Repair Engineering

The Engineering Side of Composite Structural Repairs

How bad is the crash, and what should we do to fix it right?
The kind of repair needed will depend on what kind of vessel and where the damage is located on that vessel.
If the repair is to remedy an inadequate original condition, the designer of the vessel must be contacted first to redesign the part. Even restoring to original condition may require the designer's input.
If the designer's input is not available, a determination must be made about what the existing laminates probably are.
In my work with multihulls; long, slender structures, most of the loads are governed by deflection or bending from in-plane loads. Repairs would usually then be optimized for in-plane loads. Other vessels with less slender proportions may require that repairs to be optimized for bending or shear, caused by out-of plane loads being the governing ones. If the damage is on the ends of a vessel or on a beamy powerboat, more than likely the loads will be shear or bending.
If the damage is to a stringer, on a long, slender part, or towards the middle of a hull sporting powerful backstays for example, one can be sure the loads will be bending or with deflection governing.

Even before the materials for a repair are selected, an approach must be mapped out.
How much more area than the damage will be needed to fair the repair in?
Having an idea what the repair will look like, based on what is broken and where it's broken, is very important at this stage.
Part of this is deciding what tools will be needed. Should it be infused or not? Should it be a double side lap or single side, and how much lap should be planned for?

A repair can be defined as any secondary bonding situation, though for this paper I am assuming it means restoring damage to its original condition.

Too often repair engineering is either "what we have always done" or the center of gravity of the opinions of the last five persuasive guys who visited the shop.

Truly well engineered repairs need to be based on actual, verifiable test data to be useful. Fortunately there is some research out there on this topic.

I have found two very useful papers on this subject. One is by J.A. "Kim" Baile of Lockheed, done in 1992. The other is by Loc Nugyen of NSWC, Art Wolfe and Ron Reichard, both of Structural Composites, 1996. We don't need to depend on the five guys anymore.

Baile looked at shear stress and strain transfer in a repair, while the other paper generally looks at tensile strength.

This work does assume that the proper surface preparation is understood and done for optimum secondary bonding.

Baile examined shear strength of various joint conditions. He showed that the load transfer of simple joints is concentrated at the ends and that strength is not a function of length of lap. The failure mode is peel failure at the edges of the lap. That means increasing lap area will not increase lap strength. After a certain lap area, increasing that area not only does not add strength, it can actually precipitate an early peel failure.
He also found that the type of joint used is dependant on the laminate thickness of the part. Thin laminates can use single laps. Thicker ones need double laps. He demonstrated that tapering the laps is important.

Nguyen, Wolfe and Reichard compared various kinds of joints in tensile and flexural loads.

- They compared light verses heavy fabrics.
- Isophthalic polyester vs. Vinylester resin was also compared.
- Hand lay-up was compared to resin infusion repair.
- Most important, various scarph ratios were compared.
- Single sided repairs were compared to double sided ones.
- Finally, smooth scarphs were compared to stepped bevel ones.

These results have very important implications for successful repairs. They are:

- The repairs made with more, thinner fabrics were stronger than those made with fewer, thicker fabrics. Of course the total laminate thicknesses were equal.

- Repairs made with vinylester resin were stronger in both tensile and flexural strength than those made with polyester and recovered more original stiffness than the polyester resin. In tensile strength, the vinylester was almost 50% stronger. Reichard told me he thought epoxy results would be very similar.

