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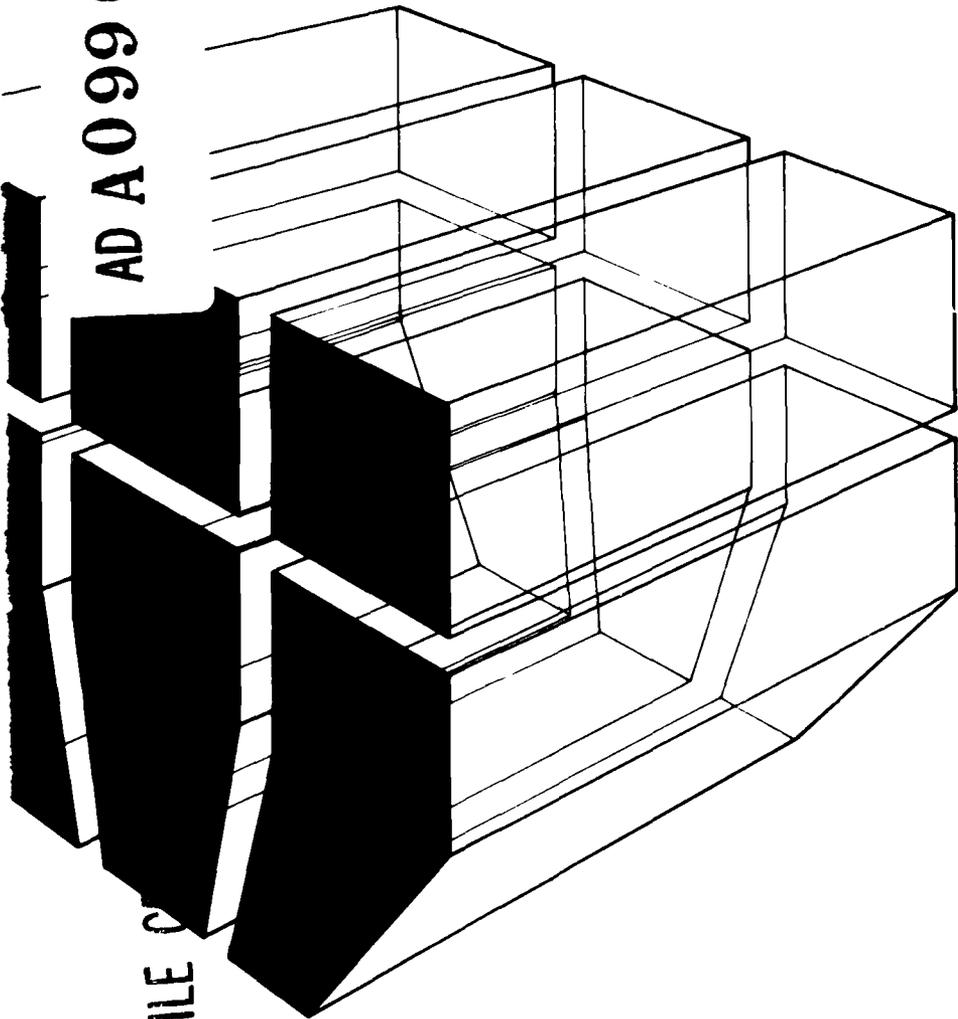
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CONCEPT PAPER: THE USE OF POLYURETHANE FOAM PLASTICS
FOR TACTICAL BRIDGING AND RAFTING OPERATIONS

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by
Alvin Smith

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22

FOREWORD

This paper was prepared for the Directorate of Military Programs, Office of the Chief of Engineers (OCE) at the request of the Directorate of Combat Developments (DCD), U.S. Army Engineer School. The point of contact at DCD is LTC Baumann.

The work was done by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (CERL). Dr. Robert Quattrone is Chief of EM. Appreciation is expressed to CPT John Buckwalter for his help in directing the focus of this study and for supplying information on present bridging/rafting equipment.

COL Louis J. Circeo is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

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CONTENTS

	<u>Page</u>
DD FORM 1473	1
FOREWORD	3
LIST OF TABLES AND FIGURES	5
1 INTRODUCTION.....	7
Objective	
Scope	
2 GENERAL DISCUSSION.....	9
Concept	
Foamed Bridging Operations	
Special Operations	
Post-Operation Utility	
3 CHARACTERISTICS OF FOAMED POLYURETHANE PLASTICS.....	11
General	
Storing, Shipping, and Making Foam	
Cost and Availability	
Design of Flotation Units	
Example: The Foam Overhead Cover System (FOCOS)	
4 FOAM BRIDGING AND RAFTING CONCEPTS.....	17
Concept 1: Foam Floating Footbridge (FFF)	
Concept 2: Foam Assault Boat (FAB)	
Concept 3: Vehicle Flotation System (VFS)	
Concept 4: Foam Raft System (FORS)	
Concept 5: Foam-Filled Boat (Foamboat)	
Concept 6: Foam Float Bridge (FFB)	
Concept 7: Upgrade Existing Float Bridge and Raft Capabilities	
5 PROPOSED RESEARCH AND DEVELOPMENT PLAN.....	25
6 CONCLUSION.....	26
REFERENCES	27
DISTRIBUTION	

TABLES

<u>Number</u>		<u>Page</u>
1	Typical Foam Material Properties	11

FIGURES

1	Relationship of Density and Compressive Strength of PU Foams	14
2	FOCOS Kit Components and Completed Foam/Fabric Structure	16
3	Foam Floating Bridge (Concept)	17
4	Fixed Floating Bridge for Vehicles (Concept)	18
5	Foam Assault Boat (Concept)	19
6	Foam-filled Fabric Cylinder	21
7	Cylindrical Longitudinal Flotation Concept	21
8	Foam-Filled Rectangular Fabric Form	22
9	Foam-Filled Raft Concept	22
10	Foamboat (Concept)	23

CONCEPT PAPER: THE USE OF POLYURETHANE FOAM PLASTICS
FOR TACTICAL BRIDGING AND RAFTING OPERATIONS

1 INTRODUCTION

Rivers are among the most formidable natural obstacles to the speed and efficiency of an attacking military force. Since almost all military operations involving large areas of activity require rivers of various widths and depths to be crossed, the use of floating bridge equipment is well established in military operations planning. Inventory assets are provided according to applicable Tables of Organization and Equipment (TOE).

