface could be very easily damaged by scraping the panels together. It was thus thought that factory-installed floor surfacing was neither cost-effective nor practical.

The raised floor system was developed to be placed within a building; however, some buildings may be placed directly on the floor. When the building is placed on the floor system the jacks are not used. Appendix F gives design drawings for the use of the floor system in this configuration.

REFERENCES

1. Army Engineer Waterways Experiment Station. Miscellaneous Paper No. 4-882: Forklift operations on T17 membrane surfacing on sand subgrade in open-storage areas, Engineer tests, by S. G. Tucker and T. W. Vollor. Vicksburg, MS, Mar 1967.

2.______. Miscellaneous Paper No. S-69-5: Evaluation of MO-MAT ground cover for use in Army depot open-storage areas, by C. J. Gerard and H. L. Green. Vicksburg, MS, Jan 1969.

3. Naval Civil Engineering Laboratory. Technical Report R-763: Layered pavement systems, by J. B. Forrest, M. G. Katona, and D. F. Griffin. Port Hueneme, CA, Apr 1972.

4. United States Steel. Catalogue USS A218: USS super C steel joists. Pittsburgh, PA.

5. Building construction cost data, by Robert Snow Means Company. Duxbury, MA.

6. Naval Facilities Engineering Command. Policies and procedures for improving contingency construction. Washington, DC, May 1969.

7. Naval Civil Engineering Laboratory. Technical Note N-981: Survey of buildings of prefabricated, expandable, inflatable, or chemically-rigidized types suitable for military use, by P. J. Rush. Port Hueneme, CA, Aug 1968.

8. E. J. Schultze. "Military shelters – looking ahead," The Military Engineer, vol. 61, no. 401, May-Jun 1969, p. 194.

9. "Housing in Vietnam," The Airman, vol. 10, no. 10, Oct 1966, p. 10.

10. "Bare base, improved tactical airpower mobility," Tactical Air Warfare Center Quarterly Report, vol. 1, Dec 1969.

11. Portland Cement Association. PCA soil primer. Chicago, IL, 1962.

12. D. P. Krynine. Soil Mechanics. New York, NY, McGraw-Hill Book Company, Inc., 1947.

13. Air Force Air Research and Development Command, Air Force Research Division, Geophysics Research Directorate. Handbook of geophysics. New York, NY, The MacMillan Company, 1960, ch. 12.

14. U.S. Army, Waterways Experiment Station. Miscellaneous Paper MPS-74-3: Small aperture testing for airfield pavement evaluation, by J. W. Hall, Jr., and D. R. Elsea. Vicksburg, MS, Feb 1974.

15. K. Terzaghi. Theoretical soil mechanics. New York, NY, John Wiley and Sons, Inc., 1947.

16. U.S. Navy, Bureau of Yards and Docks. Technical Publication TP-PW-18: Soil mechanics and earth structures. Washington, DC, Oct 1953.

17. Bureau of Yards and Docks. Design Manual Navdocks DM-7: Soil mechanics, foundation and earth structures. Washington, DC, Sep 1967.

18. U. S. Army Waterways Experiment Station. Miscellaneous Paper MP-S-71-27: Design of unsurfaced soil facilities for operations of C5A aircraft, by V. C. Barber and D. M. Ladd. Vicksburg, MS, Dec 1971.

Appendix A

TYPES OF HOUSING AND SHELTERS

The principal uses of housing and shelters in military operations are:

1. Battalion and regimental headquarters and communication, airfield, waterfront ASW, and ASTAC operational facilities.

2. Maintenance facilities for aircraft, vehicles, weapons, and electronics and communications equipment

3. Storage facilities

4. Hospitals, dispensaries, and dental clinics

5. Administration and support

6. Troop housing and messing

7. Utilities facilities for electrical power and water

Facilities constructed of prefabricated components have the following desirable characteristics [6, 7, 8]:

1. mobility

2. flexibility to satisfy both forward area and base requirements

3. minimum construction effort

4. economical recoverability

5. adaptability for use in multiple units to meet a range of requirements

6. facility in meeting initial requirements of a contingency situation at earliest possible time

7. standardization and uniformity among the services

The rigid-frame, prefabricated, steel, straight-sided, gable-roofed structure, designed to be erected on a concrete foundation slab, is one example of the prefabricated buildings utilized. The overall dimensions of the building are 40 by 100 feet 6 inches, with an eave height of 13 feet 10 inches, and a ridge height of 20 feet 6 inches. The gross weight of the building is 27,080 pounds. The building can be erected in 436 man-hours with an erection crew of six to eight men and a crane or forklift truck with operator. The building is designed for a snow or live load of 16.4 lb/ft^2, based on a horizontal projection of the roof, and a wind load of 22.5 lb/ft^2, applied to the vertical projection of the roof on the windward side of the building [7]. The rigid-frame building is available in several spans from 20 to 60 feet.

Throughout the Pacific and Southeast Asia, wooden housing has been used by military personnel [9]. These units, called hootches, measure 20 by 60 feet, have louvered sides on the lower half of the walls and screened windows above the louvers. The roof is corrugated metal. Air is circulated by one or two overhead fans. Other types of wooden structures are also common.

Other basic units include aircraft hangars and multipurpose shelter [10].

Measuring 30 by 45 by 11 feet when erected, the multipurpose shelter area can serve as a warehouse, a dining hall, or a base exchange. It can accommodate any function in which a large number of items or personnel must be sheltered. The multipurpose shelter is of modular design, and is formed from aluminum panels and double-hinged I-beams. One end wall has double personnel doors, and the other a vehicle access door. Both end walls are made of fabric impregnated with plastic for maximum durability and shelter. Broken down for shipping, the panels for a single shelter are attached on a standard pallet for air transport.

The hangar shelter is similar to the multipurpose shelter in design. The hangar weighs 16,000 pounds and measures 20 feet high with a floor space of 58 by 80 feet to accommodate aircraft maintenance functions [10]. The interior space allows freedom of movement for all large maintenance equipment and easy access for aircraft; the structure can accommodate one F-4 aircraft. All panels are covered with plastic-impregnated fabric where they join. The end walls are also made of this fabric; one wall opens to admit aircraft and equipment. Fourteen men can erect this structure in 12-1/2 hours. The module panels for one complete shelter break down easily for shipment; two knocked-down shelters can be hauled in one C-130 aircraft.

The number of buildings and modules required for Harrier Aircraft facilities and bases, excluding those for personnel billeting, are as follows:

	Facility	Base
1. ATCO* Building, Aircraft Hangar	1	7
2. ATCO Building, Storage	2	26
3. ATCO Hangar Lean-to Additions	3C	180

* ATCO Industries Ltd; Calgary, Canada

The aircraft hangar, made up of individual sections 8 feet long by 60 feet wide by 28 feet high, weighs 4,300 pounds. Sections are butted end-to-end to provide the desired length. Approximate inside dimensions are 120 feet long, 58 feet wide, and 20 feet high. The hangar can be erected on either 3 x 8-inch wood planks or on a matting foundation. The building can be installed or taken down by an unskilled crew in a matter of hours.

Sections of the storage building measure 40 feet by 10 feet by 20 feet 5 inches. The overall building size is dependent on the number of sections desired. Individual sections can be transported by a KC-130 aircraft or externally lifted by helicopter using a pallet system. The sections weigh 3,800 pounds.

The aircraft lean-to additions have 20-foot spans and are designed for use as workshops or storage areas on either one side or both sides of the main buildings. A four-man crew and crane operator can erect each 8-foot wide section in approximately 20 minutes.

Harrier aircraft bases may also contain general-purpose (GP) shelters and airmobile maintenance shops. The GP shelter is 30 feet 6 inches wide and 45 feet high at the center. Aluminum panels and arch sections are assembled at ground level and erected by means of an A-frame, cables, and pulleys. These shelters are designed to be used as dining facilities, meeting halls, or as storage areas. Panelized buildings, such as the Lewis Building are available in spans up to 36 feet. These buildings are constructed from factory-fabricated, honeycomb-core, aluminum-skin panels fastened together in the field. The structure is designed to be relocated five times. The Lewis buildings can be erected by a crew of five in 3 working days. Requirements and criteria for relocatable buildings are presented in Table A-1.

Table A-1. Requirements and Criteria for Relocatable Buildings

Organization	Dimensions	Erection	Climate	Life Expectancy		Windload	Weight (lb)	Cubage (ft^3)	Primary Use
				Field	Storage				
Navy, NAVFAC 06	Optional, but prefer 20' wide modules for personnel structures.	Erectable without specialized equipment by large number of personnel in short time without special tools.	Primarily for tropical use, but adaptable to Northern use.	30 years or 10 reuses.	"outstanding"	120 knots desirable		minimum	Personnel support facilities, work areas and warehouses.
Marine Corps Specific Operational Requirement No. LO 3.1 MARCORPS Small Extendable Shelter	Not to exceed 2,000 ft^3	Erection and striking of shelters by field troops (semi-skilled) two men	Ambient temperature of -25° to $+125^{\circ}F$	1 year normal use	3 years at temperatures of -65° to $+155^{\circ}F$	45 knots with gusts up to 65 knots	no more than 140		Aid station, small command post. personnel shelter, etc., when extended by addition of like section will provide shelter for large command post, storage, galleys, repair shop, etc.
Marine Corps Specific Operational Requirement No. LO 3.2 MARCORPS Medium Extendable Shelter	Not to exceed 4,000 ft^3	By four men without special tools or equipment and by persons wearing arctic gear.	Ambient temperature of -25° to $+125^{\circ}F$	1 year normal use	3 years at temperatures of -65° to $+155^{\circ}F$	45 knots with gusts up to 65 knots	minimized		Shelter for environmental protection of laundries, hospitals, messhalls, and maintenance and repair facilities in forward areas under field conditions. Provide portable shelter under worldwide environmental conditions for personnel, supplies, vehicles, equipment, from rain, dust, heat, and cold.

continued

Table A-1. Continued

Organization	Dimensions	Erection	Climate	Life Expectancy		Windload	Weight (lb)	Cubage (ft^3)	Primary Use
				Field	Storage				
Marine Corps Specific Operational Requirement LO 3.3, MARCORPS Multipurpose portable shelter	(Large) 8'H x 8'W x 20'L (Medium) 8'H x 7'-4"W x 12' L (Small) 6'-4"H x 6'-2"W x 6'-7"L	Erection by persons wearing arctic gear. Minimal special tools or equipment for erection.	Ambient temperature of -25° to +125°F	4 years	7 years at temperatures of -65° to +155°F	65 knots with gusts up to 90 knots when guyed	weight consistent with handling facilities and transport		Aid stations, operating rooms, dental facilities, communications centers, telephone switchboard centrals, field data processing, fire control centers, and technical repair facility. Used for combat support and combat service organizations.
Navy, Official Uniform Military Requirements Criteria for 20' x 48' prefabricated advanced base buildings	20 x 48 feet	Capable of being erected on a prepared foundation by an experienced crew in 120 man-hours or less.	U factor of not more than 0.24 at -25°F U factor of not more than 0.15 at -40°F.	5 years minimum	5 years minimum	70 mph; 20 lb/ft^2 snow load 40 lb/ft^2 floor load			
Navy, Unofficial Uniform Military Requirements criteria for 40' x 100' prefabricated advanced base buildings	40 x 100 feet	Erected by an experienced crew on a prepared foundation in 450 man-hours or less. Capable of being erected with no welding		5 years minimum	5 years minimum	70 mph; 20 lb/ft^2 snow load			

Appendix B

SOIL PROPERTIES

The California Bearing Ratio (CBR) is a measurement of the load bearing capacity of a surface, compared to a standard of crushed stone [11, 12]. To determine the CBR, a 3-square-inch loading piston is forced into the surface to depths of 0.1, 0.3, 0.4, or 0.5 inch. The CBR of the test material is the percentage of the standard load required for the same penetration. The standard loads are:

Penetration (in.)	Standard Load ($lb/in.^2$)
0.1	1,000
0.2	1,500
0.3	1,900
0.4	2,300
0.5	2,600

The modulus of subgrade reaction, K, is another measurement of load-bearing capacity [13]. A loading plate is forced into the surface, and the resulting deflection is plotted against the load; K is the ratio of load in pounds per square inch to the displacement of the plate in inches. The K-value is determined from the total elastic-plastic soil deformation, and time-related settlement from soil consolidation is not considered.

The relationship between CBR and K is shown in Figure B-1 [14]. The relationships presented in Figure B-1 are approximations since the CBR test and plate bearing test differ in test method, soil confinement, and soil saturation. The relationships give valuable approximations which will be sufficiently accurate for planning and design in a contingency situation. Knowing one value, a useful estimate can be obtained for the other. For example, knowing a silty sand to have a CBR of 10, the modulus of subgrade reaction is found to be 200 pci.

A more rigorous determination of bearing capacity may be achieved when the soil density and angle of internal friction are known [12, 15, 16].

The bearing capacity of a soil is the maximum vertical load which the soil can support without failing through shear or excessive consolidation settlement. If one assumes that the failure mode is shear, the bearing capacity may be computed from one of Terzaghi's formulas. Generally, Terzaghi's theory states that a wedge of soil immediately below a footing acts with the footing upon application of load. A footing load above the ultimate soil bearing capacity will force lateral and vertical displacements of the soil wedge as a result of slipping along a logarithmic, spiraled, failure surface. The resulting downward movement may be sufficient to produce either failure of the footing or of supported structural members.

