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Technical Memorandum M-080

DESIGN, DEVELOPMENT AND EVALUATION OF A 20-FT BY 48-FT STRAIGHT-SIDED, GABLED-ROOF, PREFABRICATED STEEL BUILDING

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port hueneme,
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W. R. Mason and J. E. Schroeder

SUMMARY

The 20-ft by 48-ft straight-sided, gabled-roof, prefabricated steel building was developed jointly by the U.S. Naval Civil Engineering Research and Evaluation Laboratory and an engineering firm under contract, to fulfill the need for a standard building. Evaluation of the design included a study of packaging and crating; erection; weathertightness; and structural adequacy for specified snow, wind, and floor loadings.

It was found that the building was satisfactory with the exception of the structural inadequacy of the floor sills. A redesign was initiated to correct this deficiency and to have the building comply with the criteria established by the Defense Supply Management Agency for a standard building for all services. An eight-foot section of the new floor design was fabricated and tested and found to be structurally adequate. The redesigned building proved to be low in shipping cube (202.0 cu ft), low in steel weight (6200 lb) and able to be easily and rapidly erected.

CONTENTS

TABLES

ILLUSTRATIONS

INTRODUCTION

To facilitate construction of naval shore establishments, a need exists for a standardized, prefabricated, 20-ft by 48-ft, northern-type building that is easily manufactured, economical in the use of materials, structurally adequate, lightweight, low in shipping cube, rapidly erected by unskilled labor, and suitable for re-erections. Original efforts in the search for such a building consisted of the evaluation at the U.S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California, of nine commercial design buildings.[1] Of the designs tested during the past two and one half years, none fully satisfied the military criteria. Therefore, the Bureau of Yards and Docks authorized the Laboratory to develop a straight side-wall design. The experience gained during the testing program at the Laboratory proved to be of invaluable aid in developing a satisfactory building.

This technical memorandum covers the design, development, and evaluation of a straight-sided, gabled-roof, prefabricated, metal, northern-type building (see Figure 1). Prior to the completion of the evaluation studies and further development, a new set of criteria based upon the needs of all the services was issued by the Defense Supply Management Agency. The design was modified to comply with these new criteria and the evaluation studies were completed.

DESIGN CRITERIA

The basic criteria covering the materials and design of the building are contained in the "Outline Specifications for 20-ft by 48-ft Prefabricated Building-Northern"[2] and the "General Criteria and Requirements for 20-ft x 48-ft Prefabricated Building-Northern" of 11 February 1952.[3] These basic criteria were revised to include a minimum interior eave height of 6-ft 6-in., a minimum interior volume of 8250 cu ft, and the requirement that the building have straight side walls. Further, the component parts of the steel building should be as interchangeable as possible with similar parts of a companion design of the building in wood.

In addition to the conditions and limitations of the above documents and amendments, other factors which had considerable weight in the final determination were:

a. The work done by private concerns in connection with the development of similar buildings.

b. The experience of the Laboratory based on two and one half years of testing prefabricated buildings.

c. The work done by the Engineer Research and Development Laboratory, Fort Belvoir, Virginia.

d. The experiences and recommendations of the Bureau of Yards and Docks Supply Office, Port Hueneme, California, in the procurement of prefabricated buildings.

e. The experiences and recommendations of the Naval Advanced Base Supply Depot, Port Hueneme, California, in receiving, handling, shipping, and storing this type of building.

f. The experience of the Contractor and other representatives of industry in designing prefabricated structures.

g. The need for simplicity in component parts and for conformity to standard shop practices for ease and speed of manufacture.

The experiences and recommendations of the above agencies along with representative viewpoints were used in developing a philosophy of design that took into consideration the various problems of the men in the field, of shipping and storage units, and of the procurement agencies and industry. The paramount rule in reaching all decisions when one or more solutions would satisfy the basic criteria, was to adopt the solution which would result in "low cost, low cube, low weight," in the order named.

DESIGN

The experience of the U.S. Naval Civil Engineering Research and Evaluation Laboratory, coupled with two years of research and design of Modular Structures Inc. and Wilson and Wilson, Consulting Engineers, and a review of the work done by the Engineering Research and Development Laboratory, Fort Belvoir, Virginia, has led to the design presented herewith. Structural computations for this design are contained in the contractor's report.

The primary factors considered in arriving at this design in addition to the basic criteria were the following:

a. There should be as few parts as possible.

b. The same general type of section should be used throughout if practical.

c. Means of fastening should be commonly available devices as far as possible.

d. Not over two gages of metal should be used in the frame to simplify fabrication.

Before presenting the detailed considerations of the various elements, the reasoning for the finally adopted dimensions of the building proper is set forth.

Over-all Dimensions

The basic module of 4 ft heretofore used in planning these prefabricated buildings has been based upon the nominal width of the 4-ft by 8-ft sheets of plywood and wallboard. It has been found in the field that unless these sheets are trimmed slightly there is a decided tendency for them to creep so that the over-all dimension of a number of nominal 4-ft wide sheets laid edge to edge would be something more than the theoretical dimension. Therefore, it was decided to allow for this creep in this design in order to eliminate the necessity for retrimming the standard product of the manufacturer of these materials.

If an allowance for width of the liner was made in each 4-ft module, it was found that the opening between adjacent 8-ft floor panels was too great. Upon inquiry it developed that the manufacturers of suitable board liners would furnish the material slightly under the nominal 4-ft width at no additional cost. This simplified the "creep" problem, leaving only the plywood floor to be considered. By allowing 1/16-in. over the nominal 8-ft panel length it was considered that the effects of creep would be eliminated. The plans, therefore, show the liner width under the usual 4-ft width and make allowance for the irregularities in the length of the plywood.

The flooring is another factor that predetermines the over-all width of the building. Controversial concepts exist as to whether the flooring should extend to the outside of the column base or to the inside face of the column. It was decided that a 20-ft wide floor covering, made up from standard-width plywood sheets, should extend to the outside of the column bases, since this would reduce the length of the floor joists and would result in a lower-cost and lower-weight floor frame. The loss of interior cubage was considered the lesser factor in the decision. A design was developed so that it was still possible to erect the building without the floor (i.e. on a concrete floor or on mud sills).

Width - The dimension of the heretofore standard shelter of 20-ft 1-in. inside the column faces at the floor line has been changed in this design to 20-ft 1-in. out-to-out of columns and exterior floor sills, the 1-in. being the space taken up by the longitudinal metal splines. This permits the complete assembly of the floor including the covering of plywood so that a substantial, properly aligned, and squared platform is provided for the erection of the superstructure.

Length - Following the same reasoning as above set forth and taking into consideration the slight increase in the module, we have arrived at a dimension of 48-ft 3/4-in. for the over-all length.

The end result of the application of this principle results in the elimination of several small parts such as filler strips, etc., which cause considerable annoyance in the field.

Floor System

The floor system is predicated upon the use of plywood panels, 1/2 in. in thickness, 4-ft by 8-ft, with the face grain running the long dimension which is the industry standard. In the analysis of one contemplated floor system, it was considered desirable to have the face grain of the plywood run the short dimension of the panels. A canvas of industry disclosed that, while they could make this material available in quantity, there would be an increase in cost. This latter type of panel was therefore dropped from consideration.

It was decided that a floor frame having four longitudinal lines of sills supported on eight-foot centers and requiring 28 supports would result in an economical system. The 40-lb liveload requirement necessitated spacing the joist on 2-ft centers to support the 1/2-in. plywood panels.

Various possibilities of the floor framing were discussed and studied and the final comparisons were made on the following types of members:

Double "C" Section
"I" Section
Box Section

Figures 2 and 3 show the types of sections considered. They are elaborated on below.

Double "C" Section

a. Sills - From the engineering computations it was determined that the minimum section modulus required for the Grade "C" material was 1.52. A section of this type, 5-1/2 in. deep by 3 in. wide of 16-gage material, has a section modulus of 1.67 and weighs 3.72 lb/lin ft (see Figure 2, No. 1). Because of the exposed flanges in this type of section, material of 16 gage is considered minimum. The 3-in. width was determined by the dimensions of the column to provide an adequate base for it.

b. Joists - Because of the limited depth it was not considered practical to utilize a double "C" section for joists. Therefore, a hat section of 16 gage was considered. The section had over-all dimensions of 3 in. by 3 in., a section modulus of 0.314 and a weight of 1.53 lb/lin ft and is illustrated in Figure 3, No. 2.

c. Manufacturing - Double "C" and hat sections are readily manufactured by conventional press brake equipment or "Yoder Mills," available throughout the country, and are assembled either by semi-automatic or automatic welding equipment which also is readily available.

d. Erection and Fasteners - Use of double "C" or hat sections complicates the connections of the joists at the sills if an attempt is made to have both of the top flanges flush. If the joists are mounted on top of the sills it leaves a bad condition along both sides of the building where the plywood is unsupported. Moreover, on previous designs it has proven difficult in the field to make the connection in the small amount of working space available in the depth of a joist, particularly when sheet metal screws are used to secure the bottom flange of the joist to the top flange of the sill. Another disadvantage of the "C" type of section is encountered when it becomes desirable to have fastening devices on the center line of the member. The two-part member does not readily receive common fastening devices without permanent distortion and loss of holding power upon reuse.

e. Packaging - Double "C" or hat sections do not pack economically since the protruding stiffeners increase the difficulty of packaging. Damage to the exposed flanges which might result, even though they are 16-gage metal, would be a serious consideration in this type of section.

f. Reasons for Rejection - From a comparison of the weight of the "C" or hat type section with the weight of that ultimately chosen for the design, it is apparent that its greater weight of steel was one of the reasons for rejecting it. Other primary reasons for rejection were the high cube of the packaged material and the complication of the joist to sill connection along with the undesirable condition of having the exterior edges of the exterior rows of plywood unsupported when the joists are placed on top of the sill.