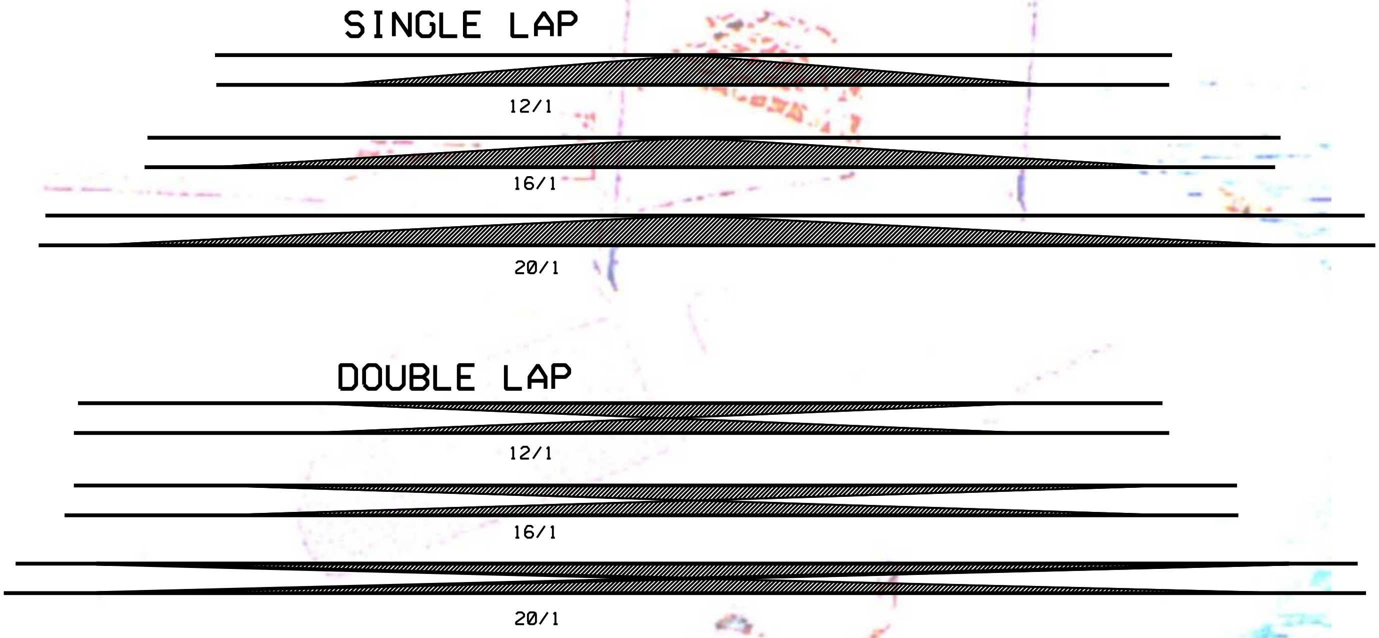
- Higher scarph angles (20:1) allow significantly more of the original flexural and tensile strength to be recovered in a repair than do lower scarph angles (16:1 or 12:1). A 20:1 scarph has some 30% more flexural strength than a 12:1 scarph.

- They found little difference between hand lay-up and vacuum infusion in repair strength.

- The 1996 study also found very little difference between single and double sided repairs and between smooth and stepped bevel repairs.

