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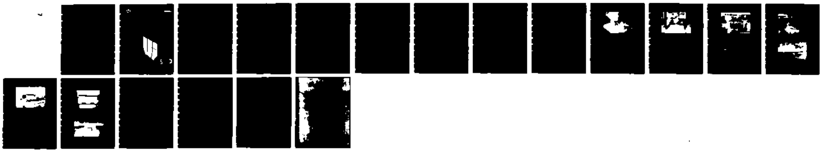

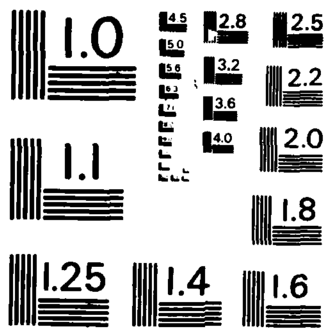

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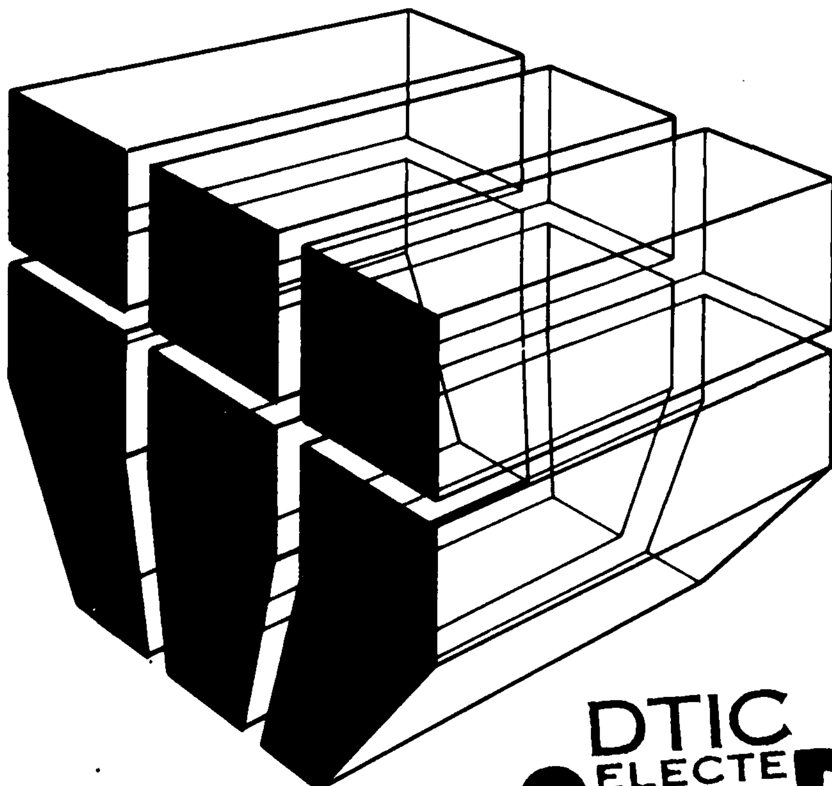
INTERIM REPORT M-348
May 1984

DEVELOPMENT OF POLYURETHANE FOAM FLOTATION BRIDGING/RAFTING SYSTEMS UP TO MILITARY LOAD CLASS 20

by
Orange S. Marshall, Jr.



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This report presents the results of research conducted to date on the development of lightweight, easily transportable materials and expedient methods for crossing nonfordable streams, lakes, and rivers by tactical vehicular traffic up to Military Load Class (MLC) 20 and by individuals or groups of soldiers.

Canvas-covered rigid polyurethane foam flotation devices were evaluated in providing the buoyancy needed to raft an M151A1 ¼ ton utility truck and an M35A2 cargo truck across water and to form both a three-man reconnaissance boat and a

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20-ft (6-m) footbridge section. These devices all provided more than enough buoyancy and stability in field tests conducted in still and slow-moving water.

Field Army units will use the products of this research.