I-Beam Type Sections

a. Sills - A section formed by spot welding back to back two 6-in. by 1-1/2-in. channels is seen by reference to Figure 2, No. 2, to provide the requisite structural strength, and to weigh only 3.47 lb/lin ft.

b. Joists - Figure 3, No. 1 shows that a double-channel section 2 in. deep by 2-1/4 in. in over-all width formed of 16-gage channels has a section modulus of 0.31 and a weight of 1.63 lb/lin ft.

c. Manufacturing Processes - These double-channel sections, like the double "C" sections, are readily manufactured by firms in various sections of the country.

d. Erection and Fasteners - The same comments which applied to the double "C" sections apply to the "I" sections.

e. Packaging - While the "I" sections package somewhat more efficiently than the double "C" sections, they are still wasteful of packaging cube.

f. Reasons for Rejection - While the "I" section for the sills weighs less than the double "C" section, it still is higher in weight than the section finally chosen. The packaged cube of these sections is likewise higher than the packaged cube of the sections finally chosen.

Box Sections

a. Sills - Investigation showed that the sill could be made from two 18-gage channels approximately 6 in. deep by 2 in. wide by toeing them in and spot welding the overlapping flanges. The shape of this section eliminates the outstanding flanges and was therefore considered acceptable when fabricated from 18-gage material. This type of assembly places a greater percentage of well-supported metal in the top and bottom flanges and results in over-all economy. The over-all dimensions of the section are 6 in. by 3 in. (see Figure 2, No. 3).

The section modulus produced by this section is adequate for the loads imposed and its weight is only 3.28 lb/lin ft. In considering the effect of the narrow slots for the attachment of the joists it was decided that these were comparable to bolt holes in the compression flanges of rolled sections which are not ordinarily considered as affecting the section modulus. In order to effectively join the overlapping flanges of the channels and to assure uniform distribution of stresses it was decided to spot weld at intervals not to exceed 6 in. This type of section has considerably more torsional strength than the double "C" or "I" sections and will undoubtedly result in a stiffer structure.

The experience of the Laboratory was used as a guide in the design of the exterior sills. It has been found from actual loading tests of similar buildings under similar conditions that the effect of the column load intermediate of supports could be practically disregarded. Apparently the indeterminate distribution by the exterior coverings relieves the theoretical concentrated load at the center of the span of the sill, at least to the point that the typical interior sill can serve adequately for the exterior sill.

b. Joists - Following the same line of reasoning which resulted in the selection of the box section for the sills, the section shown by Figure 3, No. 3, was selected for the floor joist. This 18-gage member has a depth of 2-5/8-in. and a width of 1-7/8-in. with a weight of 1.38 lb/lin ft. While this is not a complete box section, the lower flanges are turned in and protected from accidental damage, and since these flanges are in the tension area of the section, it was decided that 18-gage material would be adequate.

c. Manufacturing Processes - Like the double channels forming the "I" section, the component parts of these members are readily formed on existing equipment and can be spot welded into the box by an adaptation of existing spot welding equipment. Detailed analysis in cooperation with manufacturers of such equipment corroborated these deductions.

d. Erection and Fasteners – The use of the box sections made possible very simple connections between the floor joists and sills. By framing the joists into the sides of the sills, the lengths of the members were reduced resulting in a saving of steel. The fact that these members do not have a junction plane on their center line facilitates the use of standard devices for attaching floor coverings along the center line of the members.

The use of simple 12-gage combination hanger and hook serves to facilitate erection and at the same time to provide ties across the building adequate to resist the outward thrust at the base of the rigid frame.

e. Packaging – During the investigation which led to the selection of the box section, it was determined to proportion the joists so that they could be packaged inside the sill members. As can be seen from the drawings and the resultant final packaged cube, this proved to be both feasible and economical.

f. Reasons for Adoption – Comparison of the steel weights for the combined sills and joist with the weight of other types of sections considered shows clearly a saving of steel. In addition, by packaging the joists within the box sills an over-all saving of shipping cube is effected. Ease of attachment of the joist to the sill is another factor leading to the adoption of this design. The greater ease in handling smooth-sided box sections as compared with handling sections with outstanding flanges as well as the greater resistance of smooth-sided box sections to accidental damage in the field also influenced the choice. It was felt that these sections satisfied the basic criteria of low cost, low cube, and low steel weight.

Roof Frame

Columns and Rafters – By reference to the engineering computations it will be seen that the structural requirements for the rigid frame are almost identical with the requirements for the floor sill members; therefore, the same reasoning and conclusions follow. In order to facilitate the production of this building, the dimensions of the channels used to make the box section sills and roof rafters are the same. By proportioning the column so that it might be packaged inside the rafter, not only was the shipping cube reduced but the moment connection at the eave was simplified, to permit the field connection at the eave to be made by standard machine bolts with no other loose parts. The splice plates at the ridge are left loose to save shipping cube.

The torsional resistance of the box sections adds to the stiffness of the frame and resists accidental damage during erection. The eave and ridge connections are stiffer than other types of commercial connections used to join I-beam type sections.

Purlins - Since these members are considered secondary and are of short lengths, it was decided to utilize the hat section shown in Figure 4, No. 2. This section provides the calculated strength necessary to support the design loading and weighs only 0.84 lb/lin ft. Since the most rigorous test of these members occurs during construction when men are climbing and walking on the roof, it was decided to test this member under these conditions. Full size members, positioned both as purlins and girts, supported the weight of a 200-lb man without permanent deformation.

The sections illustrated in Figure 3, No. 1, were discarded because of their lack of stability and difficulty of attachment.

End-Wall Frame - The end-wall framing members, being secondary members in that they carry only wind loads, were formed of 18-gage metal into a modified box section proportioned for practical considerations. Computations show them to be adequate.

A study of the framing around the door in previous designs indicated that simplification and savings could be effected by increasing the width of the door. Reference can be made to the drawings which illustrate how this was accomplished. By spacing the end-wall posts at the module dimension to receive standard skin, liner, and windows, a reduction was made in the number of special parts. The formed door jamb section receives the abutting elements without a multiplicity of small parts. By attaching this section to the adjoining post, a very rigid condition is obtained for the action of the door. Surface mounting of the hinges eliminates notching and cutting.

During the consideration of the end-wall framing, cognizance was taken of the possibility of either constructing two 48-ft buildings in end to end relationship or erecting a 96-ft length of building from standard parts of the standard 48-ft building. Inquiry did not disclose that any 20-ft by 96-ft buildings, per se, had ever been supplied to advanced bases, and it was decided to make possible the adaption of standard buildings for this purpose. Examination of the details of members and assembly shows that the framework of two 48-ft buildings erected end to end can be enclosed and lined from standard parts and that the finished building would not have a "spliced" appearance.

Exterior Sheeting - A review of past experience in connection with exterior sheets clearly indicated the following points:

a. Satisfactory salvage after dismantling necessitated pre-punching of the exterior sheets.

b. There are only two economically satisfactory types of metal sheets:

1. Standard commercially available 26-gage galvanized iron corrugated sheets.

2. Deep-drawn 26-gage galvanized iron sheets with ribs on 12-in. centers.

The weights of either type of sheet are approximately the same. Because of availability, the standard corrugated sheet was used in the design, and the deep-drawn sheet was shown as an alternate.

The purlin spacing used on the design is based on standard commercial practice when used to support 26-gage galvanized iron corrugated sheets.

Interior Liner - Standard 1/8-in. hard pressed fiberboard was selected as being best suited after application of the formula: low cost, low cube, and low weight. The nominal size of 4-ft by 4-ft and the method of attachment were selected after analyzing all of the past experience with various methods of application of liner and were found to have the following advantages:

a. Most economical cutting by producer.

b. Eliminates production scrap.

c. Reduces the size of the crate with a small saving in cube.

d. This size sheet is more easily handled without breakage during erection.

e. The sheets require no other fabrication than cutting to size, which eliminates all punching, drilling, etc.

f. Attachment is accomplished by the battens which are the only members that are prepunched.

g. Dismantling can be done without damage to the sheets.

Vents and Stacks – Details of the stacks selected for this design were the result of review of various designs submitted to date. This particular detail was selected because of the small number of parts, low-cost easy packing, and low cube. Details for the rectangular ventilator were selected for the same reasons as above. This ventilator has the same free area as that of a 20-in.-diameter round ventilator.

Packaging for Single Package Procurement – The design of the building permits packaging in such a manner that each package contains only those items normally handled by one supplier. This procedure makes possible government procurement at some future date on a package basis rather than by a prime contract with resulting subcontracts, and we estimate that it would effect a saving of five to eight per cent in the total cost of the building.

DESCRIPTION OF BUILDING

The Uniform Military Building is a prefabricated, straight-sided, rigid frame, steel structure 20-ft 1-in. wide, 48-ft 3/4-in. long, and 10-ft 6-1/2-in. high at the peak of the gabled roof. The building must be placed either directly on the ground on a level site or on four rows of posts or blocking spaced 6-ft 8-in. on centers with the post or blocking of each row on 8-ft centers.

The prototype, as furnished for tests and detailed in the original construction drawings of November 7, 1952, consists of a floor system composed of four longitudinal sills spaced 6-ft 8-in. on centers and seventy-five (75) joists spaced 2-ft on centers. The eight-foot long sections of the box section sills are connected together with box splice plates and sheet metal screws. Slots are provided in the center of the top face of the sills and box splice plates to receive the hooks on each end of the 6-ft 8-in. joist members. The 4-ft by 8-ft by 1/2-in. plywood floor panels are attached to the floor framing in five longitudinal rows of six panels each with special drive screws. Twenty-four-gage metal splines are used to support the edges of the panels along the longitudinal joints.

The frame (see Figure 5) is composed of thirteen rigid frame assemblies consisting of two tapered box columns and two box-section roof beams. Twelve-gage backup plates are spot welded to the inner face of the side walls of both the columns and roof beams. Nuts to receive the 1/2-in. by 1-in. machine bolts used to effect the eave joint are projection welded to the column backup plate. The ridge joint differs from the eave joint in that the nuts are welded to loose 12-gage splice plates. The frames are connected to the floor system through special "U" shaped base plates which bear on top of the plywood floor, and are attached to the sides of the sills with sheet metal screws. The frames are interconnected with hat-shaped purlins attached to the frames with sheet metal screws. All of the framing members with exception of the joist and purlin straps and the column and roof beam back-up plates, which are 12-gage, are of 18-gage mild steel.

