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APPLICATIONS OF FIBER REINFORCED POLYMER COMPOSITES

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CONSTRUCTED FACILITIES CENTER

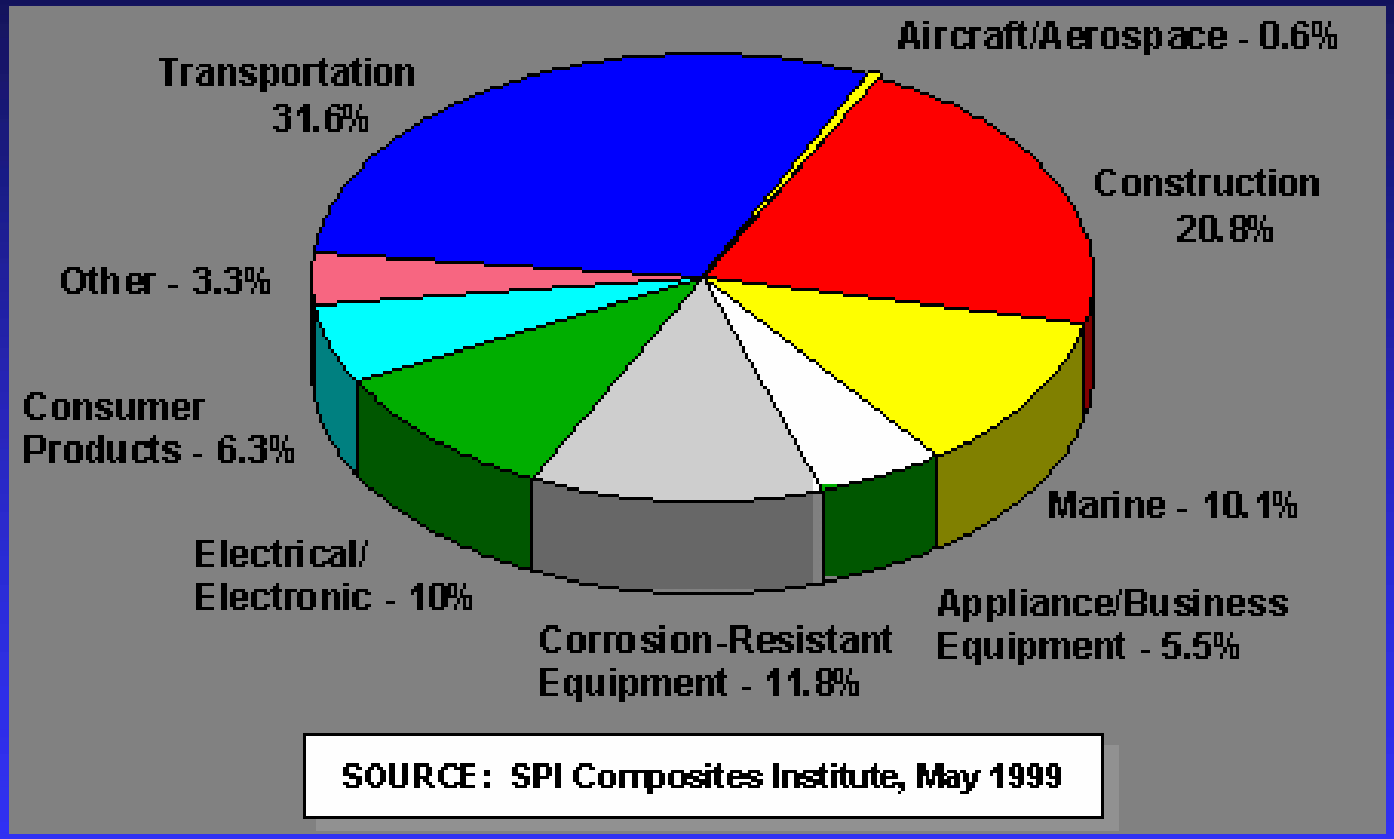
West Virginia University
Where Greatness is Learned

February 24, 2006

Presentation Overview

- FRP – the Materials of 21st Century
- CFC- WVU: FRP Center of Excellence
- Products and Applications
- Technical Solutions
- Field Demonstrations
- Conclusions

