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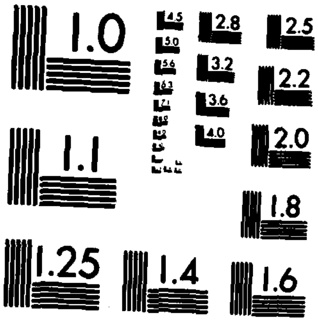

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TECHNICAL REPORT M-86/20
August 1986

Overhead Cover for Individual Fighting Position: Feasibility Study

by
Robert A. Eubanks

A study has been conducted to determine the feasibility of developing an Overhead Cover for Individual Fighting Position (OHC-IFP) that falls within a design envelope established by the U.S. Army Training and Doctrine Command's Operational and Organizational Plan for OHC-IFP and meets the criteria established by the U.S. Army Belvoir Research and Development Center in conjunction with the U.S. Army Construction Engineering Research Laboratory (USA-CERL).

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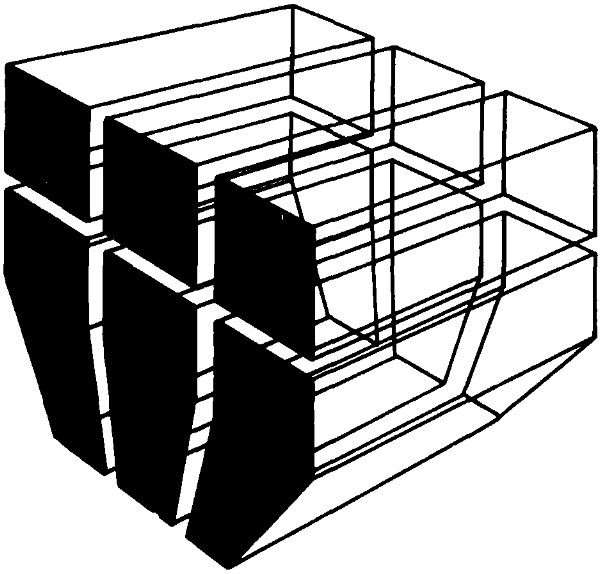

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FOREWORD

This investigation was performed for the Special Projects Branch, U.S. Army Belvoir Research and Development Center (BRDC), Fort Belvoir, VA, under Intra-Army Order A51M4, dated June 1985. Henry Schaefer is Chief, Special Projects Branch, and Tony Rodriguez was the BRDC Technical Monitor (STRBE-NCP).

This research was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. James D. Prendergast was the USA-CERL Principal Investigator. Professor Robert A. Eubanks, with the University of Illinois at Urbana-Champaign, Department of Civil Engineering, conducted the research under an Interagency Personnel Agreement. Dr. R. Quattrone is Chief, USA-CERL-EM.

COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

OVERHEAD COVER FOR INDIVIDUAL FIGHTING POSITION: FEASIBILITY STUDY

1 INTRODUCTION

Background

Several individual field fortifications have been prescribed and used in past military operations. These foxhole covers were of two basic types: natural material covers constructed onsite and prefabricated devices. The success of natural covers depends on field experience and luck in finding logs, drainage culverts, ammunition boxes, and other materials that can be used to support a soil cover over a foxhole. The prefabricated devices also have limitations in that they often must be transported by truck and placed by crane.

In 1969, Southwest Research Institute reported the development of a membrane device that weighs less than 2 lb and can support enough soil over a foxhole to offer protection from direct small-arms fire and artillery near misses.[1] This device, the Overhead Cover for Foxhole (OCF), is specification-approved (MIL-C-52707D [ME], 30 Nov 1983); however, its distribution to troops has been limited for several reasons, the most important of which are that it sags excessively when fully loaded by soil cover and that it is not a true fighting position cover because the soldier must expose most of his body to fight effectively.

An alternative overhead fighting cover is needed. Optimal design features would include portability, protective capability, ease of operation, long operational life, low maintenance, and reasonable initial cost. The U.S. Army Belvoir Research and Development Center (BRDC) asked the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to investigate the feasibility of developing such a structure.

Objective

The objective of this work is to study the feasibility of developing an Overhead Cover for Individual Fighting Position (OHC-IFP) that falls within a design envelope established by the U. S. Army Training and Doctrine Command (TRADOC) Operational and Organizational Plan for OHC-IFP and within the criteria established by BRDC in conjunction with USA-CERL.

Approach

USA-CERL considered three types of structures as potential candidates for OHC-IFP development: tension membrane, folded-plate, and fabric-covered framework. The fabric-covered framework structures showed the most promise in meeting the design requirements and therefore were analyzed in detail. Preliminary design and optimization of the structure were completed with the aid of standard finite element computer codes.

Mode of Technology Transfer

It is recommended that the results of this study be used in developing a final design for the OHC-IFP and be incorporated into any future revisions to the Military Specification for Cover, Foxhole, and Overhead Protection (MIL-C-52707D [ME], 30 Nov 1983), the TRADOC Operational and Organizational Plan for the Overhead Cover for Individual Fighting Position; and Field Manual (FM) 5-15, *Field Fortifications.*

2 DESIGN REQUIREMENTS

The OHC-IFP is basically conceived as a fighting cover for a two-man foxhole which is 2 ft by 6 ft.* Each soldier will carry half of the cover and each cover unit must be identical. It is also possible that the one-man unit can be used to cover a "gopher hole," which is 2 ft by 3 ft in plan, but this requirement is secondary. The design specifications were based on the TRADOC Operational and Organizational Plan with modifications by BRDC and USA-CERL.

