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Use of Rapidly Cured Inflatable Composite Beams For Military Small-Gap Bridging

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ABSTRACT: This study investigates the viability to used rapidly cured fiberglass composite tubes to defeat gaps thru experimentally and numerically techniques. Fiberglass pipes of 3.8in diameter and 48in long were instrumented and loaded to determine its mechanical properties based on load deformation and strain characteristics. Load cells, LVDT, strain gauges and data logger were used. Two strain gauges were attached outside the pipes, top and bottom at mid-span. A loading machine of 10-ton capacity was used to impose line load at rates of 1500 and 2000 lb/min. Results indicate that, rate of loading has no significant effects on the stiffness of fiberglass pipes. Nonlinear 3-D finite element analysis program was employed. It has been shown that, linear elastic prediction can capture pipe load-deformation response up to 5% strain. The calibrated numerical tool and the refined material parameters were used efficiently and realistically for further modeling and analysis the composite tubes subjected to military vehicle loads. Shell elements with the composite properties were utilized. Full scale 37.25 inch diameter pipes were tested first in the laboratory and then in the field with military vehicles. Results show that the pipes can sustain large deformations without failing and return to its previous shape due to its elastic properties. Since deformations are not a major concern for a short term gap defeats, they are an appropriate solution to the gap problem.

INTRODUCTION

The US Army Future Force (FF) will depend upon lightweight and fast-moving vehicles that can rapidly advance over any terrain. The FF principles of responsiveness, deployability, agility, and sustainability provide the capability to rapidly concentrate combat power in an operational area. This capability is invariably linked to the force's ability to maneuver within the theater environment. A key element of the FF will be the Future Combat System (FCS) vehicle. The FCS will be based on the 8X8 Light Armored Vehicle (M1126-M1135) Stryker personnel carrier now in service with the US Army. The FCS "Operation Requirement Document" requires that manned and unmanned ground vehicles be capable of negotiating gaps 1.5 to 4.0 meters wide. Gaps include both natural and manmade obstacles. Overcoming battlespace gaps requires the ability to effectively conduct four tasks: prediction, definition, avoidance, and defeat. The inability to overcome gaps within the theater of operations will significantly impair the FF's responsiveness, agility, and sustainability.

For this purpose, these forces will depend upon rapidly deployed and lightweight “bridges” to quickly traverse the numerous small gaps that they may encounter. While existing military bridges are adequate to carry the required loads, they are in effect overkill for numerous small gap crossings and suffer from the lack of portability and excessive weight. Thus, the Geotechnical and Structures Laboratory of the US Army Engineer Research and Development Center (ERDC) have been exploring new concepts for small-gap expedient bridging.

One of the most promising concepts explored thus far involves the use of ultraviolet (UV) rapidly cured composite inflatable tubes that can be used to expediently form culverts and several types of structural beams. These beams can in turn be pieced together to form various types of “bridge” structures.

BEAM FABRICATION

The fiberglass composite tubes used in this study were supplied by Sunrez Corporation, California. The composite is a combination of Sunrez ultraviolet cure resin and Vertigo Inc. inflation technology to create prototype beams for a rapidly UV-cured culvert pipe. Two prototype beams, 3.8in by 48 in by 0.23in thick, were fabricated and tested for bending strength according to the ASTM 6272. These beams were completely cured in approximately 10 minutes.

Two beams were fabricated with fiberglass and UV-cure resin. These beams were load-tested to failure to determine their mechanical properties. They were constructed as a proof-of-principle with fiberglass plies consisting of an inner braid, several unidirectional plies, and an outer braid. The main goal was to develop an efficient lay-up method that can provide the required strength of the pipes. The plies were laid as shown in Figure 1. Plies consisted of an inner braid, eleven wraps of 0.012in unidirectional, and an outer braid. After painting on the UV-cure resin, the beam was placed outside to cure in the sunlight as shown in Figure 2. Extra unidirectional plies and a cloudy day can make it necessary to complete the cure under UV lights. Extra plies can also make difficult to fully wet all the fibers.