The end walls consist of four studs with a door header placed between the two center studs. Girts are used to interconnect the end wall studs. The exterior is sheeted with prepunched, 26-gage mild steel, standard corrugated, galvanized sheeting. The sheeting is attached to the frame with sheet metal screws into prepunched holes. The interior is lined with 1/8-in. hard pressed fiberboard. The 4-ft square sheets are held in position by the friction of the prepunched battens transversely and by 24-gage metal splines along the longitudinal joints (Figure 6).

Interior natural light is provided by three fixed windows in each side wall and two fixed windows in each end wall. A 3-ft 8-in. by 6-ft 8-in. door is provided in each end wall for access into the building. Ventilation is accomplished by placing an operable louver in the lower panel of each door and discharging through a roof ventilator. Two smokejacks are provided for use in conjunction with space heaters. A wiring harness is provided for artificial light and convenience outlets.

TEST FACILITIES

A special facility (see Figure 7) was built for testing 20-ft by 48-ft buildings.[4] The facility consists of three test stations, one for erection studies, one for structural tests, and one for weathertightness tests. For movement of buildings between these stations, a 330-ft long, 20-ft gage, I-beam track was built to connect the stations; and a 21-ft by 50-ft, flat-deck, steel transfer cart was mounted on the track.

At station one, erection studies are made on the transfer cart with blocking placed on the deck of the cart to simulate foundation conditions. A 10-ft wide work platform was built along the track to simulate natural ground height around the cart.

At station two, simulated wind and snow loadings are applied through hydraulic cylinders attached to a bent of Navy pontoon strings framed over the track. A special hydraulic pump and control panel are used to actuate the cylinders. Loads are applied to the building by the cylinders through pads, whiffletrees (see Figure 8), or combinations of both.

Floor-loading tests are made with a special floor-testing jig which uses hydraulic cylinders in a similar manner to their use in wind and snow loadings. All strains are measured with SR-4 gages, type A-1, and are observed in microinches on a 48-channel Foxboro Scanner Recorder. Deflections are measured in hundredths of inches with deflectometers, direct-reading dials connected to the building with a flexible wire and developed at the Laboratory.

At station three, an overhead sprinkling system is used to simulate a 2-in./hr rainfall over the entire roof of a building. A portable Buffalo turbine sprayer-duster is used to simulate a 35-mph, wind-driven rain along one side wall. For a windbreak, a high wall of pontoons was built around three sides of the station.

The test facilities permit simultaneous testing of three buildings.

TEST PROCEDURE

Each package of the building as received from the manufacturer was weighed, cubed, and reviewed for adequacy of crating and for compliance with naval storage requirements. Further, the packaging scheme was studied to determine possible combinations of packages, cubage and weight reduction, and the suitability of the packaging for convenient distribution around the erection site.

Three erection studies were made to determine the suitability of the building for assembly under advanced-base conditions. To simulate these conditions, a team comprised of civilian personnel was used for all erections. The first erection was observed to determine the ease of erection with personnel unfamiliar with the procedure; to establish the most efficient size for the erection team; to check the accuracy of fabrication; to study the adequacy of the erection manual; to establish the tool requirements for efficient erection; and to record the manhours required to assemble the floor, frame, exterior sheeting, end walls, insulation, and interior wallboard. Following the weathertightness and structural tests, the building was completely disassembled, and a second and third erection and disassembly were made to determine the suitability of the design for repeated assembly and to record the erection manhours required as the team became more familiar with the building.

Upon completion of the erection, the building was weathertested. The overhead sprinkling system was turned up, and observations were made on the inside of the building to determine leaks resulting from a direct downpour. When sufficient time had elapsed to locate any possible leaks in the roof, the portable Buffalo turbine sprayer-duster was turned on and moved slowly along the side of the building at different elevations. The direct downpour fell all during the wind-driven rain test. Observations were made to locate air and water leakage along the side walls.

Structural tests were made to determine the adequacy of the building to withstand the 20-psf, the 70-mph wind, and 40-psf floor design loadings stipulated in the Military Specifications[5]. A unit stress of 18,000 psi was allowed by the specifications at design load for the light-gage-steel framing and sheeting members used in the building. To test the framing and sheeting members under the most unfavorable condition and to observe them under load, all structural tests were performed without the interior lining.

Previous tests on framed structures[6] have shown that the strains and deflections occurring in the center portion of the building are independent of the end walls. Taking advantage of this knowledge a part of each end of the building was removed, and only a 16-ft center section, which spanned five of the rigid frame assemblies was used for the simulated snow- and wind-loading tests. The design snow-loading condition diagrammed in Figure 9 was applied hydraulically to the roof through pads, as shown in Figure 10. The design wind-loading condition diagrammed in Figure 11 was applied hydraulically to the roof and side walls through pads, as shown in Figure 12. In each case, loadings scheduled to reach 190 per cent of design load were applied in 10 per cent increments until excessive strains and deflections were observed. Location of the strain and deflection gages used in these tests are shown in Figures 13 and 14.

For the simulated floor-loading test, a 16-ft by 20-ft section of the floor was selected for test. This section of floor covered the entire 20-ft width and a 16-ft length of the building. The design floor-loading condition was applied hydraulically to the floor through pads and whiffletrees. The loadings scheduled to reach 190 per cent of design load were applied in 10-per cent increments until excessive strains and deflections were observed. Location of the strain and deflection gages used in this test is shown in Figure 15.

RESULTS AND OBSERVATIONS

The test results and general observations made during the evaluation of the building are covered in the following paragraphs.

Packaging and Crating

A summary of the packages, cubes, and weights, as received at the Laboratory, is given in Table I. It is seen from this table that the 10,595-lb packaged weight and the 196.9-cu ft shipping cube are both low in comparison with other buildings of identical purpose. The total steel weight including all hardware is approaching the minimum steel weight that could be achieved for a straight side-wall design.

An examination of the drawings will reveal the excellent nestability of the various components of the building into solid, compact crates. A typical example of this nestability is shown in Figure 16 and 17 showing the end-wall crate and the parts that go in it.

The packaging scheme for layout prior to erection is acceptable. In general, the crates need not be opened until all the material in the crate is required in the erection procedure. Excellent use of the crating material as blocking and liner backing results in the shipment of a negligible amount of useless crating material. The small, compact packages also facilitate the easy handling by power equipment and decrease storage and shipping operations.

The packaging scheme also permits the procurement of the various crates directly from the manufacturer of the material, i.e., only hard pressed fiberboard in the liner crate, only plywood sheets in the floor crate, etc.

Erection

A summary of the manhours required to erect the building in any one of three erections and a breakdown of the manhours required in the third erection is given in Table 2. This table shows a team can erect the original building in 122.5 manhours in the first erection. A reduction to 107.0 manhours in achieved in the third erection.

The simplicity of the design, the ease of effecting the various floor and roof framing connections made the first erection of this building exceptionally low. No erection manual was available for this erection, but the construction drawings proved adequate to accomplish the erection. During the erection it was found that a six-man team was required for efficient erection. The tool list suggested for the building was supplemented and a list of tools necessary for efficient erection is shown in Table 3.

The second and third erections were faster, as the crew became more familiar with the parts and devised short cuts to speed the assembly.

The only difficulty encountered in the erection was in attaching the prepunched standard corrugated sheeting. The loose tolerances allowed in the manufacturing of this sheeting and the damage incurred by the sheets during erection caused mismatching of some of the holes. It was found that exact squaring and plumbing of the frame reduced the difficulty of attaching the sheeting.

The interior liner scheme eliminating all prepunching with the exception of the battens proved to be both practical and easy to install. Curving the center ceiling lower sheet into position was easily accomplished. As is borne out by the erection time, this building is quickly and easily assembled in the field by personnel unfamiliar with the building.

Weathertightness

The building proved to be essentially weathertight with the exception of the eaves. The mismatching of the eave flashing corrugations with the roof and side-wall sheets allowed leakage in this area.

Structural Adequacy

The stresses and deflections recorded in the snow-, wind-, and floor-loading tests are summarized in Table 4. All structural members in this building are of 18-gage mild steel having a minimum yield of 33,000 psi.

The snow loading was taken to 190 per cent of design and then discontinued, as this was the maximum for all loadings scheduled for this building. At design load, a maximum stress of 8400 psi compression as compared to the allowable 18,000 psi was recorded at point 6 (see Table 5) and at 190 per cent of design, a maximum stress of 17,550 psi compression was recorded at the same point. The maximum recorded deflection at design load was a vertical movement of 0.55 in. at point 5 (see Table 6); and at 190 per cent of design, a maximum vertical deflection of 1.62 in. was recorded at the same point.

The wind loading was taken to 190 per cent of design and then discontinued. At design load, a stress of 8400 psi tension, as compared to the 18,000 psi allowable stress, was recorded at point 6 (see Table 5); and at 190 per cent of design load, a maximum stress of 15,600 psi tension was recorded at the same point. The maximum deflection at design load was a horizontal movement of 0.60 in. at point 10 (see Table 6); and the maximum deflection at 190 per cent of design load was a horizontal movement of 1.43 in. at the same point. No damage occurred to the building during either the snow or wind loadings. It can be seen from Table 5 that the combination loadings of 1/2 wind and full snow and 1/2 snow and full wind will not give stresses in excess of either the wind or snow loadings.

The floor load test was taken to 120 per cent of design when a failure occurred at the midspan of an interior sill. The top face of the sill failed in compression, similar to the lateral buckling of a column, this causing the sides to buckle. This failure was attributed to the removal of too much metal in supplying the slots for the joist hooks. As the load was applied, the compressive stresses from bending coupled with the curvature of the beam resulted in the failure. At design load, a maximum stress of 16,100 psi tension was recorded at point 3 (see Figure 15) on the joist and at maximum loading of 120 per cent, a maximum stress of 19,300 psi tension was recorded at the same point. The maximum recorded deflection at design load was a vertical movement of 0.25 in. at point 3; and at 120 per cent of design load, a maximum deflection of 0.25 in. was recorded at point 3. The above values were not tabulated because it was necessary to redesign the floor system. The redesigned floor is covered under the paragraph titled "Redesign," and test data is tabulated in Tables 7 and 8. The deflections on both the sills and joists at design load were below the allowable L/240.