Military floating bridge equipment and its use is described in Army Technical Manual 5-210, and Field Manuals 31-60 and 5-34.¹ Floating bridge equipment is usually either light or heavy.

Light river crossing equipment includes the Aluminum Floating Footbridge and the Light Tactical Raft. Both are adaptable to rafting small vehicles across rivers of slow to moderate flow velocities.

Heavy river crossing equipment includes the M4T6, the Class 60 Pneumatic Float Bridge, the M4 Floating Bridge, the Mobile Assault Bridge (MAB), Amphibious River Crossing Equipment (ARCE), and the Ribbon Bridge. Heavy river crossing equipment is intended, as the name implies, for carrying more substantial loads like cargo trucks and armored vehicles. Like the light equipment, some of the heavy river crossing equipment is adaptable to rafting or ferrying operations by changing its configurations (see TM 5-210).

The disadvantages of existing bridging and rafting equipment include:

1. Mobility -- heavy, bulky, or cumbersome prefabricated pieces are required to reduce the onsite work (and time) at the near bridgehead. Although some equipment is air-transportable (by helicopter), the availability of aircraft may be questionable depending on the urgency of the situation.

2. Vulnerability -- the thin metal skins of float components and/or pontoons are easily ruptured and may or may not be field repairable. Pneumatic floats are especially vulnerable to enemy fire and river debris.

¹ Military Floating Bridge Equipment, Technical Manual (TM) 5-210 (Department of the Army [DA], 3 August 1970); River Crossing Operations, Field Manual (FM) 31-60 (DA, 27 March 1972); and Engineer Field Data, FM 5-34 (DA, 24 September 1976).

Objective

The objective of this paper is to describe several concepts for using polyurethane (PU) foam plastics for tactical flotation bridging and rafting operations. These concepts, if developed and implemented, could increase the speed of river crossing operations, reduce the complexity of river crossing equipment (and the associated logistic burden), and provide unit commanders with an organic capability of moving equipment and personnel across river obstacles.

Scope

The concepts presented here are restricted to river crossing operations in which flotation is a factor.

2 GENERAL DISCUSSION

Concept

Foamed plastics have been used in a variety of flotation and buoyancy applications for many years. For example, most lane and hazard marking buoys and watercraft such as fishing boats, ponton boats, and floating docks (including large drilling platforms) are filled with foamed plastics to keep them from sinking. Pontons used on the Army's aluminum floating footbridge (TM 5-210) each have foamed plastic between the ponton's real and false bottoms. This makes the pontons relatively unsinkable even when punctured by small arms fire, shell fragments, or waterborne debris, since presence of foamed plastic instead of air inside the ponton skin prevents or greatly delays the entrance of water.

Foamed Bridging Operations

Some floating bridge equipment uses pneumatic float cells, which are much less reliable than foamed plastic float cells. By using foam-filled instead of pneumatic cells, the incidence of unserviceability due to puncture can be reduced. Foam-filled cells also promise to be less expensive, more lightweight, faster to construct, and easier to store, transport, and construct by hand than pneumatic cells.

One potential drawback to the use of the foamed plastics is that they can only be inflated once; pneumatic cells can be deflated and reinflated for reuse. However, although nondeflatable, foamed plastics can be transported for reuse if subsequent river crossings are required. And since foam structures use lighter weight and less expensive fabric skin than pneumatic floats, the overall load and cost of each flotation cell would be low enough to justify a single use, if necessary.

Special Operations

The concept of foamed bridging operations would be directly applicable to airborne/airmobile unit operations and other special operations. Foamable bridging materials could be shipped in very compact, lightweight kits or packages that could be converted to bridging/rafting devices by organic unit personnel in a minimum time with little training or equipment requirements. These kits or packages can be designed to stand up under very rough handling; they could be delivered either by surface vehicle, helicopter, or by airdrop.

Post-Operation Utility

The foam-fabric flotation systems could be kept at the river crossing site for possible retrograde movement, moved to a new site, or destroyed. Float bodies could be transported for future use (in whole or in part) by vehicle or by helicopter. Destruction would entail cutting away a portion of

the fabric skin, introducing a small amount of fuel, and igniting the foam. In this regard, it should be noted that foamed plastics are not readily combustible from small arms fire, including tracer rounds.

3 CHARACTERISTICS OF FOAMED POLYURETHANE PLASTICS

General

Foamed plastics have two phases: a solid phase that encompasses a gas phase, which is in the form of bubbles or cells. Most polymers (plastics) can be foamed, but relatively few have significant commercial value. The two best known foamed plastics are polystyrene foam (sometimes referred to as Styro-foam)* and polyurethane (PU) foam. Polystyrene foam is not appropriate for field foaming, and will not be discussed in this report.

PU foams are the result of polymerizing reactive liquid materials which release or generate a gas which is then entrapped within the reacting mixture like air in meringue. Both rigid and flexible PU foams can be made, the degree of rigidity depends on the chemical components that are reacted together and the density of the foam that is formed.

Rigid PU foams can be made that are substantially closed celled; i.e., each cell is discrete and separate from other cells. Water absorption by this type of foam is very slow (3 percent by volume in 7 days immersion and 7 percent in 180 days). Any water resistant outer covering further retards water intake.