Weight and Volume

The OHC-IFP unit for each soldier should weigh less than 10 lb total and should be compatible with the "ALICE" pack. As a preliminary guide, this restriction was interpreted as requiring a flat pack which is no more than 24 in. long and 20 in. wide.

Static and Dynamic Loads To Be Supported

Preliminary protection from direct small-arms fire and flying debris is to be provided by a soil covering at least 24 in. deep. This cover is a dead load which, for

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[1] T. D. Dunham and E. Jack Baker, Jr., *Overhead Cover for Foxholes,* Final Report, DA Task 1J564606D46414 (Southwest Research Institute, San Antonio, TX, May 1969).

*Metric conversion factors appear on p 16.

soil weighing 120 lb/cu ft, imposes a uniform vertical pressure of 1-2/3 psi. The structure must not collapse when subjected to a dynamic load of 15 psi for a duration of 3 to 5 msec.

Geometric Configuration

No exact configuration was specified for this initial feasibility study. It was, however, pointed out that the configuration of the previously developed *Trapezoidal Parapet Foxhole Cover*[2] is satisfactory. Although the current Trapezoidal Parapet Foxhole Cover is too heavy and not portable enough for the requirements of this design, is does satisfy a major concern that each soldier have available a 45-degree angle for interlocking fire while remaining under cover. A maximum height of about 12 in. was determined to be adequate for the OHC-IFP preliminary design.

Operating and Storage Temperature Range

Since this device must be used in any location where U. S. troops could conceivably be engaged, a temperature range of −32°F to 145°F is required for both operation and storage.

Environmental Resistance

The OHC-IFP must have the same fungi resistance, waterproofness, chemical resistance, and functionality in soil as those required of the current OCF. In addition, the OHC-IFP must be able to withstand two cycles of chemical decontamination.

Operational Considerations

Two persons should be able to erect a two-man OHC-IFP in 5 min or less. Since the cover will be used in training and maneuvers, it must withstand 60 cycles of erection, loading, and disassembly within a period of 5 years. This reusability criterion does not apply to dynamic loads; the structure is required to resist a dynamic load without collapse but is not required to be reusable after it has been subjected to this load.

Cost

When manufactured and purchased in volume, the complete OHC-IFP should cost less than $200 per two-man unit ($100 per man unit, 1986 dollars).

3 INVESTIGATION AND ANALYSIS

Evaluation of Material Concepts

Fabric Cover

The current OFC uses a polyester cloth laminated on one side with a polyester or polyvinyl fluoride. Because it meets current design requirements, this material was assumed in studying the OHC-IFP. Another possible material is a fiber-reinforced glass with a Teflon coating. It is much heavier than the OCF material, expensive, and more commonly used in structures more permanent than the OHC-IFP.

Frame

The major requirements of a structural material for the OHC-IFP frame are that it be lightweight, relatively inexpensive, and strong–yet ductile to meet the dynamic load requirement. Several materials have properties that could meet these requirements. For example, aluminum alloys weigh about 0.1 lb/cu in.; standard heat-treatable alloys (Series 2014, 2024, 6061, and 7075) are commonly used in structural applications. Various plastics also have good structural properties. Polypropylene weighs about 0.05 lb/cu in. and has a modulus of elasticity (E) of 0.55×10^6. Composite plastics are stronger than pure plastics. For example, polyester with fiberglass reinforcement weighs 0.05 lb/cu in. and has a modulus of 1.06×10^6; polypropylene weighs 0.04 lb/cu in. and has a modulus of 1.00×10^6. However, these plastics' modulus values are significantly less than those of tempered aluminum alloys and, therefore it appears that aluminum may be better suited than plastic for use on the OHC-IFP. Both plastics and aluminum maintain their structural properties in the required operation and storage temperature ranges. Most current design studies also consider the possibility of using ceramics or composites (these materials could be considered for the OHC-IFP in developing the final design). The cost of these materials would almost certainly be greater than that of standard tempered aluminum alloys; moreover, the ductility needed for shock resistance may not be present and the possible additional weight savings may be minimal.

Evaluation of Structural Concepts

Three candidate structural concepts were studied to determine which type(s) showed the most promise for the OHC-IFP. These structural types were:

1. Tension fabric
2. Folded-plate
3. Fabric-covered framework.

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[2] *Survivability Through Rapid Excavation and Field Fortifications* (U.S. Army Mobility Equipment Research and Development Command, 1980); M. J. Hammons and R. W. White, *Conventional Weapons Effects on Fighting Position Covers/Shelters*, Miscellaneous Paper SL-83-2 (U.S. Army Waterways Experiment Station [WES], February 1983); W. S. Wood, *The Effects of Blast and Flechette/Fragment Penetration on Field Fortifications*, Miscellaneous Paper SL-85-2 (WES, February 1985).

Tension Fabric Structures

All proposed tension fabric structures are essentially a modification of the current OCF. These structures have framework or plate side supports that raise a membrane high enough to allow soldiers to shoot from beneath it. The membrane is placed in tension using stakes and/or dead-man supports and the entire arrangement is covered by soil. These structures also have some of the OCF's disadvantages, including sagging and difficulty in establishing meaningful angular fields of fire. Side support design is complicated by a requirement for static stability; erection procedures are complex and vary, depending on soil type, strength, and water content. Because of these disadvantages, the tension fabric structure was not considered a promising concept for further investigation.