CONCLUSIONS

As designed, the building has many desirable features warranting its consideration as the standard military building. These include the following:

1. The excellent nesting of the parts in the crates resulting in low shipping cube and weight.

2. The single package procurement allowed by the grouping of the material in the crates.

3. The simplicity of the design and connections resulting in low erection time.

4. The building is weathertight with the exception of the eave.

5. The building is structurally adequate under the design snow- and wind-load conditions.

6. The box sections allow the use of 18-gage mild steel without sacrificing ruggedness or stability.

7. The building may be disassembled and re-erected with negligible damage to the components with the exception of the exterior sheeting.

8. The building is well proportioned and presents a pleasing appearance.

However, a redesign is necessary to correct the following:

1. The ineffective seal at the eave against wind-driven rain.

2. The difficulties of prepunching standard corrugated sheeting for quick field assembly and the high susceptibility of these sheets to damage during erection.

3. The structural inadequacy of the floor sills.

REDESIGN

During the evaluation of the prototype the Defense Supply Management Agency committee on prefabricated buildings formulated a new set of criteria for a standard military 20-ft by 48-ft building that would be suitable for all the services. A directive was issued by the Bureau of Yards and Docks to the Laboratory to modify the design to comply with the new criteria. This new criteria is contained in the "Uniform Military Requirements Criteria for 20-ft by 48-ft Prefabricated Advanced Base Building" (Appendix) and the major changes are as follows:

1. Reduction of the design snow load to 15 lb/sq ft.

2. Reduction of the design floor load to 30 lb/sq ft.

3. Glazed area to be increased to 96 sq ft of which 48 sq ft is to be operable for natural ventilation. The window area to be equally divided between the two side walls.

4. Elimination of the requirement for a minimum interior volume of 8250 cu ft.

5. Minimum interior clearance to be 7'0".

These new criteria necessitated a new design based on the original but incorporating the changes in the criteria and correcting the deficiencies found through evaluation of the prototype. The difficulties encountered with the standard corrugated sheeting and the problem of effectively sealing the eave were attacked at the same time. Studies were being made during the evaluation of the prototype to determine the economic possibility of using a deep-drawn corrugated sheet similar to that being used on the Navy Rigid Frame 40-ft by 100-ft Utility Building. These studies revealed that this type of sheeting could be produced in sufficient quantity and at a competitive cost with the standard corrugated sheets. Erection studies on the Utility Building had proven this type of sheet to be more adaptable to prepunching, to be able to be fabricated more accurately and to be more resistant to accidental damage during erection or disassembly than the standard corrugated sheeting. Consequently, the standard corrugated sheet design was replaced with a deep-drawn corrugated design. Details of this sheet are shown in Figure 18.

The problem of a weatherseal at the eave was simplified somewhat by the adoption of this type sheet. A new eave flashing was designed which proved to effectively seal the eave without the use of mastic. Details of the eave flashing are clearly shown in the drawings.

The reduced liveload allowed under the new criteria was taken into consideration in redesigning the structurally inadequate sill. The nature of the failure indicated that too much metal had been removed from the top face in providing the slots for the joist hooks. This condition was corrected by replacing the slots at each edge of the top face with a single slot in the center of the top face. The member was also reduced in depth to 5-1/2-in. to take advantage of the reduced floor load. The joists were also redesigned to take advantage of the reduced load and the joist hooks lengthened to seat properly in the single slot of the sill. Details of the new floor framing are clearly shown in the drawings.

An 8-ft section of the redesigned floor was tested for the new 30-lb liveload. This loading was taken to 190 per cent of design and then discontinued as this was the maximum loading designated. At design load a maximum stress of 15,600 psi tension was recorded at point 4 on the joist (see Table 7), and at the maximum loading a stress of 30,000 psi was recorded at the same point. The maximum recorded deflection at design load was a vertical movement of 0.21 in. at point 3 (see Table 8), and at 190 per cent of design a maximum movement of 0.48 in. was recorded at the same point. The deflections on both sills and joists are below the allowable L/200. While the maximum loading was on the floor, a simulated column load due to snow loading was applied to the middle of the outer sill. Recorded stresses and deflections for these combined loadings are also shown in Tables 7 and 8.

The size of the principal roof-framing members could not be reduced in view of the reduced snow load without sacrificing ruggedness and stability. Advantage of the elimination of the interior volume requirement of 8250 cu ft was taken by dropping the eave 4-1/2-in. and the peak approximately 1-ft with a consequent saving in material.

The fixed windows in the side and end walls of the original design were discarded and the design of an operable window undertaken. Prototypes of two preliminary designs were fabricated and thoroughly tested at the Laboratory. The window adopted consists primarily of a fixed upper glazed area approximately 2-ft by 4-ft and a lower operable glazed area of the same dimensions. The sash and frames are both of steel. Details of this window design are clearly shown on the detailed drawings. Window screens are provided to cover the lower operable area.

The crating was restudied to determine if further reductions could be made in the shipping cube. Results of these studies indicated that the liner crate could be redesigned using metal and not only reduce cube but allow outside storage of this material. A metal crate of 18-gage metal was designed and a prototype fabricated (see Figure 19). Tests were conducted in accordance with the procedure outlined in the "Standard Testing Procedure for Prefabricated Buildings." Results of these tests proved the crate to be structurally adequate and watertight except for immersion.

The smoke jacks were redesigned to provide a more satisfactory jack from an operation viewpoint. Several other minor changes and improvements were made in the design but they are too numerous and have too little bearing on the design to list them here. They can be seen on the final detailed drawings[7] and specifications[8].

REFERENCES

1. RDB Project Card NY 500 002, Prefabricated Advanced Base Building, 1 July 1952.

2. Bureau of Yards and Docks, "Outline Specifications for 20-ft by 48-ft Prefabricated Building, Northern," 11 February 1952.

3. Bureau of Yards and Docks "General Criteria and Requirements for 20-ft x 48-ft Prefabricated Buildings, Northern," 11 February 1952.

4. Steele, R.K., "Production-Line Tests Maul Prefabs," Engineering News-Record, vol. 148, no. 1, 3 January 1952, p. 30-32.

5. MIL-B-15969 (DOCKS) Military Specifications "Building, Prefabricated Metal Arch Rib 20-ft by 48-ft Northern Type," 4 January 1951.

6. U.S. Naval Civil Engineering Research and Evaluation Laboratory Technical Memorandum M-038, BuDocks Design 40-ft by 100-ft Prefabricated Steel Utility Building, by R.A. Breckenridge and A.B. Bruck, 1 January 1952.

7. Bureau of Yards and Docks Drawings Nos. 603,192 to 603,216 inclusive, Steel Prefabricated Building, 2 January 1953.

8. MIL-B-17459A (DOCKS) Military Specification, "Building, Prefabricated, Steel, 20-ft by 48-ft," 16 March 1953.

APPENDIX

UNIFORM MILITARY REQUIREMENTS CRITERIA FOR 20' x 48' PREFABRICATED ADVANCED BASE BUILDING

1. Size: The basic building shall have nominal inside dimensions of 20 feet in width (clear span) and 48 feet in length.

2. Expansibility: The basic building shall be capable of expanding in length by modular increments of not more than 12 feet. This should be done without the need for bracing or special parts which will affect the use of the building. There is no requirement for expansion in width.

3. Shape: The building may be straight sided with gable, shed or other type roof which will provide a minimum clear inside height of 7'0" nominally from side wall to side wall.

4. Adaptability: The building shall not be complicated by the addition of materials for the purpose of readily assembling T, E or L shaped buildings. If this feature can be obtained at no additional cost or sacrifice of other requirements, it is considered desirable. The building shall be capable of being erected either with or without the floor. It is not required that the floor system be such that it can be readily installed, at a later date.

5. Expected Life: These buildings shall have a minimum useful service life of five years. Structural members and exterior cladding materials shall be capable of being stored in the open in temperate climates for a minimum period of five years without affecting their useful service life.

6. Insulation Requirements: Insulation shall be provided in the walls and roof (or ceiling) so as to provide a U factor of not more than .24 for a typical section for temperatures down to -25 F. The design shall be such that an additional insulation and means for preventing condensation on the interior can be added with a minimum effort with no change to the basic building, and that the structure for use in temperatures down to -40 F shall provide a U factor not greater than .15 for a typical section.

7. Physical Requirements:

a. Floor systems complete and ready for placement on the ground or on a maximum of 28 sills or posts.

b. Interior lining shall be suitable for the purpose of the building.

c. The building shall have a minimum of glazing area of 96 square feet and a minimum of manually controlled natural ventilation of 48 square feet of open area divided equally on the two side walls of the building. This minimum is 5% of the floor area and is exclusive of that provided by doors and jack-type vents in the roof. Modular increments for expansibility should maintain the same proportion of natural ventilating area as the basic building.

d. One personnel door in each end of building, three feet wide by six feet eight inches in height of wood or metal shall be provided.

e. The building shall be provided with necessary smoke stacks.

f. All openings shall be screened. Provision shall be made in the design of the door frames for installation of a 1-1/8 inch screen door.

8. Materials: All structural elements of any one design will be of either wood or steel or aluminum. Materials for cladding and other materials will be considered on the basis of their availability and acceptability for identical purposes.

9. Design Requirements: The building shall be clear span and shall be designed for a 70-mile-per-hour wind, a 15-pound-per-square-foot snow load and a 30-pound-per-square-foot floor load. The safety factor used in the design of the structures shall be the minimum acceptable, based on provisions of nationally accepted building codes incorporating standard safety factors. The following load combinations shall be used.

a. Dead load plus full snow load.

b. Dead load plus full wind load.

c. Dead load plus full snow load, plus one-half of the wind load.

d. Dead load plus one-half of the snow load plus full wind load.

Under load combinations c and d, a 30% increase in allowable unit stresses will be permitted.

When the above specified floor loading is applied, any floor structural member or any floor surfacing panel shall not exceed an average deflection of L/200.