Current Markets and Applications



U.S. FRP composites: 4.2 billion pounds in 2002

Opportunities and Challenges- New Products and Applications

- Highway Structures
  - Prodeck Bridge System
  - Auto Skyway
- Utility Poles
- Pipes
- Wind Energy
- Blast Protection of Structures
- Decking for Navy and Marina
  - Sea Basing
- Army Bridging
- Air Force Towers

FRP Composites in Highway Structures

- Bridge deck
- Stringer
- Beam
- Abutment panel
- Rebar
- Dowel bar
- Pole and post
- Signboard and signpost
- Guardrail system
- Sound barrier
- Drainage system (pipe, culvert)

Prospective Market: Bridge Decks

- $50 B was spent on highways and bridges in 1999
- $8.1 B Federal funded bridge projects in 2002
- $2-3 B estimated bridge decks annual market

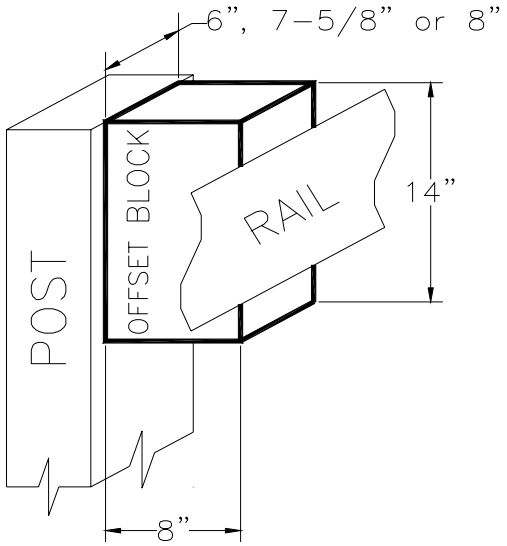
The Lions Gate Bridge (Vancouver, British Columbia, Canada) truss and deck sections were replaced during 10-hour night closures.

Prospective Market: Posts

- 36 million highway signposts are in-service with an annual replacement of about 2 million posts in U.S., generating a market of $100 to 200 million

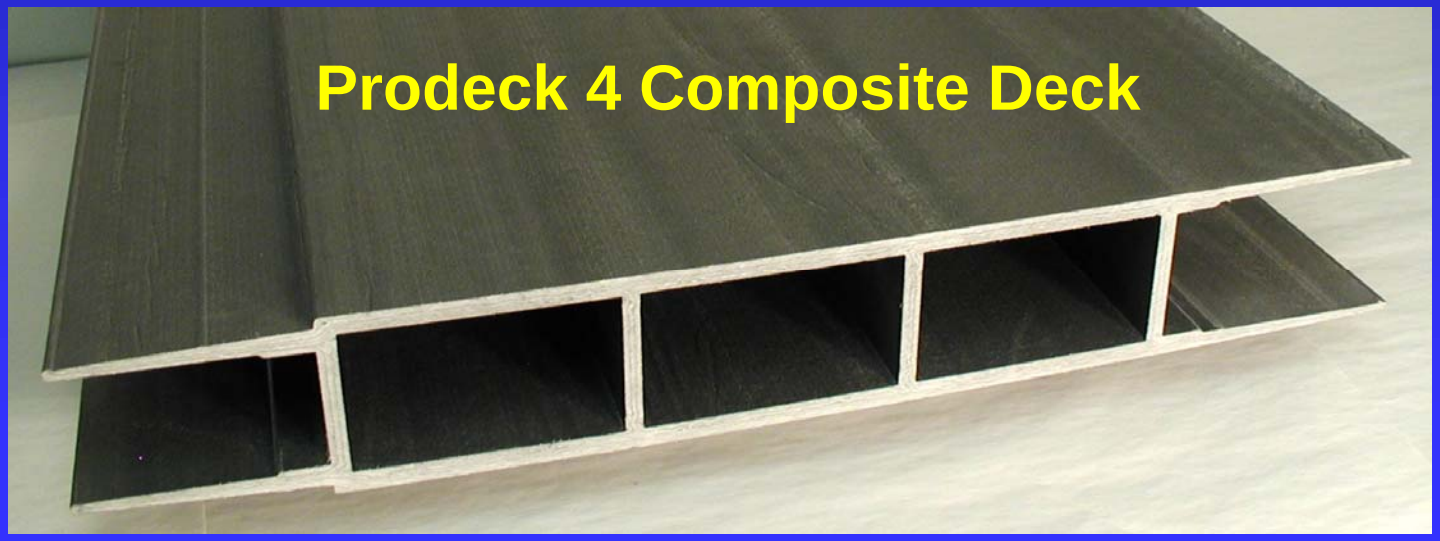
Prospective Market: Guardrail Systems

- 2000 miles of guardrails are constructed each year, leading to $180 M of material sales
- The new construction of railing uses 2 M guardrail posts and 2 M spacer blocks, resulting in another $60 M of the FRP material market
- WVDOT uses approximately 50,000 wood and 200,000 steel guardrail posts annually



