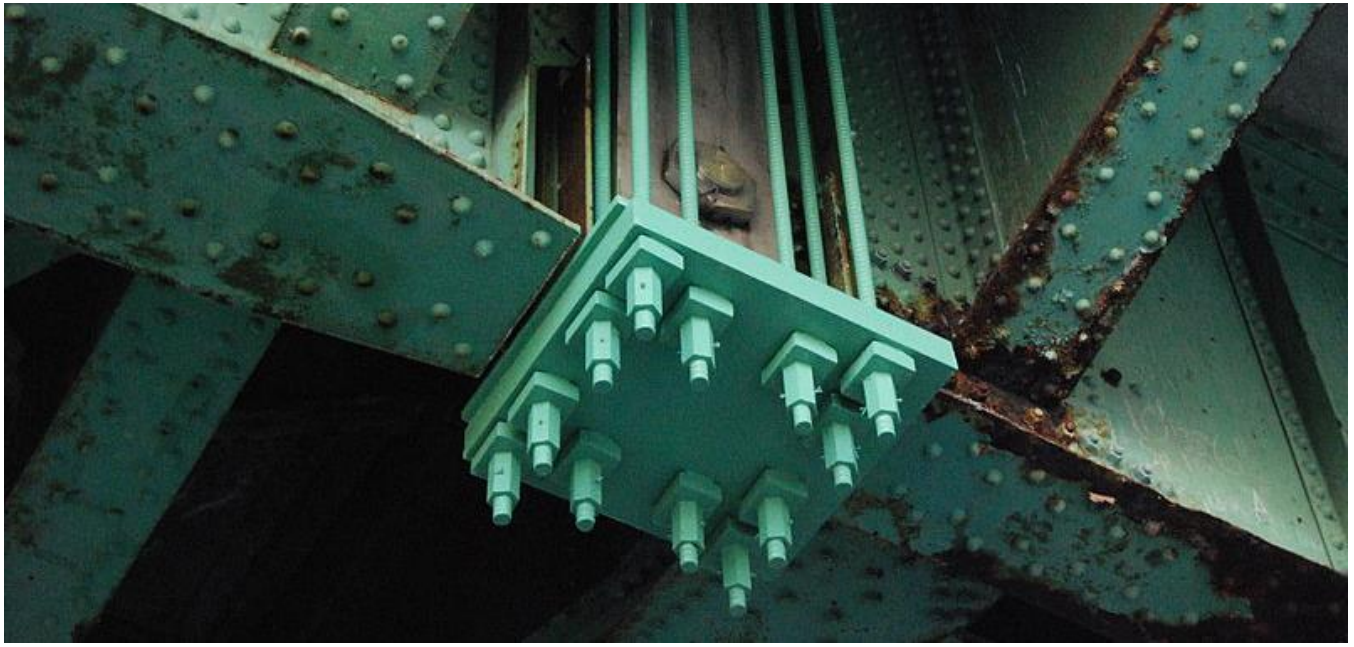
Lesson and Project Overview



Patching Steel to Rehabilitate Structures

If Superman were not the man of steel, what other material—*stronger than steel*—might he be made of?

Must this new material be a metal?