Rigid PU foams can be made in densities ranging from about 0.75 pounds per cubic foot (pcf) (12 kg/m^3) to more than 50 pcf (801 kg/m^3). A lower limit of about 2 pcf (32 kg/m^3) is normally used for flotation; foams of lower density than this are usually more open celled and consequently are less suitable for flotation applications.

The strength properties of rigid PU foams are generally a function of density; i.e., as the density increases, so do the strength properties (Figure 1). Table 1 shows the typical mechanical properties of a 2 pcf (32 kg/m^3) flotation-type PU rigid foam.

Table 1
Typical Foam Material Properties

Density, pcf (kg/m^3)	2(32)
Compressive strength, 10% strain, psi (kPa)	35(241)
Compressive modulus, psi (kPa)	1000(6895)
Tensile strength, psi (kPa)	38(262)
Shear strength, psi (kPa)	25(172)
Shear modulus, psi (kPa)	400(2758)

* Registered trademark of the Dow Chemical Company, Midland, Michigan.

Storing, Shipping, and making Foam

PU foam reactants can be shipped as liquids; they are about 1.2 times as heavy as water. The foaming action causes an expansion of about 30 times the liquid volume (for 2 pcf foam). Mixing can be done by hand in batches in the field, or by simple mixers.² Sustained action, high-volume mixers are feasible when used with large, prepressurized containers or dual pump systems.

Foam PU mixtures can be molded into shapes defined by a fabric form. The stiffness and strength of foam/fabric composites depends on the combined action of the foam and fabric. Very high stiffness/strength-to-weight ratios are possible with foam/fabric composites.³ The shippable-to-foamed volume is also very attractive, i.e., 1 cu in. = 30 cu in. foam ($163 \text{ mm}^3 = 4890 \text{ mm}^3$).

Onsite foaming requires little skill or training. In the case of hand mixing, two premeasured volumes of material are used. The chemistry of the system can be prearranged to give a slow foaming action which will allow foam-flow to fill a container. More elaborate mixing can be done by using a proportioning pump apparatus that brings together appropriate amounts of the reactants. Mixing can be done continuously by flowing two proportioned streams of materials through an inexpensive disposable mixing device.

The foaming and curing times can be varied by formulation changes in catalyst type and concentration. A typical flotation foam is hand mixed for 30 to 45 seconds, begins foaming in about 60 seconds, expands in about 3 minutes, and is hard (dry to the touch) in 5 minutes. At that point, the foam could be used for flotation. Much faster times (as little as 5 to 10 seconds for the whole process) can be achieved with an automatic mixer. Fast foams are as good for flotation as the slower ones, but may not fill forms as uniformly because of their reduced flow and quick setup time.

Foamable materials can be shipped in bulk containers such as 55 gal (208 L) steel drums, or in premeasured kits. Shelf life is usually specified to be 6 months, but is actually much longer (2 years or more). The materials present little or no toxicity problem when used in the open. They are only slightly flammable in the unreacted state; flammability increases when the foam is made, but is negated by using fire resistant fabric forms. No special storage is required, but controlled temperature storage is preferred. Foaming is temperature dependent, with foamability decreasing as the temperature decreases. The minimum practical foaming temperature in large masses is currently 20°F (-7°C). However, research is underway to lower the foaming temperature limit to -20°F (-29°C).

² Alvin Smith, Foam Overhead Cover Support (FOCOS) System for Dismounted and Mounted TOW Positions, Technical Report M-269/ADA075946 (U.S. Army Construction Engineering Research Laboratory [CERL], August 1979); and Alvin Smith, Investigation of Rapidly Deployable Plastic Foam Systems, Volume I: System Development, Technical Report M-272/ADA076332 (CERL, October 1979).

³ Alvin Smith, S. S. Wang, and A. Y. Kuo, Investigation of Rapidly Deployable Plastic Foam Systems, Volume II: Nonlinear Deformation and Local Buckling of Kevlar Fabric/Polyurethane Foam Composites, Technical Report M-272/ADA076310 (CERL, October 1979).

Cost and Availability

PU foam-forming materials are commercially available from several sources. They come as preformulated, two-component "systems" that presently cost about \$.80/lb (\$1.76/kg). Since the materials are essentially derived from oil or natural gas, they can be expected to increase in price as the cost of oil and gas rises. This cost translates into good, reliable flotation at two thirds cents per pound of buoyancy. Besides being cost effective, PU foam is especially attractive because it can be shipped in very compact form (1 cu in. [163 mm³] of liquid converts to 1 lb [0.45 kg] of buoyancy).

Design of Flotation Units

Foam-filled objects can be made in a variety of geometric shapes. Cylinders are one of the simplest forms to make and have a reasonably large volume-to-surface area, but other configurations, including fiat, rectangular surfaces, can also be formed.

The buoyancy of the foam-filled shape is directly related to its volume and density. Two pcf (32 kg/m³) density foam has a flotation factor of slightly over 60 pcf (961 kg/m³); higher density foams will provide less flotation per volume. To determine the buoyancy of a foam-filled shape, the density of the material is subtracted from the weight of an equal volume of water; the difference is flotation capacity of the foam. In some cases, a higher density foam may be required for higher stiffness or compressive strength. Figure 1 shows the general relation between PU foam density and compressive strength; stiffness generally follows the same trend.

The flotation capacity from a given quantity of shipped materials can also be predicted. For example, consider four 55 gallon (208 L) drums, two of each reactant, being shipped on a pallet. The weight of the four drums of material is about 2000 lb (909 kg). This weight plus that of the pallet, forms, etc. gives a total shipping weight of about 2500 lb (1136 kg). The cube of the shipment would be about 65 cu ft (1.84 m³). Conversion of the reactants into 2 pcf (32 kg/m³) foam will give a foam volume of about 1000 cu ft (160 m³), with a flotation capacity of over 30 tons (27 270 kg).