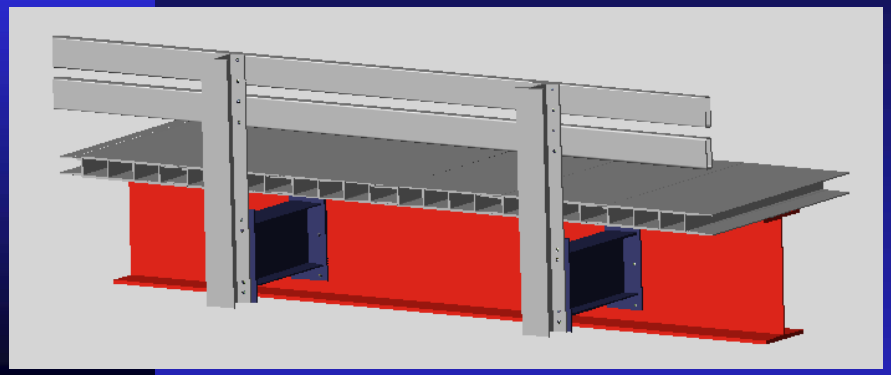
Prodeck Bridge Systems

Prodeck 8 Composite Deck

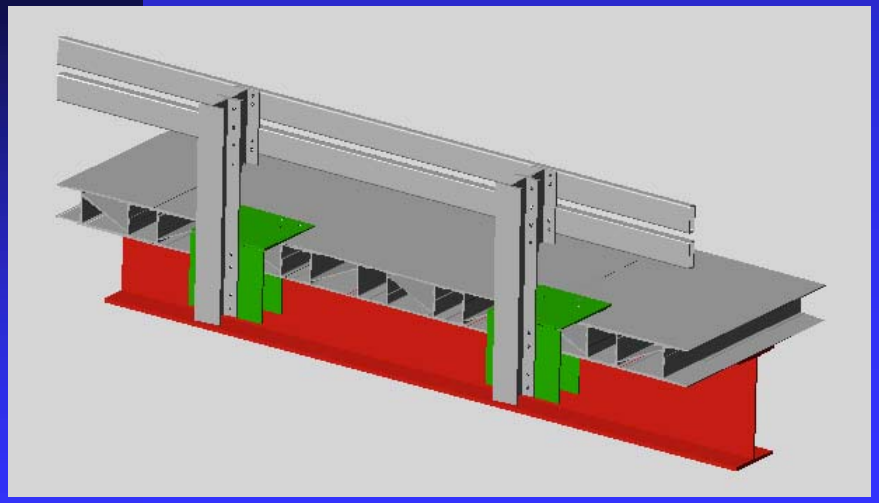


Prodeck 4 Composite Deck