Folded-Plate Structures

All folded-plate structures studied have flat- or corrugated-plate construction. The simplest types are the flat-plate A-frame (Figure 1) and the accordion cover (Figure 2). Both structural concepts were examined in simplified engineering analyses.

These design concepts were found to be limited by stability problems (Euler plate buckling). The simple A-frame promises the better performance, but stability requires a total weight of 35 lb of aluminum. A polypropylene structure was checked to determine if the rigid weight requirement could be met with this lighter material. However, the extremely low elastic modulus found with this material overshadowed the decrease in weight density and imposed a greater weight requirement in overcoming the concept's stability problems than did the aluminum. The results of these simple analyses suggested that folded-plate structures are not good candidates for the OHC-IFP.

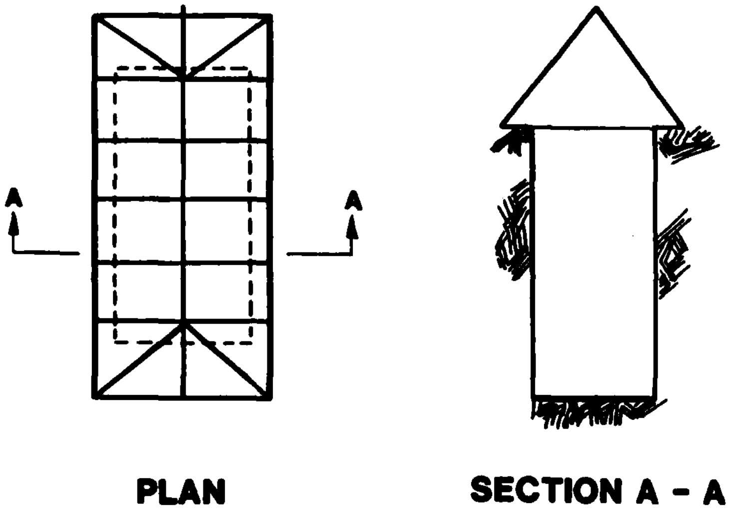
Fabric-Covered Framework Structures

The fabric-covered framework structures are composed of a series of aluminum rods and connectors arranged in a regular pattern to create a framework which is then overlaid with a fabric cover. Figure 3 is a typical perspective of the fabric-covered framework concept in the deployed mode; however, only partial soil covering is shown to illustrate the concept. Figure 4 shows only the framework to illustrate the equilateral triangles formed by interconnecting the rods and connectors. This structural concept solved the membrane sag problem characteristic of the other structures and was not as vulnerable to Euler buckling as the folded-plate structures. Based on its improved feasibility over other structural concepts, this design was further analyzed.

Fabric-Covered Framework: Preliminary Analysis and Design

Materials Selection

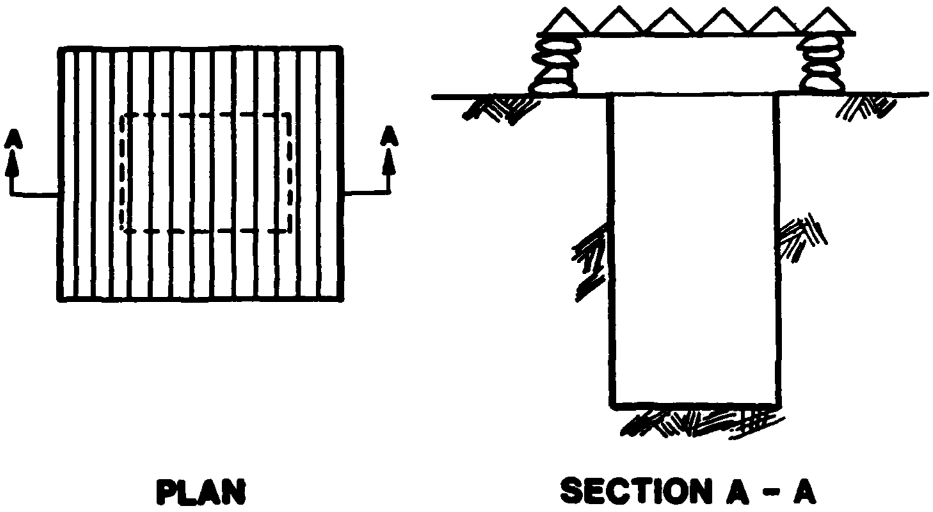
For the preliminary analysis, aluminum appeared to be the best candidate material meeting the design requirements. Tempered aluminum alloys 2024-T42 and 7075-T6 were selected for evaluation from the



PLAN

SECTION A - A

Figure 1. Flat-plate A-frame.



PLAN

SECTION A - A

Figure 2. Accordion folded-plate cover.