10. Erection Time: The basic building shall be capable of being erected on a prepared foundation, by a crew experienced in erection, in 120 manhours or less.

11. Ruggedness: Building shall be sufficiently rugged as to resist damage, during handling and erection, to the component parts and to withstand the effects of normal occupancy.

12. Re-Erection: The building shall be capable of being dismantled, repackaged and re-erected twice with a minimum loss of materials.

13. Erection Conditions: The components shall be suitable for man-handling and shall be designed for rapid assembly and disassembly under adverse weather conditions with a minimum loss or damage to components.

14. Economy: The building shall be most economical in cost and in use of materials consistent with the requirements above.

Table 1. Summary of Packages, Cubes, and Weights of Uniform Military Building

Item	Units	Quantity Original	Quantity Redesigned
Packages	no.	10	10
Cubes of crated bldg			
Maximum crate	cu ft	40.0	40.0
Minimum crate	cu ft	1.9	5.0
Total cubage	cu ft	196.9	202.0
Weight of crated bldg			
Maximum crate	lb	2332.7	2215.0
Minimum crate	lb	60.0	210.0
Total weight	lb	10,595.0	10,334.0
Steel Weight			
Floor system	lb	1494	1385
Frame	lb	2512	2435
Exterior Sheeting	lb	2185	2030
Miscellaneous	lb	216	350
Total weight	lb	6407	6200

Table 2. Summary of Erection Time Studies

A six-man erection team was used on the Uniform Military Bldg.

Item	Manhours* Original
Entire building	
1st erection	122.5
2nd erection	110.0
3rd erection	107.0
Components (3rd erection)	
Floor system	5.0
Frame	16.
Exterior sheeting	38.
End walls	10.0
Insulation	8.0
Interior wallboard	23.0
Vents and stacks	2.0
Wiring	5.0
	107.0

*It is estimated that, after the design changes have been incorporated into the redesigned building, there will be little change in the number of manhours required for erection over that of the original design. It is estimated that the operable windows will require approximately 7 manhours to erect.

Table 3. Building-Erection Tool Kit

Description	Quantity
Bar, Wrecking, gooseneck; 24-in.	1
Calking Gun; 1-pt capacity	1
Chalk, Carpenter's; blue	1
Hammers, Carpenter's; 16-oz	2
Handle, Claw Hammer; 11-in.	1
Hatchet, Broad; 4-1/2-in. cut	1
Level, Spirit; 28-in.	1
Line, Chalk; (100 ft to ball)	1 ball
Pliers, Lineman, side cutting; 6-1/2-in.	1
Punch, Metal, hand; 3/16-in.	1
Rules, Folding; 6-ft	2
Saw, Crosscut; 20-in., 10-point	1
Saw, Keyhole; 10-in., 10-point	1
Screwdriver, Wood handle; 6-in. blade	4
Screwdriver, Wood handle; 4-in. blade	4
Shears, General utility; 2-3/4-in. blade	1
Wire, Black annealed; 18-gage (166 ft to lb)	1 lb
Wrenches, Structural, offset handle; 3/4-in. opening	2

Table 4. Summary of Structural Tests

(The recorded values given in this table represent liveload values only)

Item	Units	Snow*	Wind*	Floor** (Redesigned)
Design loading	as noted	15 psf	70 mph	30 psf
Maximum loading	as noted	28.5 psf	100 mph	57 psf
Load increment	% design	10	10	10
Stresses (design load)				
Tension				
Magnitude	psi	5100	8400	15,600
Location	no.	19	6	4
Compression				
Magnitude	psi	8400	-2400	--
Location	no.	6	19,20,21	
Stresses (maximum load)				
Tension				
Magnitude	psi	9600	15,600	30,000
Location	no.	19	6	4
Compression				
Magnitude	psi	17,550	-4,650	--
Location	no.	6	19,20,21	
Deflections (design load)				
Vertical				
Magnitude	in.	0.55 dn	0.29 up	0.30
Location	no.	5	5	3
Horizontal				
Magnitude	in.	0.16	0.60	
Location	no.	9	10	
Deflections (maximum load)				
Vertical				
Magnitude	in.	1.62 dn	0.90 up	0.63
Location	no.	5	5	3
Horizontal				
Magnitude	in.	0.48	1.43	
Direction	no.	2	10	

*Roof frame only.
**Floor frame only. See Tables 7 and 8 for combination loading of snow and floor.

Table 5. Recorded Liveload Stresses on the Prototype Frame for Simulated Snow and Wind Loadings.

Gage	Snow Loading (psf) Per Cent Design Load				Gage	Wind Loading (70 mph) Per Cent Design Load			
	50	100	150	190		50	100	150	190
1	-2100	-3750	-4900	-7200	1	+2100	+4800	+7350	+10,000
2	-3000	-5700	-7300	-10,800	2	+3300	+7350	+11,500	+14,400
3	-4000	-7500	-10,300	-15,000	3	+3900	+8250	+12,600	+14,200
4	-4200	-7950	-10,900	-15,900	4	+3900	+8100	+12,500	+15,000
5	-4100	-7800	-10,900	-15,900	5	+3900	+8000	+12,500	+14,400
6	-4350	-8400	-12,000	-17,550	6	+4000	+8400	+12,800	+15,600
7	-3500	-6900	-10,000	-14,550	7	+3300	+7050	+11,800	+12,700
8	-3500	-6600	-9100	-13,200	8	+3000	+6300	+9950	+12,000
9	-1900	-4050	-6150	-8550	9	+1950	+4050	+6150	+7200
10	-2400	-4800	-7200	-9600	10	+2100	+4500	+7200	+9300
11	-3600	-6900	-10,300	-15,600	11	+2550	+6000	+9550	+11,850
12	-2700	-4900	-7200	-9100	12	+2550	+5400	+8400	+10,800
13	-2250	-3800	-5400	-7350	13	+2400	+4750	+7650	+9300
14	0	0	0	0	14	+1500	+2850	+4200	+6150
15	+1200	+2550	+3600	+4800	15	0	0	0	0
16	+2100	+4200	+5550	+6600	16	-500	-1250	-1800	-2200
17	+2400	+4500	+6100	+9000	17	-900	-2100	-3150	-3450
18	+2400	+4500	+6750	+9300	18	-900	-2100	-3150	-3450
19	+3100	+5100	+7200	+9600	19	-1150	-2400	-3600	-4650
20	+2700	+4650	+6600	+9600	20	-1150	-2400	-3600	-4650
21	+1950	+2950	+3600	+5100	21	-1150	-2400	-3600	-4650
22	-2100	-3900	-6000	-8550	22	-600	-800	-1100	-1200
23	-2100	-3600	-5900	-7950	23	0	0	0	0
24	-3300	-6600	-10,500	-14,700	24	0	0	+350	+1200
25	-3300	-6300	-10,500	-14,700	25	0	0	+350	+1200
26	-3200	-6100	-9750	-13,200	26	-600	-1200	-1350	-1350
27	+2300	+6750	+10,350	+16,800	27	+300	+350	+450	+ 600
28	-3300	-6300	-10,950	-14,400	28	+1800	+3600	+5400	+7200

Table 6. Recorded Liveload Deflections on the Prototype Frame for the Simulated Snow and Wind Loadings.

Units: in. See Figure 14 for location and positive deflection gages.

Point	Snow Loading Per Cent Design Load				Wind Loading Per Cent Design Load			
	50	100	150	190	50	100	150	190
1	-0.05	-0.13	-0.25	-0.39	+0.20	+0.38	+0.62	+0.87
2	-0.01	-0.10	-0.31	-0.48	+0.29	+0.53	+0.90	+1.28
3	+0.12	+0.35	+0.69	+1.00	-0.09	-0.11	-0.28	-0.42
4	+0.18	+0.53	+1.03	+1.50	-0.18	-0.29	-0.51	-0.80
5	+0.18	+0.55	+1.14	+1.62	-0.18	-0.29	-0.58	-0.90
6	+0.15	+0.46	+1.01	+1.47	-0.17	-0.26	-0.50	-0.80
7	+0.12	+0.37	+0.80	+1.10	-0.13	-0.22	-0.42	-0.63
8	+0.04	+0.11	+0.18	+0.23	+0.22	+0.42	+0.69	+0.90
9	+0.09	+0.16	+0.23	+0.31	+0.12	+0.24	+0.39	+0.50
10	0	0	0	0	+0.41	+0.60	+1.10	+1.43

Table 7. Recorded Liveload Stresses on Floor Framing from Floor Loading and Column Load.

Units: psi, + tension, - compression, $E_s = 30 \times 10^6$ for converting strain to stress. See Figure 15 for the location of strain gages.

Point	Per Cent Floor Design Load				190 Per Cent Floor Load plus Per Cent Snow Load on Midspan of Outside Sill			
	50	100	150	190	50	100	150	190
1	+2400	+5550	+ 8250	+10,500	+13,350	+16,500	+20,100	+23,800
2	+4500	+9450	+14,100	+17,700				
3	+6900	+15,150	+23,250	+29,550				
4	+7200	+15,600	+23,400	+30,000				

Table 8. Recorded Liveload Deflections on Floor Framing from Floor Loading and Column Load.

Units: in. See Figure 15 for location of deflection gages.