FOREWORD

This research was conducted by the U.S. Army Construction Engineering Research Laboratory (CERL) for the Assistant Chief of Engineers (ACE), Office of the Chief of Engineers (OCE). The work was conducted under project 4A162731AT41, "Military Facilities Engineering Technology"; Task E, "Military Engineering"; and Work Unit 047, "Flotation Bridging/Rafting Concepts for River Crossing Operations (to Military Load Class 70)." The ACE Technical Monitor was Dr. C. Meyer, DAEN-ZCM.

The investigation was performed by the CERL Engineering and Materials (EM) Division. CERL personnel assisting in the study were Robert E. Muncy, Steven C. Sweeney, and Richard Barrow. Dr. Robert Quattrone is Chief of CERL-EM.

COL Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The ability to cross nonfordable bodies of water with speed and efficiency is a vital part of the Army's land warfare strategy. With the lethality of modern weapons, a military force must maintain mobility to successfully carry out its mission. Since most large-scale military operations involve crossing rivers, lakes, or canals of various widths and depths, a lightweight, easily transportable bridging or rafting system will improve mobility and, thus, the likelihood of success.

The bridging and rafting equipment now used by the Army is limited in inventory, expensive, and bulky, requiring costly transportation and storage. For example, a Light Tactical Raft is issued on the basis of six per engineer float bridge company and two per division engineer battalion (except for airborne units, which are not issued any). Each raft set has a military load class (MLC) rating of 12, costs more than $111,000,[1] and requires two 2½ ton cargo trucks, one with a special trailer, to transport it.[2]

Bridging and rafting equipment with pneumatic floats is very vulnerable to damage from river debris and small arms fire. The thin metal skins of float components are easily ruptured and often are not field-repairable. The ruptured section must be removed from the water and, if aluminum welding equipment and skilled welders are available, repaired. At present, however, the availability of such equipment and welders is very limited.[3] Another problem is that most equipment now used for flotation river crossings requires much assembly time in the water, which can expose assembly crews to hostile fire.

Objective

The objective of this research is to develop and evaluate polymer-foam-based material and methods for crossing nonfordable waters by tactical vehicular traffic, individuals, and groups of soldiers. These concepts should increase the speed of water crossing by providing a quicker method of bridge assembly. They should also reduce the complexity of water crossing equipment and the related logistics burden by providing bridging equipment that has fewer components and takes less space to transport. The method will provide unit commanders with an organic ability to move personnel and equipment across water easier and at a greatly reduced price for bridging. (For example, the aluminum foot bridge can be replaced by a foam one which requires one-third the cargo space and one-seventh the cost).[4]

This report describes the fabrication and testing of various flotation devices. Equipment was developed through MLC20. Concept tests to MLC70 are planned for future studies.

Approach

Preliminary polymer-foam-based design alternatives were formulated and assessed on the basis of material availability, ease of assembly, and stability in water. Material systems were then evaluated to determine which lightweight, easy-to-handle materials would best fit the design alternatives. Prototype flotation devices were constructed and tested in both still and slow-moving waters. Following each test, needed modifications were made to the designs.

Mode of Technology Transfer

The results of this study will be transferred to the combat developer through a demonstration in the summer of 1984. Transfer from the combat developer to the material developer will be accomplished by a requirements document (optimally a letter requirement) produced by the U.S. Army Engineer School, Directorate of Combat Development.

CERL will provide technical assistance to help produce the requirements document and with the

[1] Supply Bulletin 700-20, *Army Adopted/Other Items Selected for Authorization/List of Reportable Items* (Headquarters, Department of the Army, HQDA, 1 Sep 1983).

[2] TM 5-210, *Military Floating Bridge Equipment* (HQDA, 3 August 1970).

[3] R. A. Weber, *Identification of Problems Encountered in the Field of Welding of Aluminum*, Technical Report M-301/AD109697 (CERL, October 1981); and D. Brockman and R. A. Weber, *Summary of Repair Techniques for Aluminum Bridging*, Technical Report M-324 AD122333 (CERL, October 1982).

[4] SB 700-20 and TM 5-210

full-scale development, production, and deployment of the concepts by the Belvoir Research and Development Command (BRADC). A technical report to be published in FY 85 will provide sufficient technical detail to permit BRADC to move ahead immediately with engineering development activities.