The Terzaghi formulas are modified slightly, depending on the footing geometry, and are intended for use with shallow footings where footing depth does not exceed 1.5 times the width. Terzaghi has defined bearing capacity in terms of the following general approximate equations:

$$q = cN_c + \gamma_1 ZN_q + \frac{1}{2}\gamma_2 BN_\gamma \text{ (continuous footings)}$$

$$q = 1.3cN_c + \gamma_1 ZN_q + 0.4\gamma_2 BN_\gamma \text{ (square footings)}$$

where

q = ultimate bearing capacity, lb/ft^2

c = cohesive strength of soil, lb/ft^2

γ_1 = density of soil, lb/ft^3, above footing base

γ_2 = density of soil, lb/ft^3, below footing base

Z = height of soil over bearing area, ft

B = width of the bearing area, ft

N_c, N_q, N_γ = dimensionless bearing capacity factors given by Figure B-2.

A safety factor of three is normally utilized when these bearing-capacity factors are used to estimate allowable soil-bearing capacity.

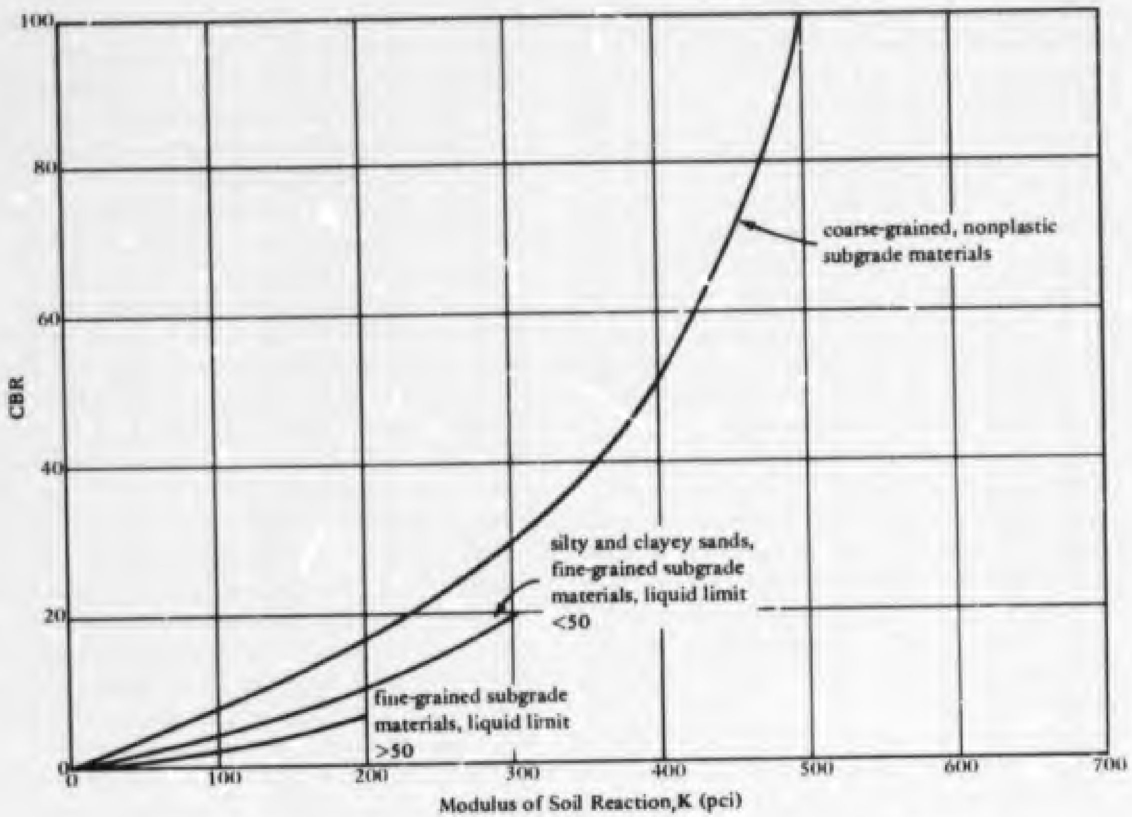


Figure B-1. Relationship between CBR and modulus of subgrade reaction, K [14].

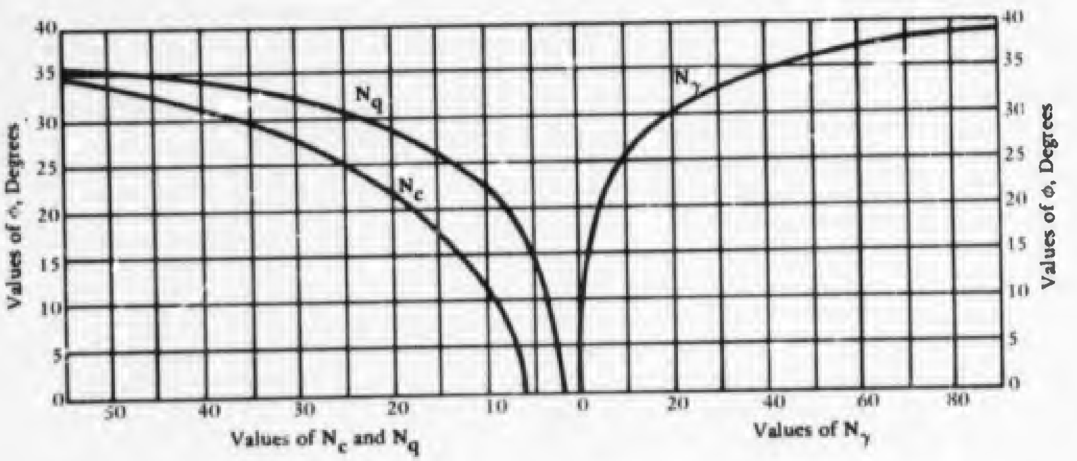


Figure Γ 2. Relationships between bearing capacity factors and angle of internal friction [16].

When circumstances do not permit use of either the Terzaghi equations or field testing, generalized bearing capacities for the various soil types may be used cautiously. Suggested allowable bearing capacities for design computations, arranged according to soil type, are presented in Table B-1 [17].

The foundation for the raised floor system may be designed for a variety of soil-bearing capacities by varying base plate or concrete pedestal dimensions to properly distribute the vertical reaction of the jacks. The controlling factor may not be shear. In situations where an underlying soil stratum is weak and floor live loads are sustained over long periods, consolidation settlement should be investigated.

The flooring design criteria specify an allowable soil-bearing capacity of 2,500 lb/ft^2 which could be roughly equated to a modulus of subgrade reaction (K-value) of 174 pci where 0.1 inch of settlement could be tolerated. From Figure B-1 a K-value of 174 pci corresponds to a CBR of 8, thus the on-grade warehouse floor would be designed for a soil having a CBR of about 8. The loaded RT-150 and 540-RS forklifts would produce the most severe pavement stresses. Rather than limit the warehouse floor to one particular CBR value, design conditions were iterated for a range of CBR values and several combinations of forklift payloads. The results are plotted in Figure 3. These curves are plotted such that plywood stresses are within allowable limits, thus failure would not occur under a static loading condition.

As with any pavement, failure will occur after a given number of coverages. One coverage is generally defined as one application of the vehicle wheel over every point in the traffic lane. The precise number of coverages required to initiate failure cannot be determined except through field testing. Figure B-3 was developed to give an estimation of soil strengths required for repeated coverages of C5A aircraft on the same unsurfaced runway [18]. Without field testing of the proposed plywood pavement, Figure B-3 can be utilized to present a rough approximation of the plywood pavement service life. The design assumptions for Figure B-3 consider the soil surface as having failed when the average rut depth exceeds 3 inches, when the soil surface deviates by at least 4 inches from the bottom of a 10-foot straight edge laid transversely across the traffic lane or when the elastic deflection exceeds 1.5 inches. The plywood pavements of Figure 3 are designed to produce initial static deflections of approximately 0.1 inch, and failure of the pavement would occur prior to reaching the soil failure criteria of Figure B-3.

The addition of a plywood pavement to a previously unsurfaced soil probably will not improve the number of coverages indicated by Figure B-3. A plywood pavement should significantly reduce the amount of wheel rutting and the elastic deflection experienced during trafficking. Figure B-3 should present an approximation of RT 150 forklift coverages over a plywood pavement for soils with CBR values ranging between 4 and 10. With higher CBR values, Figure B-3 would probably indicate a greater number of coverages than would be actually experienced since the plywood pavement could be expected to fail through fatigue before the soil fails.

Using Figure B-3 and the data from Table C-1 for an RT 150 forklift with a 10-kip payload on a soil having a CBR of 8 (the dual-drive wheels represent 10.3-kip loads on single wheels with 81-psi contact pressure), we find that the unsurfaced soil should sustain 750 coverages before one of the failure criteria for an unsurfaced soil is achieved. The addition of plywood surfacing to the soil would cause a distribution of wheel contact pressure and a reduction of stresses and strains induced into the soil system and would reduce rutting and deflection while giving the approximate same coverage life. Figure B-3 was developed for pneumatic tires; therefore, its use is not recommended for estimating the life of plywood pavements subjected to solid-tired vehicles, such as the 540-RS forklift.

Table B-1. Nominal Values of Allowable Bearing Pressures for Spread Foundations

Type of Bearing Material	Consistency in Place	Allowable Bearing Pressure (tons/sq ft)	
		Ordinary Range	Recommended Value for Use
Massive crystalline igneous and metamorphic rock: granite, diorite, basalt, gneiss, thoroughly cemented conglomerate (sound condition allows minor cracks).	Hard, sound rock	60 to 100	80
Foliated metamorphic rock: slate, schist (sound condition allows minor cracks).	Medium hard sound rock	30 to 40	35
Sedimentary rock: hard cemented shales, siltstone, sandstone, limestone without cavities	Medium hard sound rock	15 to 25	20
Weathered or broken bed rock of any kind except highly argillaceous rock (shale)	Soft rock	8 to 12	10
Compaction shale or other highly argillaceous rock in sound condition	Soft rock	8 to 12	10
Well graded mixture of fine and coarse grained soil: glacial till, hardpan, boulder clay (GW-GC, GC, SC)	Very compact	8 to 12	10
Gravel, gravel-sand mixtures, boulder-gravel mixtures (GW, GP, SW, SP)	Very compact	7 to 10	8
	Medium to compact	5 to 7	6
	Loose	3 to 6	4
Coarse to medium sand, sand with little gravel (SW, SP)	Very compact	4 to 6	4
	Medium to compact	3 to 4	3
	Loose	2 to 3	2
Fine to medium sand, silty or clayey medium to coarse sand (SW, SM, SC)	Very compact	3 to 5	3
	Medium to compact	2 to 4	2.5
	Loose	1 to 2	1.5
Fine sand, silty or clayey medium to fine sand (SP, SM, SC) . .	Very compact	3 to 4	3
	Medium to compact	2 to 3	2
	Loose	1 to 2	1.5
Homogeneous inorganic clay, sandy or silty clay (CL, CH) . . .	Very stiff or hard	3 to 6	4
	Medium to stiff	1 to 3	2
	Soft	5 to 1	0.5
Inorganic silt, sandy or clayey silt, varved silt-clay-fine sand (ML, MH)	Very stiff to hard	2 to 4	3
	Medium to stiff	1 to 3	1.5
	Soft	5 to 1	0.5

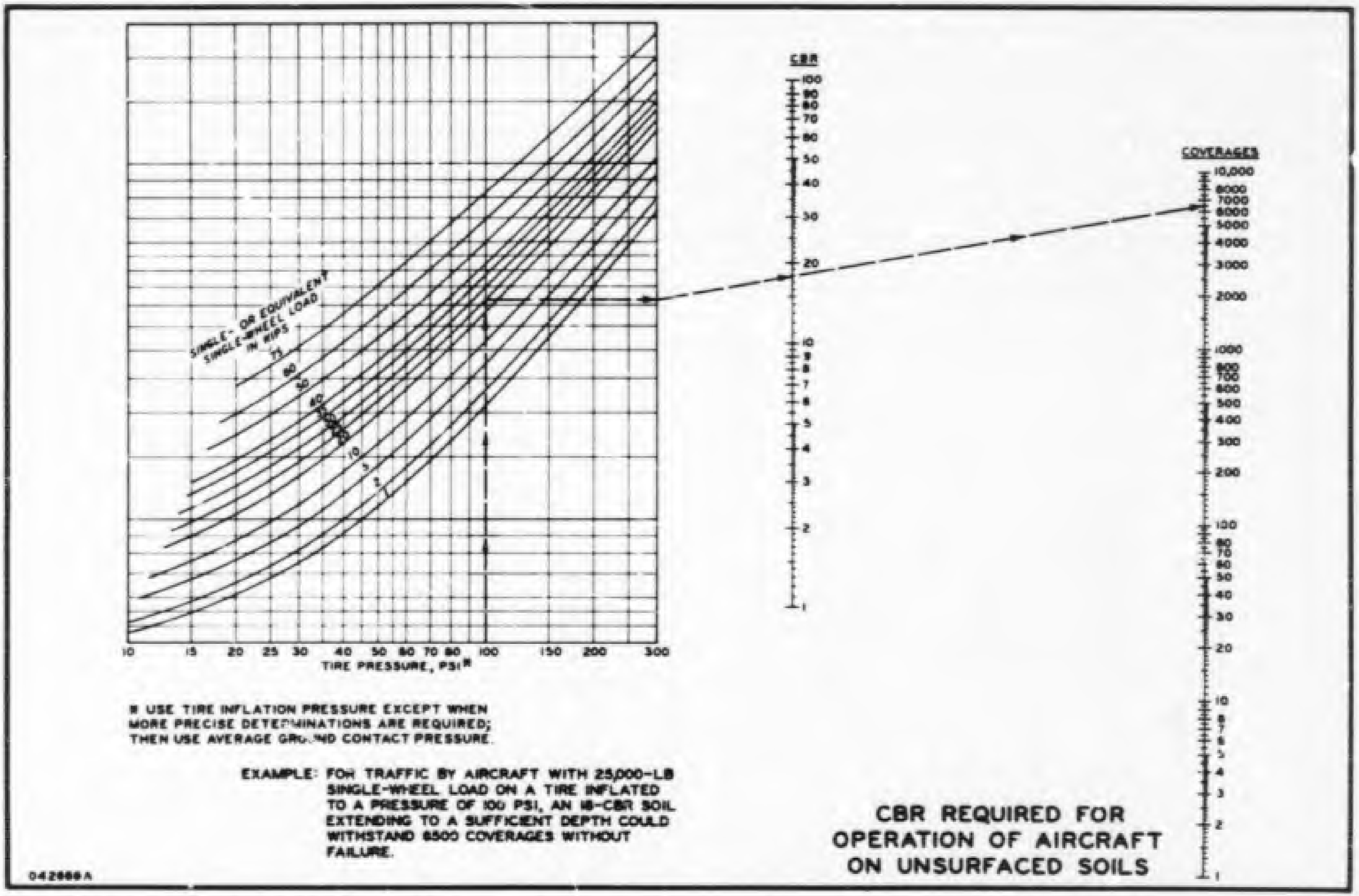


Figure B-3. CBR required for operation of aircraft on unsurfaced soils [18].