The fabric skins (forms) can be made of any tightly woven cloth (or coated fabric) such as cotton, canvas, nylon, polyester or Kevlar.* The choice of fabric will be determined primarily by the structural requirements of the flotation systems. The cost of each form will depend on both the fabric chosen and the complexity of fabrication. As with the foam materials, purchase quantities will also affect the final cost of the flotation unit. The logistical weight and volume of foam-fabric systems are expected to be very favorable when compared to other flotation bridging and rafting systems.

* Registered trademark of E. I. DuPont de NeMours, Wilmington, Delaware.

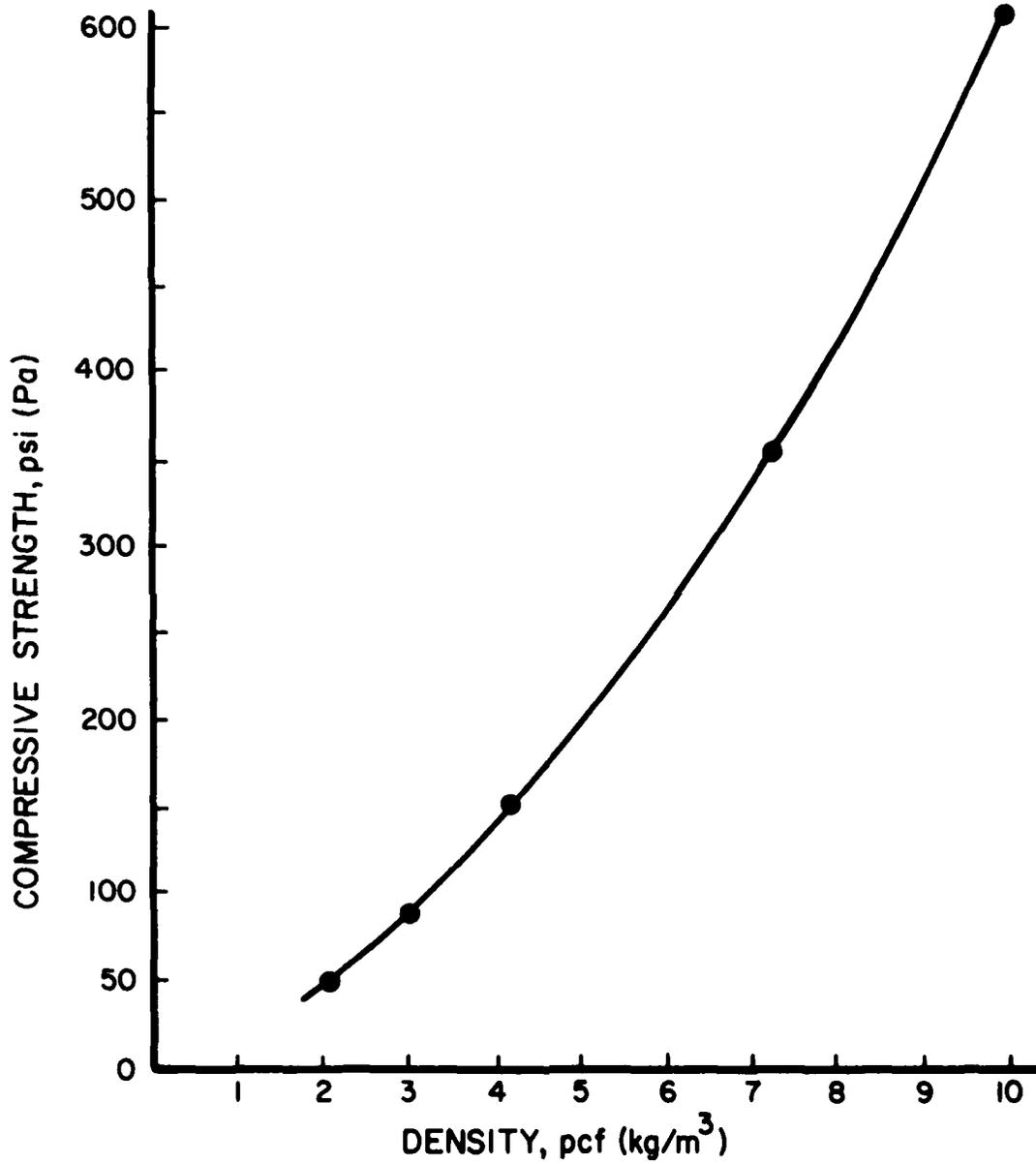


Figure 1. Relationship of density and compressive strength of PU foams.

Example: The Foam Overhead Cover System (FOCOS)

CERL developed the Foam Overhead System (FOCOS) to provide antitank weapon (TOW missile) crews overhead cover protection against fragments from indirect suppressive fire. The objective of the study was to give the weapon crew a small, lightweight kit that was easy to transport and that could be erected, without engineer assistance, into a protective shelter.

PU foam was selected for the system because it can be shipped in liquid form and converted onsite into a lightweight foam which has excellent strength-to-weight properties. The system uses foam materials that are hand mixed and poured into a fabric form. The foam expansion "inflates" the form into a rectangular mattress about 5 ft wide by 13 ft long by 6 in. thick (1.5 m x 4 m x 152 mm). The mattress is shaped into an arch by standing it on edge and bending it around a 4-ft (1.2-m) radius semicircle of stakes driven into the ground. In less than 5 minutes, the foam becomes rigid enough to retain its shape. The arch is then set upright over the weapon position and covered with 18 in. (457 mm) of soil to provide ballistic fragment protection. Figure 2 shows the relative size of the kit and the completed foam/fabric structure.