Point	Per Cent Floor Design Load				190 Per Cent Floor Load Plus Per Cent Snow Load on Midspan of Outside Column			
	50	100	150	190	50	100	150	190
1	0.02	0.04	0.06	0.08	0.11	0.17	0.22	0.28
2	0.06	0.13	0.18	0.22				
3	0.06	0.21	0.34	0.48				

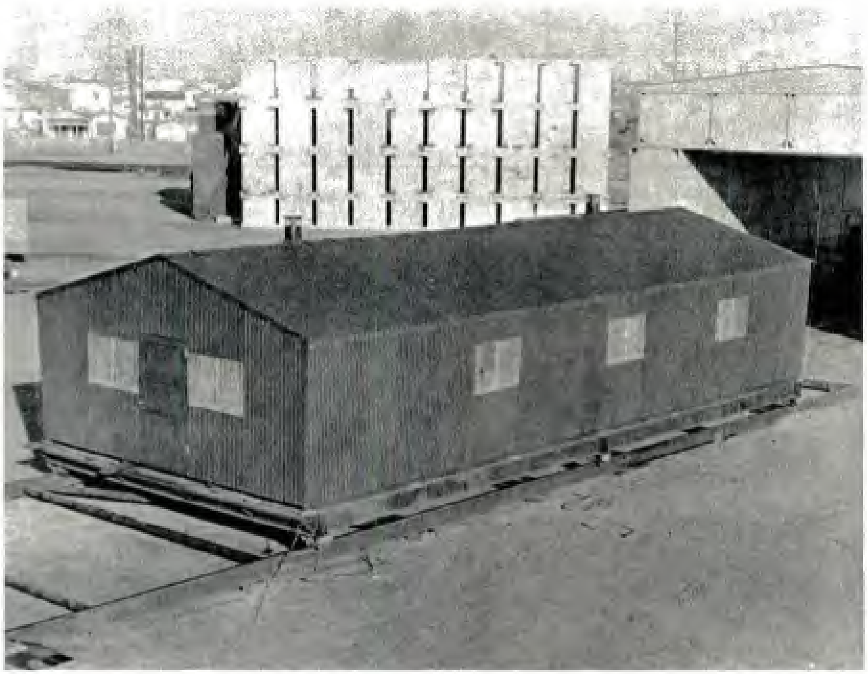


Figure 1. Original prototype of the Uniform Military Prefabricated 20-ft x 48-ft steel building.

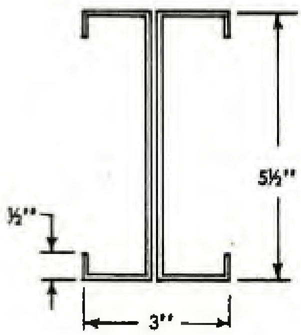
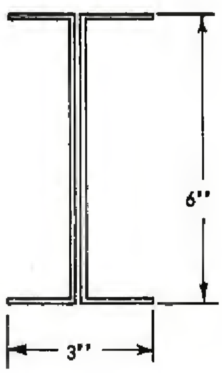
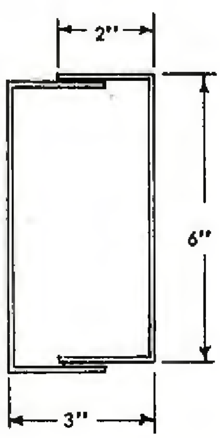
NO.	SECTION	GAGE	I	S_c	S_t	WEIGHT
1		16 Ga	4.6 $in.^4$	1.67 $in.^3$	1.67 $in.^3$	3.72 lb/ft
2		16 Ga	4.8 $in.^4$	1.6 $in.^3$	1.6 $in.^3$	3.47 lb/ft
3		18 Ga	4.95 $in.^4$	1.65 $in.^3$	1.65 $in.^3$	3.28 lb/ft

Figure 2. Sill studies.

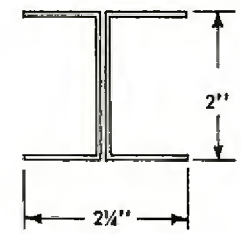
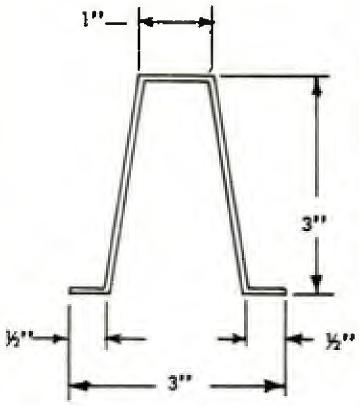
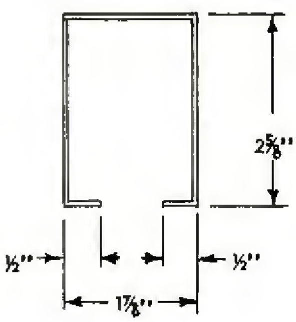
NO.	SECTION	GAGE	I	S_c	S_t	WEIGHT
1		16 Ga	.31 $in.^4$	.31 $in.^3$	.31 $in.^3$	1.63 lb/ft
2		16 Ga	.474 $in.^4$	.314 $in.^3$	.314 $in.^3$	1.53 lb/ft
3		18 Ga	.386 $in.^4$	.314 $in.^3$	.28 $in.^3$	1.38 lb/ft

Figure 3. Joist studies.

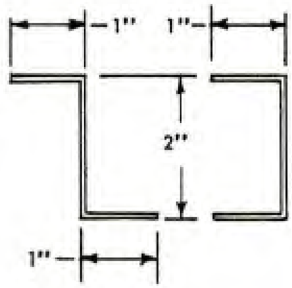
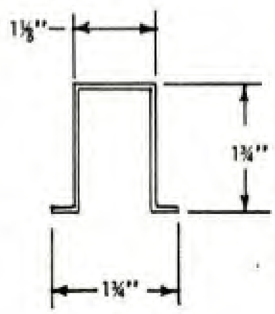
No.	SECTION	GAGE	I	S_c	S_t	WEIGHT
1	 	16 Ga	.141 $in.^4$	.141 $in.^3$	.141 $in.^3$	.78 lb/ft
2	 	18 Ga	.099 $in.^4$	.125 $in.^3$	.109 $in.^3$	.84 lb/ft

Figure 4. Purlin studies

Figure 5. Structural frame of building.

Figure 6. Interior view of building.

Figure 7. Test facility layout.

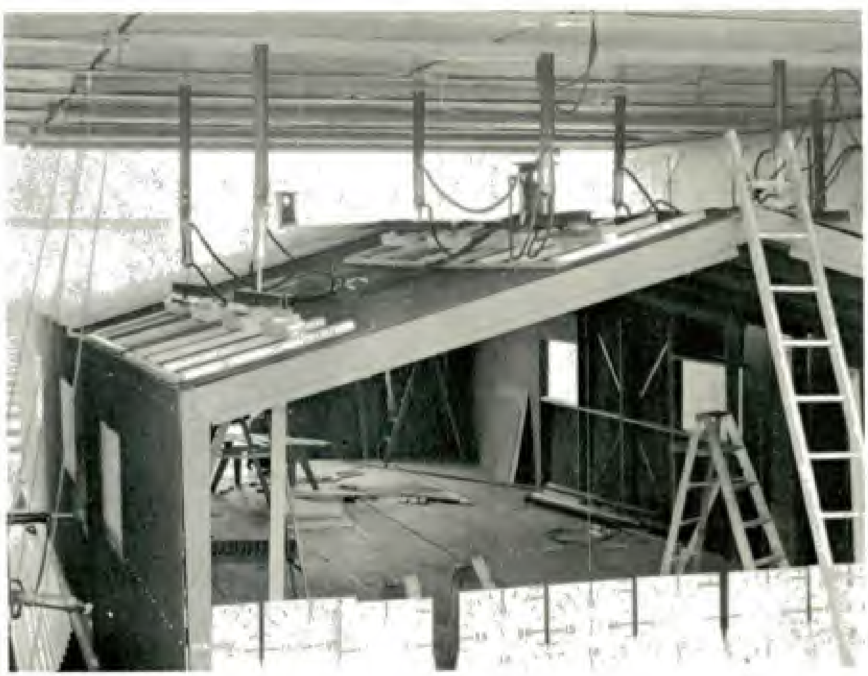


Figure 8. Applying simulated snow load hydraulically.

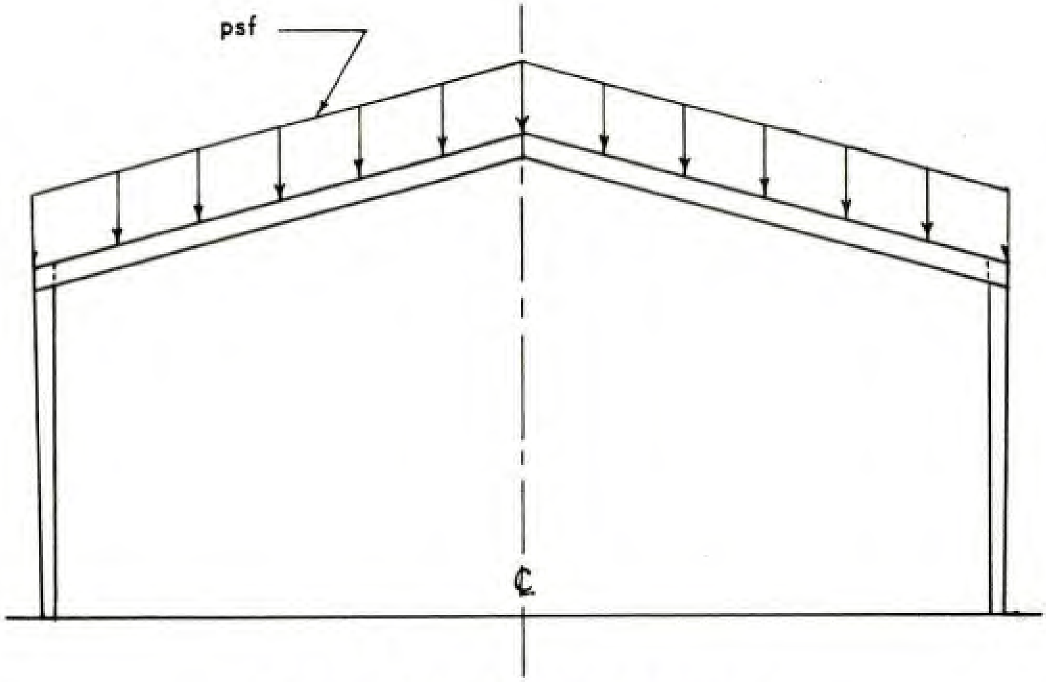


Figure 9. Design snow-loading condition.