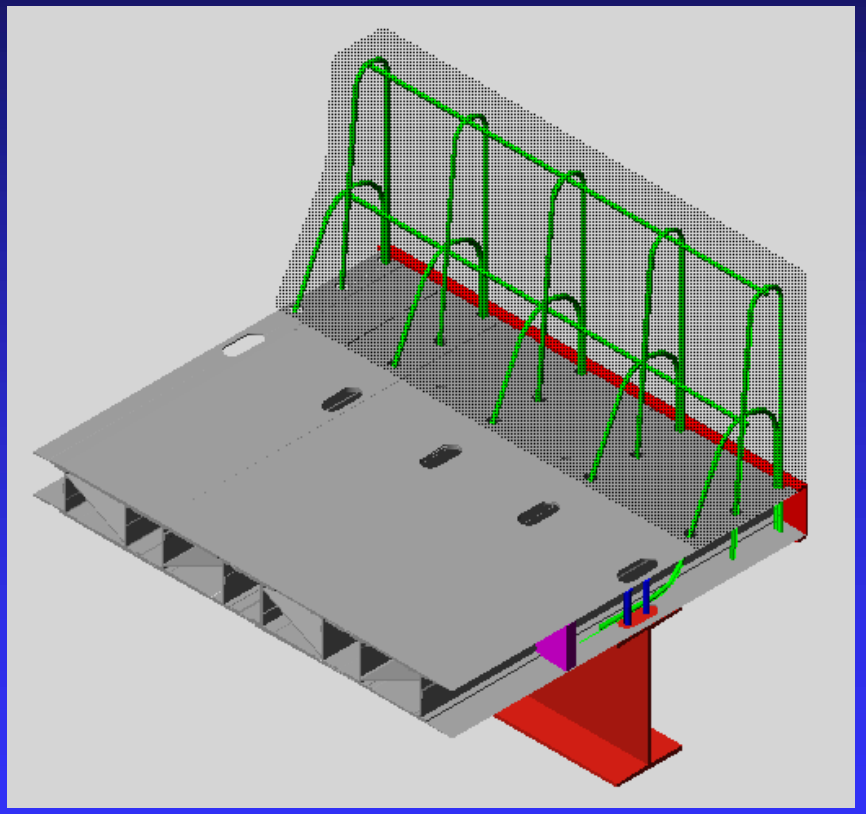
Prodeck Railing Details



Railing Cantilevered From Girders



Railing Attached to Deck

