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DEPARTMENT OF THE ARMY
U. S. ARMY MOBILITY COMMAND

Technical Report 1769-TR

RIGID FOAM PLASTICS SHELTERS BY SPRAY APPLICATION TO AIR-SUPPORTED MOLDS

Task 1D643303D550-04

3 March 1964

U. S. Army Engineer Research And Development Laboratories

FORT BELVOIR, VIRGINIA

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Distributed by

The Commanding Officer
U. S. Army Engineer Research and Development Laboratories

Prepared by

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Developmental Fabrication Branch
Technical Service Department
U. S. Army Engineer Research and Development Laboratories
Fort Belvoir, Virginia

PREFACE

The investigation described in this report was conducted under authority of Project 1D643303D550 (formerly 8F71-04-001) and Task 1D643303D550-04. A copy of the task card is included as Appendix A.

CONTENTS

SUMMARY

This report covers the fabrication of two rigid foam plastics shelters by spray application of plastic resins to the inside surface of air-inflated molds. The first shelter was constructed of sprayed polyurethane foam with steel rib reinforcement. The second shelter was constructed of sprayed glass fiber-polyester laminate with sprayed polyurethane core.

The report concludes that the disadvantages of the spray method of fabrication far outweigh the advantages.

RIGID FOAM PLASTICS SHELTERS

BY SPRAY APPLICATION TO AIR-SUPPORTED MOLDS

I. INTRODUCTION

1. Subject. This report covers the fabrication of two rigid foam plastics shelters at the U. S. Army Engineer Research and Development Laboratories (USAERDL) by spray application of plastic resins to the inside surface of air-inflated molds. The first shelter, constructed of sprayed polyurethane foam with steel rib reinforcement, was fabricated under contract by personnel of Raven Industries, Sioux Falls, South Dakota. The second shelter, consisting of sprayed glass fiber-polyester laminate with sprayed polyurethane core, was fabricated by personnel of USAERDL.

2. Background. Military prefabricated buildings are normally produced in a fabricating plant and shipped to worldwide locations for erection and use. Buildings such as the 20- by 48-foot straight wall and arch rib Quonset types weigh approximately 11,000 pounds and occupy approximately 240 cubic feet packaged for shipment. Panelized buildings, while not appreciably heavier, occupy three to four times the shipping volume of these buildings; however, the arctic-type panel buildings are rapidly erectable under severe weather conditions. The impact of hauling heavy tonnage of building panels was particularly felt during the construction in 1958-60 of Camp Century, 135 miles out on the ice cap in Greenland. Polyurethane foam plastics solve the logistic problem by providing a worldwide-use building, considerably lighter in weight and fabricated of materials which are expanded in the field to reduce shipping volume manyfold. Experience with foam plastics structures manifested their many advantages; however, operations in field fabrication of panel structures to date have been costly and time consuming. Sufficient possibility for reduction of both cost and time was indicated by so-called inflated bag methods to warrant research along these lines.

II. INVESTIGATION

3. Raven Shelter. The Raven Shelter was constructed of polyurethane foam sprayed on the interior surface of an air-inflated mold spread over a steel framework.

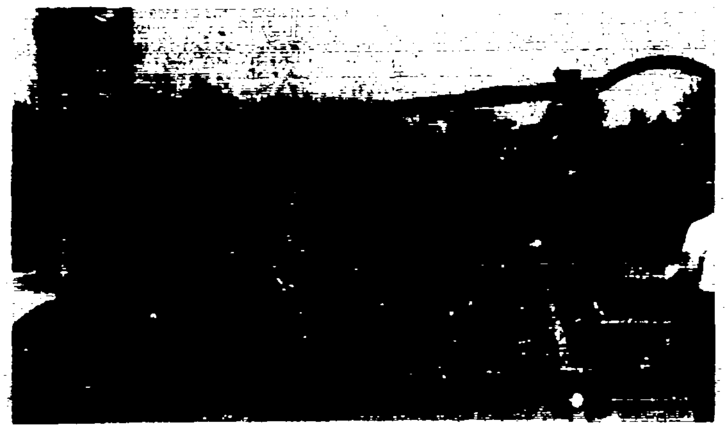
a. Description of Shelter. The completed shelter is a one-piece foam structure 20 feet wide by 45 feet long by 10 feet high at the center with an average thickness of 5 inches. Its shape, in section, is a true hemisphere with an outside diameter of 20 feet and a quarter sphere at each end.