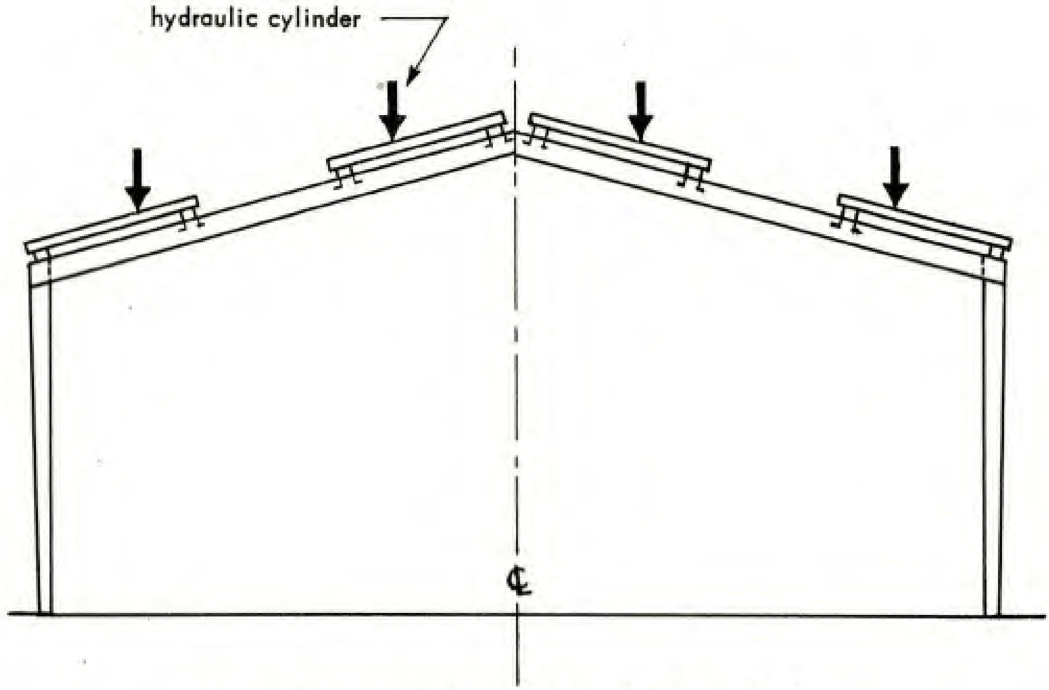


Figure 10. Method of applying simulated snow load.

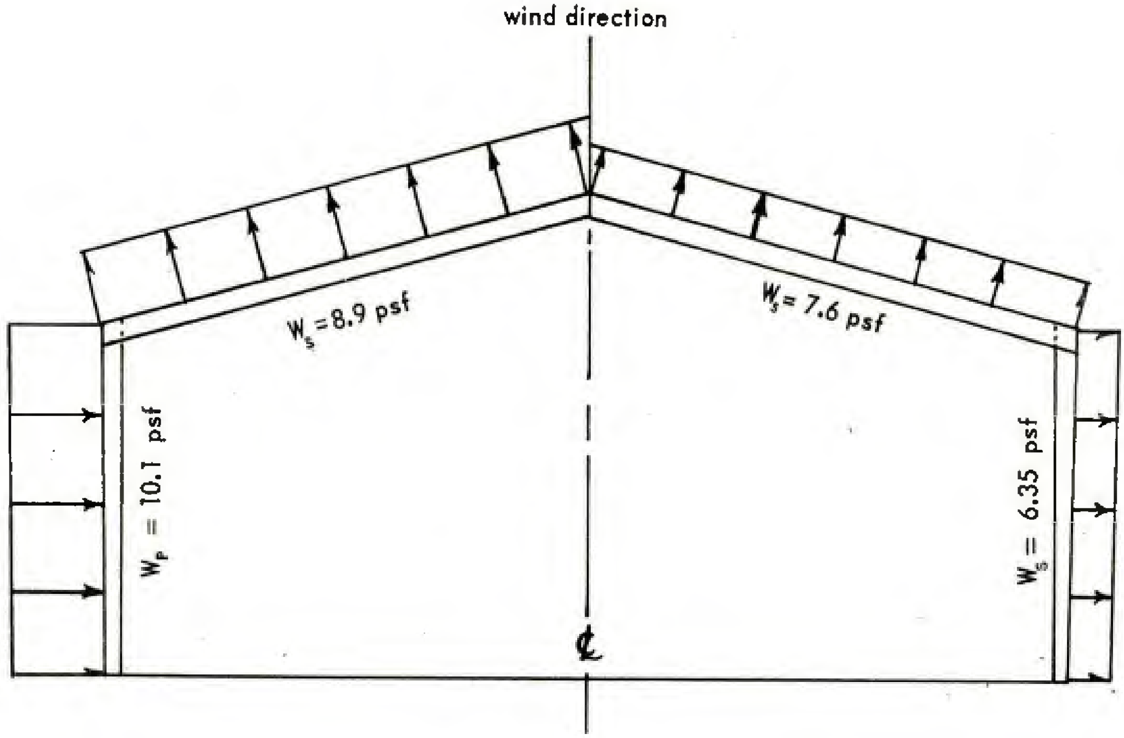


Figure 11. Design wind-load condition for 70 mph wind.
Reference: Y and D drawing No. 427314
design data for wind and earthquake.
Dated 3 August 1948.

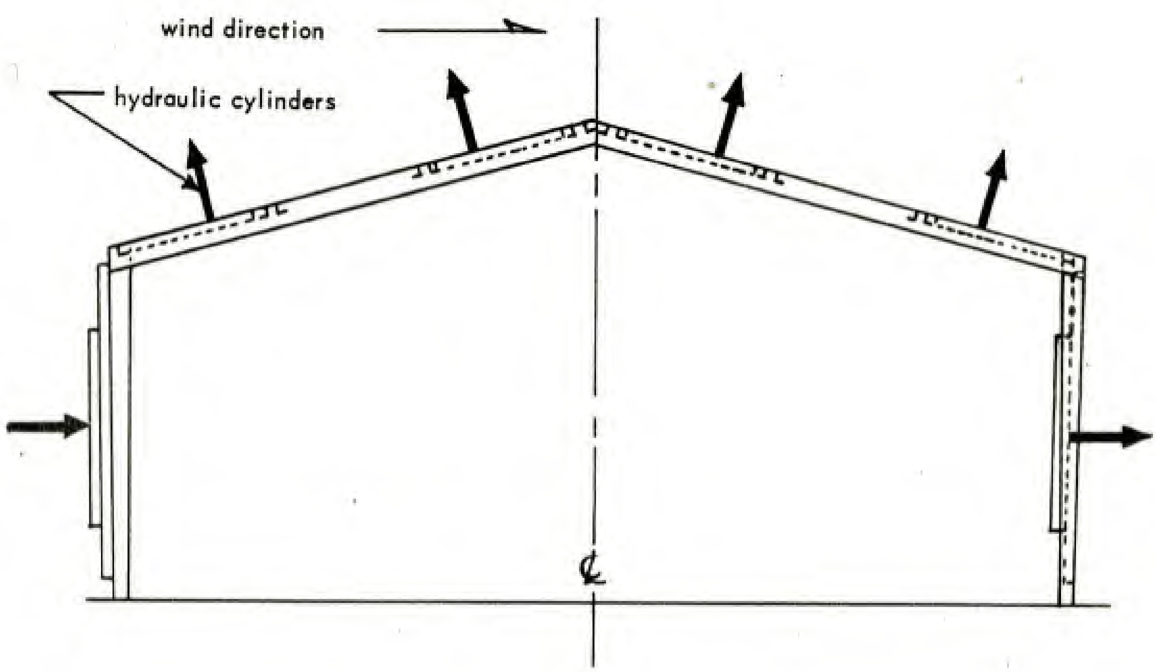


Figure 12. Method of applying simulated wind loading.