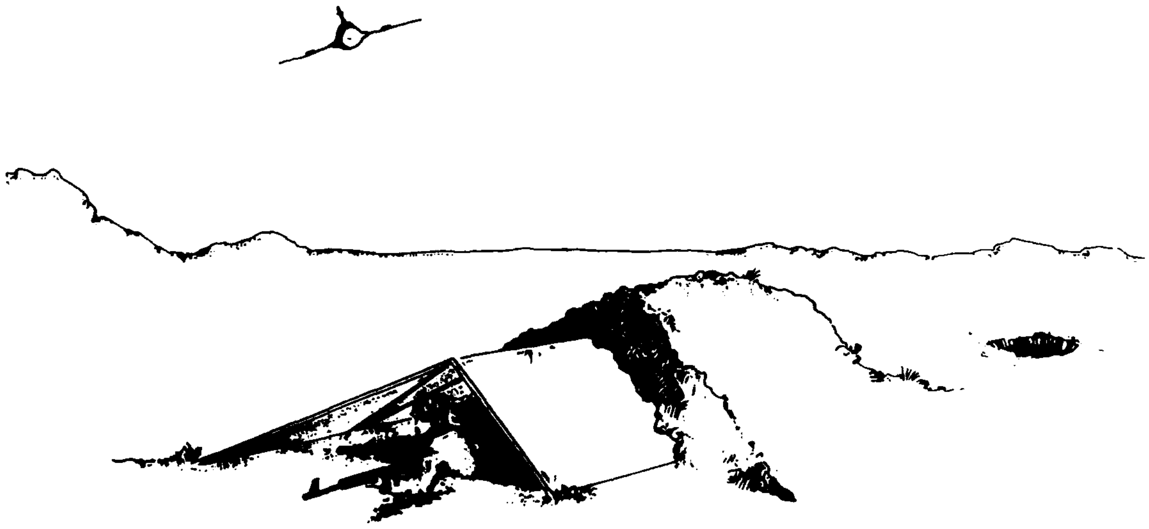


Figure 3. Deployed fabric-covered framework structure.

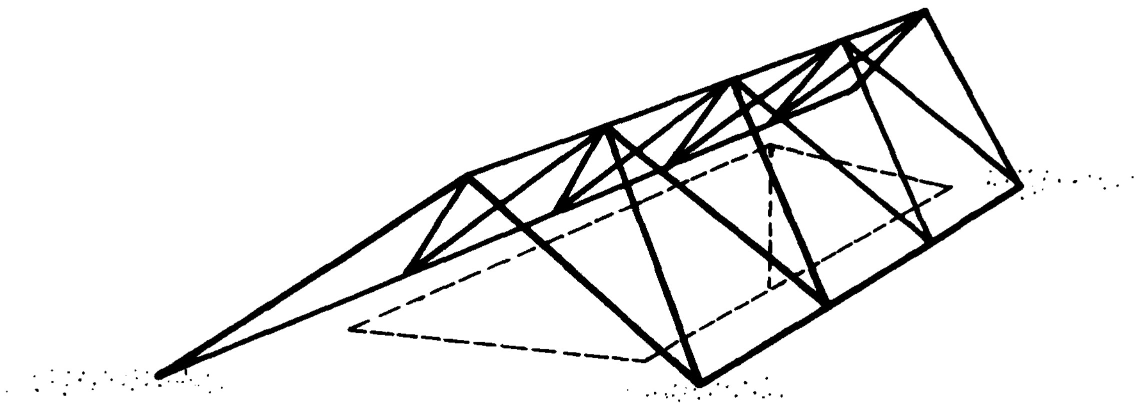


Figure 4. Fabric-covered framework structure frame.

2014, 2024, 6061, and 7075 alloy series. These alloys have high yield stress and/or high elongation capability relative to others.

Figure 5 is a reconstructed stress-strain diagram for 2024-T42 tempered aluminum alloy, which has a yield stress of 38,000 psi at 0.2 percent offset and an ultimate stress of 57,000 psi. The elongation of 14 percent in a 2-in.-gauge length implies excellent ductility. The ability of this material to absorb energy is reflected by the area under the stress-strain curve in Figure 5. Although this alloy may satisfy all the specifications, it is susceptible to corrosion without the addition of paint or another protective coating. One protective coating, "Alclad," provides high corrosion resistance but reduces the alloy's tensile strength by about 5 percent compared with bare alloys; such a coating must be added to meet the environmental resistance requirement, however.

To examine the effect of changing the material to a more expensive, high-strength, low-corrosion alloy, Type 7075-T6 extruded aluminum tubing was evaluated. Figure 6 is a reconstructed stress-strain diagram.[3] When the tube wall thickness is less than 1/4 in., this tubing demonstrates a 70,000 psi minimum yield stress, 78,000 psi minimum ultimate stress, and 7 percent minimum elongation. This elongation represents significantly less ductility than that characteristic of 2024-T42. However, Figure 6 shows that the 7075-T6 still has a high plastic energy-absorbing capacity. For the final OHC-IFP design, a detailed engineering analysis would need to be done to determine whether stresses due to combined static and dynamic loads are less than the ultimate stress of this alloy.

Framework Geometry

Figure 7 shows the geometric configuration of the framework concept. The frame-work is composed of 30 identical aluminum rods, each 24 in. long with 3/4 in. outside diameter, 1/2-in. inside diameter, and 1/8-in. wall thickness. The rods are joined together by 15 identical couplers; the total framework is thus composed of 16 equilateral triangles, each 25 in. on a side. The structure has a lateral span of 36 in., permitting a bearing leeway of 6 in. on each side of the foxhole. The framework is constructed asymmetrically and is 75 in. long on one longitudinal edge, 100 in. long at the crown, and 125 in. long at the second longitudinal edge. The resulting endports permit frontal as well as flanking fire. The geometry and construction of the framework structure meet the requirement that the OHC-IFP fit in the ALICE park.

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[3] *Aluminum Standards and Data* (The Aluminum Association, Inc., Washington, D.C., 1984).