A probability study was done to determine the degree of protection likely to be given by the open-ended arch. Using a random distribution of air, surface, and subsurface bursts greater than 10 and less than 150 ft (greater than 3 and less than 46 m) from the shelter, ten 155-mm HE rounds would cause about a 99 percent chance of casualty if no protection were provided. Under the same conditions, the 8-ft (2.4-m) diameter by 5 ft (1.5 m) long dirt-covered arch would give better than a 50 percent chance of survival and mission accomplishment.

Field testing demonstrated that while direct hits by rounds up to 155-mm could not be withstood by the overhead cover, misses of about 10 ft (3 m) or greater could be tolerated. Fragments from such rounds did not penetrate the dirt cover or foam/fabric arch support.

The kit proposed as a result of CERL's study is a compact 18 x 18 x 12 in. (457 x 457 x 304 mm), weighs just under 100 lb (45 kg), and costs about \$200. Two individuals can erect the arch in less than 20 minutes; placing the dirt on the arch takes additional time, depending on the type of soil.



Figure 2. FOCOS kit components and completed foam/fabric structure.

4 FOAM BRIDGING AND RAFTING CONCEPTS

New methods of conducting tactical river crossing operations are possible if foam-fabric float bridging concepts prove feasible. These concepts would result in a more rapid crossing capability with less dependence on elaborate systems and equipment that require specialized bridge units to be transported to the crossing site. The following bridging and rafting concepts could provide the Army with a new generation of inexpensive, lightweight, and rapidly erectible tactical float bridges and rafts.

Concept 1: Foam Floating Footbridge (FFF)

A Foam Floating Footbridge (FFF) to span water obstacles could be developed to replace or augment the existing aluminum footbridge. The FFF could be made from kits that would be much more compact and lightweight than the aluminum floating footbridge, could be built by organic unit personnel, and could be deployed onsite; in fact, the entire footbridge could be assembled on shore and pushed across the river. Development of the FFF would most likely parallel the requirements of the aluminum footbridge. This concept appears to be readily adaptable to a prototype foam-fabric system, with a high probability of success (Figure 3). Figure 4 shows the same basic concept applied as a fixed floating vehicular bridge.

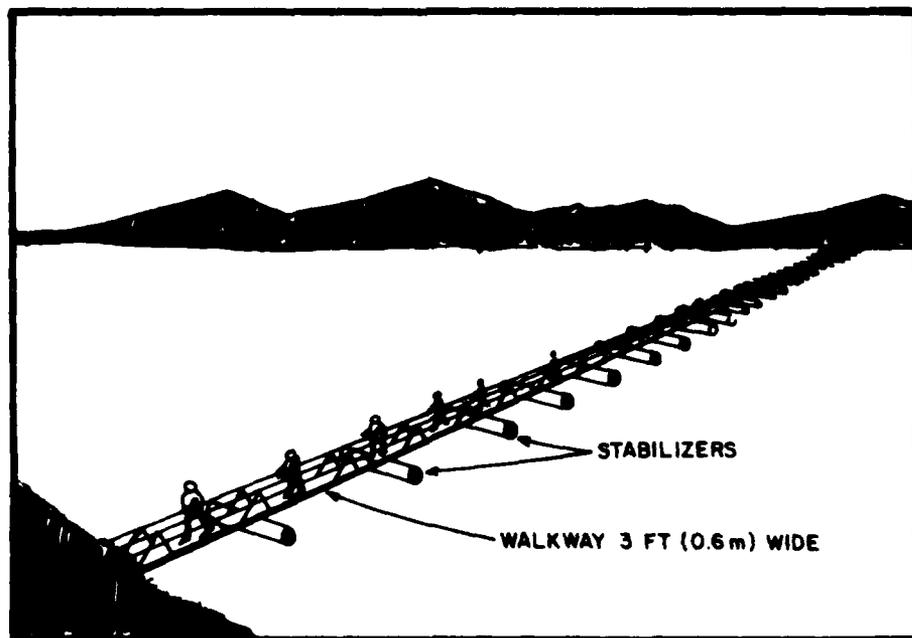


Figure 3. Foam floating bridge (concept).