2 MATERIAL AND METHODS

Concept

Foamed plastics have been used in flotation and buoyancy equipment for several years. Many boats, floating platforms, and marking buoys use foamed plastics to displace enough water to stay afloat. The pontoons used on the Army's aluminum floating footbridge use foamed plastic between the false and true bottoms to make the pontoon relatively unsinkable, even when subjected to small-arms fire and shell fragments.[5]

Foam Criteria

Several criteria must be met when selecting a foamed plastic for use in bridging and rafting. The lower the foam density, the greater its displacement per unit volume, the more weight it will support in water, and the less the final flotation system will weigh. The foam must have a very high percentage of closed cells (each cell discrete and separate from all other cells) so it will not absorb water and become waterlogged quickly. The foam components must be easy to mix and safe to use, and the foam cannot require special equipment such as ovens for curing. Furthermore, it must have the mechanical properties necessary to withstand the loads from vehicular and foot traffic and must be priced low enough to justify use. Polystyrene foam meets these criteria very well, but it must be made in a plant and shipped as a very high-volume, low-density material. Rigid polyurethane foam, on the other hand, meets these criteria and can be foamed onsite.

A 2-lb/cu ft (32-kg/m^3) density rigid polyurethane foam system meets all of these criteria best. One cubic foot (0.3 m^3) displaces enough water to float 60.4 lb (27.4 kg) of material. The foam contains about 95 percent closed cells so the water absorption is low—about 3 percent by volume in 7 days immersion and 7 percent absorption in 180 days.[6] The foam is generated by mixing two reactive liquid components. The foam formulation contains all ingredients needed to react and form a highly crosslinked, foamed polymer. It has suitable mechanical properties (Table 1), and currently costs around $1.25/lb ($2.65/kg).

CPR 399.2® polyurethane foam system was used in the prototypes evaluated.* The reactants consist of two liquid components, "A" and "B." The A component is a polymeric polyisocyanate; B is a polymeric polysubstituted alcohol (polyol) combined with a small amount of silicone surfactant as a foam cell size control and trichlorofluoromethane as a blowing (foaming) or expanding agent. When the two components are mixed, they expand to more than 25 times their original liquid volume.

To make a foam bridge or raft section, the A and B components are mixed and introduced into the fabric form section through a zippered opening (Figure 1). The zipper is then closed and the foamed plastic fills the form. When the expansion stops, the bridge or raft section can be used.

Table 1

Typical Rigid Polyurethane Foam Properties**

Density, lb/cu ft (kg/m^3)	2 (32)
Compressive strength, psi (kPa)	30 (207)
Compressive modulus, psi (kPa)	800 (5516)
Tensile strength, psi (kPa)	40 (276)
Shear strength, psi (kPa)	24 (165)
Closed cell content, percent	94

**From the UpJohn Company Product Information Bulletin on CPR 399.2.

Bridging/Rafting System Components

Prototypes developed to date were a three-man reconnaissance boat, a floating footbridge, a rafting system for the M151A1 ¼ ton utility truck and one for the M35A2 2½ ton truck. To provide lightweight, compact forms to contain the polyurethane foam needed for enough water displacement, a water-resistant, sewn fabric (canvas) was evaluated. The final filled volume and shape was defined by the form's size, the sewing pattern, and the volume

[5]TM 5-210

[6]Alvin Smith, *Concept Paper: The Use of Polyurethane Foam Plastics for Tactical Bridging and Rafting Operations*, Special Report M-291/A099033 (U.S. Army Construction Engineering Research Laboratory [CERL], April 1981).

*This commercial product was selected based on its representative properties.

Figure 1. Mixed foam components are poured into a fabric footbridge form.

of foam used. Zippered openings were provided in the fabric forms to permit introduction of the foamable mixture.

To fasten the foam flotation bodies to a vehicle without modifying it, mounting devices were constructed from aluminum channel which attach to the vehicle with pins. These mounting devices serve a dual purpose: to help support the foam flotation bodies to keep them off the ground while crossing a water access/egress area and to cradle the vehicle between the flotation bodies while crossing the water.