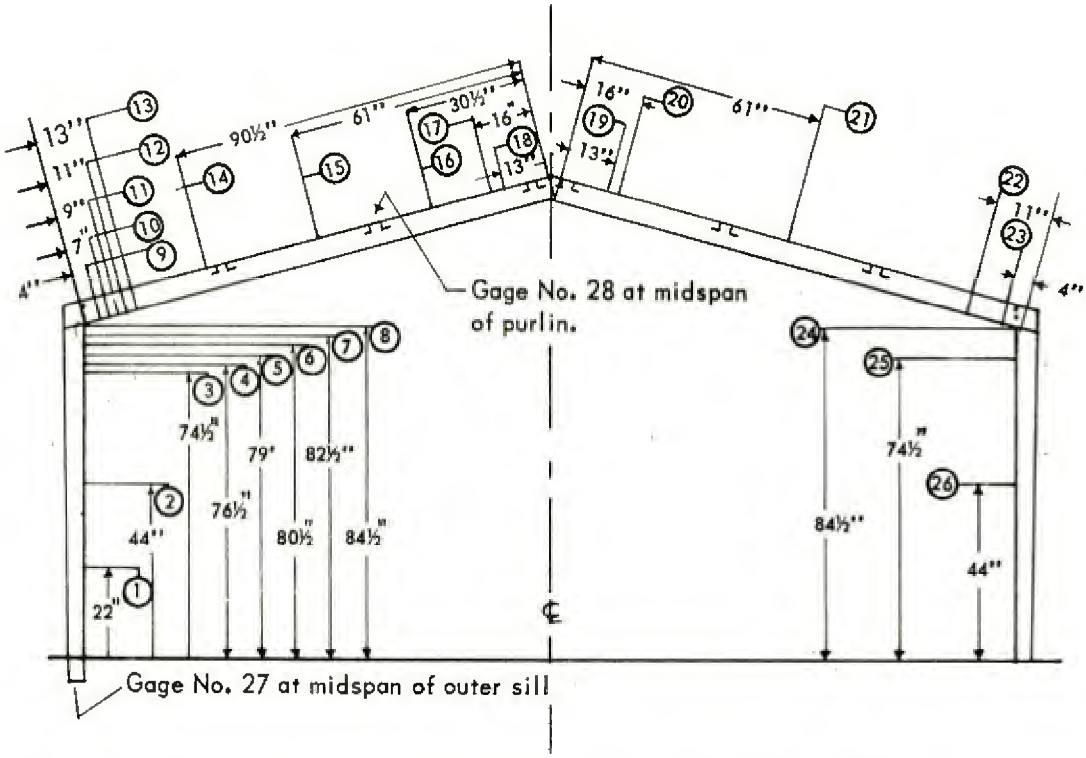


Figure 13. Location of strain gages on rigid frame

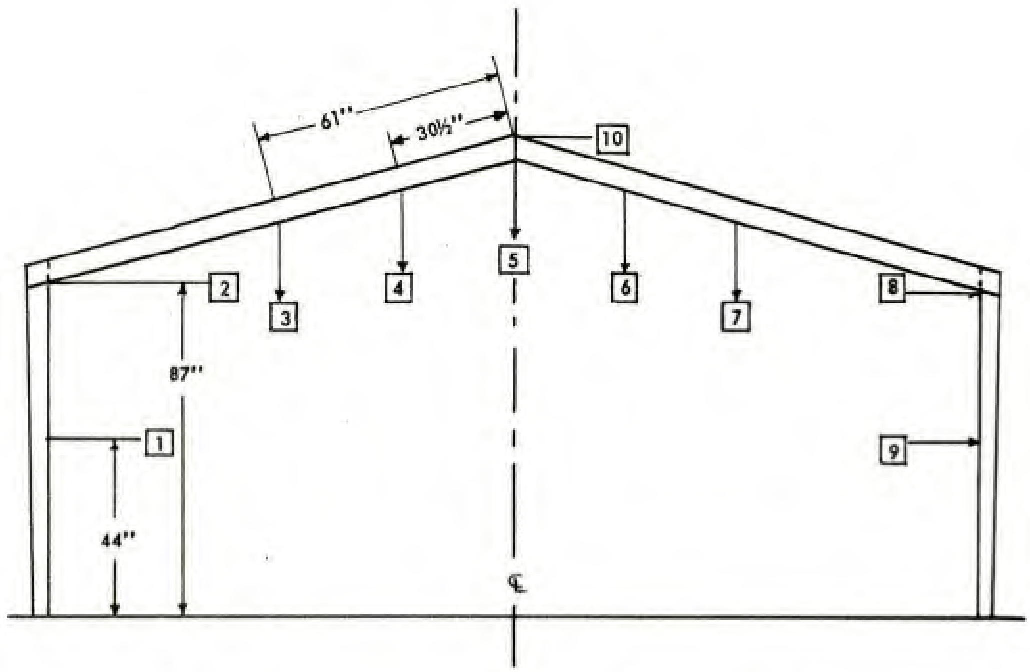
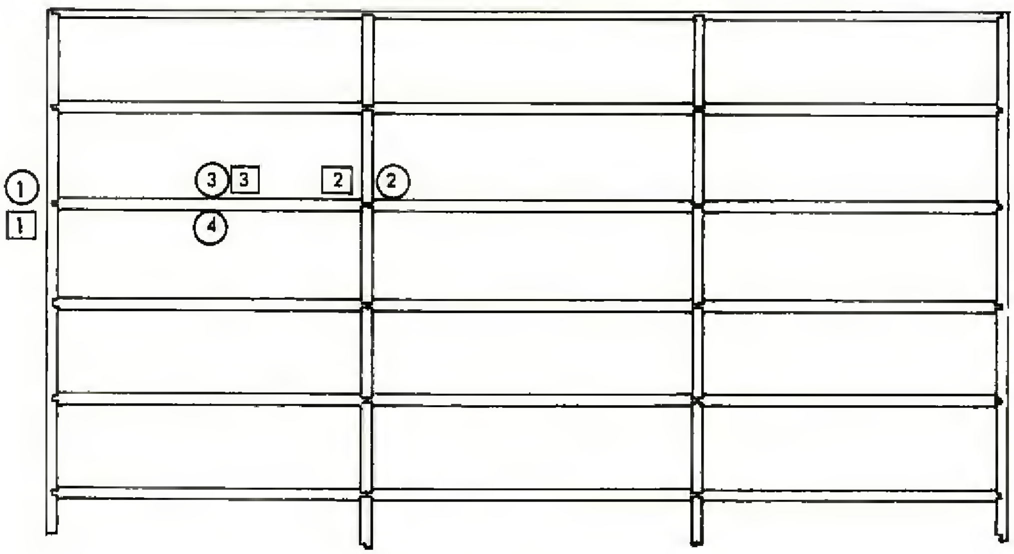


Figure 14. Location of deflection gages on rigid frame.



planned view of floor frame

section view of floor frame.

Figure 15. Location of strain and deflection gages on floor framing.

Figure 16. End-wall crate.

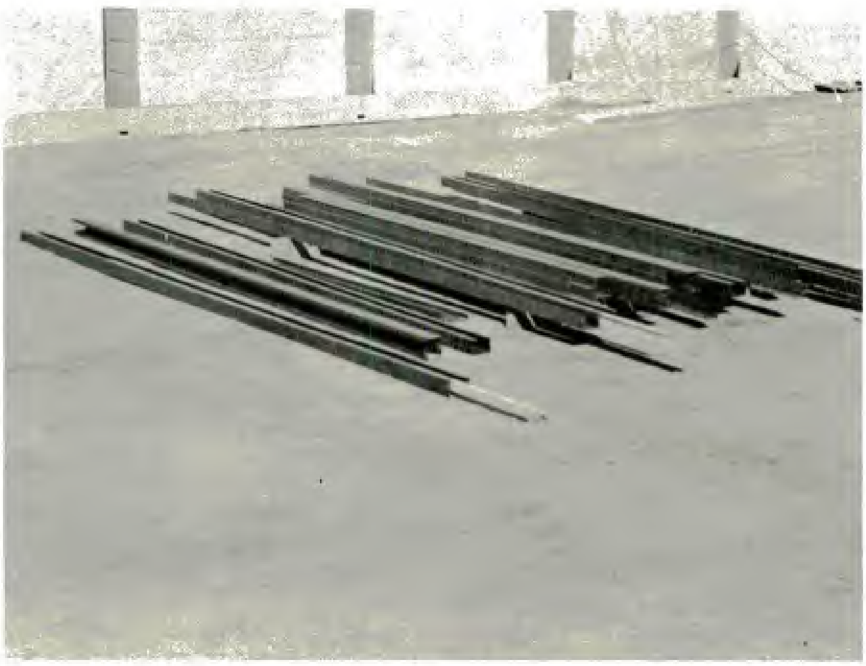


Figure 17. Contents of end-wall crate.

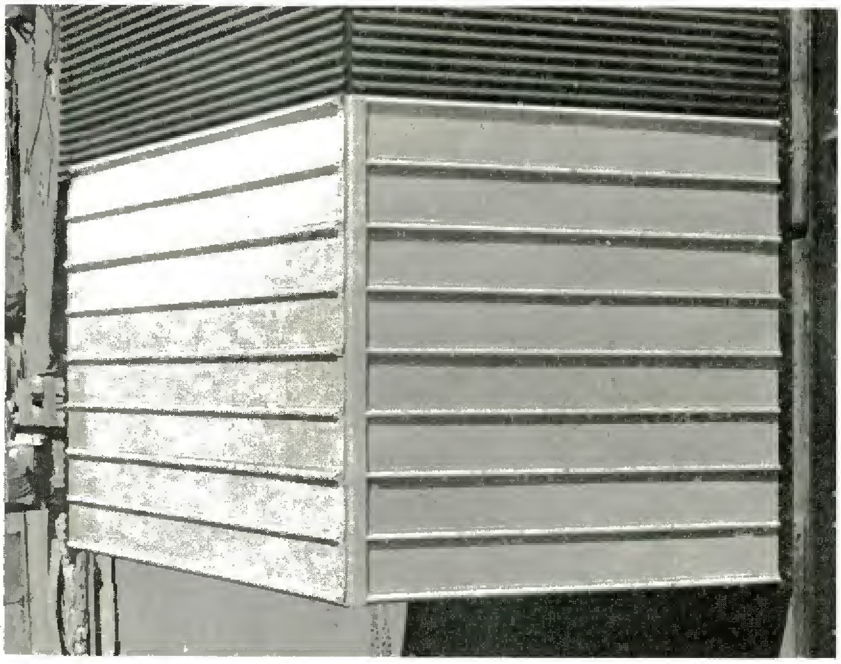


Figure 18. View showing deep-drawn exterior sheeting.

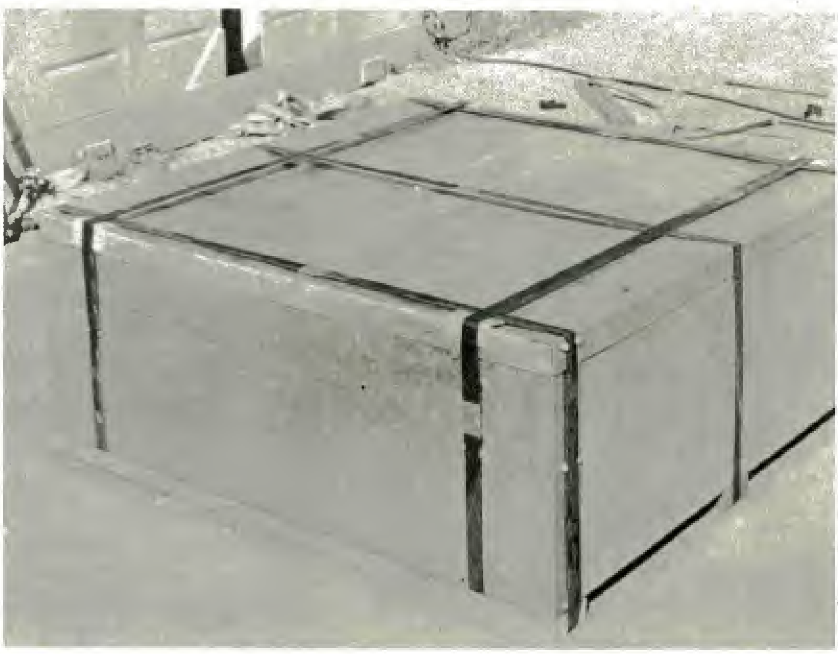


Figure 19. All metal waterproof crate for interior liner.