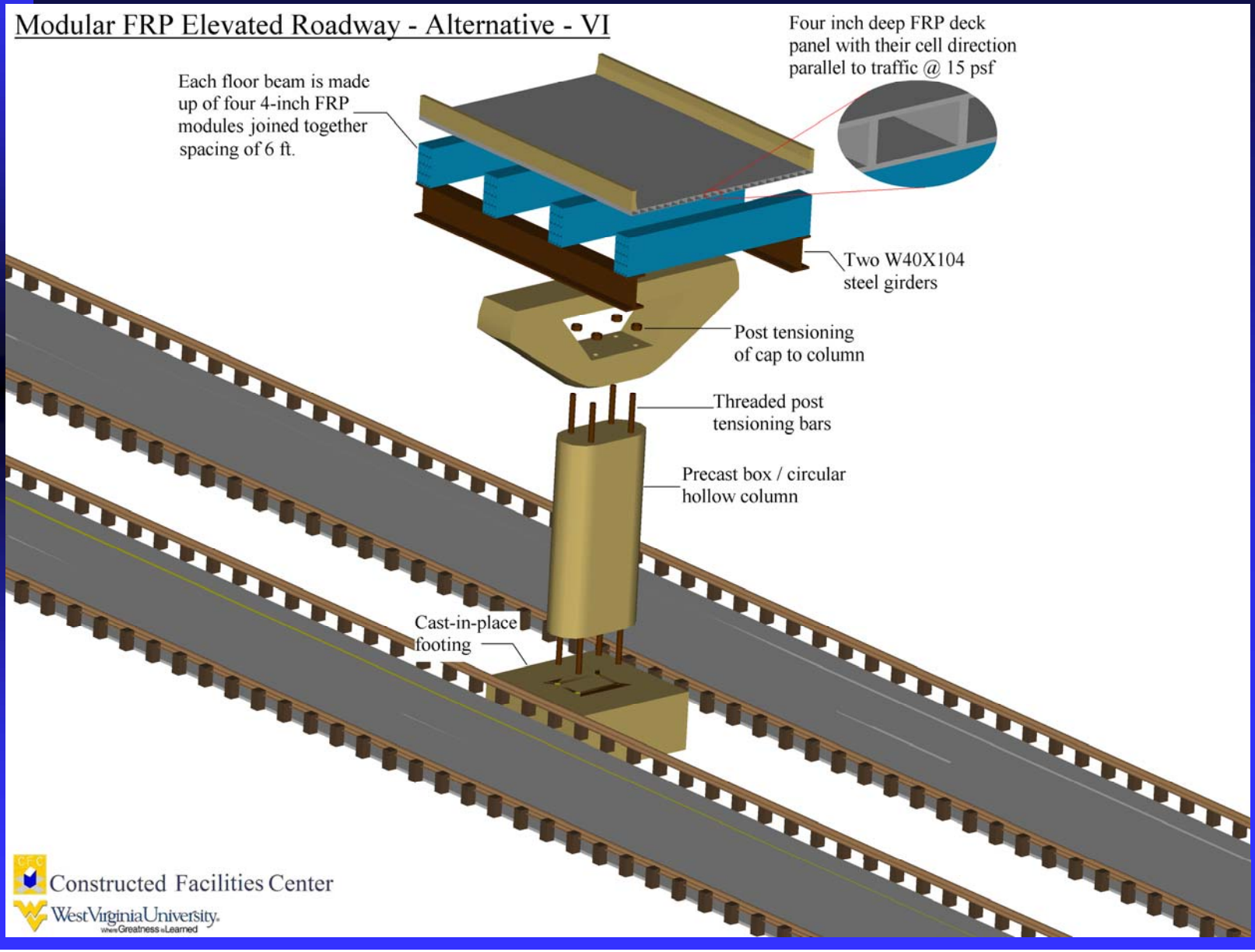


Concrete Barrier Attached to Deck

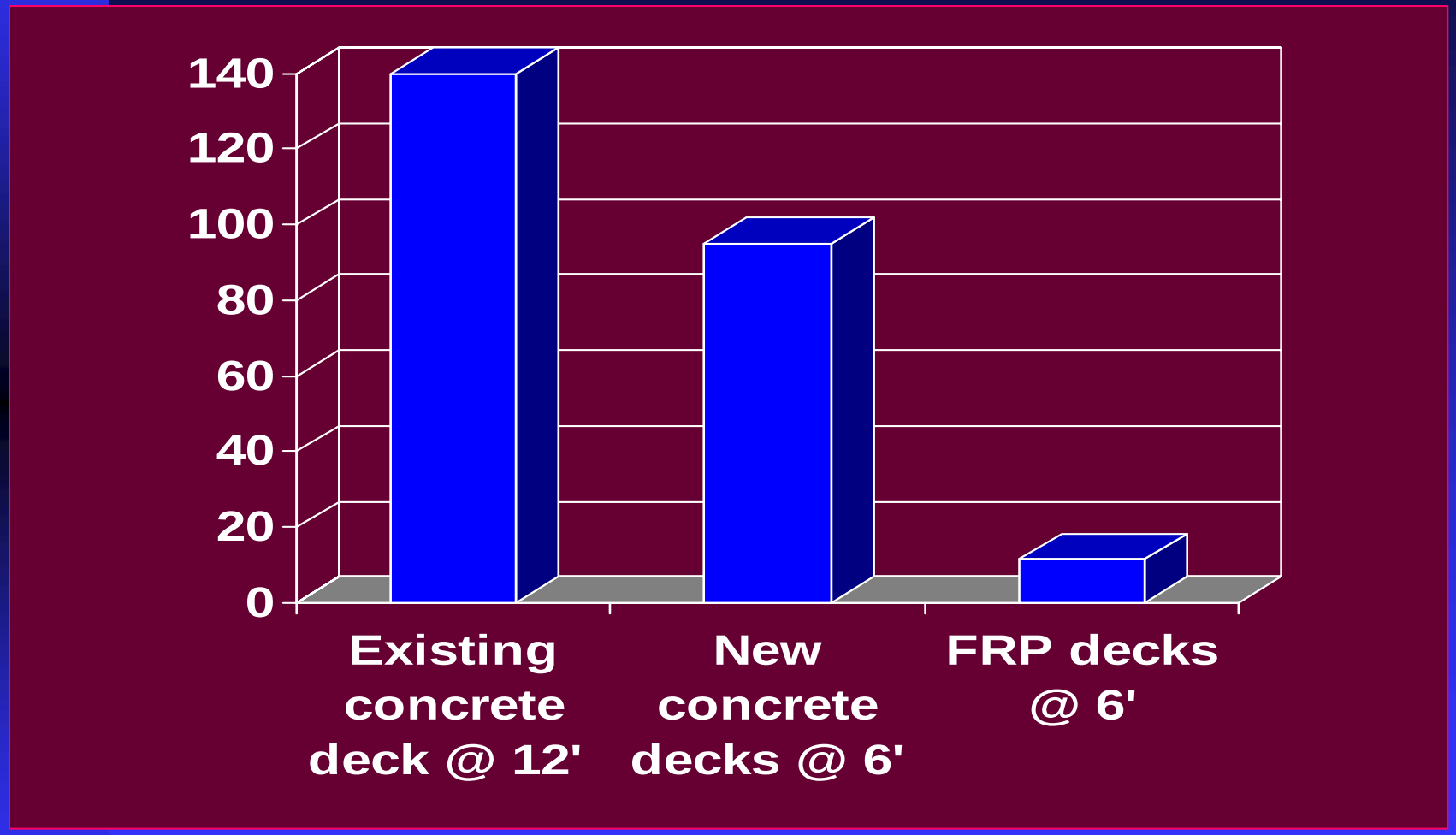
ANOTHER APPLICATION
Auto Skyway
- Needs -