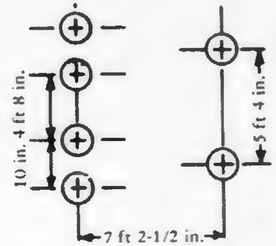
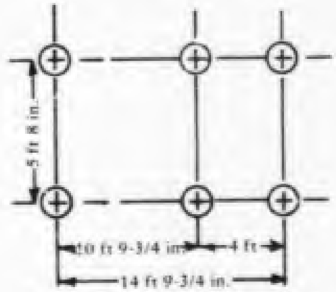
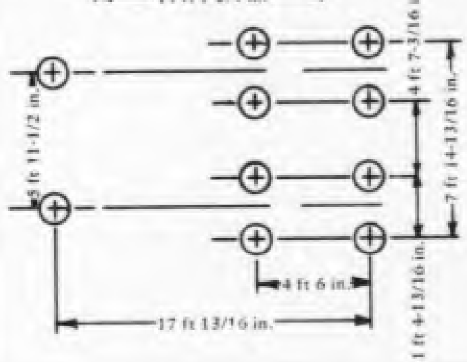
Appendix C

VEHICLES AND MATERIALS

Tables C-1, C-2 and C-3 present a summary of loading characteristics of common forklifts and trucks.

A summary of possible flooring materials is given in Table C-4 along with a detailed description of each item. Test data are usually limited. Most of the materials have been evaluated for use as airfield surfaces. Thus, wheel loadings tested are generally higher than those used on floor loads. Many of the items listed, although developed, have not been produced in quantity and are not readily available.

Table C-1. Wheel Loadings for Forklifts and Trucks

Vehicle	Payload (lbs)	Tire Size (in.)	Tire Pressure (psi)		Wheel Configuration	Axle Loading (kips)		Contact Area per Axle (in.^{2})		Contact Pressure (psi)	
			Front	Rear		Front	Rear[a]	Front	Rear	Front	Rear
Forklift RT-150	0	8.25 x 15	80	80		6.3	10.8	145	126	43.4	85.7
	5,000	8.25 x 15	80	80		13.0	8.5	198	114	65.7	74.6
	10,000	8.25 x 15	80	80		20.5	6.0	253	100.5	81.0	59.7
	15,000	8.25 x 15	80	80		28.0	3.5	308	88	90.9	39.8
2-1/2-ton cargo truck 6 x 6 M35 A-1	18,000	11.00 x 20, 12-ply	35	35		6.3	6.1	120	185	52.5	33
5-ton cargo truck M54	30,000	11.00 x 20, 12-ply	35	35		9.2	10.6	256	320	35.9	33.1

[a] For total rear load, double the load given.

Table C-2. Characteristics of Towmotor Model 540-RS and Hyster Model RT-150 Forklifts

Item	Forklift	
	540-RS	RT-150
Gross weight (empty)	10,990 lb	17,070 lb
Gross weight with maximum capacity payload	16,990 lb	32,070 lb
Length (axle-to-axle)	4 ft, 6 in.	7 ft, 2-1/2 in.
Spacing of steering wheels	3 ft, 0 in.	5 ft, 4 in.
Tire		
Size, drive and steering	solid tire	8.25 x 15
Pressure	not applicable	80 psi
Diameter, drive wheels	21 in.	not applicable
Diameter, steering wheels	16-3/4 in.	not applicable
Thickness of rubber	2-1/2 in.	not applicable
Hoist bar clearance (empty)	2-1/2 in.	7 in.
Differential clearance (empty)	–	8 in.

Table C-3. Cargo Truck Data

Vehicle	Description	Load		Tire Inflation Pressure (psi)
		Axle	Weight (lb)	
M151 Utility Truck and M100 Trailer				
M151	1/4-ton, 4 x 4	Front Rear Total	1,360 2,275 3,635	20 25
M100	1/4-ton		1,040	28
M37 Cargo Truck and M101 Trailer				
M37	3/4-ton, 4 x 4	Front Rear Total	3,230 4,935 8,165	45 45
M101	3/4-ton		2,550	45
M35 Cargo Truck and M101 Trailer				
M35	2-1/2-ton, 6 x 6	Front Intermediate Rear Total	5,125 14,180 4,410 23,715	70 70 70
M101	3/4-ton		2,625	45

Table C-4. Summary of Flooring Materials

Item	Federal Stock Number	Source	Cost ($\$/ft^2$)	Weight (lb/ft^2)	Panel Dimensions	Emplacement Rate (ft^2/man-hr)	Removal Rate (ft^2/man-hr)	Packaged Volume Per Unit Placing Area (ft^3/ft^2)
Nonmetallic Membranes								
T1				0.34	30 ft x 56 ft	1126		0.0104
T2				0.17				
T15				0.13				
T16		Reeves Bros. Inc. New York, NY Uniroyal, Inc. Mishakawa, IN Firestone Tire and Rubber Company Akron, OH	0.26 (1968)	0.13				
T17	100 x 60 ft 5680-921-8730 100 x 30 ft 5680-921-8731	Reeves Bros. Inc. New York, NY Uniroyal, Inc. Mishakawa, IN Firestone Tire and Rubber Company Akron, OH	0.50 (1967)	0.33		147	444	0.018
WX 18		Reeves Bros. Inc. New York, NY Uniroyal, Inc. Mishakawa, IN Firestone Tire and Rubber Company Akron, OH	1.08 (1968)	0.44				0.034
Celtex			0.052(1966) 0.079(1966) 0.175(1966)	0.081 0.12 0.27				

continued

Table C-4. Continued

Item	Federal Stock Number	Source	Cost ($\$/ft^2$)	Weight (lb/ft^2)	Panel Dimensions	Emplacement Rate (ft^2/man-hr)	Removal Rate (ft^2/man-hr)	Packaged Volume Per Unit Placing Area (ft^3/ft^2)
Griffolyn 55			0.045(1966)	0.03				
Griffolyn 105			0.125(1966)	0.07				
Herculite (2-ply)			0.06 (1966)	0.028				
Herculite (3-ply)			0.09 (1966)	0.042				
Herculite 20 (3-ply)			0.168(1966)	0.071				
Herculite 70 (3-ply)			0.195(1966)	0.098				0.0042
TAC1		Greengate Polymer Coatings Ltd. Lancashire, England	0.92 (1971)	0.12		1600		0.0096
TAC3		Greengate Polymer Coatings Ltd. Lancashire, England	1.29 (1971)	0.26		1600		0.0096
Phillips Polypropylene		Phillips Petroleum Co. Bartlesville, OK	0.05	0.035	300 ft x 15 ft			0.0059
Phillips Polypropylene (asphalt coated)		Phillips Petroleum Co. Bartlesville, OK	0.06	0.13	300 ft x 15 ft			0.0059
Dupont Polypropylene			0.024	0.028				
Aluminum Mats								
AM1		Butler Mfg Co. Kansas City, MO			12 ft x 2 ft x 2 in.	250		
AM2	5680-072-8680	Harvey Aluminum Co. Torrance, CA	6.50 (1974)	6.3	12 ft x 2 ft x 1.5 in.	350	250	0.18

continued

Table C-4. Continued

Item	Federal Stock Number	Source	Cost ($\$/ft^2$)	Weight (lb/ft^2)	Panel Dimensions	Emplacement Rate (ft^2/man-hr)	Removal Rate (ft^2/man-hr)	Packaged Volume Per Unit Placing Area (ft^3/ft^2)
AM3		Alcoa New Kensington, PA		7.87	8.11 ft x 3.27 ft x 5.5 in.	18.1 (water) 10.6 (marsh)	5.0 (water) 4.6 (marsh)	0.46
AM5				4.31	12 ft x 2 ft x 1.5 in.			0.16
AM6		Harvey Aluminum Co. Torrance, CA	4.50 (1971)	3.7	12 ft x 2 ft x 1 in.	350		
M9M1			1.32 (1971)	5.[illegible]	12 ft x 2 ft x 1.7 in.	200		0.21
M9M2			1.32 (1971)	7.6	12 ft x 2 ft x 1.9 in.	100		0.[illegible]1
XM18	5680-089-7260	Dow Chemical Co. Midland, MI	5.30	4.8	12 ft x 2 ft x 1.5 in.	684		0.16
XM18E1		Dow Chemical Co. Midland, MI	3.72 (1971)	4.8	12 ft x 2 ft x 1.5 in.	684		0.17
XM19	5680-089-5920	Kaiser Aluminum and Chemical Sales Co. Oakland, CA	5.00 (1970)	4.1	4.19 ft x 4.13 ft x 1.5 in.	573	250	0.15
XM19 All Bonded		Kaiser Aluminum and Chemical Sales Co. Oakland, CA		4.25	4.19 ft x 4.13 ft x 1.5 in.	269		0.15

continued

Table C-4. Continued

Item	Federal Stock Number	Source	Cost ($\$/ft^2$)	Weight (lb/ft^2)	Panel Dimensions	Emplacement Rate (ft^2/man-hr)	Removal Rate (ft^2/man-hr)	Packaged Volume Per Unit Placing Area (ft^3/ft^2)
XM20		Dow Chemical Co. Madison, IL	4.35 (1968)	6.08	12 ft x 2 ft x 1.5 in.	648		0.19
Goodyear All-Bonded		Goodyear Aerospace Corp. Akron, OH	4.00 (1971)	3.99	4.08 ft x 4.08 ft x 1.5 in.	446		0.19
Harvey 1 by 6 feet		Harvey Aluminum Co. Torrance, CA	4.00 (1971)	4.6	6 ft x 1 ft x 1.5 in.	197		0.12
Modified T11		Dow Chemical Co. Madison, IL	3.00 (1968)	4.5	12 ft x 2.16 ft x 1.6 in.	314		0.11
Alcoa T11		Alcoa New Kensington, PA		3.8	12 ft x 2 ft x 1.6 in.	253		0.19
Fenestra				5.0	8.5 ft x 1.78 ft x 1 in.	492		0.12
Aluminum Trackway			2.38 (1967)	4.10	255 ft x 11 ft	1720		0.15
Magnesium Mats								
T7		Dow Chemical Co. Madison, IL		3.93	12 ft x 1.65 ft x 1.63 in.	30		
T8		Dow Chemical Co. Madison, IL		4.27	12 ft x 2.29 ft x 1.63 in.	172		0.095

continued

Table C-4. Continued

Item	Federal Stock Number	Source	Cost ($/ft^2)	Weight (lb/ft^2)	Panel Dimensions	Emplacement Rate (ft^2/man-hr)	Removal Rate (ft^2/man-hr)	Packaged Volume Per Unit Placing Area (ft^3/ft^2)
Steel Mats								
M8		Military	0.56 (1971)	6.96 7.27	11.81 ft x 1.63 ft x 1.14 in.	361		0.085
M8A1	5680-782-5577	Kaiser Steel Fontana, CA	1.00 (1971)	7.5	11.81 ft x 1.63 ft x 1.13 in.	243	180	0.092
U. S. Steel 3.5A		U. S. Steel Pittsburgh, PA		3.6	4 ft x 4 ft x 1.5 in.	30		0.16
U. S. Steel 4.5A		U. S. Steel Pittsburgh, PA		4.9	4 ft x 4 ft x 1.6 in.	154		0.18
Republic Ground Mat		Republic Steel	0.50 (1971)	3.05	11.5 ft x 3.14 ft x 1 in.	237		0.020
Thin Steel Membranes		Inland Steel Co. Chicago, IL		0.45	29 ft x 2.67 ft x 0.011 in.			
Thin Steel Membranes		Inland Steel Co. Chicago, IL		0.62	29 ft x 2.67 ft x 0.015 in.			
Plastic Mats								
Mo-Mat		Air Logistics Corp. Pasadena, CA	3.89 (197[illegible])	1.0	48.5 ft x 12.17 ft x 0.63 in.	416		0.23

continued

Table C-4. Continued

Item	Federal Stock Number	Source	Cost ($\$/ft^2$)	Weight (lb/ft^2)	Panel Dimensions	Emplacement Rate (ft^2/man-hr)	Removal Rate (ft^2/man-hr)	Packaged Volume Per Unit Placing Area (ft^3/ft^2)
Modified T12		Strato-Tek Los Angeles, CA		4.44	12 ft x 2 ft x 1.2 in.	172		0.21
T13		Lunn Laminates Huntington Sta., NY		5.40	12 ft x 3 ft x 1.8 in.	161		0.17
T14		Pacific Plastic Co. Seattle, WA		6.29	11.87 ft x 1.85 ft x 1.75 in.	254		0.26

Appendix D

FORKLIFT OPERATIONS OVER LAYERED PLYWOOD SURFACING ON CLAYEY SAND

Introduction

To verify the validity of the concept for the use of two layers of plywood as an on-grade warehouse floor, a test section of plywood was constructed over a prepared subgrade of known strength. The subgrade strength was measured through laboratory soils testing to determine the soil CBR value. The subgrade was found to have an average CBR value of 13. The case of a Hyster model RT 150 forklift carrying a 10,000-pound payload was chosen for the traffic tests. (See Appendix C for forklift data.) Using the design information presented in Figure 2, two layers of 3/4-inch plywood were chosen for the surfacing.