The air-supported mold was fabricated of 11-ounce vinyl-coated nylon and could be stripped off the foam structure for re-use. A zipper access door, blower tube, grommet base, and pressure flap were also incorporated in the mold design. A flexible steel cable was sewn into the perimeter of the air-supported skirt and ground anchored with 4-inch arrowhead anchors. The requirement of air transportability of the finished structure necessitated the incorporation of an integral steel framework which would distribute the four-point pick-up loading throughout the structure. The frame consisted of a peripheral ring to which were attached six full arches in the half cylinder section and two quarter arches in the end sections with two purlins located 10 feet apart on the arches and extending 25 feet in length. To provide for pick-up points, four free-turn swivels were bolted to the purlins, one at each end. Each arch in the half cylinder section was provided with a welded base plate that extended inside the shelter periphery and served as an anchor plate through which the structure could be ground anchored with stakes. These ground anchor plates were used also as the anchor method for the finished structure. All the members were constructed of square steel tubing except the two purlins which were fabricated from 5-inch steel pipe.

b. Description of Equipment. The polyurethane spraying and pouring equipment was designed and manufactured by Raven Industries. It consisted of the usual positive displacement pumps, metering unit, and hose to deliver the materials to the spray gun. The basic design philosophy of such equipment is one of minimal material handling, thus the raw materials are pumped to the machine from the original shipping containers. An axial flow fan for the inflation of the mold was also provided by the Contractor. USAERDL provided the power source consisting of one 10-kilowatt field generator and one truck-mounted air compressor. An additional generator and compressor were available as standby in case of breakdown.

c. Fabrication Technique. A cleared area was chosen for the erection site as it offered the best location for the air transportability test. The first part of the erection consisted of assembling the steel framework, starting with the base ring and subsequently proceeding with the arches (Figs. 1 through 4). A forklift was necessary to position the two longitudinal purlins, due to the excessive weight of these members. The air mold was spread over the finished framework and secured at the ground with stake anchors. The staking operation was difficult due to the nature of the terrain, which was very dry and compact. The next phase of the fabrication

H9814
Fig. 1. Assembly of steel framework. (Subassembly of steel arches on ground.)



H9818
Fig. 2. Positioning of longitudinal purlin with the help of a forklift.

H9820

Fig. 3. End of purlin being bolted to steel arch. (Note lifting hook for helicopter pick-up.)

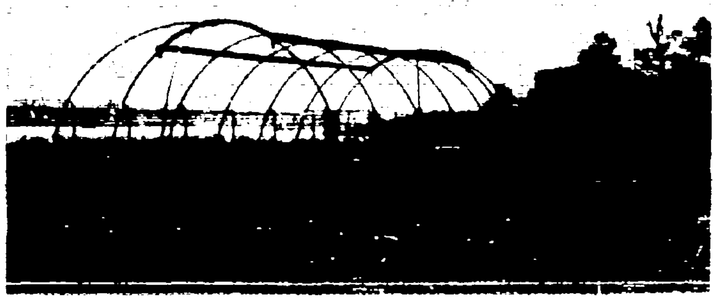


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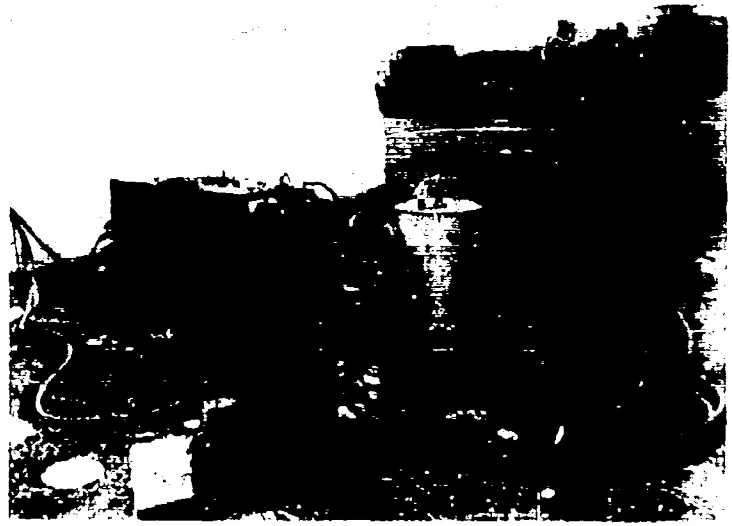
Fig. 4. Completed steel framework.

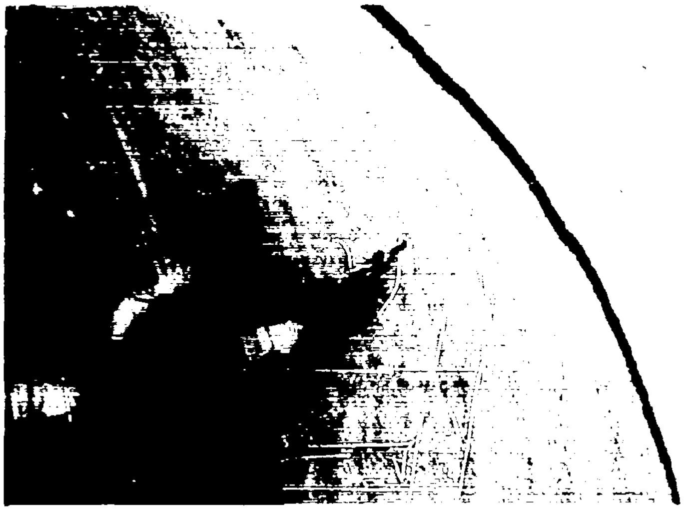


H9691

Fig. 5. Air-supported mold and equipment used in spraying operation. (Note that chemicals are pumped directly from containers (55-gallon drums).)

process consisted of setting up and calibrating equipment and inflating the mold (Fig. 5). Spraying of the polyurethane foam against the inside of the air-inflated mold followed. Two operators took turns in the actual spraying operation while a third person stood outside the inflated membrane keeping a check on the equipment. The operators were provided with masks and safety respiratory equipment while spraying inside the mold (Fig. 6). A 2-inch layer of polyurethane foam was first deposited over the entire inner mold surface. This was followed by another complete pass of about 3 inches, bringing the total thickness of the foam to about 5 inches. This was sufficient material to completely cover the steel framework.