- Urban Sprawl
- Right-of-Way
- Economic Growth
- Efficiency
- High Volume VPD

Prefabricated FRP Auto Skyway: 2 Lanes



Deck Weight Comparison Per SF

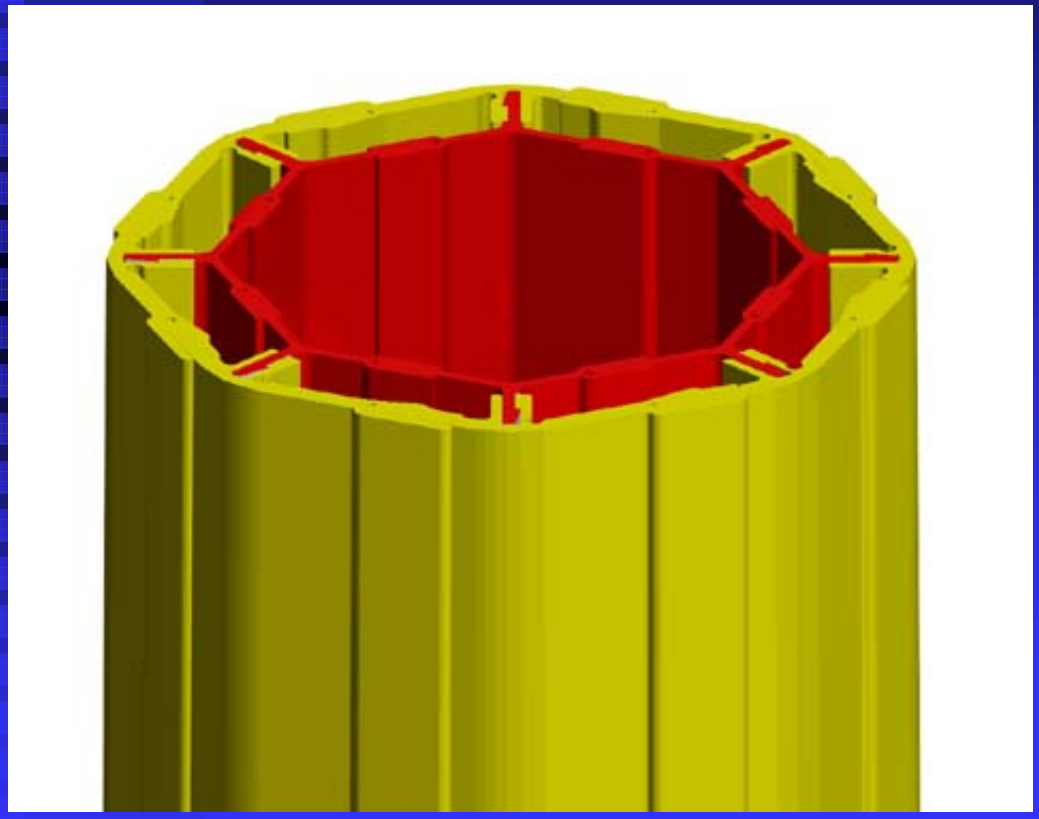


Note: These weights do not include wearing surface.

Prospective Market: Utility Poles

- 130 million utility poles in-service in USA
  - 98% chemically treated wood poles
  - ~4 million poles replaced per year
  - ~90,000 poles in WV
- $4 billion treated wood poles annually
  - $2.8 billion for replacement
  - $1.2 billion for new construction

FRP Composite Utility Poles



Courtesy of Hiel, 2001

The double wall structure of a FRP transmission pole with excellent buckling strength, assembled from two pultruded “building-block” elements

Extensive Pipeline Infrastructure

- **Extensive pipeline infrastructure in service in U.S.**
  - 161,189 miles liquid pipelines
  - 320,000 miles natural gas transmission pipelines
  - 1,100,855 miles natural gas distribution pipelines
  - 1,500,000 miles water and sewage pipelines