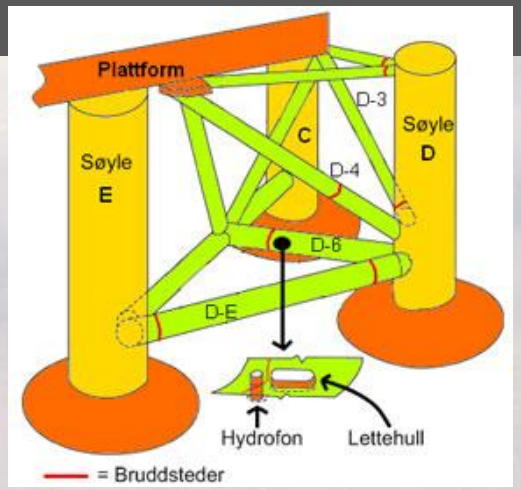
The Problem

I-35W Mississippi River Bridge collapse

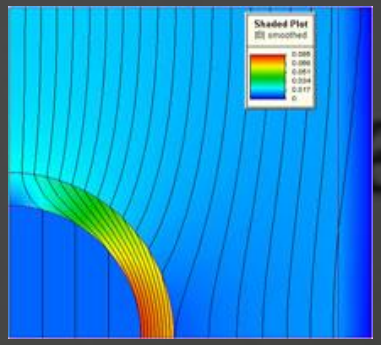
Minneapolis, MN, August 1, 2007

Alexander Kielland Platform

Norwegian North Sea | March 27, 1980

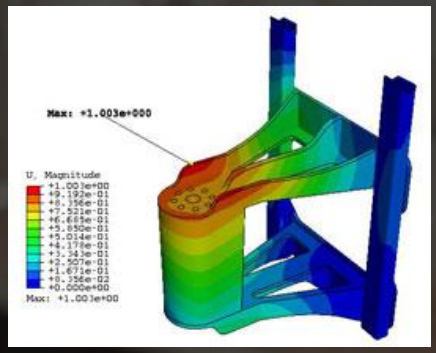


The Engineering Challenge



Under repeated loading, cracks propagate compromising the integrity of structure

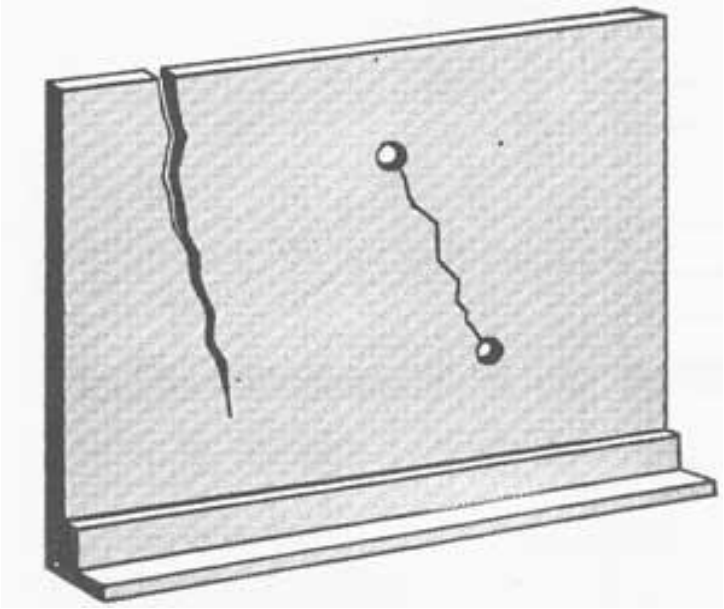
Fatigue cracks form in steel structures due to cyclic loads. These initiate at locations of stress concentrations such as notches, weld details and holes.

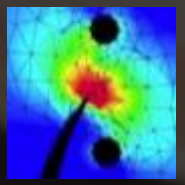


Once a crack is detected, is it possible to stop it from growing?

Traditional Methods to Repair Cracked Steel

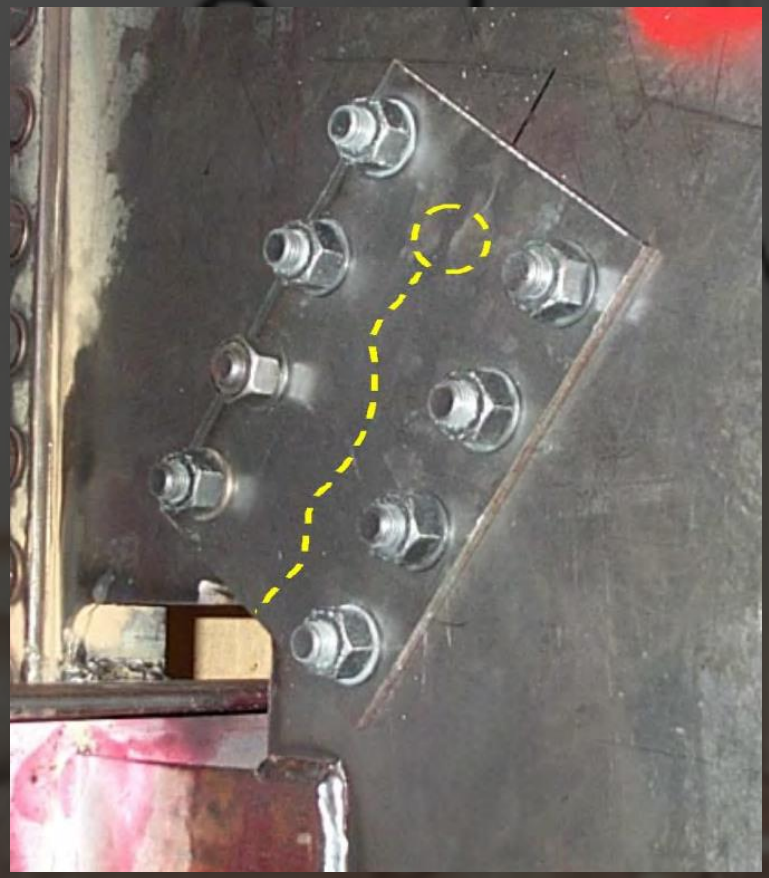
Crack Stop Holes





- Difficult to drill in reduced places
- Holes may compromise structure strength

Traditional Methods to Repair Cracked Steel



Cover Plates

- Difficult to drill and collocate in reduced places
- Difficult near bolts and angles
- Induces stress concentrations