(1) Man-Hours. The complete operation of fabricating the 20- by 45-foot polyurethane foam spray shelter, including the erection of the steel framework; laying out of equipment; spreading, inflating, and anchoring of the air mold; and spraying of the shelter, was done in seven 8-hour days. The actual spraying required four 8-hour days. A total of 2,430 pounds (approximately five 55-gallon drums) of polyurethane foam was used.



H9688

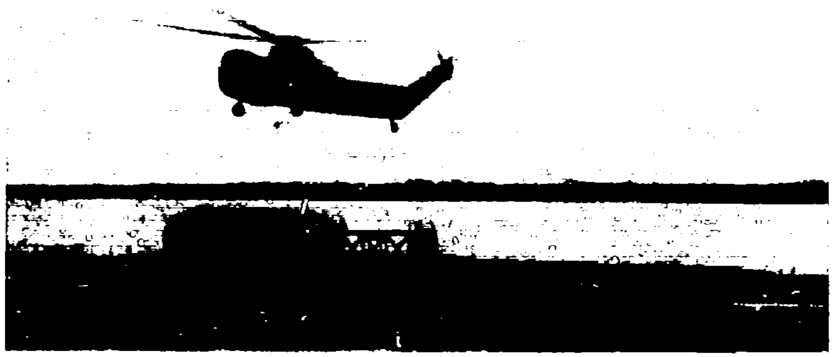
Fig. 6. Spray operators wearing safety equipment. (Note simplicity of spray gun.)

(2) Stripping of Air Mold. When the spraying operation was finished and the foam had cured overnight, the stripping of the air mold proceeded. In order to unfold the skirt or flaps of the air mold from under the shelter, it was necessary to use two forklifts lifting simultaneously from each side of the shelter until the flaps were brought to the outside. The remainder of the skirt was loosened around the periphery of the shelter by carefully prying under the frame with bars. A cable was tied to the lower end of the air mold, and with the help of a crane and two guide ropes, the final stripping of the shelter was accomplished.

d. Air Transportability Tests. In order to comply with the contract, the shelter was exposed to the following air transportability tests:

(1) Crane Lift Test. The completed shelter was lifted from the ground by a crane with a cable sling attached to the four lifting hooks provided in the frame. A visual examination of the shelter revealed no signs of failure.

(2) Helicopter Lift Test. The second test was an attempt to lift and transport the completed shelter with a helicopter (Fig. 7). As the shelter was being lifted by the helicopter, it started to spin and had to be brought down. One end of the shelter struck the ground, causing progressive failure. The shelter was damaged beyond repair, and only the structural framework could be salvaged (Fig. 8).



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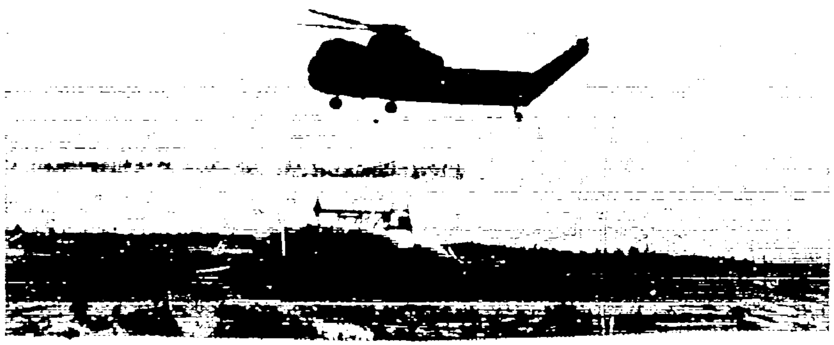


J2623

Fig. 7. Helicopter transportability test.
Top: Take-off. Bottom: Landing.

J2631

Fig. 8. Shelter after air transportability test.

4. ERDL Shelter. Inflated bag structures are becoming increasingly popular for use as temporary storage and housing. Considerable research has been expended in developing methods of rigidizing these structures, but practically all of this research has been in rigidizing with various materials on the outside of the air-inflated membrane. Since this is impractical in cold climates, the intent in the approach discussed here was to perform these operations in the interior of an air-inflated structure being maintained in the expanded position with heated air.

a. Description of Shelter. The building, as completed, is a one-piece structure, the shape approximating a half hemisphere, 12 feet high and 20 feet in diameter, with the equator located 24 inches above the base line.

b. Description of Equipment. The glass laminating equipment is comprised of a spray gun and chopper head, two pressure containers for resins, and a container for the reel of glass fiber roving. This equipment is mounted on a dolly as one compact unit with a swinging boom to carry the fluid lines and glass roving to the gun. In operation, the two resin components are delivered through the lines by regulated air pressure to twin nozzles on the spray gun. The resin components emerge from the nozzles and converge on a stream of glass fibers which are simultaneously being cut and ejected from the same gun. When these two streams commingle, they become reactive, and when deposited on a surface along with the chopped glass fiber and compacted, the whole hardens into a strong, weathertight skin.