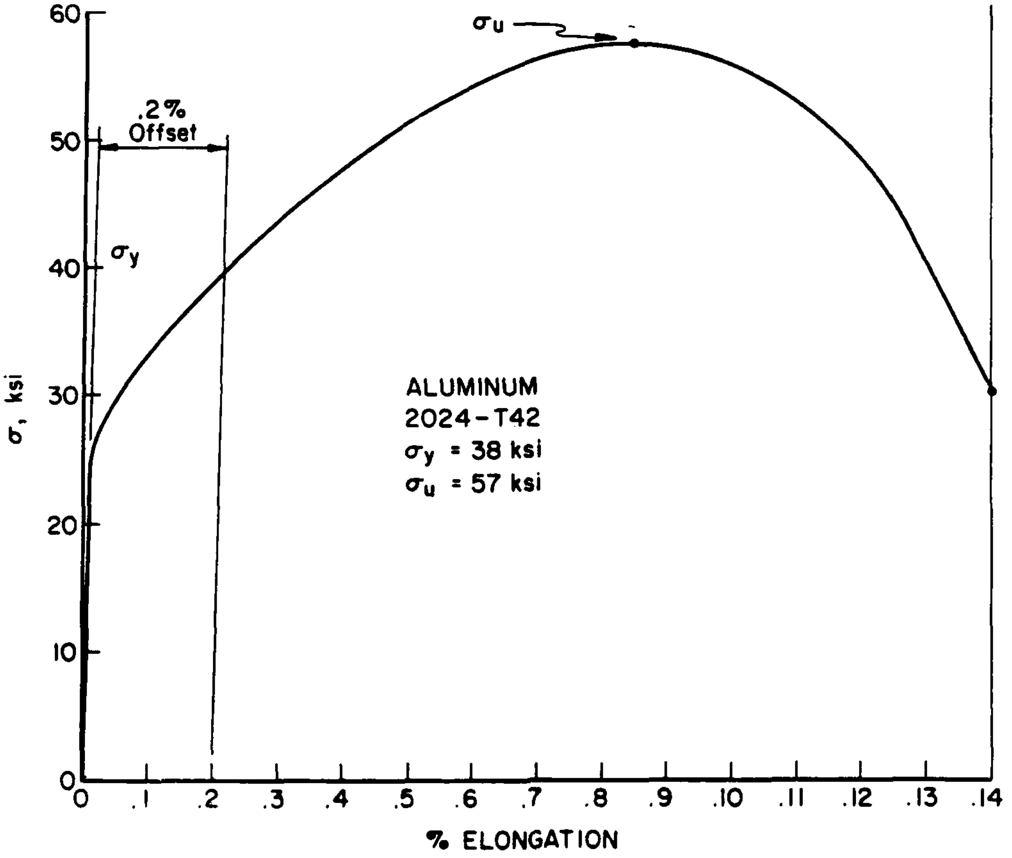


Figure 5. Stress-strain diagram for series 2024-T42 aluminum alloy.

Supports

The structure is supported both laterally and vertically by the soil. For this initial feasibility study, the soil support was represented by horizontal and vertical springs which act at each joint along the two lateral edges. Reasonable foundation spring constants for soil range from 50 to 500 psi/in. Exploratory analyses showed that the structure itself is so stiff that a variation in the soil constant does not make significant differences in structural stresses. Since the 500-psi/in. soil tested had the greatest effect in the analyses, this soil was used for all further calculations. Based on the analytical concept of elastic foundations, the horizontal and vertical springs at the four corners were calculated to have spring constants of 4687.5 lb/in.; the interior springs along the lateral edges had a calculated spring constant of 9375.0 lb/in. (Figure 8).

Frame Types

Two frame types were considered in analyzing the framework concept. The first, which will be called the "rigid frame," has joints that resist all forces and moments except for torques about the axis of the rods. Moment-resisting connectors can be spheres with holes into which the rods are inserted or spiders that plug into the hollow rods (Figure 9).

The second structure is a space truss. This structure can be connected by elastic cords that run through the rods together with rod end pieces that keep the cords from fraying (Figure 9).

Because of the support conditions and load distribution provided by the fabric cover, both structures resist loading by a combination of axial and moment resistance.