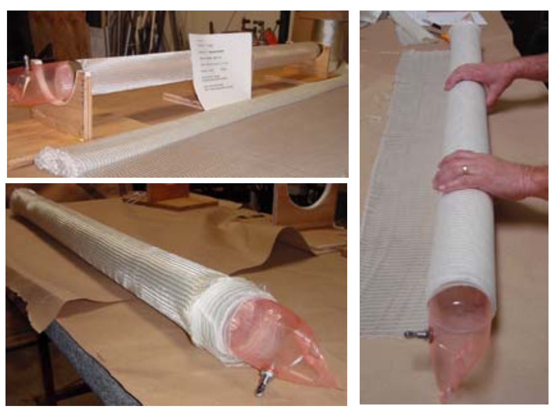

Figure 1: Clockwise from Upper Left: Inner Braid on Inflatable Form; Eleven Unidirectional Plies are Wrapped; Outer Braid is in Position.

Figure 2: Left-Beam 1 Begins Curing in Sunlight. Right-Curing with UV Lamp.

The pipes were load-tested as shown in Figure 3. They were supported at each end and concentrated loads were applied at third points as specified in ASTM 6272. A load cell recorded the force applied, up to failure at 3,700lb. The beam failed in compression at the third points where the loads were applied (Figure 4). The failure load compared well to the finite element model predicted results. An additional pipe was saturated in UV-cure resin and placed in a resin retention bag as shown in Figure 5. This Figure shows one of the major advantages of this concept; minimum space is required for storage. This method also eliminates the logistics of having available materials on the field to defeat a large amount of small gaps.

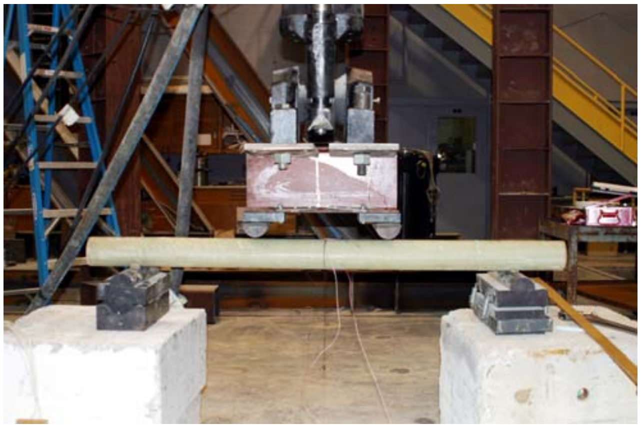

Figure 3: Load – Deformation Test Setup for 3in Pipes

Figure 4: Area of Compression Failure in 3in Pipes

Figure 5: Packed Beam Ready for Inflation and UV Cure

EXPERIMENTAL STUDY

Since the compressive strength of fiberglass composite materials is typically lower than the tensile strength, it was assumed that the tube would fail on the compression side under a bending load, as a simply supported beam with concentrated loads at third points. A typical value for the compressive strength of unidirectional fiberglass is 44,000psi for a fiber-to-resin ratio of about 50%. The pipes failed at a total load of 3,700psi, as shown on Figure 6. Since the pipe failure occurs under the concentrated loads, and not at mid-span where the pipe was supposed to fail, a minimum compressive stress was deducted from the strain results as 25,000psi (Figure 7). Based on the results the pipes had an average stiffness of 3,700psi. Using the results obtained from the experimental test, a simply finite element model was made, as shown in Figure 8. From the model it was deducted that the beams failed at 3,700lb based on a local failure due to narrow load points.