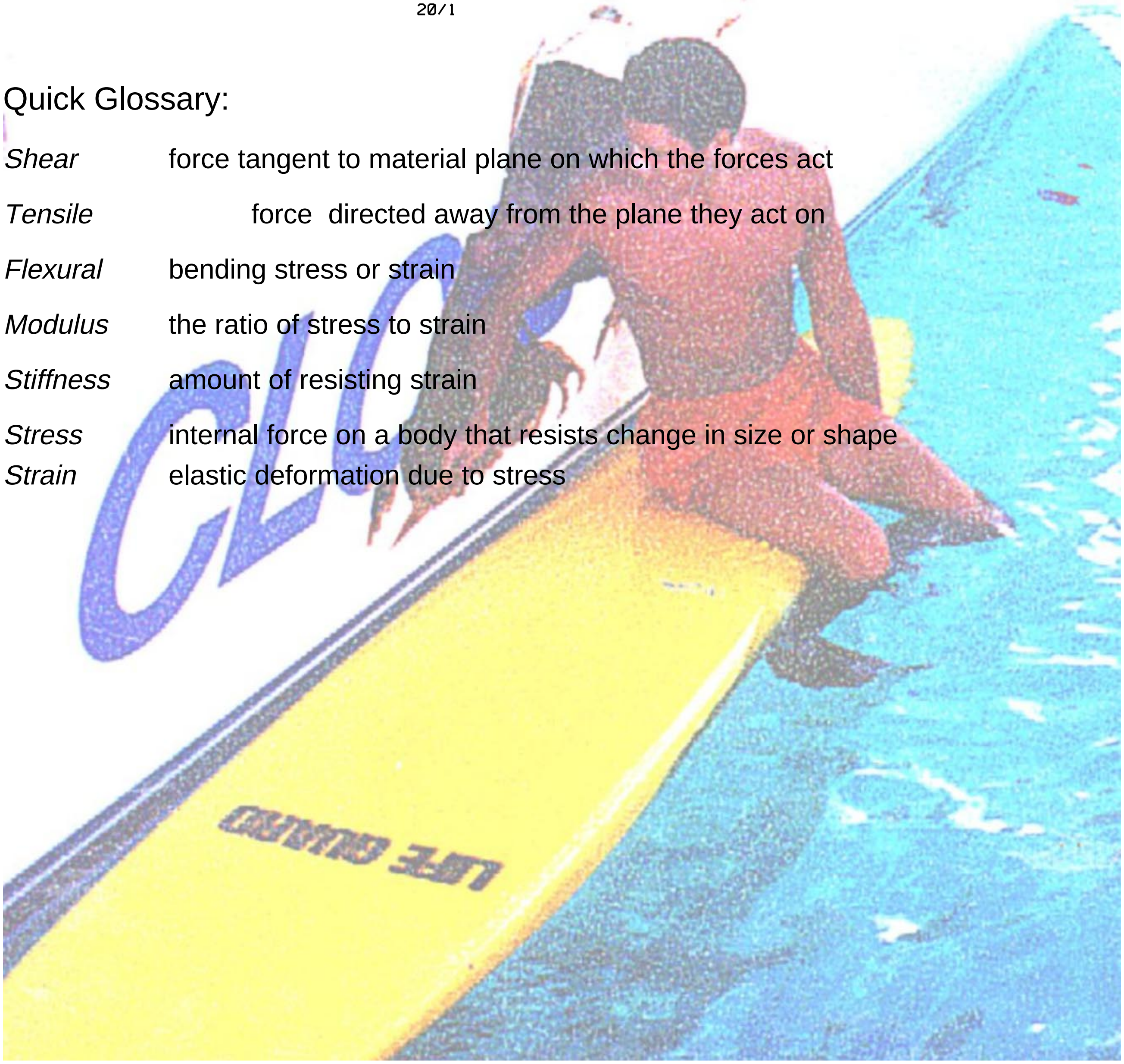
Knowing the results of the various kinds of repairs noted, at the outset, will help designers and boatyards properly anticipate what kind of repair will be needed to best restore that particular vessel.

The conclusions for those doing repairs are on the last page in a detatchable reference page.



Quick Glossary:

Shear	force tangent to material plane on which the forces act
Tensile	force directed away from the plane they act on
Flexural	bending stress or strain
Modulus	the ratio of stress to strain
Stiffness	amount of resisting strain
Stress	internal force on a body that resists change in size or shape
Strain	elastic deformation due to stress



Repaired Right!

1) Match original layup, thickness and fiber orientation as much as possible.
2) Use more, thinner laminates instead of fewer, thicker layers in a repair.
3) Use epoxy or vinylester resin instead of polyester resin. Epoxy may be easier to use.
4) Use tapered scarphs on all laps. Cut higher scarph angles up to 20:1 if possible.
5) Hand layup sacrifices little strength compared to resin infusion. Hand layup or vacuum bagged hand layup is adequate.
6) Stepped bevel repairs can be as strong as smooth scarphs. Use either.
7) A single sided repair can perform nearly as well as a double-sided one on thin laminates.