The foam spray equipment consists of two positive displacement gear pumps with variable drive. The pumps are calibrated to deliver resin and prepolymer (foaming components) from the reservoirs to a mixing chamber. At the mixing chamber, a high-speed impeller blends the two components, and the material is discharged as a reactive mix. The chemical reaction is controlled by formulation to expand the material approximately 30 times its original volume within a desired time interval. The mixing head in this application is designed to discharge the material into a secondary turbulence chamber from which it is discharged as a spray. The formulation used is one having a short reaction time, so that the material, when deposited on a surface, immediately expands to form a self-supporting foam.

The additional equipment used consists of blowers and heaters for inflating the structure, air supply masks or helmets, paint rollers, air compressors for masks and spray apparatus, ladders, solvents, and hygienic equipment.

c. <u>Fabrication Technique</u>. The structure was fabricated directly on the leveled ground and anchored during construction by a water ballast boot around the perimeter of the inflated membrane as shown in Fig. 9.

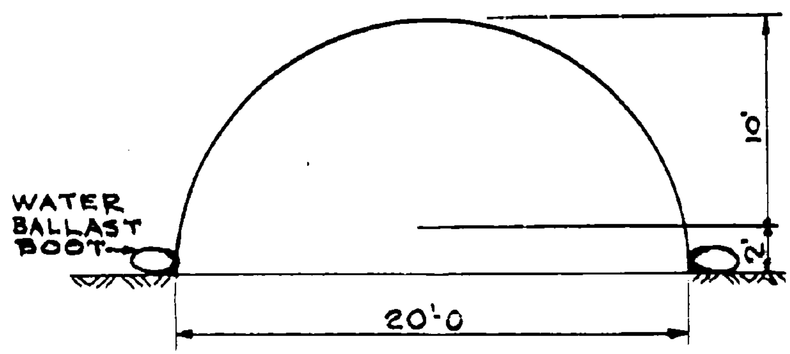


Fig. 9. Water ballast boot used to anchor structure.

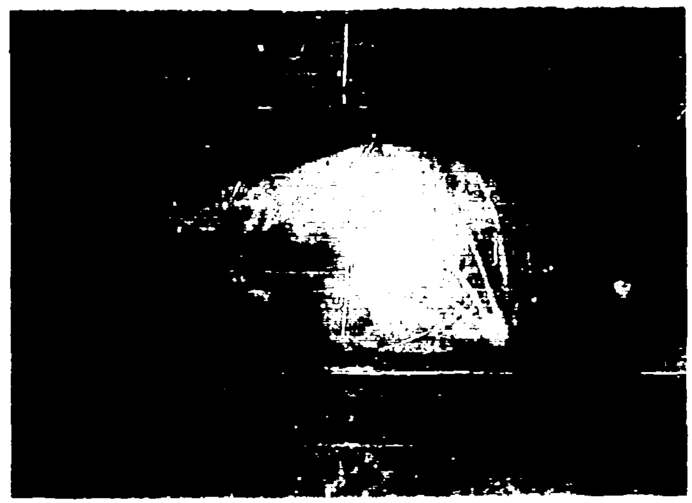
The fabricating process consists of unfolding and spreading the air-inflated plastic membrane over the floor area, positioning the air lock, filling the ballast boot around the perimeter with water, and then inflating the membrane through a circular opening in one end. In order to maintain temperatures within the membrane sufficiently high to facilitate proper cure and expansion of the laminates and polyurethane, the air for inflating the membrane is supplied by a forced air electric heater. The equipment to be used on the inside of the structure is placed under the membrane before inflating, to avoid the necessity for transporting it through the air lock.

The interior surface of the membrane is sprayed with glass fiber and polyester resin and compacted with rollers. As soon as the polyester laminate has cured and become self-supporting, a coat of sprayed polyurethane foam is applied. The polyurethane expands to a lightweight insulating material which, in turn, is covered with another glass fiber resin laminate similar to the first. The composite structure ends up as a lightweight, stressed skin structure with high strength and insulating value. Upon completion of the operations, the membrane is intended to be capable of being removed and reused, if desired, or may be left on the structure.

(1) Preparation of Area. Preparation of the site consisted of clearing trees and leveling a space approximately 40 by 60 feet and then covering the leveled area with a 2-inch layer of sand. Glass fiber-faced honeycomb panels, 3 feet by 22 feet by 6 inches, were fabricated and used as a floor. The panels were supported on a series of stringers made of the same material. The floor was placed on the prepared area and covered with polyethylene film to prevent moisture penetration into the paper core.