Traditional Methods to Repair Cracked Steel

Repair Welding

- Difficult to weld in reduced places
- Risk of explosion
- Induces stress concentrations

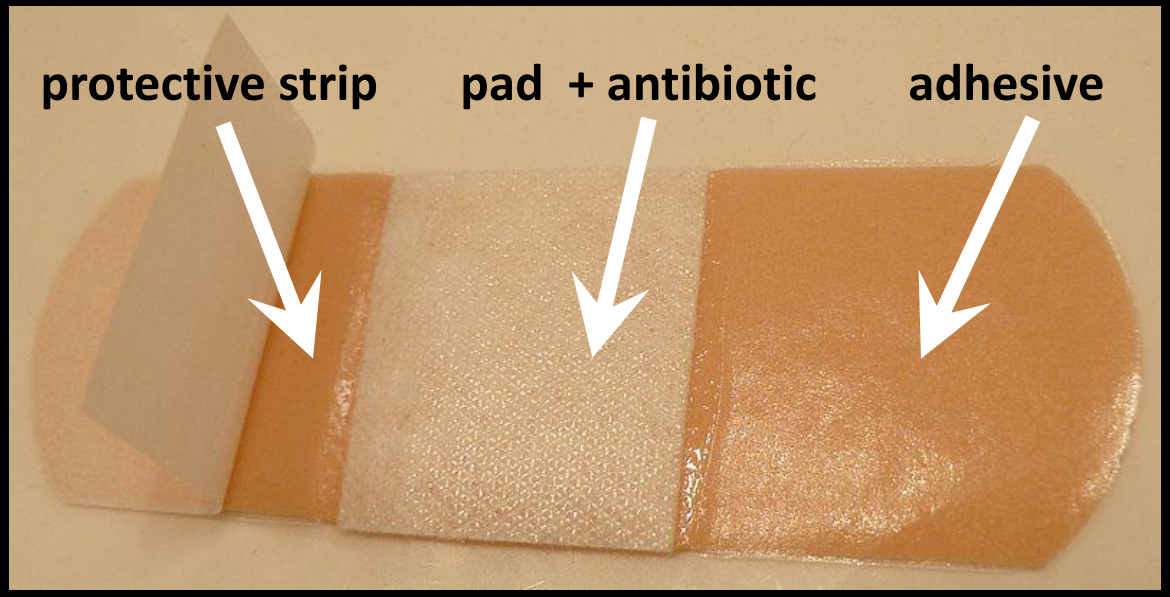
Traditional Methods to Repair Cracked Steel

These techniques require the use of heavy equipment and produce irreversible modifications of the underlying structure

Better solutions?

Could you repair a crack in steel using something like a band-aid?

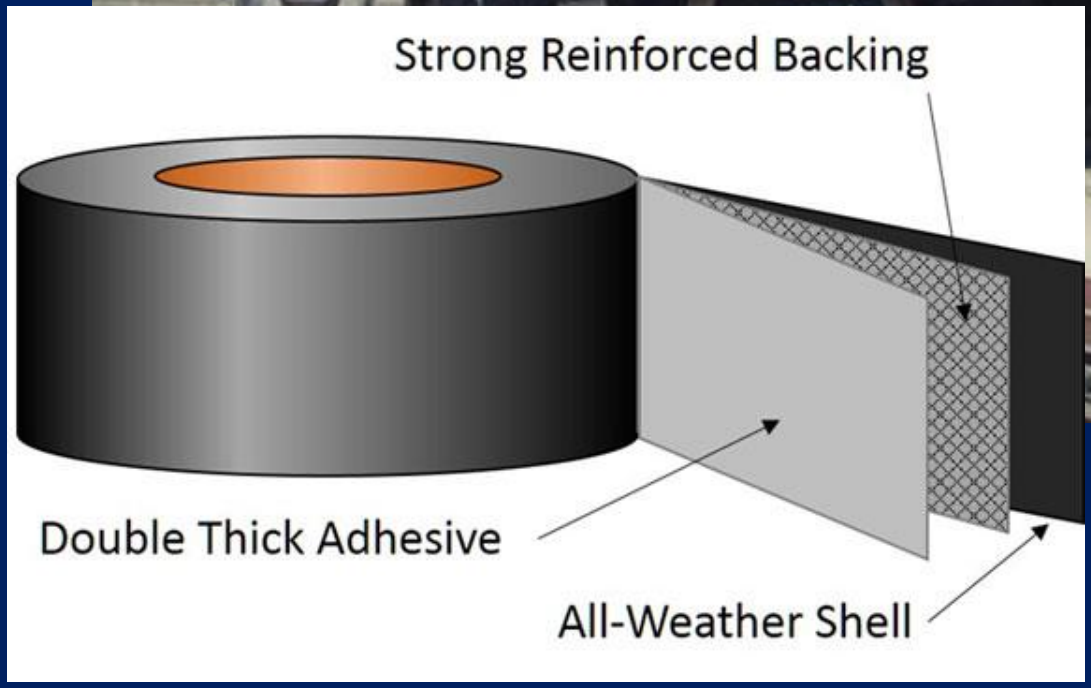
Initial question: *Why does a Band-Aid work*?