The flotation bodies were wrapped with nylon cargo netting to spread the load of the vehicle in water over the bodies' surface and to hold them securely. The netting was attached to the vehicle mounting devices with steel clevises.

Foam Mixing

Three mixing techniques were evaluated: (a) hand stirring with a paint mixing paddle, (b) using a high-speed electric mixer, and (c) using a pressurized container with an in-line static mixer which mixes by turbulent flow.

Hand Stirring

Hand stirring is the least expensive and requires the fewest components—a stirring paddle and a mixing container. It is also the least efficient method evaluated. Foam mixed this way typically has a large, nonuniform cell structure resulting in somewhat reduced mechanical properties. The foam mixture was poured into the form through zippered openings and the zippers were then closed.

Electric Mixing

A high-speed electric mixer consisting of an electric drill motor with a Jiffler #130 mixer[7] was evaluated. The cell structure was fairly uniform and the foam had good mechanical properties. The foam mixture was introduced into the fabric form the same way as with hand mixing.

Static Mixing

Static mixing (Figure 2) is more complex than the other two techniques. The foam produced has good cell structure and strength. In addition, the foam is automatically introduced into the fabric form and the mixing time is 1/5 that of the other methods.

[7]Patent 3,030,083 held by Jiffler Handy Products, Inc.

Figure 2. Foam components are mixed by a static mixer and introduced into a fabric footbridge form.

The most important part of a static mixing system is the mixer. A static mixer continuously splits the flow streams and brings them back together again at a different flow orientation or direction, which mixes the two liquid streams effectively. Two static mixers were developed using perforated metal plates inside a pipe.

For the chemicals to mix in the static mixing head, they must flow through the mixer with some velocity. The faster the liquid flows, the more turbulence is introduced into the fluid and the better the mixing. To achieve high-velocity flow, the chemicals were placed in pressure cylinders (Figure 3). Nitrogen gas was then used to pressurize the containers in the tests and prototype production. The containers were pressurized to 150 psig (1034 kPag) and two ball valves, one at the base of each container, were opened simultaneously, allowing the foam chemicals to flow through the mixing head.

This high-velocity liquid stream had to be poured into the fabric forms in such a way to fill the form uniformly. To do this, a fill tube was run inside the full length of the form with perforations in the tube spaced for even distribution. A length of layflat polyethylene tubing was used. The hole size and spacing were predetermined empirically and then tested to verify mixing and essentially even distribution. It was found that the tube volume had to be equal to or greater than the incoming liquid volume to prevent the liquid backpressure from slowing or stopping the flow through the mixing head. The footbridge section requires two tubes with a device to split the incoming stream between the two (Figure 4). After the mixing, the internal distribution tubes were removed from the mixing head, the tube ends were tied off to prevent foam backflow, these ends were pushed into the form, and the zipper was closed.

3 PROTOTYPE DEVELOPMENT

Three-Man Reconnaissance Boat

The three-man reconnaissance boat (Figure 5) made of fabric was filled with polyurethane foam. It has essentially the same dimensions as the pneumatic three-man reconnaissance boat currently used by the Army. It weighs more than the pneumatic version—51 lb (23.1 kg) versus 37 lb (16.8 kg)—but since it is filled with foam, it resists puncture and if puncture occurs, it does not sink.

Figure 3. Foam chemical pressure cylinders with static mixer and foam stream splitting device.

The prototype was filled using a static mixing system. It has been tested and will support 700 lbs (313.6 kg) safely in the water.

Foam Footbridge

The foam footbridge (Figure 6) is made of fabric filled with polyurethane foam. Each footbridge section is 20 ft (6.1 m) long and will support 1200 lb (544.3 kg) in water. The walkway is 3 ft (0.9 m) wide and 4 in. (10 cm) thick. Along each side of the walkway is a 10-in.- (25.4-cm)-diameter cylinder for added buoyancy and stability in the water. Each section is tied to the end of the next section using ¼-in. (0.6 cm) hemp rope. Handrails are ⅜-in. (1-cm) hemp rope secured at each bank and tied to the bridge joints with pieces of rope stretched vertically.