Prospective Market: Pipes

- ~1000s miles new natural gas pipelines into service each year while ~1000s miles deteriorated natural gas pipelines replaced
- Over 50,000 miles of new natural gas transmission pipelines are being built in the 2001-2010 timeframe at a cost of over $80 billion in North America

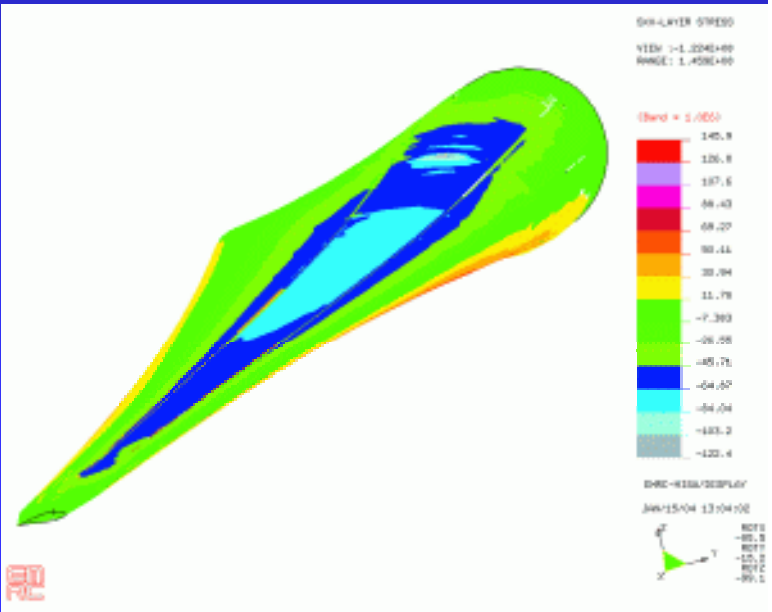
FRP Pipes for Sewerage Works, Bolivar Project, Australia

Composite Turbine Blades for Wind Energy

Global market for wind turbines: US $ 9.4 billion in 2005
US $935 billion in 2020

The scale of LM Glasfiber's 177' blade as well as transport challenges

A FEA of the Aerodyn 185' blade identifying axial strains



Composites for Blast Protection of Structures

Armored HMMWV deployed in Iraq

An ISO Composite Shelter Constructed with Sandwich Panels

FRP Composite Safe Room for Underground Mining Operation

Some of Design and Requirement Issues:

- Fire- Smoke- Toxicity (FST) proof
- Blast proof
- CO proof
- Water proof
- CO conversion into CO2
- Oxygen generation
- Battery/ back-up light
- Emergency kit
- Safe room locator
- Communication tool with surface rescue team
- Prefabrication for ease of installation
- Lightweight for ease of portability

FRP Composites for Waterfront Infrastructure

Few materials can survive long under the following aggressive waterfront environment:

- **Onslaught of sea waves**
- **Impact from vessels**
- **Corrosive salts**
- **Sand and pebble erosion**
- **High atmospheric humidity**
- **Inter-tidal wetting and drying**
- **Sun and marine borers**
- **Immense storm forces, etc…**

U.S. Navy currently spends $40-50 M annually on replacing treated wood structures

Prospective Market: Waterfront Structures

- $3.4 billion U.S. marina decking industry
- Est. 5.1 billion board feet market by 2005
  (Marina Today, July 2002)

Deployment of Composites for U.S. Navy Ships

- Structures contributing 35% to 45% of the overall weight of any ship
- 52 % of a ship's manpower focusing on maintenance due to corrosion
- Use of FRPs will reduce life cycle costs, enhance ships' readiness, and improve their performance