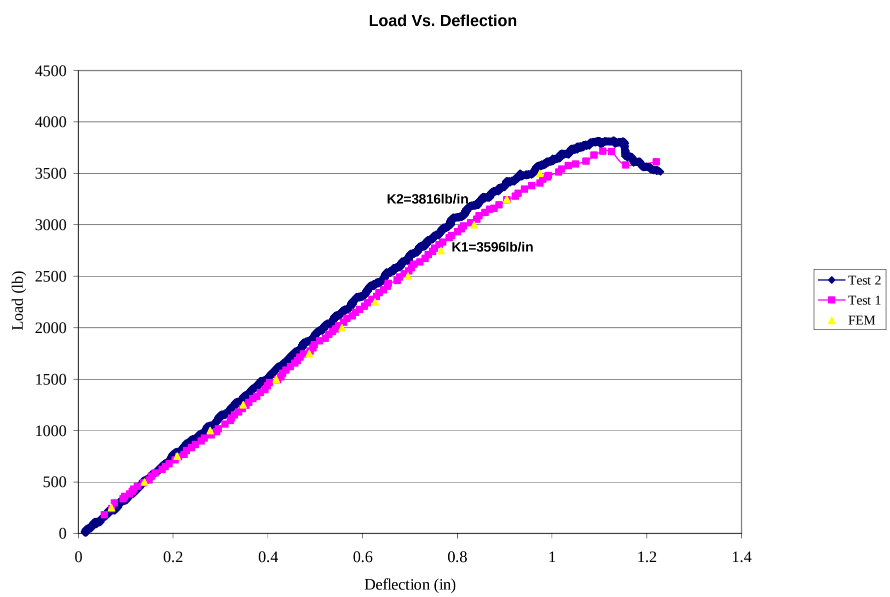

Figure 6: Load-Deflection Results for 3in Pipes

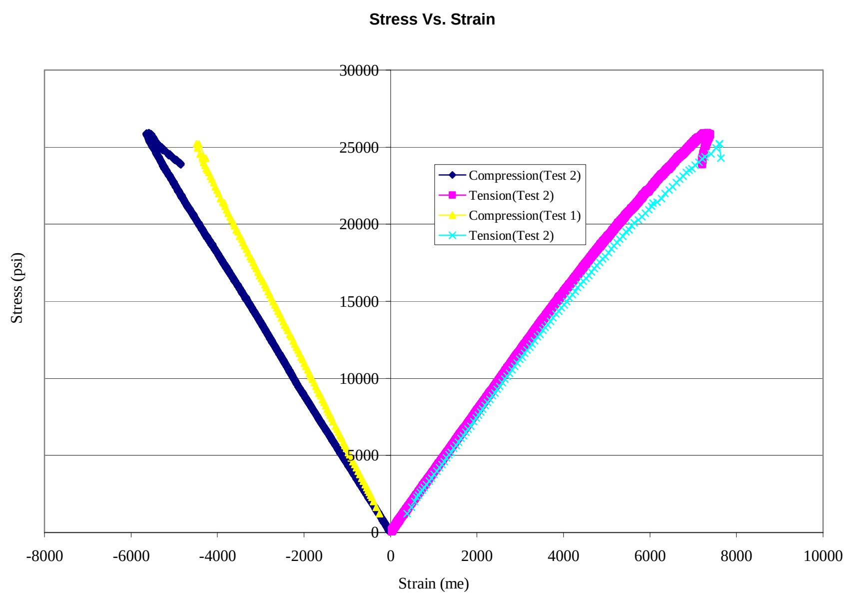

Figure 7: Stress-Strain Results for 3in Pipes

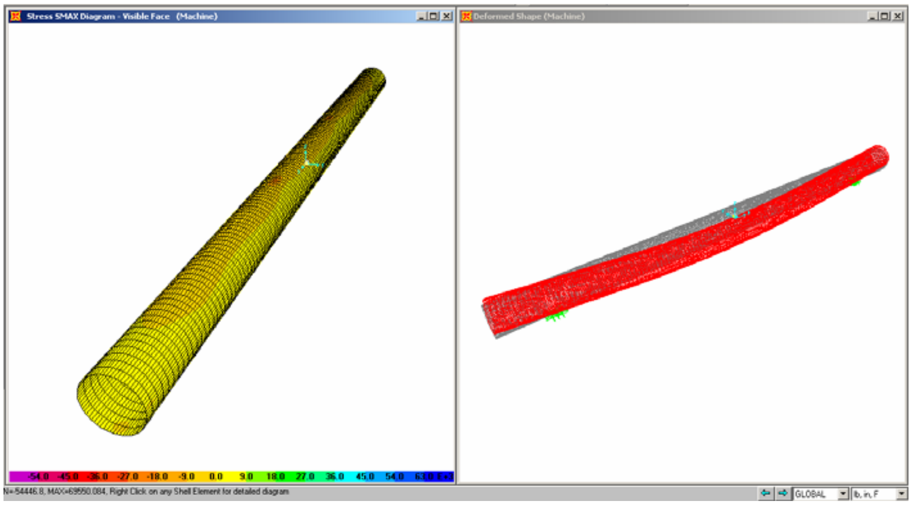

Figure 8: Finite Element Analysis Model for 3in Pipes

The next step consisted on the testing of 37.25 by 120in by 0.4in thick pipes with two equal concentrated loads, and a 6ft separation between loads. This spacing was set to simulate the spacing of civilian wheeled vehicles (Figure 9). The results from the test show that the pipes were able to sustain a total average load of 14,000lbs (Figure 10). Relatively large deflections, an average of 13in on the top, were obtained during the test, but the pipes returned to their original shape as shown on Figure 11. The test ended because the pipes slip from the support due to the lack of restrain on the support points. The pipes never completely failed during the test but certain areas started to show signs of delamination of the fibers.