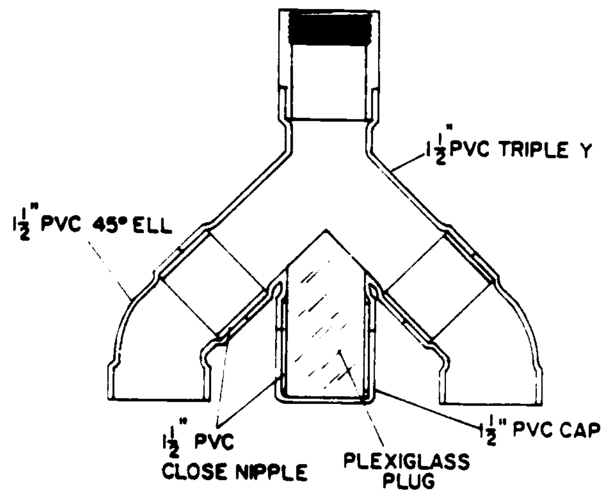

Figure 4. Foam stream splitting device.

The foam footbridge forms were filled using both the hand mixing/pouring and the static mixer methods. Each section weighed 132 lb (59.9 kg). A 200-ft- (61-m)-long footbridge was built across a slow-moving river. It was very stable in the water when persons walked across it and even more so when they ran across.

Utility Truck Rafting System

The utility truck rafting system (Figure 7) consists of two foam-filled fabric cylinders 11 ft (3.4 m) long and 25-¼ in. (0.64 m) in diameter. It has aluminum channel members to attach the cylinders, one on each side, to an M151A1 ¼ ton utility truck. The aluminum float body mounts are pinned to the lifting shackles on the front and rear bumpers of the vehicle, cargo netting is wrapped around the foam-filled cylinders to spread the vehicle load throughout the foam and confine the cylinders, and the

Figure 5. Three-man reconnaissance boat.

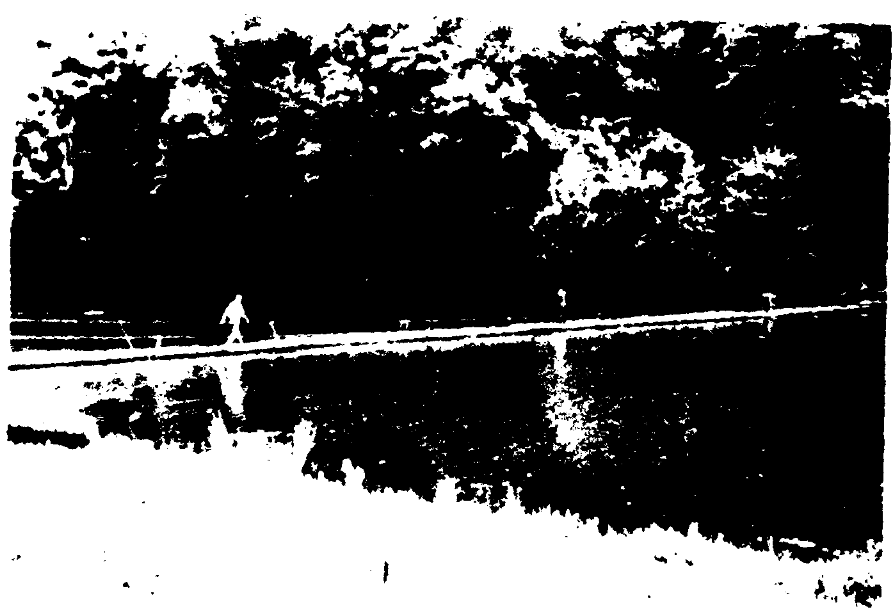

Figure 6. Foam footbridge.