The subgrade consisted of a clayey sand classified as an SC soil by the Unified Soil Classification System. The clayey sand offers fair value as a subgrade, although it rapidly looses strength when wetted.

Subgrade Preparation

The subgrade was prepared by initial grading with a motor grader followed by final hand grading. Density tests were conducted on the surface of the subgrade after grading. The average moisture content was found to be 6.5%, and the average dry density was 105.2 pcf. Three CBR tests were conducted in the laboratory on unsoaked samples of the subgrade soil. Each CBR was compacted to a different density although the moisture content was held constant at 7.4%. A plot of CBR values versus sample molding density is presented in Figure D-1, which indicates that a dry density of 105.2 lb/cu ft would correlate with a CBR value of 13; thus, the plywood thickness was chosen for a CBR value of 13.

General classification information for the subgrade soil is presented in Table D-1.

Table D-1. Subgrade Soil Properties

Sieve Size	% Passing	Grain Size	% Passing
3/8	100.0	0.05 mm	47.0
No. 4	100.0	0.03 mm	39.7
No. 10	97.8	0.02 mm	33.0
No. 20	93.3	0.01 mm	24.2
No. 40	83.1	0.005 mm	19.3
No. 60	69.5	0.002 mm	8.4
No. 80	62.3		
No. 200	49.5		

Specific gravity	2.59
Liquid limit	25
Plasticity index	8
Unified classification . .	SC (clayey sand)

Plywood Surfacing Placement

The plywood surfacing was constructed by first laying plywood sheets on the subgrade and, subsequently, bonding a second plywood layer to the first. The plywood sheets for the upper layer were oriented at 90 degrees with respect to the bottom sheets, and all joints were staggered (Figure D-2).

In Area 1 the plywood sheets were fastened together with no. 14 x 1-1/2-inch Hex Head/Washer Head fasteners spaced at 12 inches on center. In Areas 2 and 3 the plywood sheets were both glued and fastened together. In Area 2 a two-component resorcinol glue was used, and in Area 3 a plywood subflooring and underlayment glue meeting American Plywood Association (APA) performance specification AFG-01 were used.

The components of the resorcinol glue were mixed in a bucket and spread with a squeegee over the bottom surface of the top plywood sheets. The top sheets were then positioned and fastened with the screw fasteners. The underlayment glue, which is packaged in 28-ounce tubes, was applied in a bead using a caulking gun. The underlayment glue was also applied to the bottom surface of the top plywood sheets. Beads were run along the perimeter of each panel and longitudinally along the panel at 12-inch centers.

Test Method

After construction of the plywood surfacing, the two traffic lanes (Figure D-3) were marked on the surface with tape. Two passes over the traffic lane were necessary to provide coverage of the total traffic lane. A mechanical traffic counter recorded the number of passes of the test forklift.

A grid pattern was established (Figure D-3) on the plywood surface, and elevations were recorded before the traffic tests were begun and at intervals during the test.

Test Results

Forklift traffic was suspended after 1,900 passes (800 coverages) over the traffic lane. No failure of the plywood panels was noted. Twenty-eight screws were added to the panel edges at transverse joints within the traffic lane. For future applications, it is recommended that transverse panel joints within traffic lanes be fastened with screws near the panel edges at spacings not greater than 12 inches on center.

The Hyster RT 150 produced an initial static deflection of 0.22 inch under the front wheels and a static deflection of 0.43 inch (Figure D-4) after 1,900 passes. Transverse profiles were plotted (Figure D-5) to illustrate the permanent deformation induced into the soil/plywood system. Rutting was minimal or nonexistent, and average permanent deflection of the plywood was approximately 0.50 inch. After the final pass the plywood surface appeared nearly level with no visible defects (Figure D-4).

Figure D-6 shows the permanent plywood deflection as a function of the number of forklift passes. It is estimated that 20,000 passes would be necessary to produce a permanent deflection of 0.75 inch. The eventual failure mode would probably be fatigue failure of the plywood rather than excessive deflection or rutting.

Although there was no measurable difference in the performance of the different test sections, it is recommended that a subflooring and underlayment glue meeting APA specification AFG-01 be used. The glue should be applied by a caulking gun to the underside of the second layer of plywood along the intended screw line pattern and along the panel perimeter. AFG-01 adhesives may be used under a variety of moisture and temperature conditions, have a gap-filling capability, and add only slight construction labor. The AFG-01 adhesives require approximately 30 days for full curing and would eventually impart shear strength between plywood layers and compensate for any loss of fasteners over the plywood pavement life. However, since the fasteners initially provide sufficient shear, the plywood can be trafficked immediately after construction.

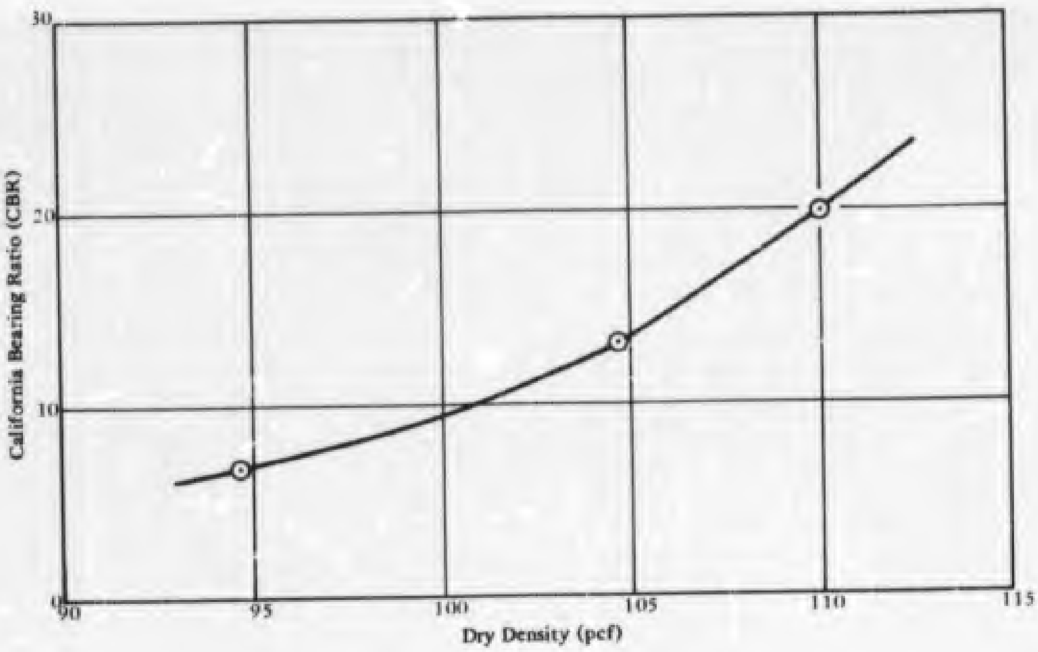


Figure D-1. CBR and dry density relationships for NAVSCON soil.

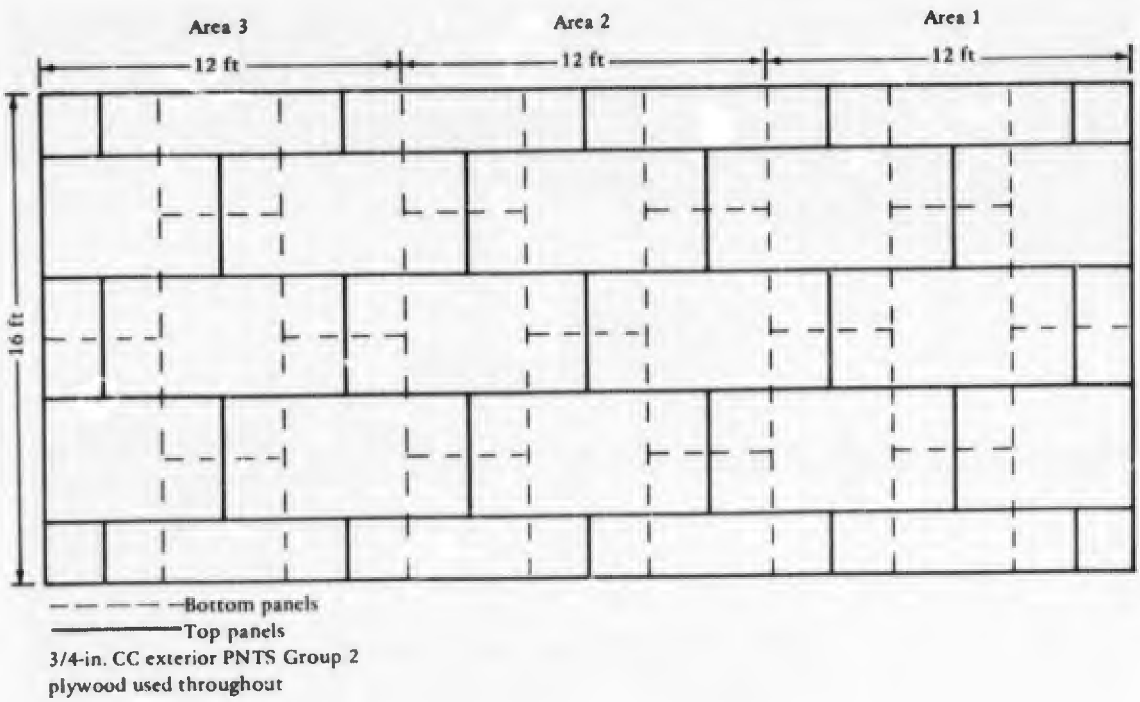


Figure D-2. Plywood panel placement.

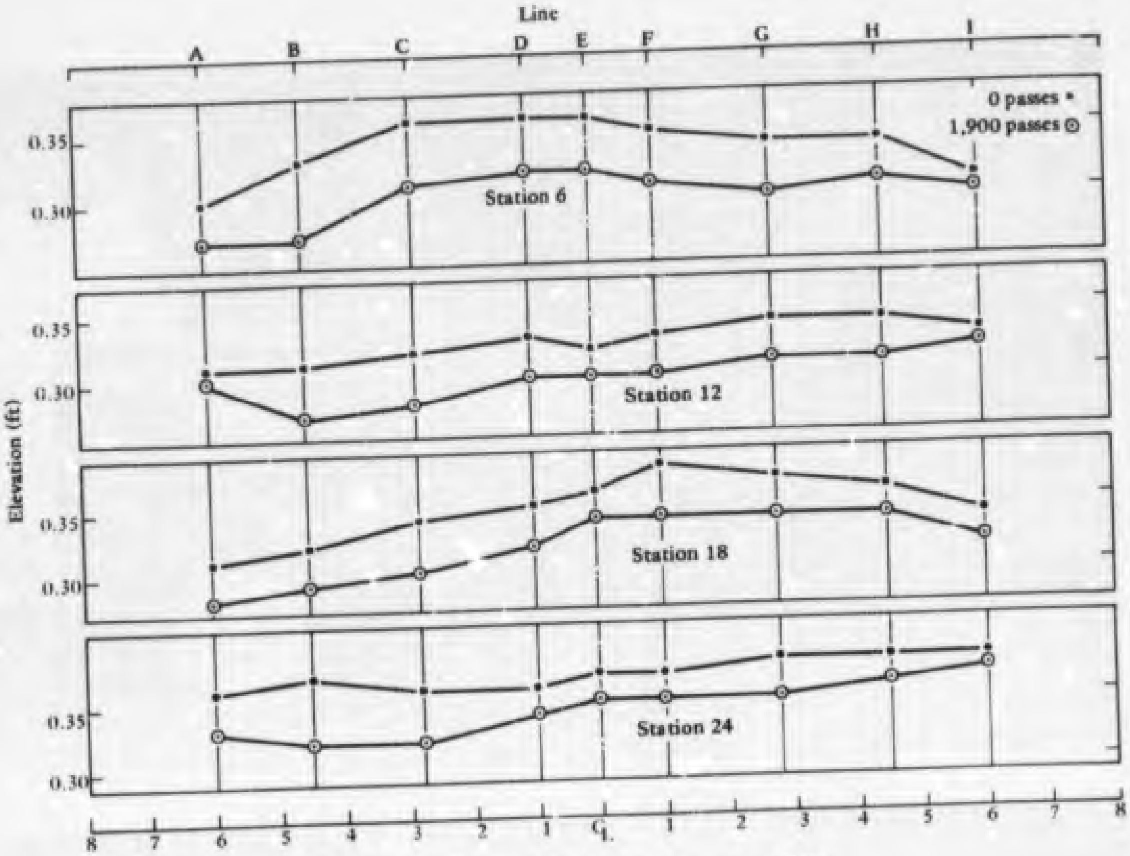


Figure D-5. Plywood surface transverse profiles.