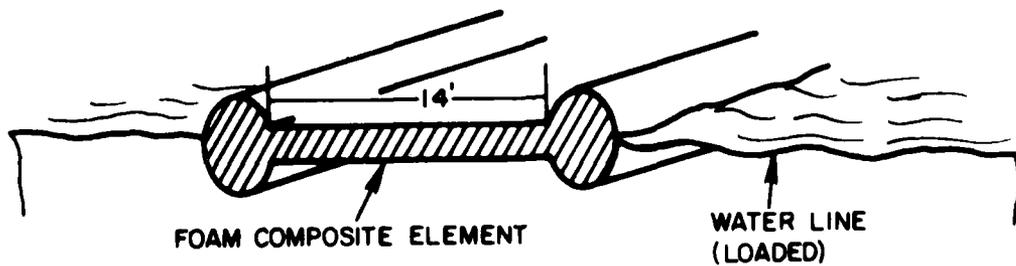
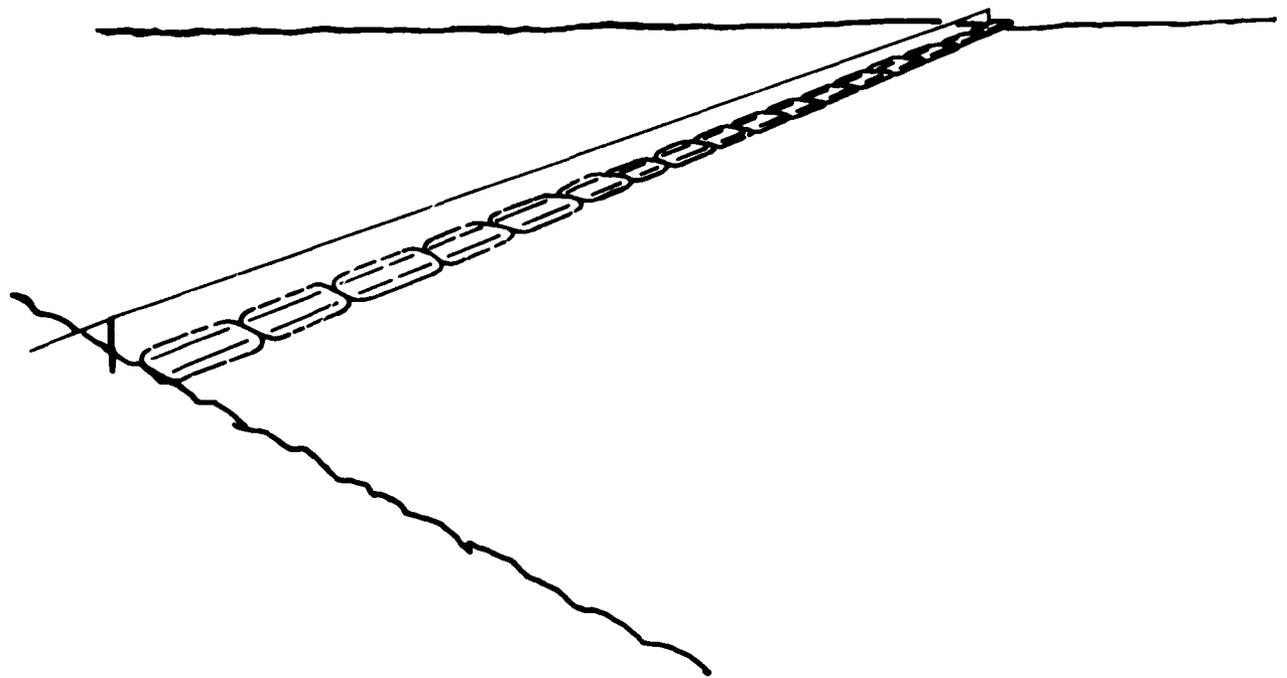


Figure 4. Fixed floating bridge for vehicles (concept).

Concept 2: Foam Assault Boat (FAB)

Engineer and infantry personnel assault boats could be constructed on-site from a kit containing the necessary foam chemicals and prepared fabric forms. The kit could be made up of materials that would require a preparation time of about 10 minutes (if the chemicals are hand mixed) or as little as a 1 or 2 minutes (if the kit has prepressurized containers and an automatic mixer and dispenser). The size and shape of the FAB and the selection of foam and fabric properties would be developed to provide a kit that would occupy the least volume and have the lowest possible weight. Compared to existing pneumatic assault boats, the FAB is expected to be lighter, more compact for storage, less expensive, and more reliable. It is anticipated that the FAB kit would approximate the size and cost of the FOCOS (excluding oars). This concept is also relatively straightforward, with a high probability of success (Figure 5).

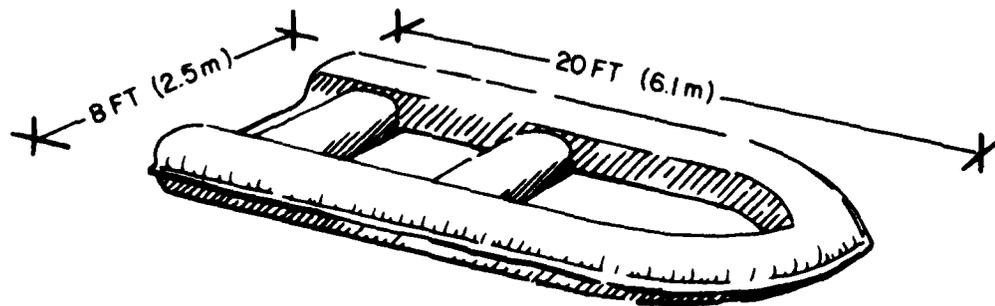


Figure 5. Float assault boat (concept).

Concept 3: Vehicle Flotation System (VFS)

This concept is a vehicle flotation system (VFS) for individual vehicles. The VFS would be attached to the vehicle to make it buoyant, letting it float and, in slow currents, cross a river under its own power.

Each vehicle could carry an individual VFS kit which could be deployed just before entering the water. Or selected vehicles could carry kits and deploy them for initial use, with a return system for getting them back across the river for reuse by another vehicle or group of vehicles of the same class. Once used, the VFS could remain with the vehicles for use in future river crossing operations.

Under the existing concept, the VFS would be cylindrical foam-fabric structures located longitudinally along the sides of a vehicle. They would be attached so as to maintain flotation while allowing a noncritical portion of the vehicle to be submerged (See Figures 6 and 7). The VFS could be attached by web slings passed beneath the frame of the vehicle or by hooking it with loops to the vehicle frame. The center of buoyancy would be above the center of gravity of the vehicle.

Concept 4: Foam Raft System (FORS)

A Foam Raft System (FORS) would transport individual or multiple vehicles across bodies of water. The FORS would have rectangular, prismatic foam-filled fabric modules with enough displacement capacity to carry vehicles. The FORS would load like a conventional raft (See Figures 8 and 9); vehicles would sit on the raft and be towed across the river. The raft would be large enough to resist overturning, and its thickness, fabric, and foam density would be stiff enough to resist deformation. FORS modules could be connected to create rafts of different sizes, depending on the class of vehicles to be transported.