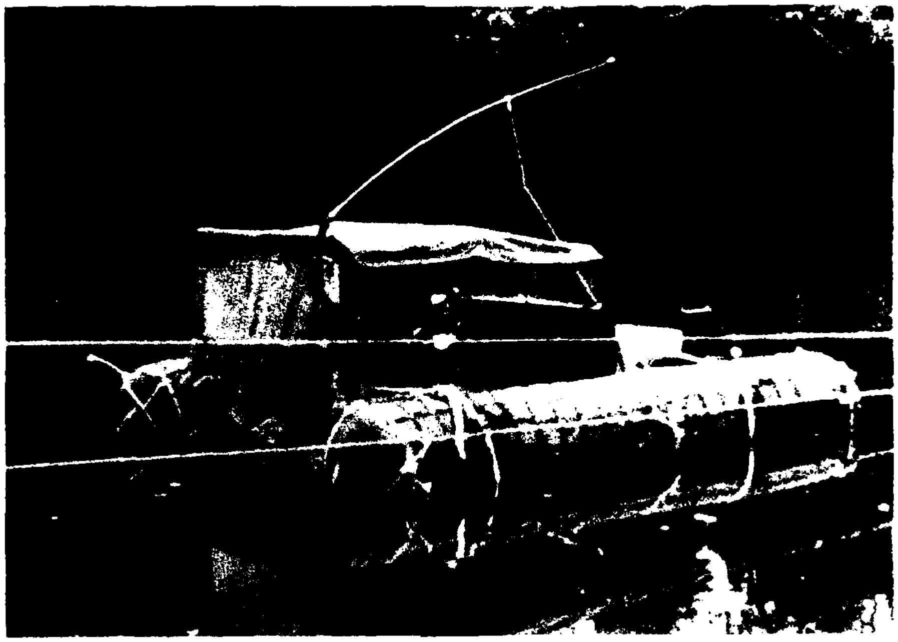

Figure 7. M151A1 ¼-ton utility truck crossing river with the utility truck rafting system.

cylinders are attached to the float body mounts with clevis devices. Nylon cargo straps are attached to the cargo netting and tightened across the hood and rear of the utility truck body to lift the cylinders off the ground as it drives into the water.

Each cylinder weighs 100 lb (45.5 kg) and will support more than 2200 lb (998 kg) in water (two cylinders have 4400 lb [1996 kg] of displacement). An M151A1 utility truck weighs 3073 lb (1396.8 kg) with its cross-country load. During a water crossing, 16 in. (40.6 cm) or 61 percent of the cylinders are submerged. This keeps the vehicle's depth in the water above its 21-in. (53.5-cm) fording depth.

The flotation cylinders were filled, one with a static mixer and the other with a high-speed electric mixer. During tests in still and slow-moving water, the vehicle was empty except for a driver, and the cylinders were about 50 percent submerged.

The first two trials tested the possibility of attaching flotation cylinders to the wheel hubs, the sling load lifting points for the vehicle. These points proved too unstable as the vehicle was driven into the water. It was difficult to steer with the cylinders attached to the front hubs, and the mounting shackles on the back wheel could not be kept straight enough to prevent wheel rotation from binding the attachment system.

Two additional tests were conducted, one in still water and the second in slow-moving water. The rafting system proved very successful in both tests. H-shaped mounts (Figure 8) made of aluminum channel were attached to the front and rear lifting shackles with the horizontal cross member below and in contact with the front and rear bumpers. The water level on the vehicle was about 1 in. (2.5 cm) below the top of the rear bumper.

MLC20 Rafting System

The MLC20 Rafting System (Figure 9) is basically a larger version of the ¼ ton utility truck rafting system. The flotation cylinders are 23 ft (7 m) long, 3 ft 5-½ in. (1.05 m) in diameter, and weigh 500 lb (226.8 kg) each. Each cylinder will support 13,000 lb (5897 kg) in the water. Aluminum float body mounts for an M35A2 cargo truck are pinned in three positions to the frame of the vehicle. Like the utility truck rafting system, the foam-filled cylinders are wrapped in cargo netting and attach to the float body mounts with clevises. Again, the flotation cylinders are held off the ground by nylon cargo straps across the hood and rear bed to allow driving into the water.