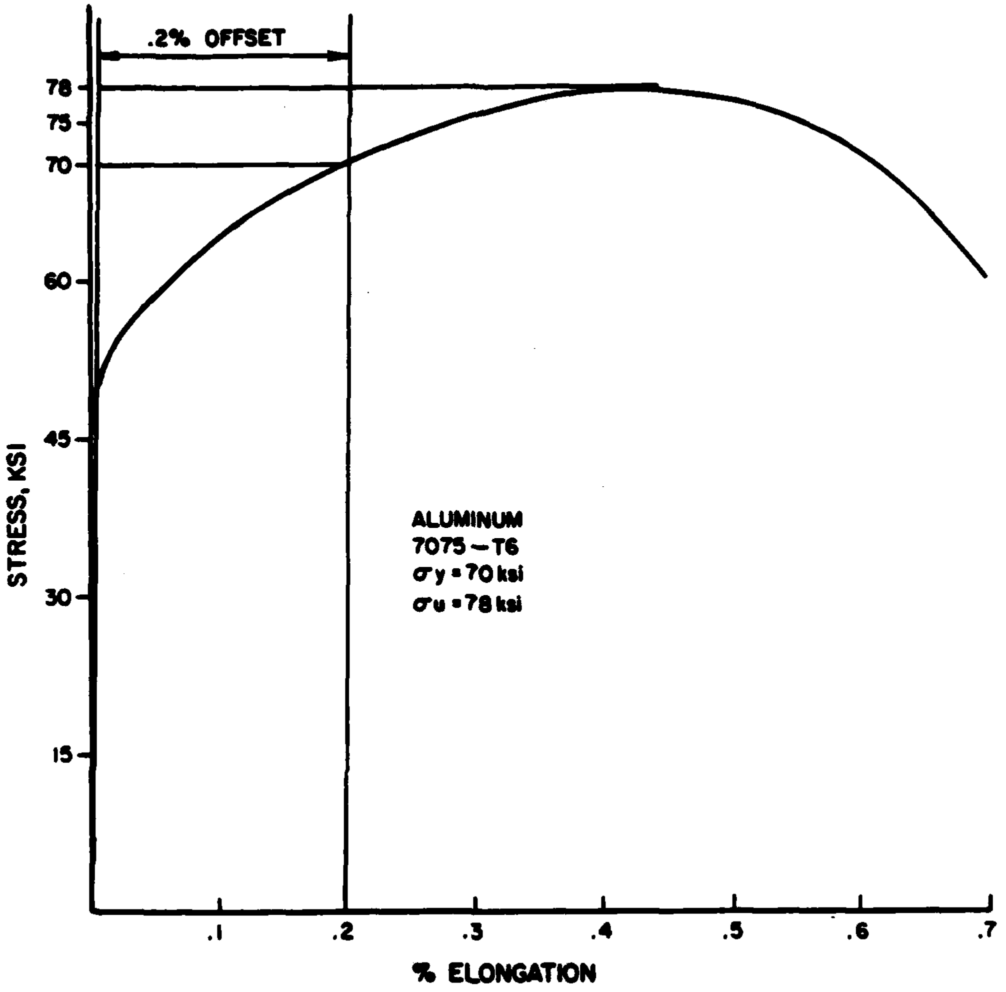
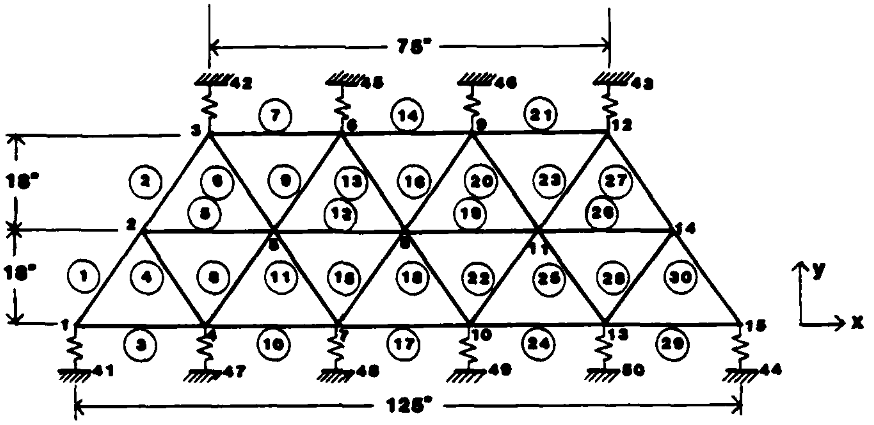


Figure 6. Stress-strain diagram for series 7075-T6 aluminum alloy.



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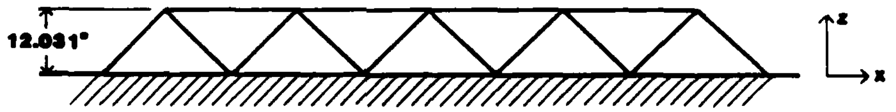

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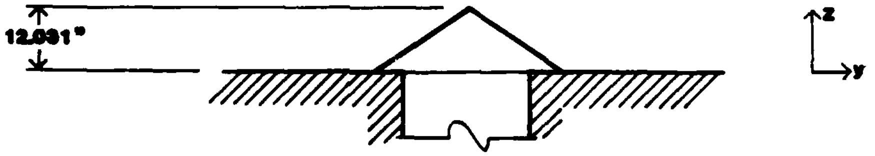

TRANSVERSE ELEVATION

Figure 7. Geometric configuration–three views.

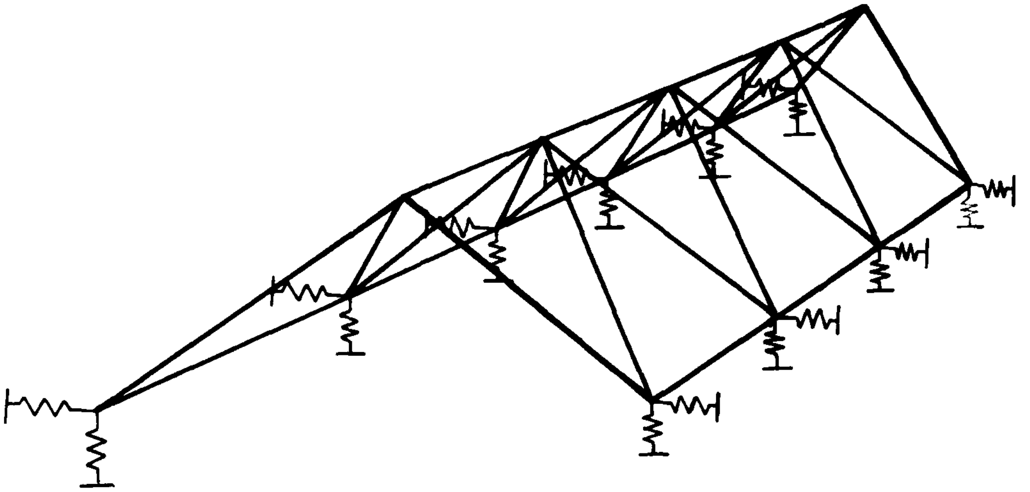

Figure 8. Structural schematic showing support concept.