Concept 5: Foam-Filled Boat (Foamboat)

The Foamboat concept would float very heavy pieces of equipment such as tanks or other armored vehicles. For example, if the outline shape of a medium tank is made watertight, it has an average displacement of about 5 tons (4545 kg) per foot of depth. Additional displacement volume required to float the tank can be provided by using fabric skins filled with foam. The outline shape of the tank will provide short-span rigidity to the foam-filled structures; the thickness of the foam can be designed to give the necessary added water displacement to float the tank (Figure 10).

For example, if the shape and size of the tank displaces 5 tons (4545 kg) per foot of depth and the support vessel has walls 2 ft (0.65 m) thick, the displacement increases to almost 9 tons (7950 kg) per foot of depth. Assuming a platform thickness of 2 ft (0.61 m) as a bottom in the Foamboat, and a 2-ft (0.61-m) gunwale height required to prevent swamping, a 70-ton tank could be transported submerged 4 ft (1.2 m) into the water. The chemical requirements to transport such a tank could be contained within four 55-gallon drums.

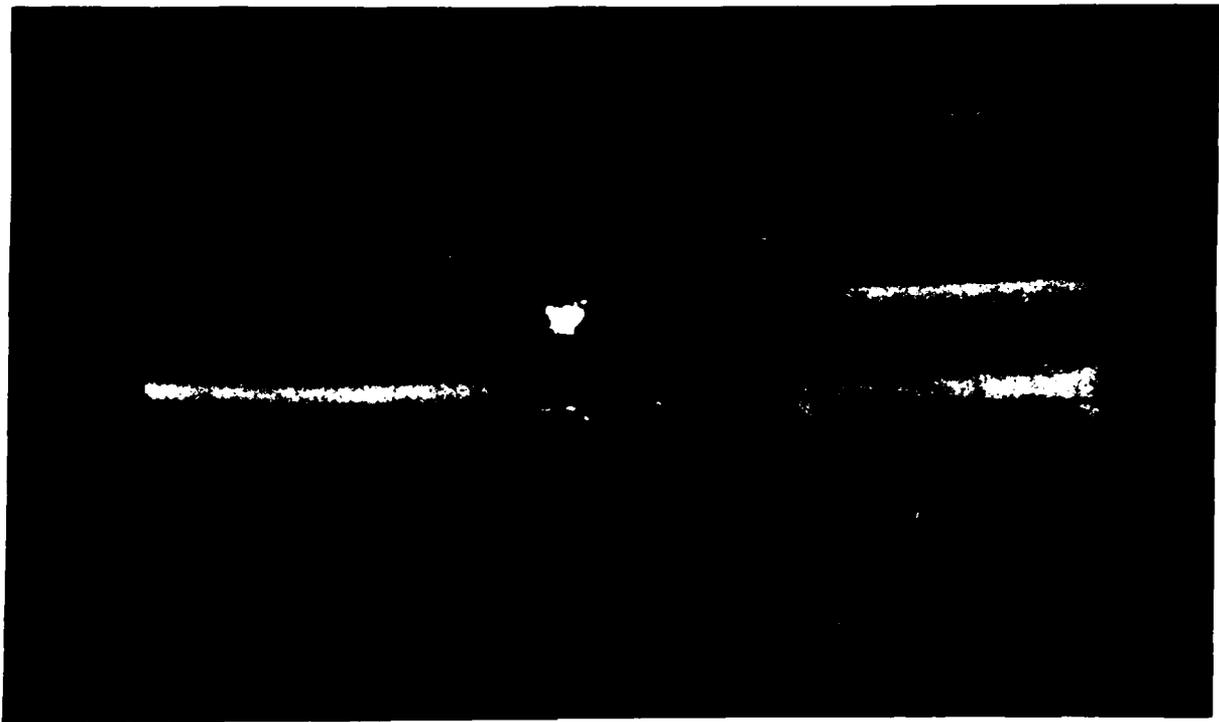


Figure 6. Foam-filled fabric cylinder.

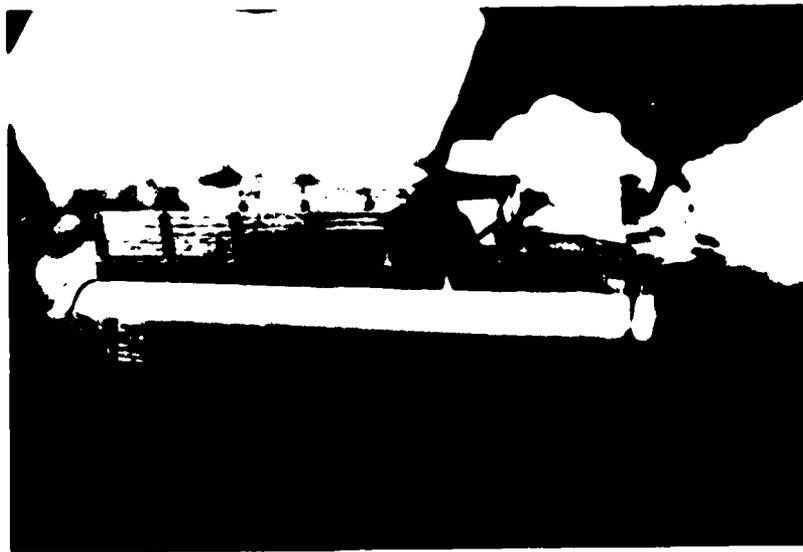


Figure 7. Cylindrical longitudinal flotation concept.



Figure 8. Foam-filled rectangular fabric foam.



Figure 9. Foam-filled raft concept.