(2) Preparation of Equipment and Materials. The equipment was installed on this floor, and the membrane and air lock were positioned as required. The ballast boot was then inflated with water to anchor the structure. This operation was extremely difficult because the water flowing to find its own level rolled the ballast boot and forced it completely off the floor. After several unsuccessful attempts to secure the ballast in position with sandbags and by other means, the elevated floor was removed and operations proceeded directly on the earth floor. Some adjusting and anchoring of the ballast boot were still necessary because of unevenness of the ground. The boot, being continuous, permitted the water to flow to the lower levels and to empty completely in the higher elevations. When the ballast boot was adjusted, an electric-powered

blower-heater was attached by flexible hose to the air inlet fitting provided for the purpose, and heated air was introduced (Fig. 10). The heater supplied was found to be inadequate in both heat and air output, making it necessary to supplement this with a gasoline-powered blower. This was considerably more input than was originally expected to be required, but experience in later operations showed that a great volume of air had to be evacuated and replenished in order to clear the area of dust, mist, and fumes. The amount of air necessary to maintain inflation of the structure during off hours was considerably less.



J4013

Fig. 10. The air-supported structure fully inflated and ready for the spraying operations. The plastic membrane consists of nylon mesh with an inner facing of Mylar and an outer facing of polyethylene.

(3) Fabrication Process. It was planned to simulate as much as possible the environment that normally could be expected in a field of operation, with support from local facilities not exceeding that which would be available in such areas. For this reason, the project was scheduled during a cool month (April) so as to adequately evaluate the practicability of heating the work area and maintaining working conditions in inclement weather. Personnel had no preliminary training in this operation but did have a background of plastics fabricating

J4011

Fig. 11. The first operation - spraying the base with glass fiber and polyester to stabilize the ballast boot.

J4050

Fig. 12. Continuing the process of generating a self-supporting skin of glass fiber polyester laminate. One operator is depositing the laminate, and another operator is compacting the sprayed laminate by rolling. (Note the heavier passes at the seams. This technique was intended to lend rigidity by creating a supporting grid.)

technology. It was conceded that a minimum nucleus of semi-trained troops would be necessary for similar operations in the field. The equipment used was standard and was available from commercial sources. The membrane and special apparatus were designed for compact packaging. Personnel were instructed in the assigned task and operated independently of USAERDL facilities, drawing only electric power from line source and air from a portable compressor. When the structure was stabilized, the glass laminating and foam dispensing equipment was prepared for operation, and safety and hygiene equipment was readied for use. It was expected, and soon became evident, that no operations could be conducted without respiratory equipment for the operators. The equipment used was Mine Safety approved full air supply masks with air supply lines extending to fresh air pumps or blowers installed outside the structure. Since it was realized that the materials deposited on the interior surface would add even more burden on the air support blowers in order to maintain inflation, the glass fiber laminate was deposited in such a way as to rigidize the structure without appreciably adding to the weight. This was done by spraying the glass fiber polyester laminate in a grid pattern so as to form a structural skeletal framework, when cured (Figs. 11 and 12).

At the same time, it became obvious that the size of the inflated structure was such that the entire operation would consume a much greater man-hour effort than had been anticipated. It was decided, therefore, to continue the operations only as far as the "spring-line" at one of the ends and to terminate the structure with a straight closure wall on the open end as shown in Fig. 13.

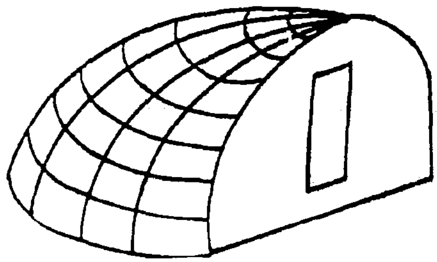


Fig. 13. Structure as modified, with a straight closure wall on the open end.

The operations proceeded on this smaller area, and the glass fiber laminate was deposited over the entire surface and compacted by rolling the laminate with paint rollers. Three men were employed in this operation: One to spray, one to tend equipment, and one to roll or compact the sprayed laminate. When an average thickness of 1/16 inch of material had been deposited over the designated area, this operation was terminated and the polyurethane foam spray operation was commenced (Fig. 14). The end wall closure was not fabricated at this stage, so as to not restrict access to the processing equipment while the major part of the structure was being fabricated.

The optimum thickness of the foam layer which would constitute the core is generally considered to be 2 inches; however, in spray applications it is difficult to maintain a uniform deposited thickness, and the experience in this case was that variations from 2 to 4 inches were dictated by limitations of equipment and operator technique.

The expanded foam was built up as a core layer over the previously deposited glass fiber laminate. In consideration of the minimum load-bearing capabilities of the structure at this stage, the polyurethane deposit was applied in horizontal passes, beginning at the base line and progressing toward the dome. This technique materially assisted in creating the strength required to support each successive pass.

After the polyurethane application was complete, the second glass fiber laminate was applied in the same manner as the first except that the compacting or rolling operation was eliminated above the 5-foot height on the walls and roof. This was necessary because of the extreme roughness of the polyurethane spray coat.