Static Loading and Analysis

Two frame types were assumed to be loaded with 24 in. of soil weighing 120 lb/cu ft. It was also assumed that the fabric covering distributes this load uniformly to each of the framework's component triangles. Thus, the outer lateral elements (numbers 3, 7, 10, 14, 17, 21, 24, and 29 in Figure 7) support a load of 5.448 lb/lin in. The crown elements (numbers 5, 12, 19, and 26) carry twice this load—10.986 lb/lin in. The end elements (numbers 1, 2, 27, and 30) carry a vertical load of 4.776 lb/lin in., and the remaining internal elements carry a vertical load of 9.552 lb/lin in.

Static member forces and stresses for both structures were determined by using the general finite element computer programs FINITE[4] and IMAGES 3-D of Cybernet Express.[5] A preliminary static load analysis was performed assuming the dimensions given in *Framework Geometry* above. This system would weigh 17.67 lb when constructed of aluminum. The total system weight will be slightly less than the upper weight limit of 20 lb (10 lb per soldier).

In the rigid frame, elements 5 and 26 along the crown have maximum stresses of 21,600 psi. In the space truss, the maximum stresses also occur along the crown, with elements 12 and 19 showing maxima of 26,500 psi at the center of their spans and elements 5 and 26 showing maxima of 26,000 psi. The tempered aluminum alloys described in *Materials Selection* fit into these elastic stress levels comfortably.

Dynamic Loading and Analysis

The dynamic load specification was interpreted to mean that the loaded structure must be able to absorb a minimum energy input without catastrophic failure. The dynamic load is specified as an impulse of 15 psi for a duration of 3 to 5 msec. The period of the structure was calculated to be 0.13 sec in the fundamental mode of vibration. Using the results of the static analysis, the dynamic analysis was approximated using a triangular shock spectrum[6] which represents a dynamic magnification factor (DMF) as a function of the load duration, t_1, relative to the period of the structure, T. For the preliminary analysis, t_1/T is about 0.04; therefore, the DMF was approximated to be 0.10.

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[4] L. A. Lopez, R. H. Doddson, Jr., D. R. Rehak, and J. Urzua, *FINITE, A Structural Mechanics System for Linear and Non-linear Analysis*, Technical Report (University of Illinois, undated).

[5] *IMAGES-3D, Version 1.2* (Celestial Software, Inc., Berkeley, CA, August 1985).

[6] R. W. Clough and J. Penzein, *Dynamics of Structures* (McGraw Hill, Inc., New York, 1975).

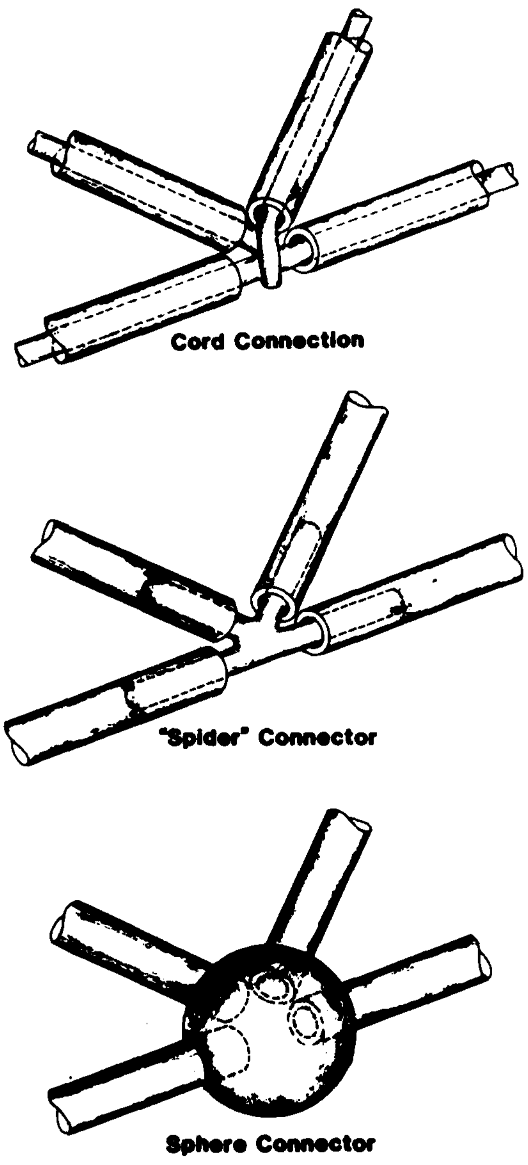

Figure 9. Connector alternatives.

For the space-truss frame, the estimated maximum elastic stress under dynamic load is 23,800 psi. The combined elastic overstress under static and dynamic loads is approximately 50,300 psi. If the ductility ratio is assumed to be represented by the ratio of the elastic overstress to the yield stress, both aluminum alloys selected can supply the required ductility.

Results of the static and dynamic loading tests indicate that this framework structure would be a feasible design for the OHC-IFP. The fabric cover is well supported by the framework and does not need the membrane strength of the current OCF cover. On the other hand, the OCF membrane construction appears to be the best material to meet some of the other specifications for the OHC-IFP (e.g., environmental resistance).