A Band-Aid is a composite

Material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components

stronger material + stronger adhesive?

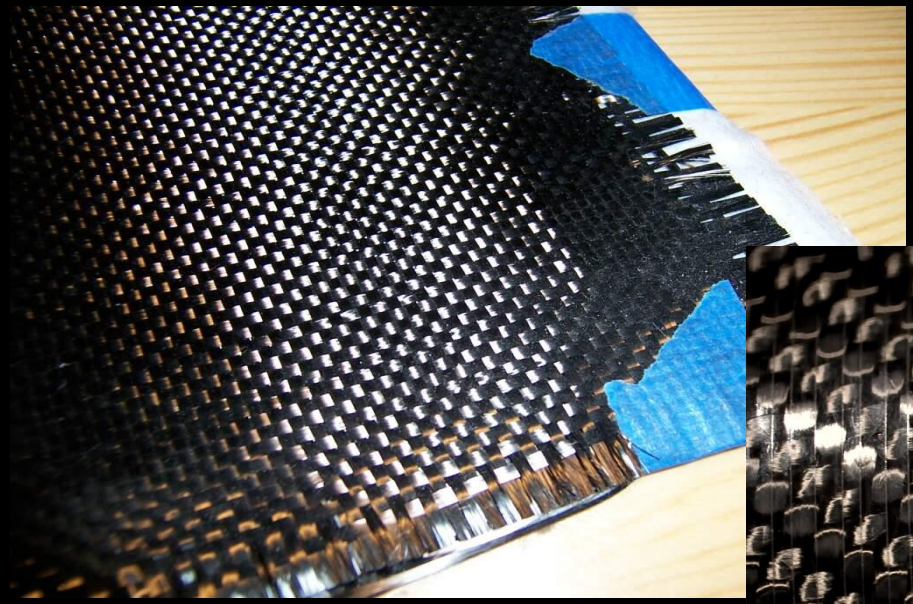


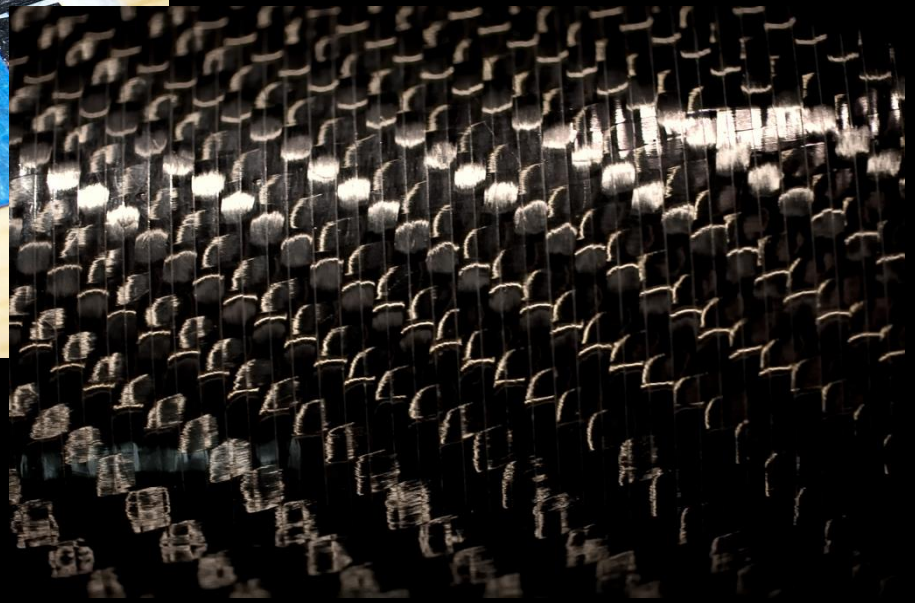
stronger material + stronger adhesive?