The end wall closure was then fabricated by draping the opening with burlap and spraying resin and glass fiber and polyurethane foam, using the same procedures used in the rest of the structure. An access door approximately 3 feet by 7 feet was cut out of the end wall closure as shown in Fig. 15.

After the equipment was removed, and the membrane was stripped from the structure, the construction phase of the project was considered closed (Figs. 15 and 16).

J4096

J4094

Fig. 14. Polyurethane foam spray operation. (Note the uneven buildup of the successive passes with the gun.)

K6456

Fig. 15. Closure wall and access door of completed building.

K6457

Fig. 16. Completed building.

d. Tests. The only purposeful tests on the structure were considered to be those of weatherability and aging. In this regard, the evidence after 1 year shows that no visible change is taking place except that the polyurethane foam is gradually darkening in color due to the action of sunlight.

III. DISCUSSION

5. Raven Shelter. The basic concept of using expanded foams as a structural material came as a possible solution to the logistic problem of having to ship heavy and bulky panels to remote areas at great expense. The method of spraying foam against a reusable air mold provided a suitable approach toward the solution of this problem, but other methods have proven more practical and economical.

a. Disadvantages of Spray Technique. The disadvantages of the spray method are as follows:

(1) Too many different pieces of equipment are required to do the job. The generator and compressor have to operate continuously until the foam is self-supporting, otherwise the shelter will collapse.

(2) High humidity affects the spraying operation. In this test, spray operations had to be suspended because of high humidity and resultant poor quality foam. It was determined that 75 percent relative humidity was the maximum allowable for spraying foam.

(3) The concentration of toluene diisocyanate (TDI) fumes released during the spraying operation constitutes a health hazard (many foams do not possess this characteristic), requiring the spray operators to be equipped with protective masks and respirator equipment, thus impairing the speed and effectiveness of the operation.

(4) Although the air mold is reusable, it is necessary to use an excessive amount of equipment such as forklifts, cranes, and pry bars (not always available at a construction site) to remove the air mold from the shelter.

(5) In this test, the quality of the foam obtained from the spraying process was inferior, in many ways, to that of straight poured foams. Although the density of the foam was about 2.6 pounds per cubic foot, the compressive strength was in the 20-pounds-per-square-inch range, which is considered low.

There were sections in the shelter where the foam was so saturated with water that it could be squeezed out as from a sponge. This condition probably accounted for the high coefficient of thermal conductivity (0.63) which is considered much too high for polyurethane foam. (See Appendix B, Materials Branch Report No. 9579-1.)

(6) The general appearance of the interior is not satisfactory for use of the shelter as personnel quarters. The spray foam leaves a rough finish which collects dirt and is unattractive.

(7) After being stripped from the mold, the shelter has to be covered with some protective skin, adding an extra time-consuming step to the operation.

(8) A highly skilled crew is required to do this fabrication, and the rate of production is much slower compared to that of the straight pour method.

b. Advantages of Spray Technique. The advantages of the spray method are as follows:

(1) The air-inflatable mold offers a versatile, lightweight, low cubage pack for easy transportation. It is reusable and can be constructed of different materials.

(2) By spraying on the inside surface of the air mold, personnel engaged in the operation are provided protection from the weather.

(3) The spray method provides a continuous monolithic structure which is free from joints, thus avoiding the use of fasteners.

(4) The shelter can be adapted to various types of terrain without necessitating special foundations.

6. ERDL Shelter. Insofar as possible, this experiment was conducted under average field conditions in order to observe power requirements and to establish guidelines for fabrication techniques. The work was done in the early spring and continued daily without shutdown because of weather or temperature.

The rate of production was considerably below that which had been anticipated. This was partly due to the experimental nature of the job and novel techniques but mainly because of problems with materials, handling, equipment breakdown, maintenance of support equipment, and operator's awkwardness of manipulation when encumbered with protective equipment such as air supply helmets. Some of the problems were resolved, but other problems are little closer to solution. For instance:

a. An air-supported building becomes increasingly more difficult to maintain in proper form as the various sprayed materials add their weight to the inflated film or membrane.

b. Regardless of air input or exhaust volume, it is extremely difficult to effectively scavenge the contaminated air from the structure.

c. The BTU input required in cold climate to maintain satisfactory working temperatures in the structure is in excess of capacity of normal available equipment.

d. Spray application of foaming materials is wasteful in that spray mist or overspray loss accounts for as much as one-third of the materials used.

