SAMPE '98
Super Lightweight Bridge Building Contest

by

Dr. Howard Kliger

The first super lightweight bridge competition, held at the 43rd SAMPE Exhibition on June 2, 1998 is now history. Thirty-eight contestants submitted 30 bridges for load testing at the show.

The competition was modeled after a high school contest that had been sponsored by the SAMPE New Jersey Chapter for the past six years. Of course the level of competition comes up a notch when you allow trained composites engineers to compete.

The full rules for the contest had been published previously (see Jan-Feb 1998 SAMPE Journal). The criteria for winning was simple. Just build a bridge 23" long by 4" wide, and the one with the highest ratio of ultimate load to bridge weight wins. There were four different classifications based on fabrication method and professional or student status. An additional award was given for the most innovative design. Test results are shown in the following table and photographs of some of the bridges are also shown.

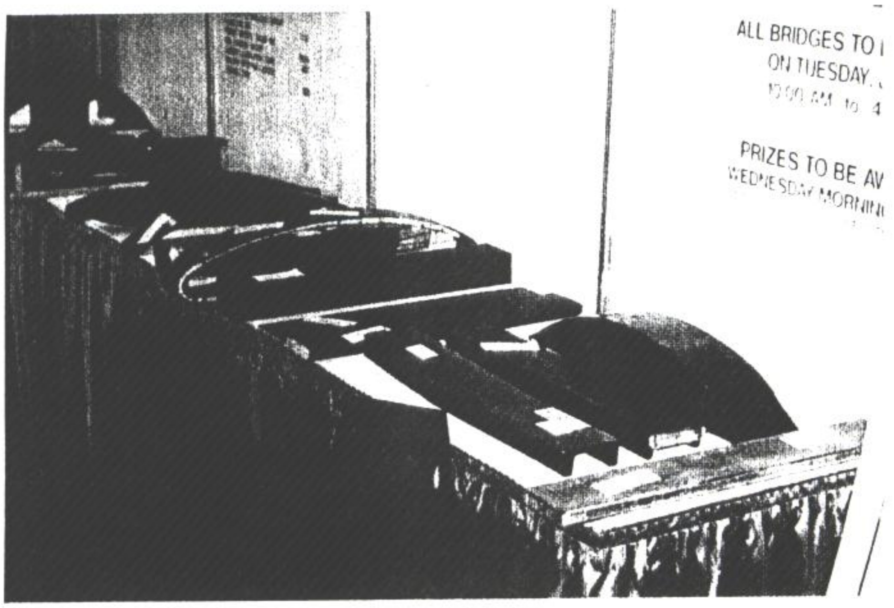
SAMPE '98 Super Lightweight Composite

Bridge Building Contest Results June 2, 1998

Contestant	Affiliation	Max Force P (lb)	Weight W (gms)	Efficiency (P/Wt)
Prof/Gr 1				
Fenske	NASA Goddard	1114	307.3	3.625
Stamper	Aerostructures	1780	87.5	3.030
Stawski	Scaled Composites	999	336.1	2.971
Paulson	NASA Ames	871	326.9	2.664
Gillette	Compositech	2214	881.5	2.512
Duke	D3 Composites	1764	881.5	2.001
Wu	United Airlines	624	351.1	1.777
Goulding	Ratech Ind. Inc.	2050	2461.5	0.832
Prof/Gr 2				
Neubert	PCI	4419	492.6	8.971
Dugan	Self	5260	725.5	7.250
Wadsworth M.Inov.	Wadsworth Dev Co	1777	546.2	3.254
Dorworth	ABARIS Training	373	302.0	1.235

Contestant	Max Force P (lb)	Weight W (gms)	Efficiency (P/Wt)
Univ/Gr 1			
Univ. Washington (Team 1)	4049	772.4	5.242
Cerritos Comm. College (Team 1)	1725	668.0	2.583
University of Maryland (Team 1)	398	196.1	2.030
University of West Virginia	3763	2632.7	1.429
University of Nevada/Reno	249	334.4	0.744
Cerritos Comm. College (Team 2)	546	814.6	0.670 M.Inov.
Univ/Gr 2			
Univ. of Washington (Team 2)	6423	514.0	4.242
CA St San Luis Obispo (Team 1)	1175	727.5	1.616
Weber State University	1945	1230.9	1.580
CA St San Luis Obispo (Team 2)	956	740.5	1.291
University of Maryland (Team 2)	197	211.7	0.929

Results Compiled Using United DATUM
For Windows Test Program
United Testing Systems
Huntington Beach, California



Bridges on display (after testing). Arrow points to Hans Neubert's double T design, which had the highest efficiency (8.97) of all entrees.