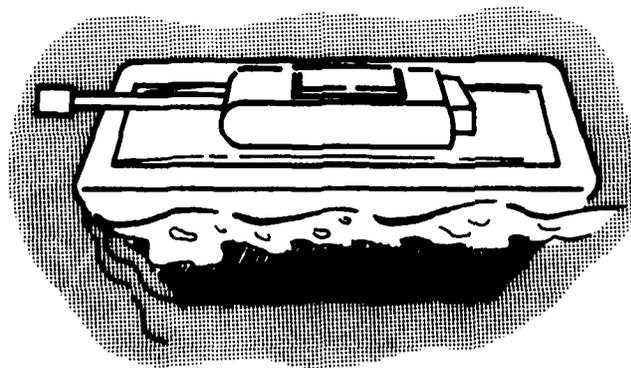
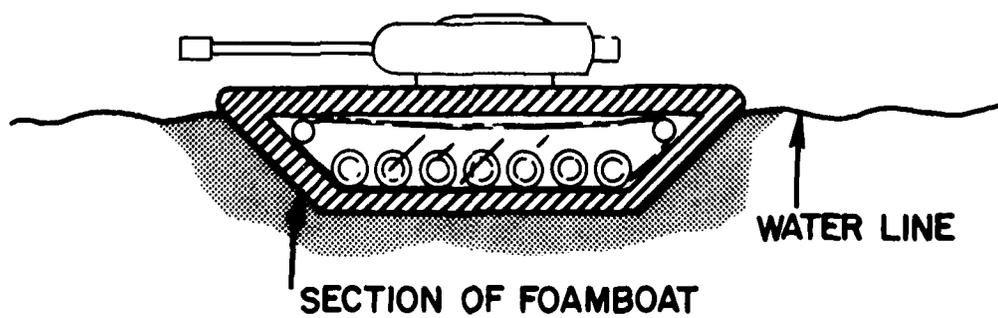


Figure 10. Foamboat (concept).

The tank's low profile during the river crossing could also have distinct operational advantages.

The Foamboat would be designed for onsite construction. The sides, ends, and bottom platform junctions would be hinged so they could be folded up and around the tank and sealed to prevent water entry. After the Foamboat is assembled, it would be put into the water with one end opened as an approach ramp to the shore. This would let the tank become buoyant under its own power. (Specific access/egress criteria would have to be considered in the Foamboat design.) The Foamboat could have attachment points for securing it to the vehicle being transported or to a towing power boat, tow line, or guideline.

Foamboats would let heavy vehicles be transported at an early stage of a river crossing operation. The boats could be returned across the river for reuse. Propulsion would have to be external; e.g., power boats, capstan lines, or winches with tow and guide cables crossing the river.

Concept 6: Foam Float Bridge (FFB)

A Foam Float Bridge (FFB) could be made by connecting FORS modules or Foamboats together to make a deck roadway for vehicles to drive on. The FFB design would have to include float-to-float attachment, anchoring (criteria and methods are already available), decking, and means of forming and deploying.

It may be possible to design new flotation cells to accept existing hardware from other bridging equipment. This would reduce the volume and weight of materials to be shipped to a bridging site. A foam generator could also be developed to allow rapid foaming and construction of FFBs.

Concept 7: Upgrade Existing Float Bridge and Raft Capabilities

PU foam can be used to upgrade existing float bridge capabilities; e.g., to increase the weight classification of current bridges and rafts. Foam-filled fabrics similar to the VFS and FORS concepts could be developed to add to existing military bridges. PU foam structures could be developed as a permanent addition to existing bridges, or fabricated at the bridge assembly area for a one-time use.

5 PROPOSED RESEARCH AND DEVELOPMENT PLAN

The concepts described in this paper could be studied over a 4-year period. The phases planned in the study and time spans are:

1. Determine application limitations of the use of foam for bridging/rafting (12 months).
2. Design foam/fabric composite material systems for bridging/rafting (9 months).
3. Conduct material systems and design evaluations (15 months).
4. Prepare draft Technical and Field Manual inserts (3 months).
5. Prepare technical reports (6 months).
6. Effect technology transfer with the U.S. Army Engineer School (USAES), the Training and Doctrine Command (TRADOC), and Mobility Equipment Research and Development Command (MERADCOM) (3 months).

Foamable PU plastics considered during concept research and development will include only those that are foamable in a field environment and that have good flotation characteristics. Insofar as possible, only commercially available materials will be used in the investigations.

All materials and procedures will be selected to avoid safety hazards in the investigational phase and in subsequently specified systems. Particular attention will be paid to foam chemical component toxicity and to flammability of materials before, during, and after foam formation.

6 CONCLUSION

Foamed plastics have been used in a variety of flotation and buoyancy applications for many years. They are an effective and efficient way of reducing the vulnerability of pontoons, floating docks, boats, and drilling platforms. When used in spaces where air voids are normally located, foamed plastics reduce puncture leakage.

Foamed plastics, particularly PU foam, can be adapted to many military flotation uses. The chemical reactants can be shipped as liquids (1 cu in./lb of buoyancy), and converted to rigid foam by expansion of the liquid to about 30 times its volume. The rate of expansion can be varied by formulation changes that cause foaming to occur within about 5 seconds to several minutes, depending on the requirements. The resulting foam can have very high strength-to-weight ratios with strength and stiffness a function of density. Foam chemicals are commercially available in large volume from many suppliers at a cost of about \$.80/lb, or 0.6 cents/lb of buoyancy.

Foam bridge and raft concepts are adaptable to Airborne/Airmobile operations and other special operations, since the shipping volume and weight are low, and the systems can be manhandled and erected with a minimum of equipment.

The composite action of fabric and foam has been demonstrated in the CERL FOCOS; field mixing of foam has been demonstrated to be quick and easy, requiring little skill or training. Foam materials can be shipped as dense liquids and rapidly mixed and foamed into stable, lightweight materials.

The successful development of the concepts described in this paper would result in inexpensive, lightweight, rapid, and operationally mobile techniques for overcoming water obstacles; they would significantly increase the river crossing options available to the field commander.

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