Composites

Epoxy Adhesives

Carbon-Fiber-Reinforced Polymers (CFRP)





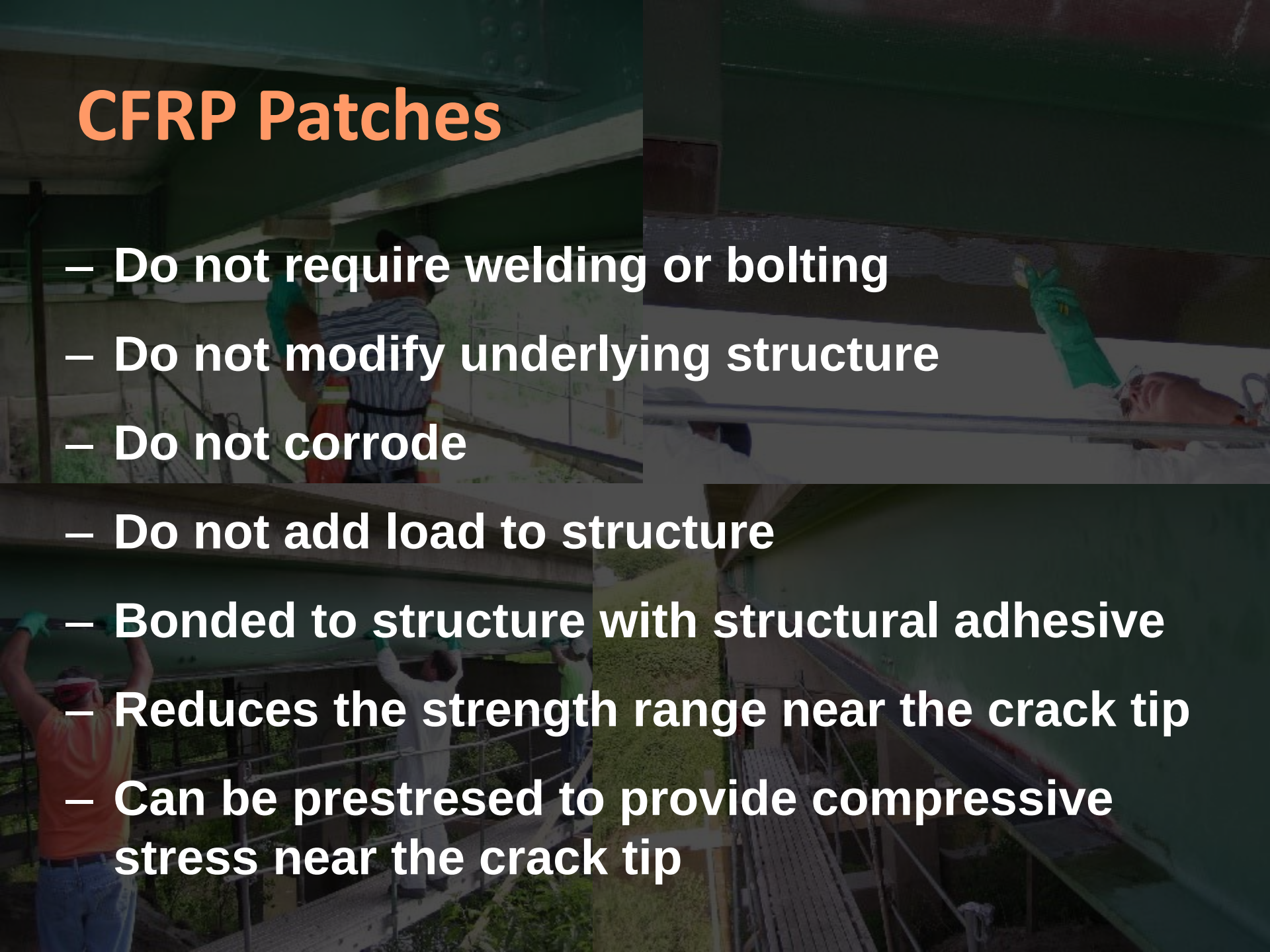
CFRP-Epoxy Adhesive Composites

Fiber Reinforced Polymers

- Composite material made of a polymer matrix reinforced with fibers
- The polymer is usually an epoxy, vinylester or polyester thermosetting plastic
- Fibers are usually glass, carbon or aramid; paper, wood or asbestos may be used
- The alignment and weave of the cloth fibers is designed to optimize the strength and stiffness properties of the resulting material

Carbon-Fiber-Reinforced Polymers

- To create CFRP parts, sheets of carbon fiber cloth are layered into a mold in the shape of the final product.
- Then the mold is filled with epoxy resin and heated or air-cured
- The resulting part is very corrosion-resistant, stiff, with high fatigue strength, and strong for its weight