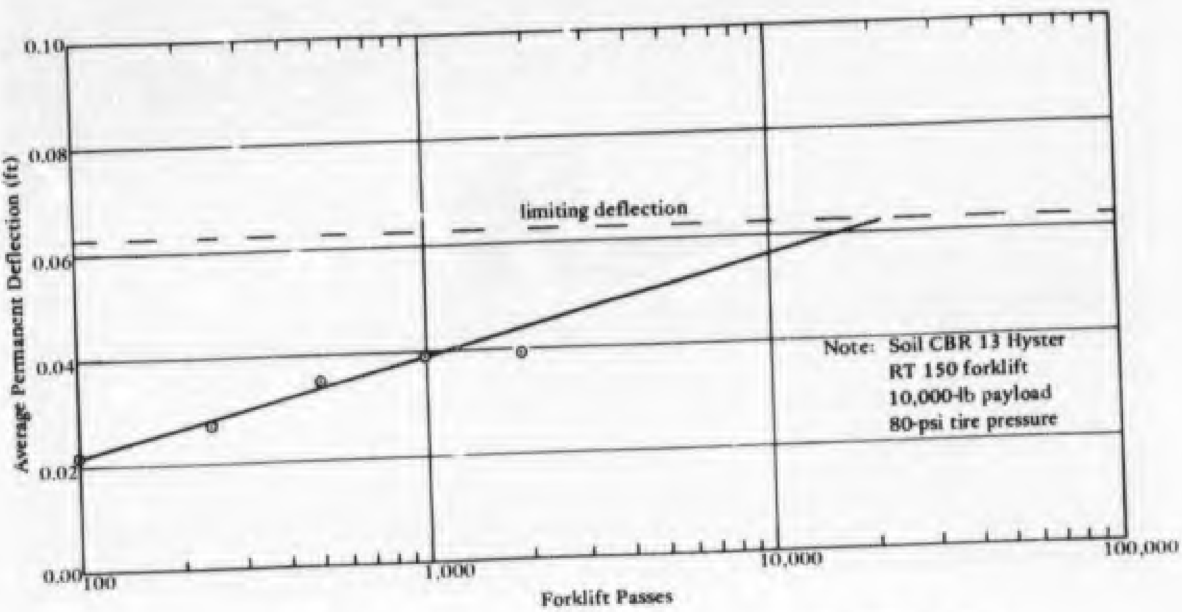
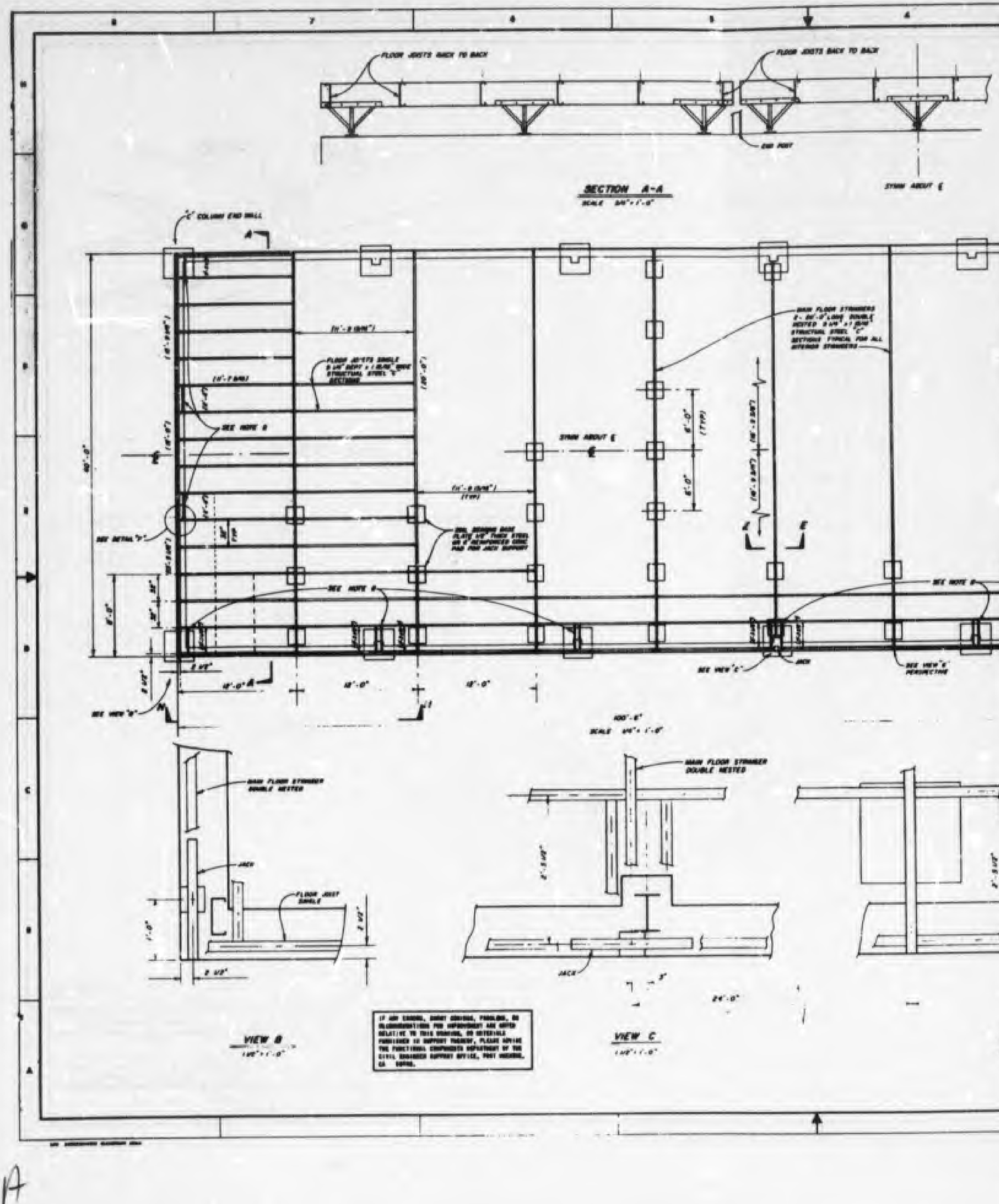


Figure D-6. Forklift passes required to produce permanent surfacing deflection.

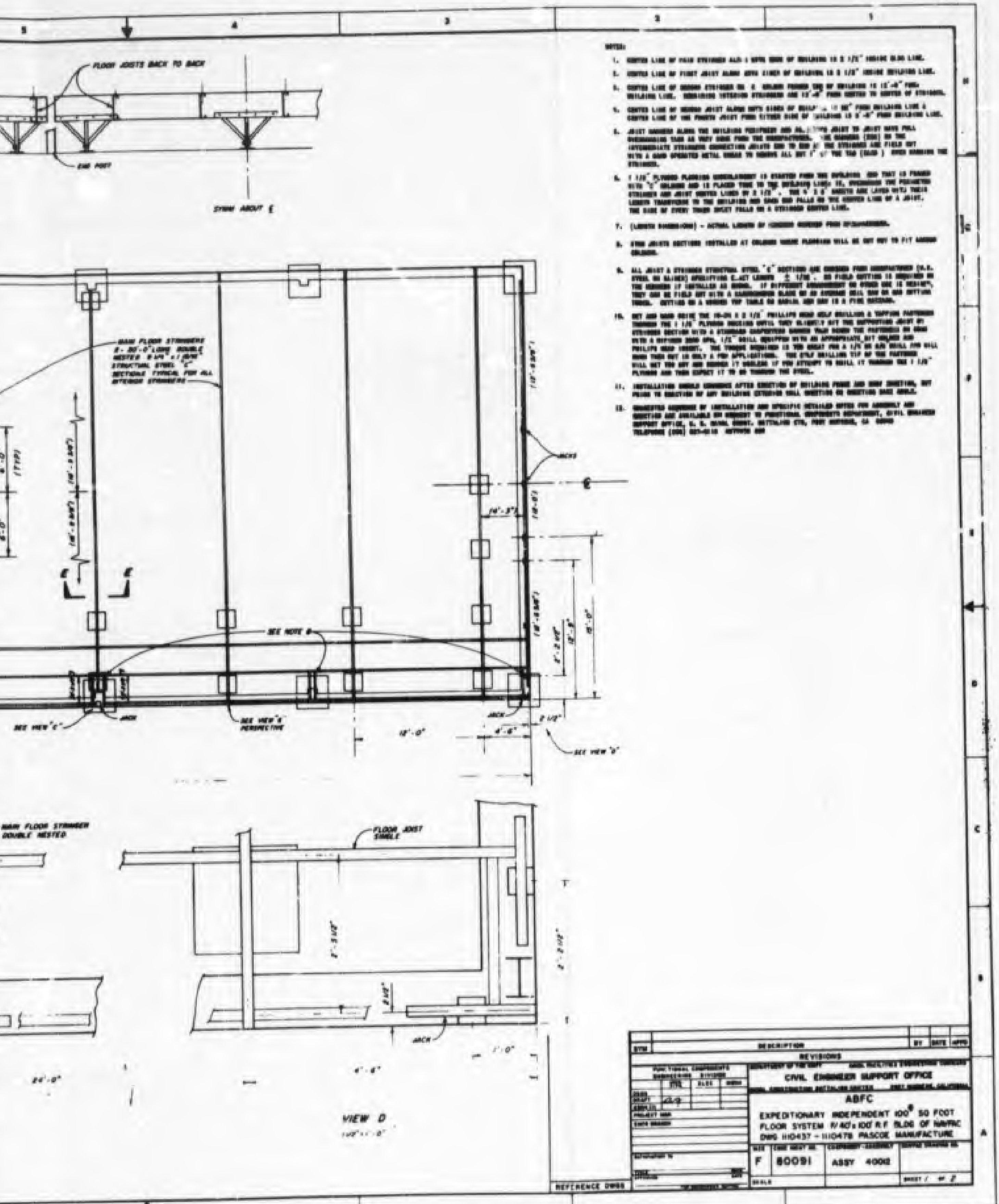
Appendix E

CESO FLOOR SYSTEM DESIGN DRAWINGS



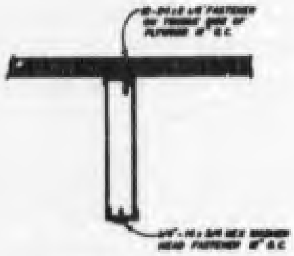
FLOOR JOISTS BACK TO BACK
FLOOR JOISTS BACK TO BACK
END POST
SECTION A-A
SYMM ABOUT ℄
"C" COLUMN END WALL
SYMM ABOUT ℄
SEE DETAIL "F"
SEE NOTE 8
SEE VIEW "B"
SEE VIEW "C"
JACK
12'-0"
12'-0"
12'-0"
100'-0"
MAIN FLOOR STRINGER DOUBLE NESTED
JACK
FLOOR JOIST SINGLE
2 1/2"
1'-0"
JACK
24'-0"
VIEW B
VIEW C