Weight Optimization

Assuming the present OCF membrane material is used, a fabric cover for the design structure will weigh approximately 1.25 lb. The connectors and/or connecting devices' weights will depend on design specifics. Several possible designs were examined and it was found that, in each case, adequate connectors weighed a total of less than 1 lb. If these values are accepted as guidelines and the 17.67-lb frame weight is added, the total fabric-covered framework will weigh about 19.9 lb. This weight depends significantly on the rod wall thickness. Since this design weight is only slightly under the limit of 20 lb for a two-man OHC-IFP, weight optimization was indicated. Therefore, previous analyses were repeated with the depth of soil cover varied.

Twenty-Four-Inch Soil Cover. With 24 in. of soil cover and a rod wall thickness of 0.039 in., a rigid-frame OHC-IFP has a total rod weight of 6.27 lb. The maximum combined axial and moment element stress due to static load for this structure is 49,500 psi. The total weight of the rods, 16 connectors, and the fabric cover should be less than 8.60 lb. This system yields a total unit weight of 4.30 lb per soldier.

Eighteen-Inch Soil Cover. If the rod wall thickness is decreased to 0.28 in., the rod weight drops to 4.57 lb. The rigid-frame OHC-IFP will support 18.1 in. of soil with a respective element stress of 50,000 psi.

Results. These results show that reducing the specification for soil cover produces little weight advantage —less than 1 lb per soldier. Therefore, the 24-in. soil cover is recommended because it affords the soldier the greater protection under dynamic loading of the structure. With 24 in. of soil cover, the two-man OHC-IFP requires 6.27 lb of aluminum. If each soldier carries a spare rod and a spare connector, the total field unit weight will still be less than 4.6 lb per soldier.

Cost

All costs include overhead, materials, and manufacturing. The 70-series high-strength aluminum alloy is more expensive than the 20-series and therefore was used to establish maximum cost. The rods can be purchased for about $3/lb in 40,000-lb carload lots. This price includes having the rods cut to the desired dimensions; no other significant manufacturing costs are envisioned. The approximate cost for the rods is thus $20 per two-man unit. The major cost associated with the connectors is for their manufacture; a cost of about $1 per connector can be assumed for a total cost of $16. The cover cost is estimated to be $50 based on the amount of material required for the fabric-covered framework structure and the cost of the material required for the current OCF. The total cost for this type of overhead cover is $86, or $43 per soldier.

Discussion

The two types of fabric-covered framework structures studied appear to be feasible designs for the OHC-IFP. The preliminary fabric-covered framework designs are constructed of 30 24-in.-long aluminum rods with 3/4-in. outside diameter and 0.039-in. or 0.125-in. wall thickness. They can be made of either 2024-T42 or 7075-T6 aluminum alloy.

A simplified analysis of the 7075-T6 alloy design with a 0.039-in. wall thickness determined the DMF to be 0.10 and estimated a combined elastic overstress of about 93,960 psi. The material meets the required ductility of 1.3.

The static load analysis for 24 in. of soil showed a maximum axial load of 707 lb. This value is well below the Euler buckling load of about 1200 lb for the rods. Therefore, the capacity for additional axial load due to dynamic loading would be insured.

The geometry and construction of the two types of fabric-covered framework structures make it feasible for the design to meet the operational requirement for rapid assembly. The final OHC-IFP will have to be tested to insure that this requirement can be met. This testing was outside the scope of the preliminary OHC-IFP design undertaken here.

In the final design phase, alternative features for the structure may be considered. For example, greater weight optimization may be possible. In the preliminary design, all rods and connectors are identical; this system wastes material because some members do not need to be as strong as others. The ridge elements are subjected to much higher stresses than any of the other elements; therefore, weight could be saved if rod elements had different strengths, depending on position. However, any savings in weight due to this type of change would have to be assessed carefully against the potential for complicating manufacture, inventory, and assembly. A lack of interchangeability in the field, along with more complicated assembly, could be disastrous.

Another design option would be to use hinged subassemblies to reduce assembly time and possibly the training required for assembly/disassembly. Although the introduction of hinges at joints will redistribute stresses somewhat, the maxima will not increase significantly. This option also must be approached with care, however, because if the frame cannot be designed with identical subassemblies, some of the same problems described above could result.

Finally, the preliminary OHC-IFP is 12 in. high. A height of 16 to 18 in. would increase operational ease and improve the geometry, thus reducing the stresses.

4 CONCLUSIONS AND RECOMMENDATIONS

Three designs for overhead foxhole covers have been investigated to determine their feasibility for the OHC-IFP concept. The fabric-covered aluminum framework design shows the most potential in meeting OHC-IFP design requirements.

Two different frame types are feasible: rigid frame and space-truss frame. These structures can be made of either 2024-T42 or 7075-T6 aluminum alloy. However, the most promising option uses 70-series high-strength, low-corrosion aluminum rods and results in a total field unit weight of less than 4.6 lb per soldier. This weight is well below the 10-lb maximum, and the frame is durable and corrosion-resistant.

Based on these results, it is recommended that a detailed engineering analysis be done as the first phase of final design. This analysis could consider some design alternatives to the preliminary concept:

- Greater weight optimization
- Hinged subassemblies
- Greater height.

Each option should be analyzed carefully and assessed for impact on the OHC-IFP design requirements—particularly the one for operational ease in the field.

Metric Conversion Factors

1 ft = 0.3048 m
1 in. = 2.54 cm
1 lb = 0.453 kg
1 psi = 6.89 Pa
1 cu ft = 0.028 m^3
°F = 32 + (°C X 9/5)

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