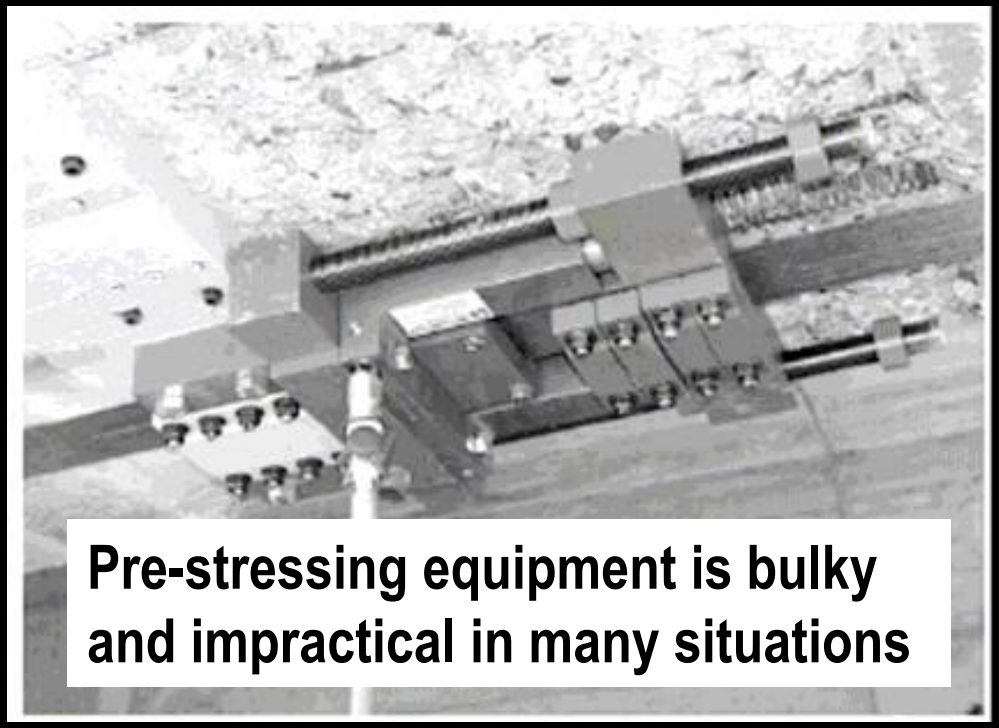
CFRP Patches

- Do not require welding or bolting
- Do not modify underlying structure
- Do not corrode
- Do not add load to structure
- Bonded to structure with structural adhesive
- Reduces the strength range near the crack tip
- Can be prestresed to provide compressive stress near the crack tip

CFRP Patches to Rehabilitate Steel Structures

Engineering fact: Pre-stressed patches halt crack propagation

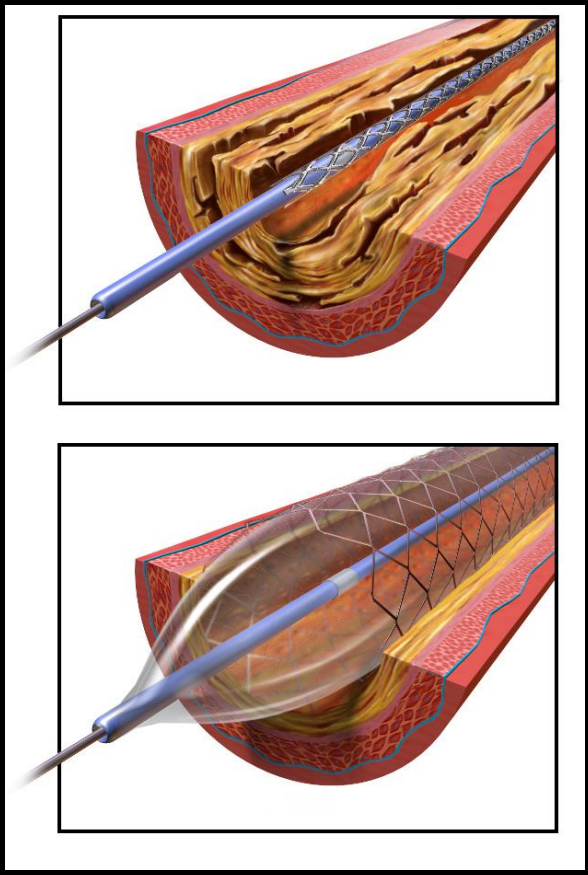
CFRP Patches to Rehabilitate Steel Structures