IV. CONCLUSION

7. Conclusion. It is concluded that the disadvantages of the spray method of construction far outweigh the advantages.

APPENDICES

APPENDIX A

AUTHORITY

RDT & E PROJECT CARD

1. Type of Report	☐ New ☐ Final ☒ Replaces (No. & Date) 1D643303D55001 1 Jan 1963
Report Control Symbol	CSCRD-1 (R3)
2.	Task Title: Rigid Foam Plastic Shelters (U)
3. Security of Project	Unclass
4. Project No.	1D643303D550-04
5.	5.41.33.03.1
6. Report Date	1 Jan 64
7. Basic Field or Subject	RD-CAT Engineering Dev
8. Sub Field or Subject Sub Group	
9. Category	DT
10a. Cognizant Agency	AMC - MOCOM
b. Directing Agency	MOCOM - ERDL
c. Requesting Agency	CDC
11a. Contractor and/or Government Laboratory	USAERDL, Fort Belvoir, Va
b. Contract Number	
12. Participation by Other Military Depts. and Other Govt. Agencies	None
13. Coordination Actions w/Other Military Depts. & Other Govt. Agencies	None
14. Supporting Projects	None
15. Date Approved	
16. Priority	III
17. Budget Code	5600
18. Est. Completion Dates	Dev. 1966; Engr Test 1967; User Test 1968; Operational 1969
19. Est. Support Level	☒ Under $50,000; ☐ $50,000 - $100,000; ☐ $100,000 - $250,000; ☐ $250,000 - $500,000; ☐ $500,000 - $1,000,000; ☐ Over $1,000,000
20.	
21. Special Codes	AMC MS Code No 5659.12.762

22. Requirement and/or Justification

a. Requirements exist for lightweight rigid shelters and buildings which can be fabricated in the field from low shipping bulk materials transported at a density of approximately 60 pounds per cubic foot and expanded at construction site to form a rigid building core material of approximately two pounds per cubic foot density, thereby obtaining approximately 30 cubic feet of building material on the site for each cubic foot shipped.

b. The above concept is in consonance with paragraph 1612d, CDOG, which states that military requirements exist for all weather shelter units in all ranges of covered space provisions, including maintenance of vehicles, missiles, and other mechanical/electrical equipment, command posts, air stations, fire direction centers, personnel housing, collective protection and other general purpose requirements.

23. Brief of Project and Objective

a. Brief:

(1) Objective:

(a) Development of low shipping bulk, high density materials which can be stored in all environments and expanded in the field to form a rigid lightweight building material.

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RDT & E PROJECT CARD CONTINUATION	REPORT DATE 1 Jan 64	PROJECT NO. 1D643303D550-04

(b) Development of field techniques and means of expanding low bulk materials of high density to form rigid lightweight panels or shelter modules that can be assembled into shelters in the field with a minimum of skilled labor.

(c) Development of fabrication equipment and all necessary accessory equipment for rapid production of panels or shelter modules in the field.

(2) Technical Characteristics: See Exhibit A

b. Approach:

(1) Engineer research and development work will be performed by the technical staff of the Engineer Research and Development Laboratories with assistance from research and engineering staffs of commercial suppliers as needed.

(2) Engineering research and studies will be undertaken in the following areas to determine the most suitable means of satisfying the overall military requirements:

(a) Development of foam plastics, honeycomb, or other type of suitable materials which may be shipped in high density low bulk packages, stored in all environments, and expanded at the construction site to form rigid, lightweight, economical shelters or buildings.

(b) Portable field fabrication equipment.

(c) Techniques of fabricating shelters in all climates.

(d) Methods of reinforcing shelter core materials to produce high-strength, stressed-skin structures capable of sustaining forces produced in areas where high snow and wind loads are encountered.

(e) Development of structural design criteria for structures fabricated of reinforced rigid foam plastic or other lightweight core materials.

(f) Design of shelters and buildings in consonance with the concept which may be produced and erected at a very high rate under field conditions with a minimum of unskilled labor.

(3) Comprehensive engineering tests of pilot model shelter, field fabrication equipment, including techniques, will be conducted to determine the general suitability and to determine necessary modifications prior to submittal for user tests. Drawings and purchase descriptions shall be modified to reflect the equipment passing the tests.

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(4) Service test equipment shall then be procured and furnished to the weapons systems or application for which the equipment was developed.

(5) After all tests and necessary revisions of the equipment have been accomplished, complete drawings and specifications will be prepared, together with recommendations regarding classification action on the equipment developed.

c. Tasks: Not applicable

d. Coordinated Test Plan (CTP):

Coordination will be made with the U. S. Army Test and Evaluation Testing Agency in connection with the engineering-service test phase.

e. Other Information:

(1) Scientific Research: None

(2) Reference: None

(3) Discussion:

Agencies interested in this project, with which liaison will be maintained and which will be furnished copies of reports on the project are USACDMARC, Medical Corps and Quartermaster Corps.

EXHIBIT "A"

TECHNICAL CHARACTERISTICS FOR
RIGID FOAM PLASTIC SHELTERS

1. The rigid type shelters formed in the field by use of low density core materials shall consist of all weather units in all ranges of covered space provisions, including maintenance of vehicles, missile, and other mechanical/electrical equipment, command posts, air stations, fire direction centers, personnel housing, collective protection and other general purpose requirements.

2. Means shall be developed for fabrication of shelters under all environmental conditions as specified in AR 705-15.

3. Shelters shall be capable of being constructed for all climate operations to withstand steady winds of 60 miles per hour and to support snow loads of 20 pounds per square foot. Features shall be incorporated (in kit form if applicable) to permit the shelters to be used in areas where snow loads reach 40 pounds per square foot and wind loads correspond to velocities of 80 miles per hour with gusts of 120 miles per hour.