A

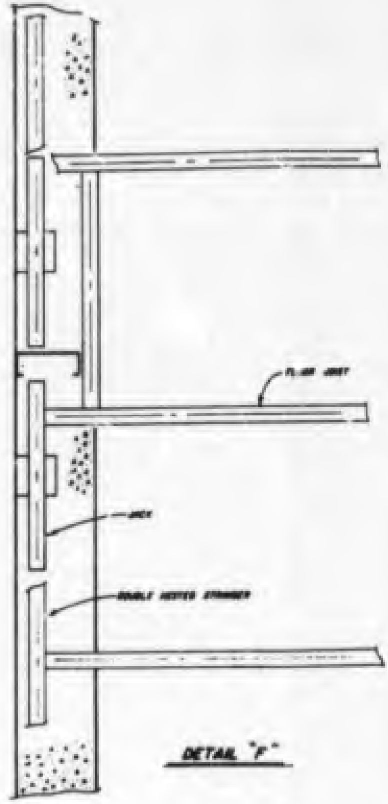


Preceding page blank

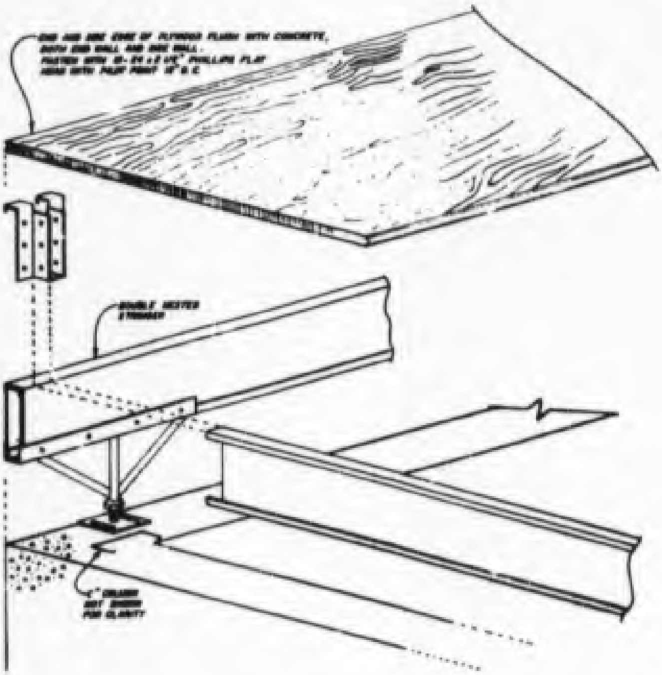
B



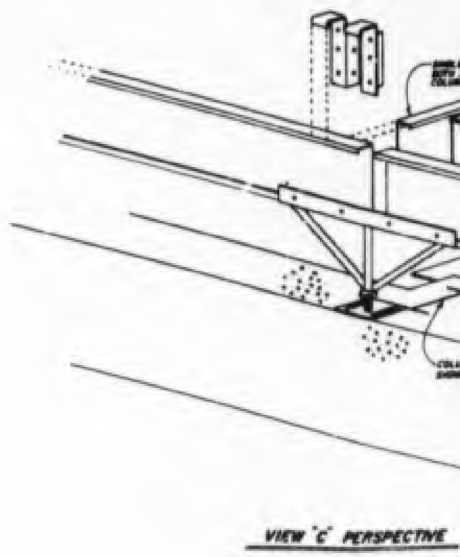
SECTION E-E



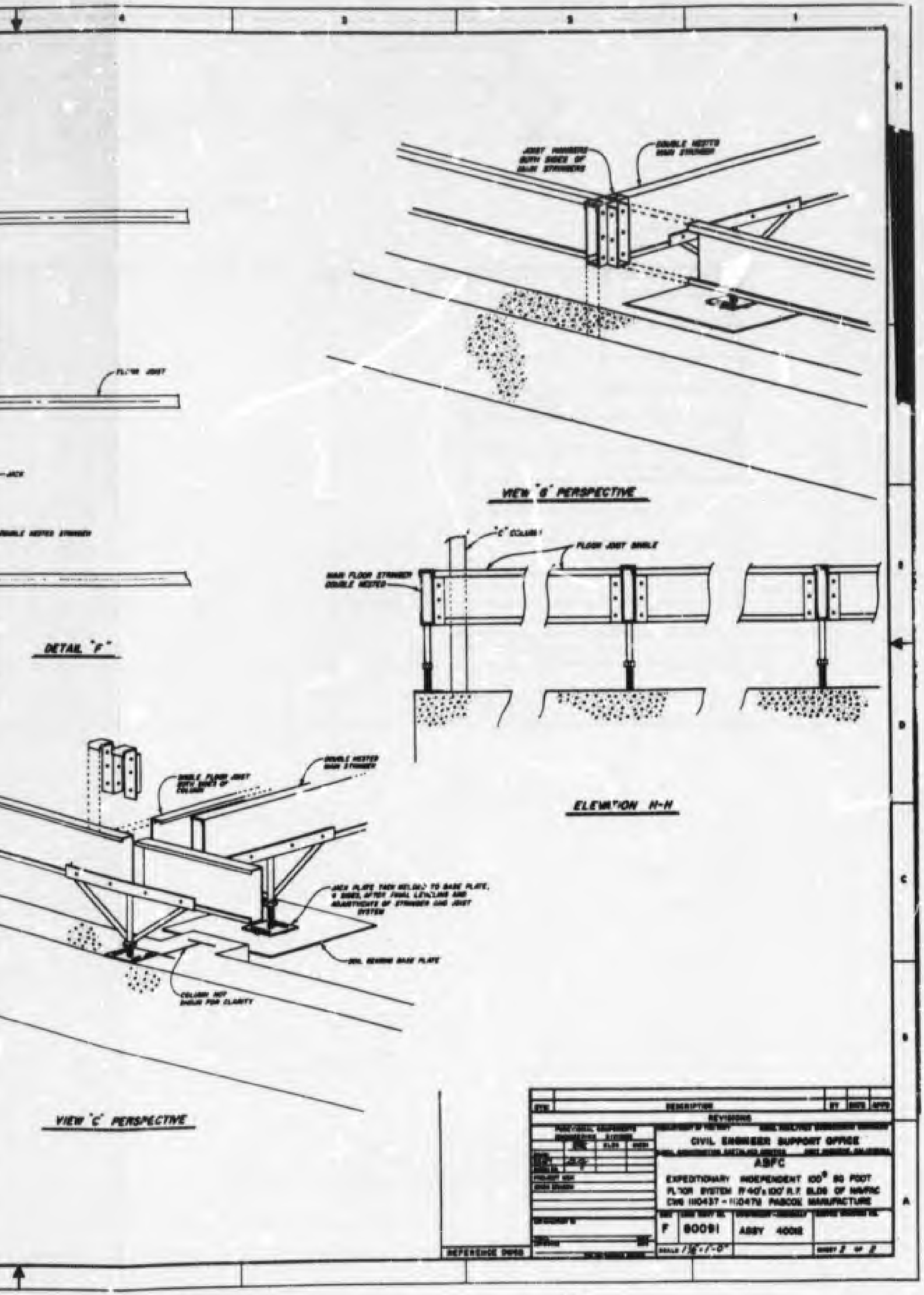
DETAIL "F"



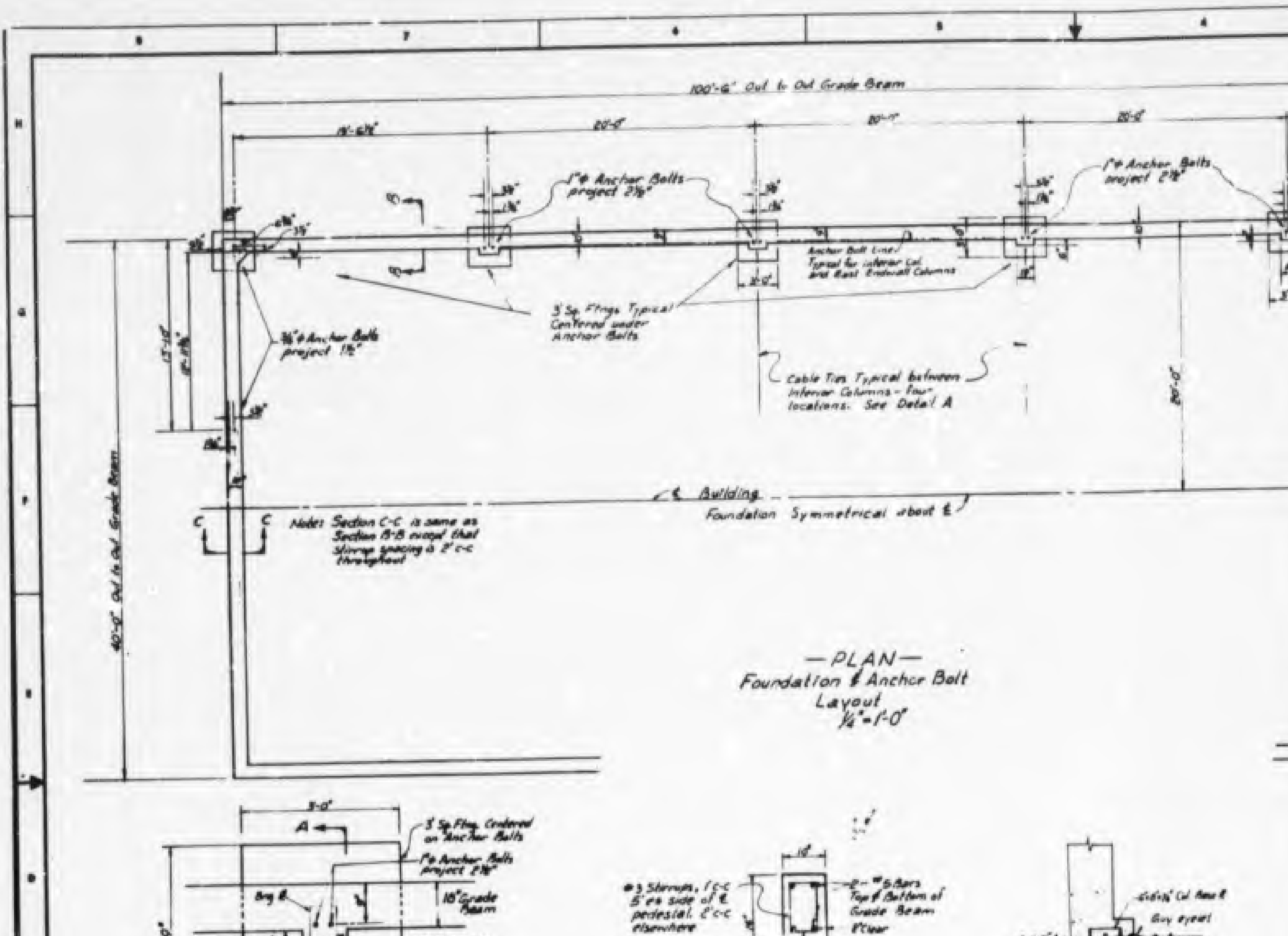
VIEW "B" PERSPECTIVE



VIEW "C" PERSPECTIVE

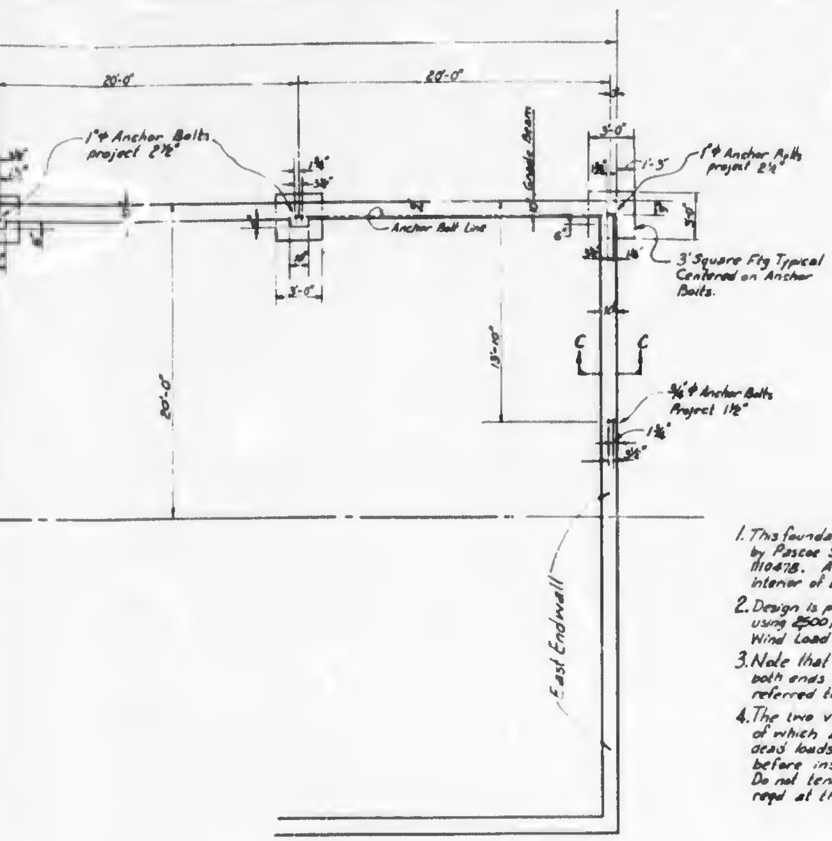

VIEW "G" PERSPECTIVE
ELEVATION H-H
DETAIL "F"
VIEW "C" PERSPECTIVE
DOUBLE NESTED MAIN STRINGER
"C" COLUMN
FLOOR JOIST
SOIL BEARING BASE PLATE
REVISIONS
DESCRIPTION
CIVIL ENGINEER SUPPORT OFFICE
ABFC
EXPEDITIONARY INDEPENDENT 100 80 FOOT
FLOOR SYSTEM F/40'x100' R.F. BLDG OF NAVFAC
DWG 110437 - 110478 PASCOE MANUFACTURE
F 80091 ABSY 40018
REFERENCE DWGS

B



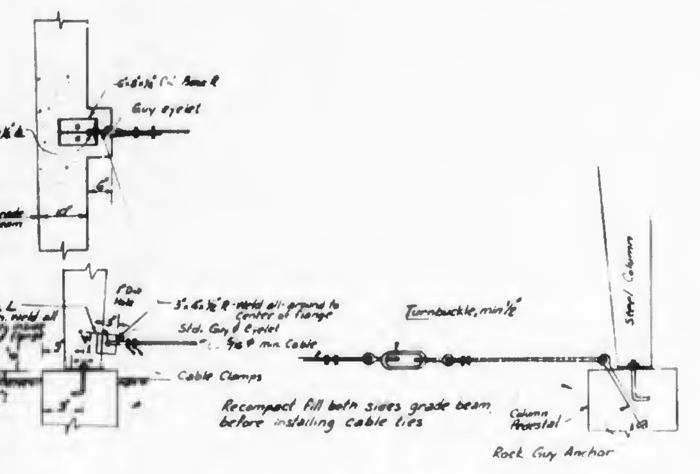
100'-6" Out to Out Grade Beam
20'-0"
1" ⌀ Anchor Bolts project 2⅞"
3' Sq. Ftngs. Typical Centered under Anchor Bolts
Anchor Bolt Line - Typical for interior Col. and East Endwall Columns
¾" ⌀ Anchor Bolts project 1½"
Cable Ties Typical between Interior Columns - four locations. See Detail A
℄ Building
Foundation Symmetrical about ℄
40'-0" Out to Out Grade Beam
Note: Section C-C is same as Section B-B except that stirrup spacing is 2" c-c throughout
— PLAN —
Foundation & Anchor Bolt Layout
¼" = 1'-0"
3' Sq. Ftg. Centered on Anchor Bolts
1" ⌀ Anchor Bolts project 2⅞"
18" Grade Beam
6x15 Base Pl.
Section A-A
Typical Interior Ftg and Col Pedestal
1" = 1'-0"
Bond 6-#4 Bars into Grade Beam, 6" c-c
6-#5 Bars Both Ways
#3 Stirrups, 1" c-c 5' ea side of ℄ pedestal, 2" c-c elsewhere
2-#5 Bars Top & Bottom of Grade Beam
Section B-B
1" = 1'-0"
Guy eyelet
Cable Clamps
COLUMN

A



— NOTES —

1. This foundation is designed to support the 40'×100' R.F. Buildi , mfg by Pascoe Steel Co. and shown on NAVFAC drawings 1104;) thru 110478. A raised floor s.stem using steel joists will be used on interior of bldg.
2. Design is premised on loadings shown on NAVFAC dwg. 11?438 using 2500 psi conc.ete. Soil bearing capacity = 1500 psf. Wind Load = 70 MPH.
3. Note that endwalls and endwall anchorage are not the sam e for both ends of building. For convenience, one end of building is referred to as "East Endwall."
4. The two views shown for column cable ties are alternates, both of which are designed to resist thrust due to wind, snow and dead loads. In both instances, tension cables to approx 200# before installation of roof or sidewall sheeting on building. Do not tension cables more than 300#. Cable ties are reqd at the 4 pairs of interior columns, only.