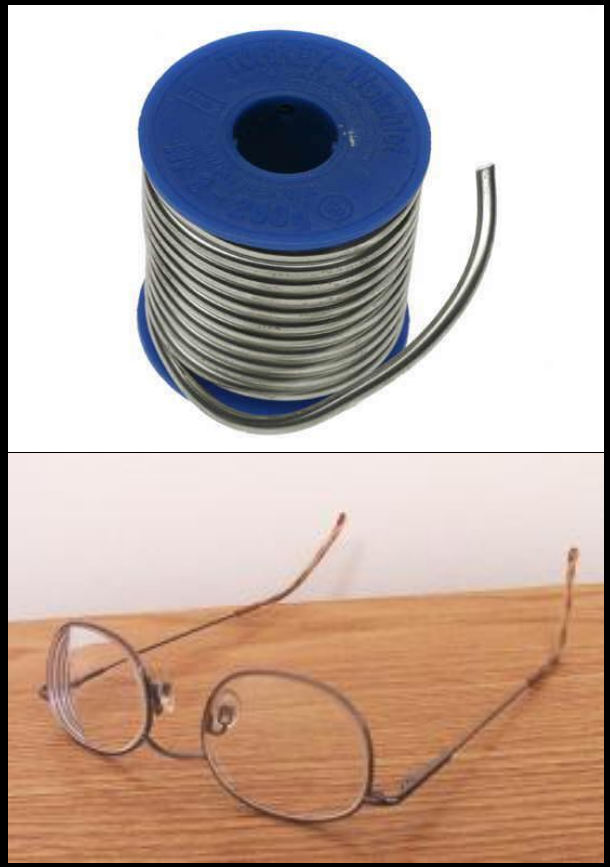


Is there an alternative to stress the CFPR patches?

Shape Memory Alloys— Nitinol

Example applications

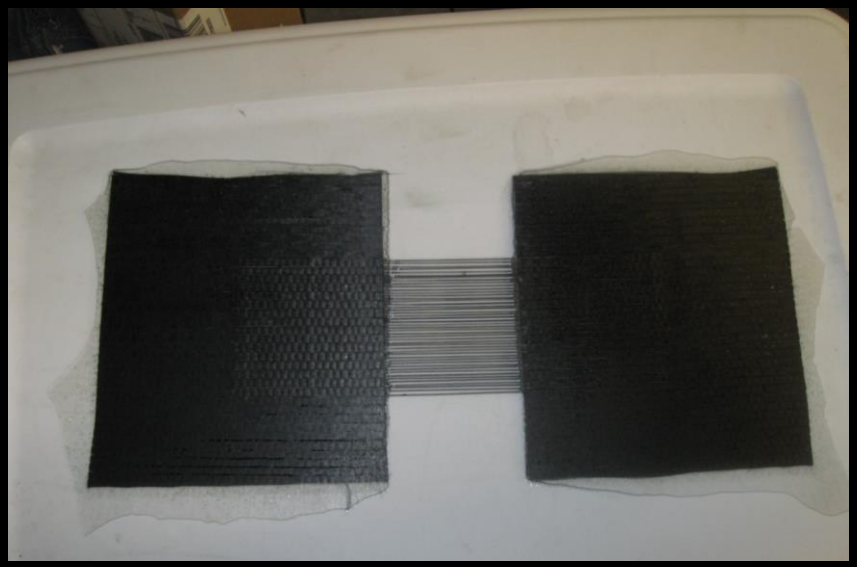




Shape Memory Alloys—Nitinol

Could nitinol be used to pre-stress CFRP-epoxy adhesive composite patches?

NiTiNb-CFRP Patches to Rehabilitate Steel Structures



A NiTiNb-CFRP patch is simple to pre-stress and apply, but… **how effective is it?**

List of embedded video and web page link in slides

Slide 3: While in slide show mode, click on bottom right inset image to go to MDPI image source web page: “Fatigue-Prone Details in Steel Bridges” by Reza Haghani in *Buildings* at http://www.mdpi.com/2075-5309/2/4/456/htm

Slide 4: While in slide show mode, click the three camera icons to open the following three videos:

(left) When a Bridge Falls: Disaster in Minneapolis | Retro Report | The New York Times (9:56 minutes) https://www.youtube.com/watch?v=74JNl5n-YdI

(middle) Seconds after Minneapolis Bridge Collapse! (1:56 minutes) https://www.youtube.com/watch?v=5euNMj9oEZs

(right) I35-W bridge collapse (actual footage) (39 seconds) https://www.youtube.com/watch?v=z1uscpZt8EQ

Slide 5: While in slide show mode, **click the two small images** to open the following online videos:

(top diagram) Alexander Kieland by luis282008 (2:39 minutes) https://www.youtube.com/watch?v=7QVn3NUW_aQ

(bottom photo) Alexander Kielland ulykken by Inger Mari (3:17 minutes) https://www.youtube.com/watch?v=fNI6_8JQXzQ

Slide 6: While in slide show mode, **click the small blue 2D drawing and rainbow part images** to open the following online videos:

(blue drawing) Crack propagation, finite elements (8 seconds) https://www.youtube.com/watch?v=G5K_04I_XkE

(rainbow part) Crack propagation through grain boundary (10 seconds) https://www.youtube.com/watch?v=qMBtYq9vc78