4. The shelters shall be made of the smallest possible number of components and component types, and be capable of easy handling and rapid erection by personnel within companies and battalions.

5. The shelters shall be compatible with chemical, biological, and radiological protection.

6. The shelters shall be durable, weatherproof and fire retardant. They shall not be subject to appreciable weather deterioration, or attack by insects, fungi, bacteria, or rodents.

7. Wearing surfaces, both exterior and interior, shall withstand normal barracks type use.

8. The completed system shall permit erection of variable length shelters.

9. Provisions shall be made in the design of the shelters for the installation of standard or fabricated on the site doors and windows located on both sides and/or ends.

10. The shelter equipment shall be lightweight and portable for field service, sufficiently rugged to withstand prolonged cross-country movement and transportation in Phase II of airborne operations. It shall be designed with maximum simplicity commensurate with intended performance and be capable of manufacture in quantity by modern fabrication methods.

APPENDIX B

The Materials Branch
U. S. Army Engineer Research and Development Laboratories
Fort Belvoir, Virginia

ERD SM 3 October 1961

EVALUATION OF POLYURETHANE FOAM FROM BUILDING
FABRICATED BY RAVEN INDUSTRIES

Report No. 9579-1

Requested by: Special Equipment Branch

Authority: Project No. 8F71-04-001-04

1. The purpose of this work was to evaluate a sample of polyurethane foam taken from a shelter which was formed by spraying. The foam was made from a Cook Paint Company product. The shelter was fabricated by Raven Industries personnel, using equipment supplied by that company.

2. The properties which were tested were density, flame resistance, compressive and flexural strength, and the coefficients of thermal expansion and thermal conductivity. They were determined in accordance with the following procedures:

a.	Compressive Strength	Fed. Spec. LP406b Method 1031 Samples were 1 in. by 1 in. by 1 in.
b.	Flexural Strength	Fed. Spec. LP406b Method 1031 Specimens were 1 in. by 1 in. by 6 in.
c.	Density	Fed. Spec. LP406b Method 5012
d.	Flame Resistance	A flexural specimen was marked with a crayon with lines spaced 1 in. apart. The specimen was then held with a clamp at one end in a horizontal position in

a hood and ignited with a Bunsen burner at the unclamped end. When the flame reached the first line, the burner was removed, and the speed of propagation was measured with a stop watch. If the flame did not propagate beyond the first line, another specimen was taken. This was held in a vertical position, and the test was repeated. If the flame did not propagate beyond the first line when the burner was removed, the specimen was considered self-extinguishing. Otherwise the results were reported in inches per minute when the specimen was held in the horizontal position.

e. Coefficient of Thermal Expansion	Specimens approximately 12 in. long and 1 in. thick were measured both before and after being exposed to a temperature differential of 200° F. The thermal conductivity was then calculated by using this data.
f. Thermal Conductivity	A specimen approximately 0.10 in. thick was used in conjunction with a Cenco-Fitch heat conductivity apparatus No. 77555. In principle, the apparatus comprises a source of heat (boiling water) at constant temperature and pressure in contact with a layer of the material under test, and, on the other side of the layer, a receiving block of copper of known thermal capacity. The heat source and receiver are provided with a thermocouple for measuring the temperature difference between the two sides. A galvanometer connected to appropriate binding posts shows a deflection proportional to the temperature difference between source and receiver.

3. The results of the tests were as follows:

Density (lb/cu ft)	2.68
Compressive Strength (psi)	22
Flexural Strength (psi)	41
Flame Resistance (in./min.)	Self-extinguishing
Coefficient of Thermal Expansion (in./°C)	4.77×10^{-5}
Coefficient of Thermal Conductivity (BTU/(hr)(sq ft)(°F)(in.))	0.63

4. The foam has very good flame resistance and exceptionally high thermal conductivity. The latter may be attributed to the weather at the time of foaming. The humidity was so high at one time that a halt was called to the spraying. Evidently moisture had been trapped in the foam, resulting in an increase in the coefficient of thermal conductivity (K factor). It was reported later by Mr. Bartelmes and Mr. Hedrick of the Special Equipment Branch and by Mr. Robertson of the Climatic Research and Test Branch that water could be squeezed out of the foam from the wall on the inside of the shelter. This may partially account for the unusually high density, since it is understood that the foam density was supposed to be in the neighborhood of 2.0 lb/cu ft. There was an accident during the preparation of the foam which resulted in the loss of a quantity of foaming agent.

5. It is concluded that the foam is outstanding in its high K factor but that this may be due to the high humidity existing during the foaming operation.

6. It is recommended that a further investigation be made of the effects of atmospheric conditions on the qualities of foam produced by spraying.

Submitted by: S. GOLDFEIN
Chief, Plastics Section

Forwarded by: A. W. VAN HEUCKEROTH
Chief, Materials Branch

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