COLUMN CABLE TIES
Not to Scale

REV	DESCRIPTION	BY	APPD
REVISIONS			

CIVIL ENGINEER SUPPORT OFFICE

FOUNDATION PLAN
40'×100' R.F. BUILDING
W/RAISED FLOOR

F	80091	12012	6027807

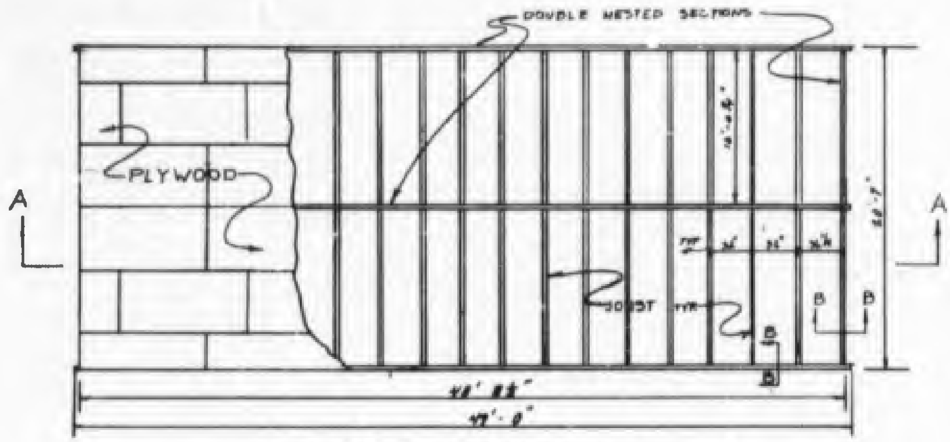
SHEET 1 OF 1

REFERENCE DWGS

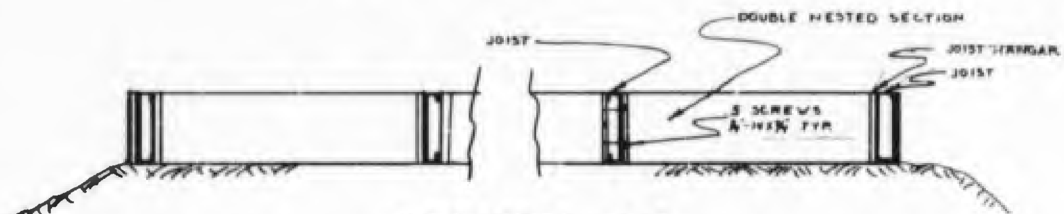
Appendix F

RELOCATABLE FLOOR SYSTEMS

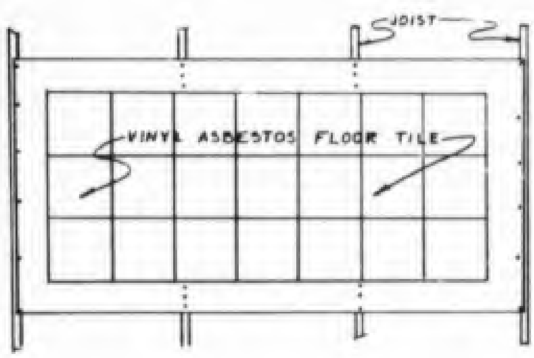
Preceding page blank



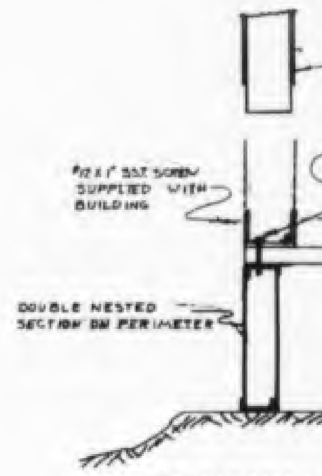
FLOOR PLAN



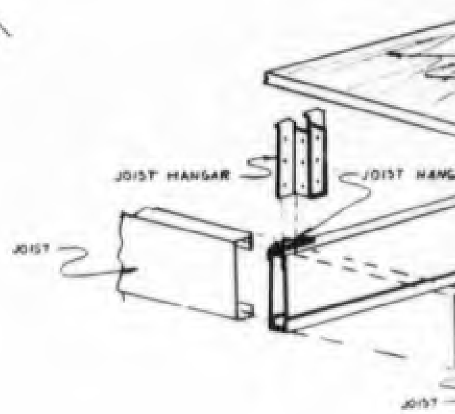
SECTION A-A



DETAIL A

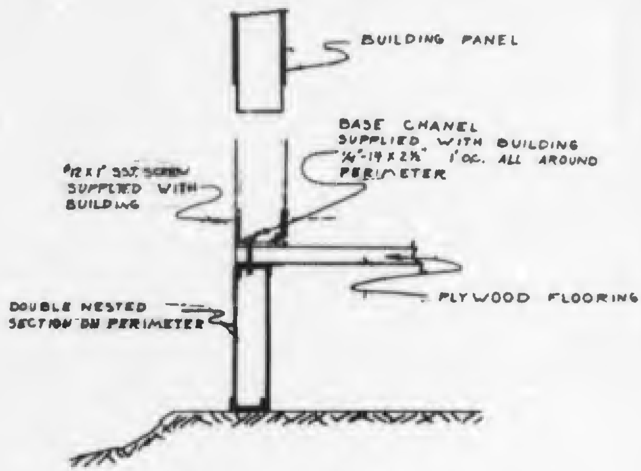


SECTION



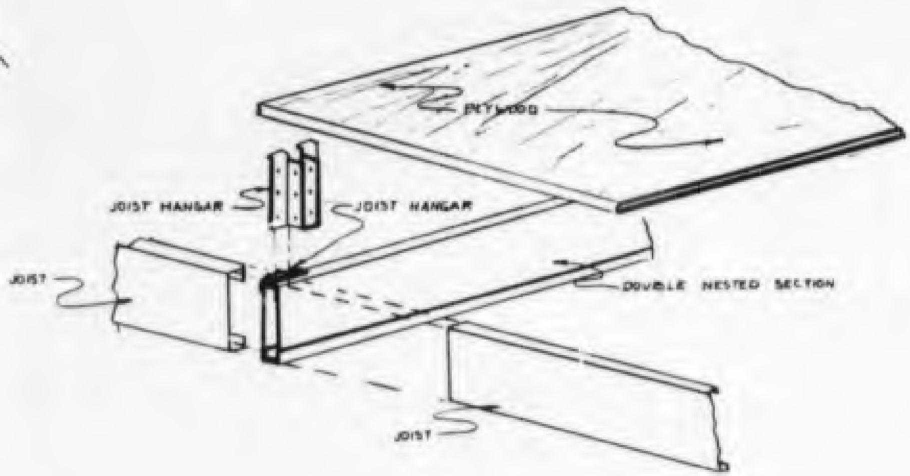
DETAIL B

NOT TO SCA



SECTION B-B TYPICAL DETAIL

1. Building reaction approximately 300 lb/ft vertical and 80 lb/ft horizontal. Soil bearing capacity 2000 lb/sq ft.
2. All joists to be USS Super C joist 8-1/4 - 14 ga (SC 10 - 14). Joist hanger to be SC 10 #5 steel to steel.
3. Use double nested sections on all perimeter sides and center longitudinal mate stringer.
4. Use 1/4" - 14x3/4 hex washer head zinc or cadmium plated for fastening joists to hanger.
5. Use 1-1/8 - 061 CD underlayment grade plywood laid so building exterior lines (20' - 7" x 48' - 8-1/2"). Use 10-24-2-1/2 Phillips flat head with pilot self drilling screw zinc or cadmium plated for fastening to joist.
6. Install tile as per pattern Detail A. This will allow screws to be removed for relocation without removal of all tile. Floor tile to be 12x12 inch squares 1/8 inch thick vinyl asbestos.
7. Stagger splice in double nested longitudinal mate stringers using short section for left half and longer section for right half. Use 1/4 - 14 x 3/4 screw at 24 inches on center on bottom side to join together.

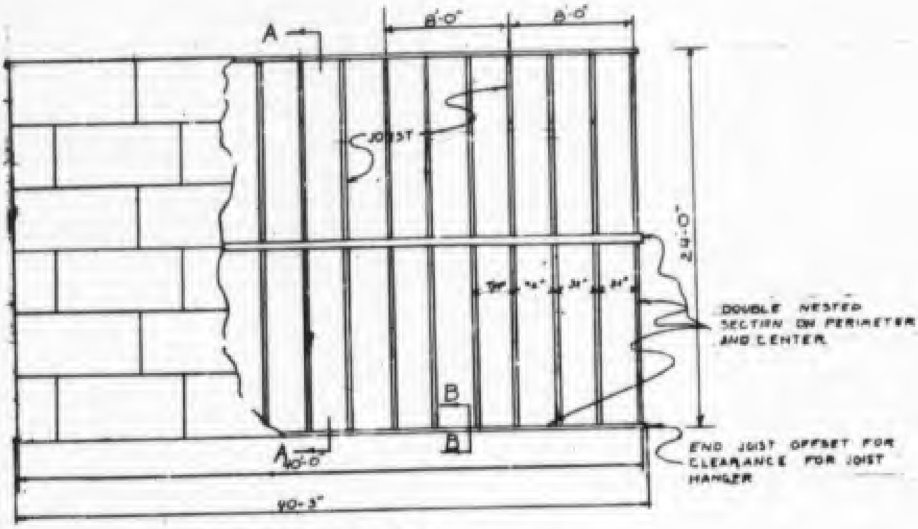


DETAIL B
NOT TO SCALE

MODULAR RELOCATABLE FLOOR
20' X 48'
LEWIS BUILDING

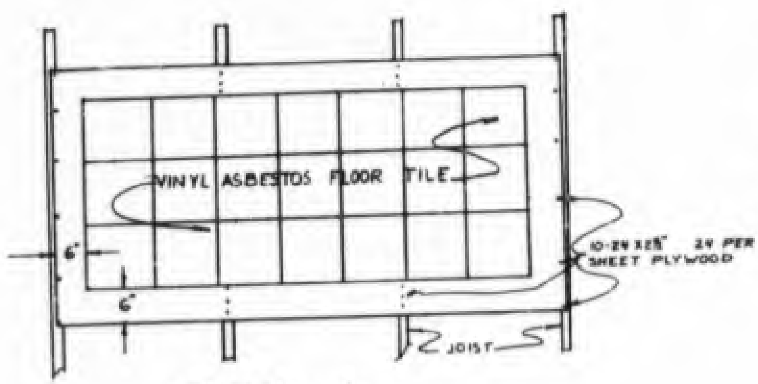
Preceding page blank

B

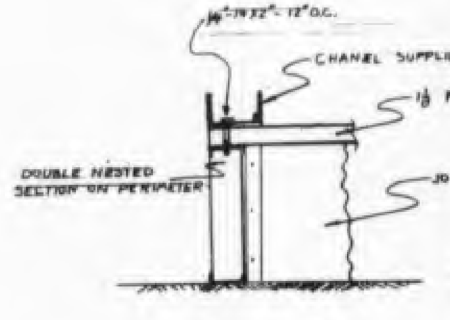


FLOOR PLAN SCALE [illegible]

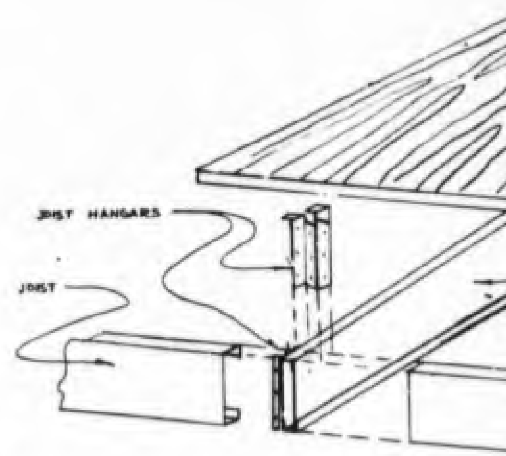
SECTION A-A SCALE [illegible]