Figure 9: Load – Deformation Test Setup for 37.25in Pipes

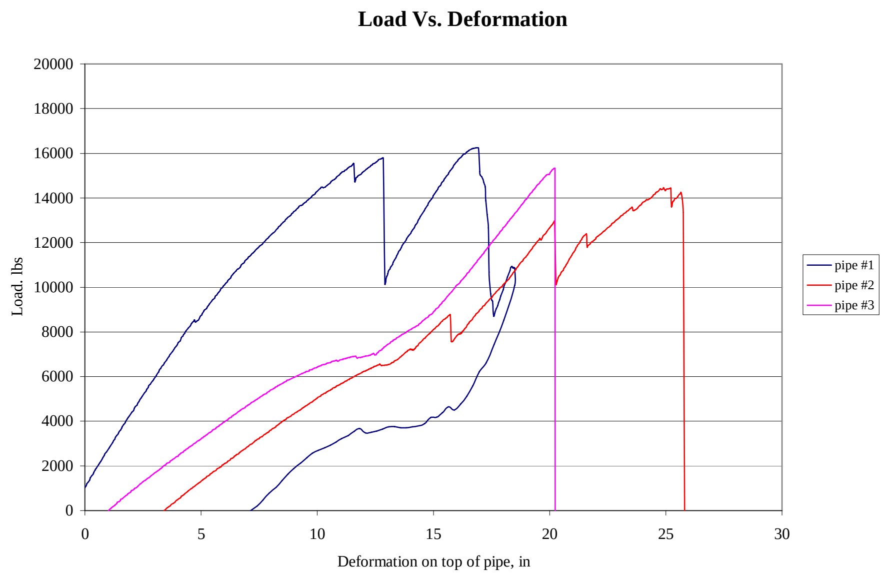

Figure 10: Load-Deflection Results for 37.25in Pipes

Figure 11: Left-13in Deflection on 37.25in Pipe. Right-Pipe Pull Out and Returns to Original Shape.

After a review of the results obtained in the laboratory it was decided to perform a full scale test using the same 37.25in pipes. Note that the pipes sustain a relatively large deformation and they were delaminated from the previous test. A 9ft gap was chosen on the grounds of the Waterways Experiment Station in Vicksburg, MS, as a site to deploy 3 pipes. The pipes were strapped with commercial straps of 1000lb, not to provide an additional stiffness to the pipes but to maintain them together. Also, a flexible plastic mat was deployed over the pipes to define the traffic lane for the vehicles. Several types of wheeled and tracked vehicles performed a low-speed (less than 5 MPH) crossing thru the pipes, including wheeled and tracked bobcat vehicle, F-150 civilian vehicles, HHMMV and M113 wheeled and tracked military vehicles.

The heaviest load was imposed by the HHMMV and M113 military vehicles. Both military vehicles were weighted on a scale. The HHMMV weighted a total of 6,620lbs, the front axle weighted 3,280lbs and the back axle weighted 3,340lbs. The M113 weighted a total of 30,000lb distributed equally on his five axles. A mat wearing surface and 3in pipes were used in combination with the 37.25in pipes to minimize bumps between pipes. Both vehicles were able to defeat the gap as shown on Figures 12 and 13 for the HHMMV and the M113 respectively.

Figure 12: HHMMV Defeats the 9ft Gap

Figure 13: M113 Defeats the 9ft Gap

CONCLUSIONS AND RECCOMENDATIONS

Final results of the research show that the combination of Sunrez ultraviolet cure resin with the Vertigo inflation technology is an appropriate solution to defeat gaps from 1.5 to 4 meters. The small amount of time required for the composite to cure, the minimum space required for shipment / storage and the hydraulic properties of the pipes are major advantages that will beneficiate the US Army future force. In fact, the fiberglass composite tubes comply with the general approach to achieve a fast, lightweight and field-deployable pipe culvert. Based on the analysis of this research it is recommended that military vehicles crossing the pipes be restricted to a maximum of 9,000lb per axle for wheeled vehicles and 45,000lb total weight for tracked vehicles for these prototype pipes. Recommendations for future works include field testing with the Light Armored Vehicle as well as a fatigue analysis for the pipes to determine the maximum number of passes for military vehicles.

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