The prize for the highest efficiency ratio was captured by the bridge designed by Hans Neubert of Programmed Composites (see arrow on photo).

Neubert offered the following commentary on his successful entry:

> "My overall winning design carried a load of 4419 pounds at a weight of 492.6 grams, yielding a P/W ratio of 8.97. The bridge had a smooth, flat upper surface constructed of variable thickness Textron's Hy-Bor Boron/ epoxy with a single ply of graphite cloth. The cross section was Pi shaped, with two layers of graphite cloth cured to the underlying aluminum honeycomb core. The tension members were variable thickness M46J/ cyanate ester. At failure, the shear webs fractured across the entire section simultaneously with the top facesheet delaminated from the core. I believe I can readily improve over this year's entry, since the design and construction was not started until about a week before the show. No FEA analysis was used"
>
> "In contrast to the typical sandwich beam test specimen per ASTM C 393, which is loaded across the full width, the SAMPE Bridge is loaded at four discreet points. Assuming unidirectional material is employed for the compression and tension elements, the full 4-inch width of the bridge is not effective in bending due to shear lag (St. Venant principle). Consequently, a uniform cross section adds weight without increasing bridge strength. The bridge can be considered as two beams held together by the thin, uniform road surface. This led me to the Pi configuration, or in civil engineering terms, a double T beam.
>
> The designer of a successful bridge must have a good appreciation for the mechanical properties of materials to be employed. All graphite laminates have less strength in compression than in tension. For tension and compression strength failure to occur simultaneously, the area of the compression member must be compensated. Alternatively, one can use a material that has exceptional compression strength, such as Hy-Bor. It turns out that M46J and Hy-Bor have about the same unidirectional modulus, and M46J tension strength is about the same as Hy-Bor compression strength. Since stresses due to bridge bending vary linearly from the support point

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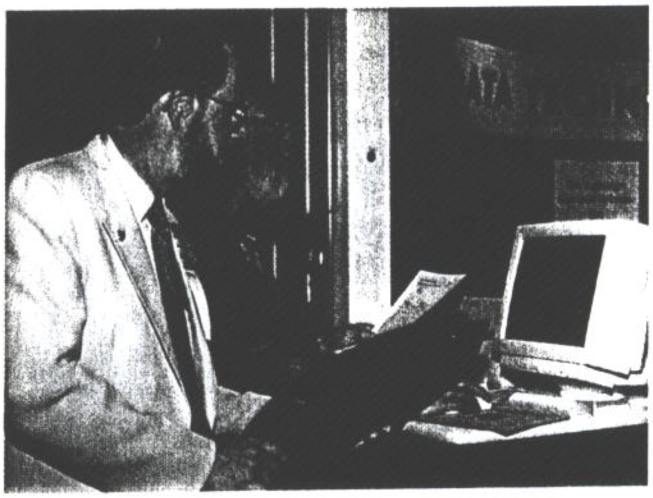


Reviewing the test scored of one of the bridge contest entries.

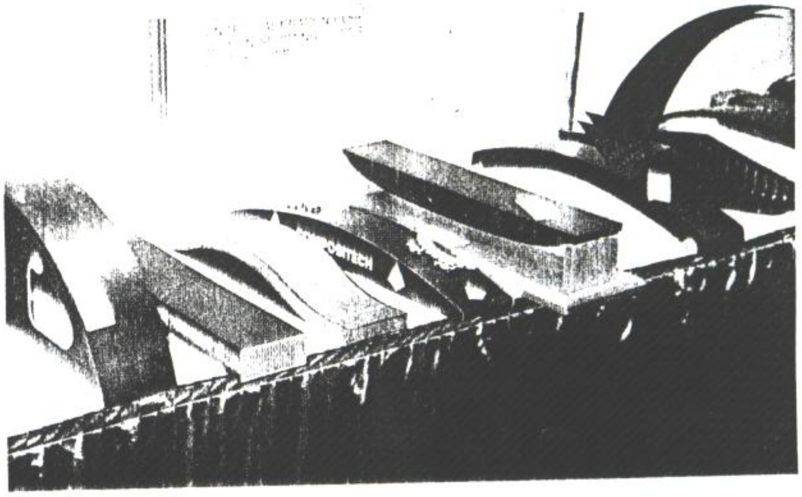
> to the load point, a constant thickness layup for the tension and compression elements is not appropriate for minimum weight."
>
> One solution to an optimum design will be when failure strength and maximum allowed deflection are satisfied simultaneously. Taking the strength and displacement equations found in ASTM C 393, one can readily solve for the bridge thickness (or height)."
>
> "Shear load between the support point and the load point is constant. If the bridge designer desires to have uniform shear member thickness, then a uniform height over the span length is appropriate. For designs that intend to use a curved lower surface, then shear strength requirements dictate increased material thickness as the height is reduced."
>
> "Having satisfied strength requirements for a given design load, elastic stability needs to be checked to verify this failure mode is not critical. For sandwich construction, Hexcel's TSB 123 provides equations for intercell, shear and compression buckling, as well as face wrinkling. MIL-HDBK-23 is another comparable resource, as well as the Plantema text. For designs using unsupported laminated plates, the Timoshenko text series provides all necessary buckling solutions."
>
> "The ultimate, optimum bridge is one where all failure modes are satisfied simultaneously. This may require a solution using Calculus of Variations. Since laminated composites have finite cure ply thickness and are added in integer units, the ultimate design should be considered a goal. Nevertheless, P/W ratios in excess of 20 are within the realm of possibility, feasible only by the use of composite materials."