DETAIL A

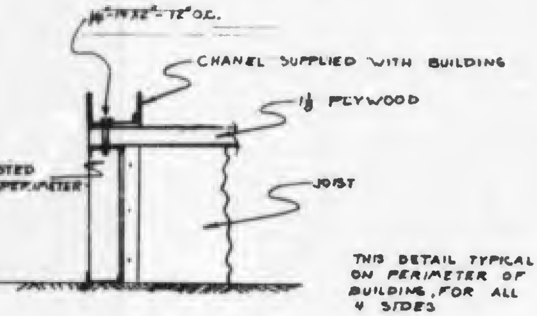


SECTION B-B
TYPICAL



DETAIL

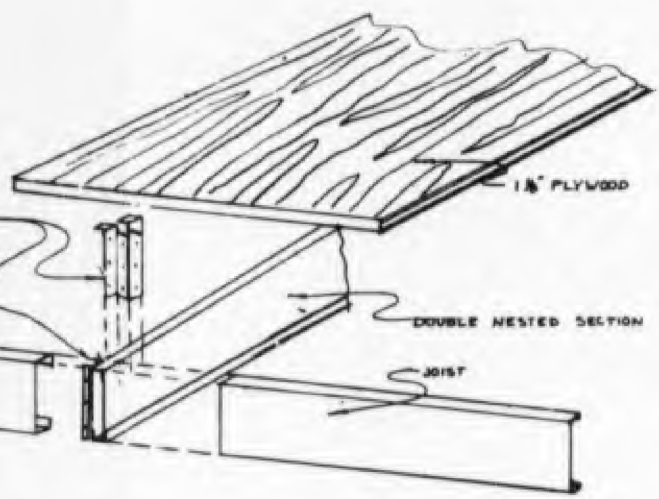
A



SECTION B-B
TYPICAL

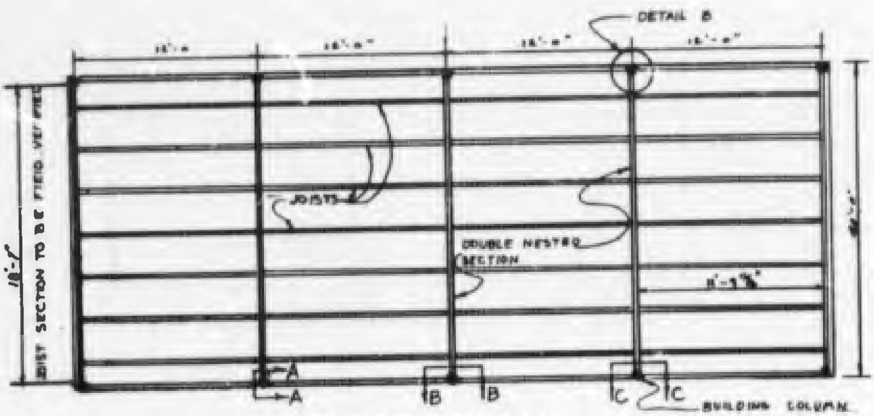
SCALE 1/4" = 1"

1. Typical building reactions dead load 0.2 Kip horizontal, 13 Kip vertical; Snow load 30 psf 1.0 Kip horizontal, 3.0 Kip vertical; Wind load 15 psf average 40 psf gust 1.3 k horizontal 3.0 k vertical
2. Soil bearing allowable 2000 lb/sq ft.
3. All joists to be U.S.S. Super C Joist 8-1/4 - 14 ga (SC 10 -- 14). Joist hanger to be SC 10 HS steel to steel hanger. Use 1/4" - 14 x 3/4 hex washer head zinc or cadmium plated for fastening joists to hanger. Use 1/4 - 14 x 2 hex washer head zinc or cadmium plated for fastening building channel to joists.
4. 1-1/8 - 2-4-1 CD underlayment grade plywood laid to building exterior line. The 4x8' sheets are laid with their length transverse to the building and each end falls on the center line of a joist. Every third sheet falls on a stringer center line. Use 10-24- 2-1/2 Phillips flat head with pilot, self drilling screw zinc or cadmium plated for fastening plywood to joist.
5. Install tile as per pattern Detail A. This will allow screws to be removed for relocation without removal of all tile. Floor tile to be 12 x 12 squares 1/8 inch vinyl asbestos.
6. Stagger splice in transverse double nested stringers using short section for left half and longer section for right half. Use 1/4-14 x 3/4 screw at 24 inches on center on bottom side to join together.
7. Continue sections for 24 x 60 building using same spacing as 24 x 40 plan.
8. Use channel supplied with building for framing wall panels on perimeter for all 4 sides.

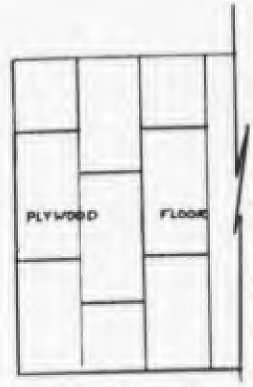


DETAIL B

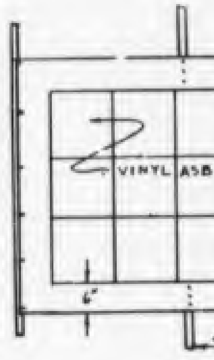
RELOCATABLE FLOOR SYSTEM
24' x 40'   24' x 60'



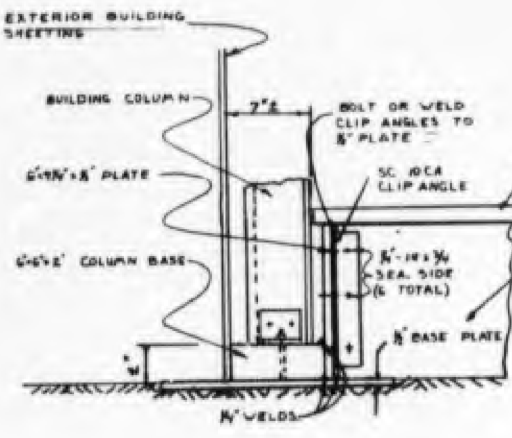
FLOOR PLAN SCALE



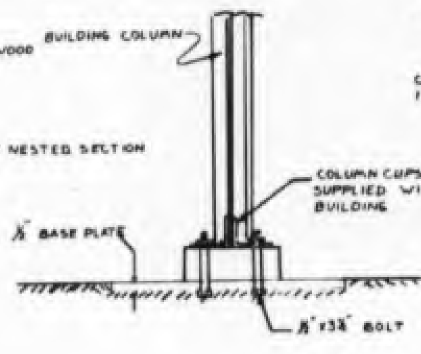
DETAIL A
PLYWOOD FLOOR DETAIL



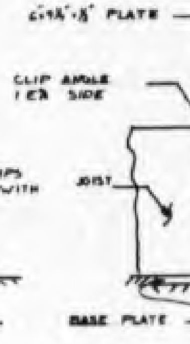
DET



SECTION A-A



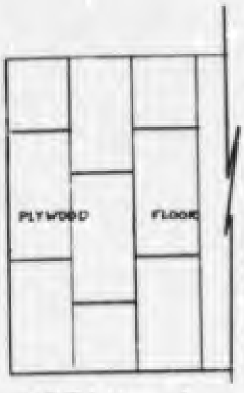
SECTION B-B



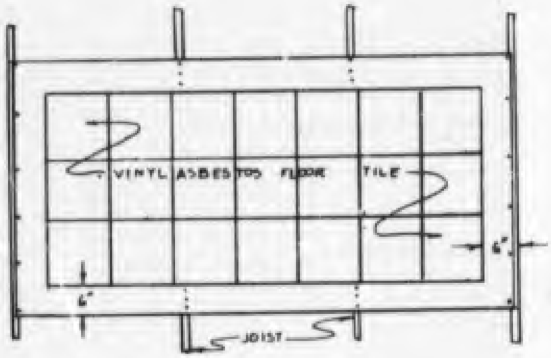
S

A

1. Building reaction D. L. 5.00 Kip vertical 2.4 Kip horizontal, wind load 2.35 horizontal 1.0 Kip uplift.
2. Soil bearing allowable 2000 lb/sq ft.
3. All joists to be USS Super C joist 9-1/4 - 14 ga (SC 10 - 14). Joist hanger to be SC 10 HS steel to steel hanger. Use 1/4" - 14 x 3/4 hex washer head zinc or cadmium plated for fastening joists to hanger.
4. 1-1/8 - 2-4-1 CD underlayment grade plywood laid to building exterior line (20x48-6). Plywood overhangs edge joists. The 4x8' sheets are laid with their length transverse to the building and each end falls on the center line of a joist. Every third sheet falls on a stringer center line. Use 10-24- 2-1/2 Phillips flat head with pilot, self drilling screw zinc or cadmium plated for fastening plywood to joist.
5. Install tile as per pattern Detail C. This will allow screws to be removed for relocation without removal of all tile. Floor tile to be 12 x 12 squares 1/8 inch vinyl asbestos.
6. Clip angles to be U.S.S. SC 10 GA.
7. Use clip angles and bolts supplied with building for attaching clips to columns.

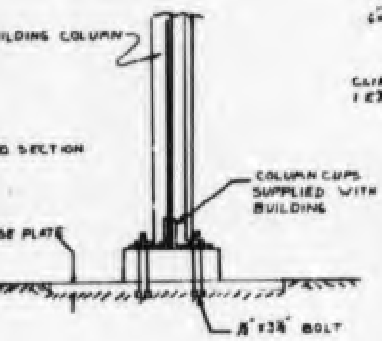


DETAIL A
PLYWOOD FLOOR DETAIL

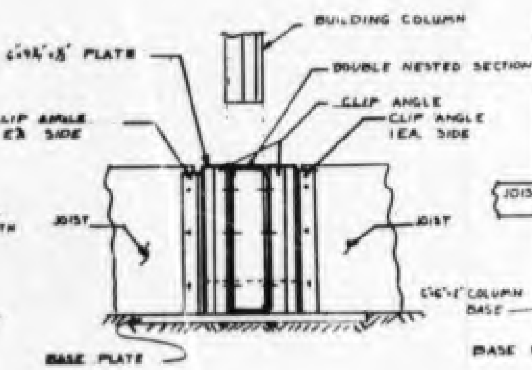


DETAIL C

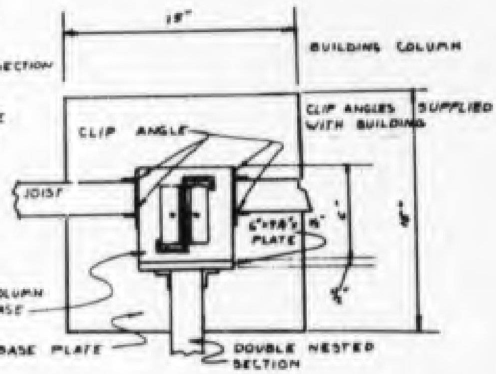
NOTE:
USE 10-24-2½"
29 SCREWS PER SHEET
AS SHOWN



SECTION B-B

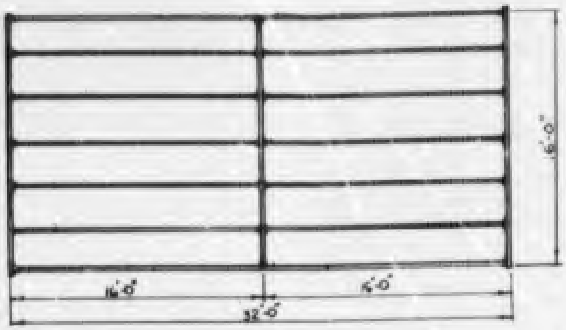


SECTION C-C

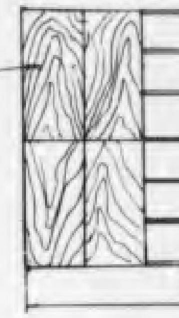


DETAIL B

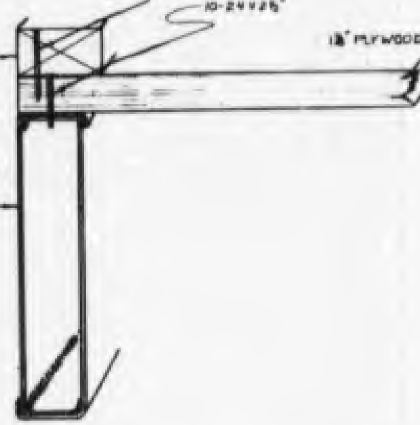
RELOCATABLE FLOOR SYSTEM
20'×48'
RIGID FRAME BUILDING



FLOOR PLAN 32'

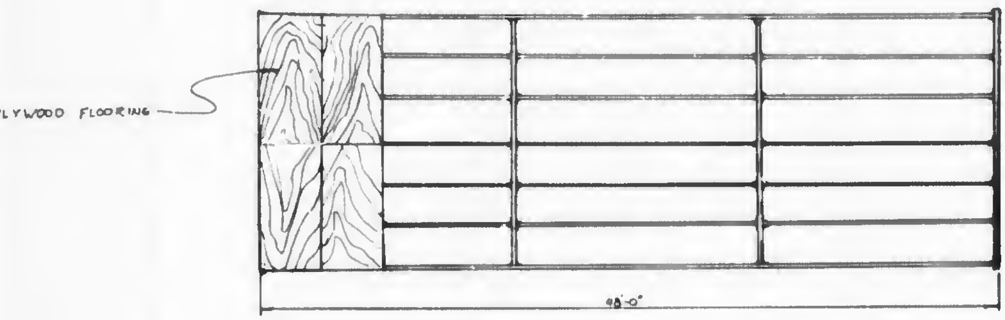


FLOO

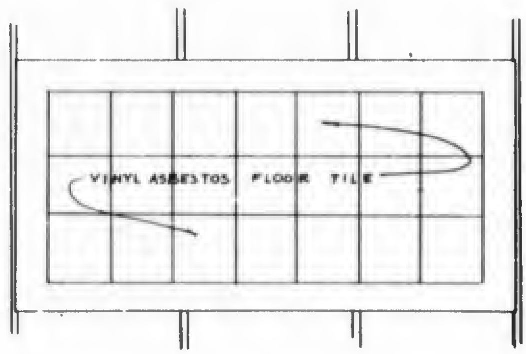


TYPICAL SECTION

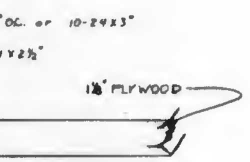
A



FLOOR PLAN 48'



TYPICAL DETAIL



SECTION

RELOCATABLE FLOOR SYSTEM
16' x 32' 16' x 48'
RIGID FRAME BUILDING

DISTRIBUTION LIST

SNDL Code	No. of Activities	Total Copies	
–	1	12	Defense Documentation Center
FKA1C	1	10	Naval Facilities Engineering Command
FKN1	6	6	NAVFAC Engineering Field Divisions
FKN5	9	9	Public Works Centers
FA25	1	1	Public Works Center
–	6	6	RDT&E Liaison Officers at NAVFAC Engineering Field Divisions
–	141	143	CEL Special Distribution List for persons and activities interested in reports on Floor Systems