Slide 7: While in slide show mode, click the small bluish image to open the following online video: Cracking with Holes (20 seconds) https://www.youtube.com/watch?v=03tQhVDHbQs

Slide 14: While in slide show mode, click on the four smaller images to open the following online videos:

(plane) Composites in Aviation by BioNetwork (6:37 minutes) https://www.youtube.com/watch?v=wXxn-8OA8Ac

(tire) Intro to Composites by BioNetwork (4:12 minutes) https://www.youtube.com/watch?v=WYqCnEvTRUQ

(bridge) 5 Steps of the Pultrusion Process (2:05 minutes) https://www.youtube.com/watch?v=1sH9rIGWNvc

(watch) Graphene: Composite Materials (3:22 minutes) https://www.youtube.com/watch?v=LTa_ileMJxE

Slide 15: While in slide show mode, click on the four smaller images to open the following online videos:

(clear drop) 3M’s Tough Stuff vs. 3/8 Rivet Shear Test (31 seconds) https://www.youtube.com/watch?v=4kHflHJEfAM

(brush) Physical Strength Propereties of Epoxy Adhesives (2:57 minutes) https://www.youtube.com/watch?v=4WhBvSk8ajA

(2 bottles) Fabrico, a Division of EIS – High Strength Adhesives (4:26 minutes) https://www.youtube.com/watch?v=MKIlireFOIQ

(gray caulk) 3M’s Tough Stuff vs. Spot Weld Impact Test (32 seconds) https://www.youtube.com/watch?v=CPR28olqf5Y

List of embedded video and web page link in slides (continued)

Slide 16: While in slide show mode, click on the two smaller images to open the following online videos:

(fabric with blue tape) Carbon Fiber by Maddbluntz (camera zooms in from a bicycle part to the highest possible visual magnification of carbon fiber) (3:17 minutes) https://www.youtube.com/watch?v=q0mQk1s4tKo

(carbon fiber weave) Rhino Carbon Fiber Shear Pin Strength Test (3:05 minutes) https://www.youtube.com/watch?feature=trueview-instream&v=vgH8eyCN8MI

Slide 17: While in slide show mode, click on the six smaller images to open the following online videos and website:

(yellow-suited man) Concrete Bridge Repair w Fiber Reinforced Polymers – Carbon Wrap Solutions (shows three bridge repair examples) (4:32 minutes) https://www.youtube.com/watch?v=NSbpl9f0lO8

(runners on track) Oscar Pistorius runs 400M London Summer Olympics 2012 (4:50 minutes; start at 2 minutes in) https://www.youtube.com/watch?v=vB_g-RSIGfM

(artificial legs) High-Tech Running Prosthetics (2:05 minutes) https://www.youtube.com/watch?v=P27GVE6n8lU

(BMW car frame) Steel Shaft vs. Carbon Fiber Shaft (5:31 minutes) https://www.youtube.com/watch?v=hjErH4_1fks

(car bumper honeycomb) Getting to Know Fiber Reinforced Polymers (7:27 minutes) https://www.youtube.com/watch?v=iqD9hBQXi5Y

(artificial leg) Imasen Engineering Corporation's Lapoc System Prostheses web page showing various products http://www.imasengiken.co.jp/en/lapoc/sport.html

Slide 21: While in slide show mode, click on the image to open the following online video: Sika CarboDur – Carbon fiber laminate for structural strengthening (2:09 minutes) https://www.youtube.com/watch?v=_oSGDt_XGHY

Slide 23: While in slide show mode, click on the five smaller images to open the following online videos:

(angioplasty-stent) 3D Animation of Coronary Stent Procedure (1:14 minutes) https://www.youtube.com/watch?v=t-zCBKRg7Cs

(roll of solder) Powerful Nitinol engine running on hot water (5:10 minutes) https://www.youtube.com/watch?v=YsOSqwrBb1I

(eyeglasses) SpaceMETA present NITINOL explanation by MIT (memory shape materials) (5:01 minutes) https://www.youtube.com/watch?v=2YVwpBAiA1A

(nitinol wires) Nitinol – Metallic Muscles with Shape Memory (watch deformed wire objects return to original shape when heated) (4:23 minutes) https://www.youtube.com/watch?v=-K57cbOhA5g

(dental braces on teeth) Nitanium Palatal Expander2 Multi-Purpose Finishing Appliance (43 seconds) https://www.youtube.com/watch?v=dqbzmKIUmuk

(dental braces off teeth) Nickle Titanium-NiTi-Orthodontic Wire (45 seconds) https://www.youtube.com/watch?v=cArEU2hLSFU

Slide 24 – While in slide show mode, click on the image to open a website about a professor who is developing a patch for repairing cracked steel: https://www.egr.uh.edu/news/201103/professor-developing-patch-repairing-cracked-steel