So now you know Hans' secret - boron fiber. Well, we've already talked to a boron fiber supplier and they have tentatively agreed to supply the material to all contestants in the SAMPE '99 bridge contest. Hans, you can kiss that edge good-bye.

Two prizes for innovation (professional and student) were another aspect of this competition. We did not provide guidelines for this award. Instead we asked our two judges, Brant Goldsworthy and Gary Hawkins, to look at all the designs and pick the ones that they felt represented the most innovative approach. The team from Cerritos College won the student innovation award although their bridge had the lowest P/w value of all tested. That just shows that innovation and performance don't necessarily work together. Mark Wadsworth had the most innovative professional bridge (frankly, it doesn't look like any bridge I've ever seen - see photo.)

Mark offered the following insights into his thoughts on how to design and build an optimum composite structure:

> "Simply stated, the bridge contest tested structural efficiency. That basically dictated how well the materials were used. One of the



Bridges on display (after testing). Arrow points to Mark Wadsworth's most innovative desing.

most important factor was how thick to make the bridge. There was no limit on this dimension and a very thick bridge would obviously hold more weight, but how thick was too thick? A rudimentary math model was concocted to describe the weight function and the thickness benefit function and the point at which they crossed (roughly 3.5") was taken to be the best thickness. At some point deck loads at the points of application will cause failure, but predicting this is difficult. One could design a bridge to hold as much weight as possible and reinforce the deck where the load is applied (along the entire span as rules require), and place this deck where it will contribute the most to the overall structure. With this reasoning, possible cross sections were conceived and analyzed in terms of their moment of inertia and sectional area. The deck was moved to the tension side the beam, where buckling is not a failure mode and the superior tensile properties of composites can be utilized."


Some of the contest winners display their prizes. Also shown are contest organizers Howard Kliger (on the left) and Jerry Bauer (on the right).

Then consideration was given to the geometry of the compression flange. The flange was intended to carry only compression loads so buckling was the primary concern. The flanges were centered on the shear web to minimizes the distance to a free edge, and the outer flange was further stiffened by the addition of a return flange with a rolled edge. To carry the shear load between the compression and tension sides, a sine shear web was chosen to minimize the web thickness without shear buckling. The sine geometry also added buckling support to the compression flange.

Once the section had been defined, how this section would vary had to be determined. Since the bending moment diagram for this beam is similar to an inverted V, the upper edge of the shear web was similarly shaped in the interest of efficiency. The lower edge was defined by a parabola to smoothly transition the tensile loads into the shear web. The outer compression flange was also tapered in width to reduce weight as the bending moment dropped off at the ends.

The material selected was intermediate modulus graphite unidirectional and bidirectional fabrics. The sizing process started with the shear web which was selected for minimum gage (0.025 in) and the stresses calculated for various flange and deck thicknesses until the stresses in all areas were near ultimate at the same load. The final design incorporated features to optimize performance but increased the complexity of the structure. Finally it evolved into a shape that could probably only be made by the resin transfer molding process. Since tooling costs are typically higher with RTM and only one part was to be produced from a single surface pattern; rapid and low cost tooling was required. The resulting tooling was cast urethane and fiberglass outside combined with cast urethane and aluminum inside. The outside tooling was made from a translucent material to allow observing the RTM process and increase the likelihood of producing a good first part. The inside tooling was designed to be disassembled in order to be removed from the undercut flanges. Only one part was laid-up, injected and used in the competition."

The contest would not have been successful without the contributions of the sponsoring companies, listed below. These companies supplied the composite materials which went into the kits sent to each team. The sponsors also supplied composite related prizes, some of which are displayed in the photograph of selected winners.

Lastly, special thanks to John Mistretta, Jerry Bauer and John Osterndorf, all of whom spent many hours organizing and conducting the contest.