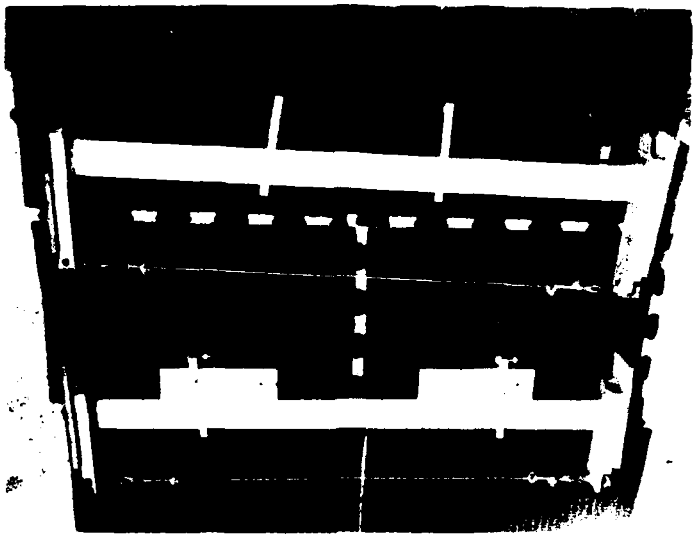

Figure 8. M151A1 ¼-ton utility truck flotation body mounts. The upper one fits the front of the vehicle; the lower one fits the rear.

Figure 9. M35A2 truck testing the MLC20 rafting system.

The first two field tests were conducted using flotation cylinders made using a high-speed electric mixer. The foam was made in 4-ft (1.2-m) lengths in a mold and then placed in the fabric forms by removing one end of the form and pushing the foam sections inside. After the form was filled, the end was sewn back in place. For further field tests, the forms were modified into six compartments separated by fabric bulkheads and each compartment was filled separately using a static mixer.

In the first field test, nylon cargo netting alone attached the flotation cylinders to the truck. The flotation cylinders rode up too high while floating, so the truck was too low in the water. Two aluminum flotation body mounts were used for the second test, one attached in front of the front wheels and one behind the rear dual wheels. The aluminum mounts held the cargo netting attachments less than 7 in. (17.8 cm) above the ground. An empty truck (except for a driver) floated as desired with the water line 6 in. (15.2 cm) below the fording depth. With only two mounts and the 4-ft (1.2-m) foam pieces in the fabric form, the form bowed up in the middle excessively and a third flotation mount was required. Also, during this test, the truck weighing 13,860 lb (6287 kg) only submerged the ends of the bowed flotation cylinders halfway. During a tactical river crossing, an M35A2 cargo truck with its cross-country load would submerge 28 in. (71.1 cm) or 66 percent of the flotation cylinders in the water.

A third test was conducted modifying the aluminum flotation body mounts so they "accordioned," forming an upside down "W." The amount of expansion was fixed by a horizontal ⅜-in. (.95-cm) steel cable between the two cylinders and under the truck. Rather than attaching the cargo netting around the flotation cylinders to the mounts, it was attached to metal snap rings on the cargo straps used to tie the netting to the flotation cylinders. As the truck was driven into the water and began to float, the snap rings pulled open because of the load and separated from the cargo netting. This allowed the aluminum body mount members to drop, and the truck ran over the center mounts as it left the water, bending them so they were no longer usable.

Engineering and design work is now being completed for an MLC20 raft system with the capability of driving a vehicle onto a deck rather than attaching pontoons to the vehicle. It also has the option of attaching several rafts together to form a bridge.

4 CONCLUSION

Using polyurethane foam to provide the displacement necessary to bridge or raft across water is a feasible option available to the Army. The prototypes developed so far in this study show that river crossing equipment made with polyurethane foam is lightweight, quick and easy to use, and can be transported easily.

These prototypes were developed to show the feasibility of using foams for bridging and rafting. Further refinement of the prototypes is necessary and will be made as the study progresses. For example, more quickly used, lighter-weight vehicle attachment systems can be developed by design refinement. The fabric forms will be modified to include strong attachment points in the fabric so cargo netting will not be required.

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