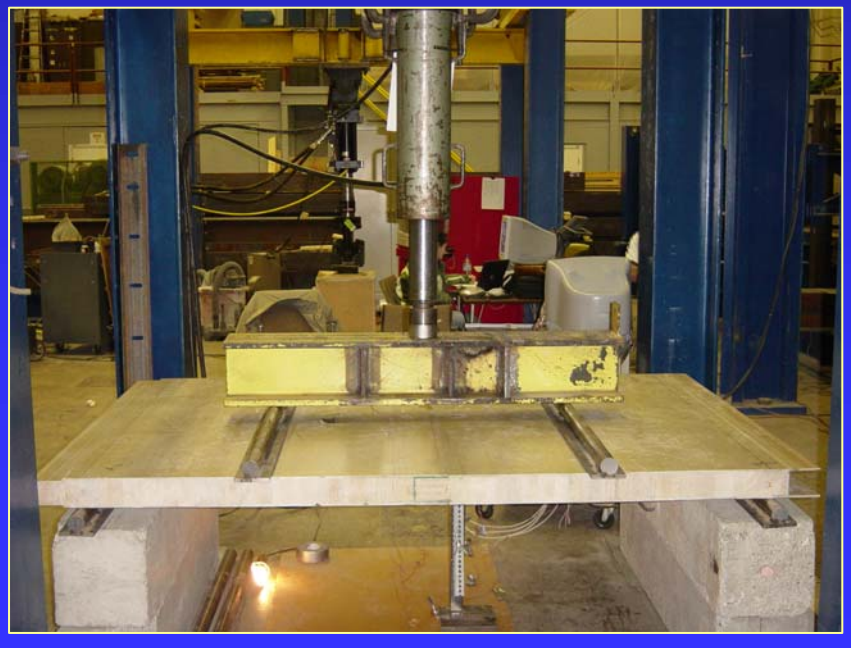
USS John F. Kennedy, Naval Reserve's First Aircraft Carrier

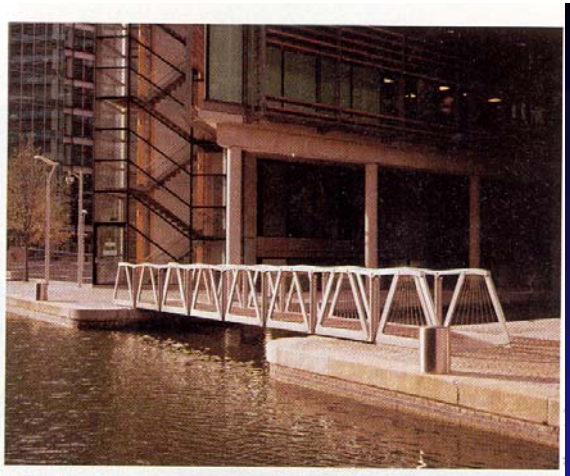
Photo courtesy of http://fas.org/man/

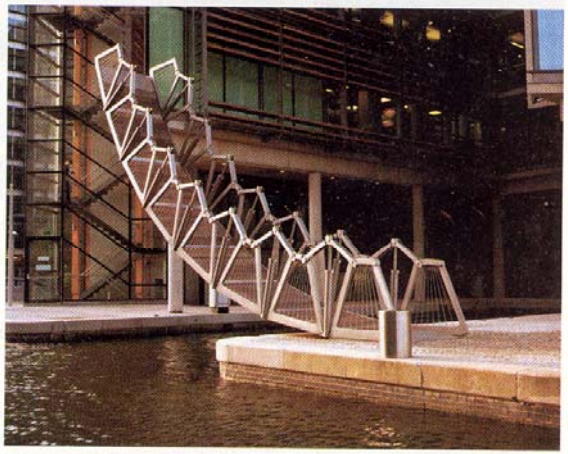
DD-963 Spruance-class Destroyer, Anti-Submarine Warfare

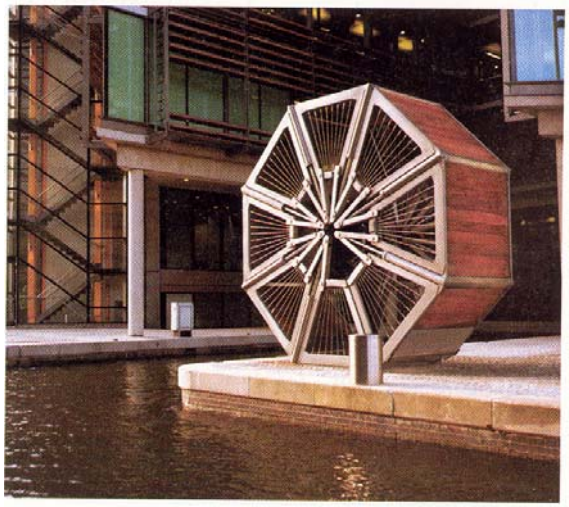
Composite Sandwich Panels for Naval Applications

- Conventional: E-glass /vinyl ester resin with balsa core thru SCRIMP
- Sponsored R&D: Advanced pultrusion integrated with a number of recent technological innovations developed at CFC-WVU









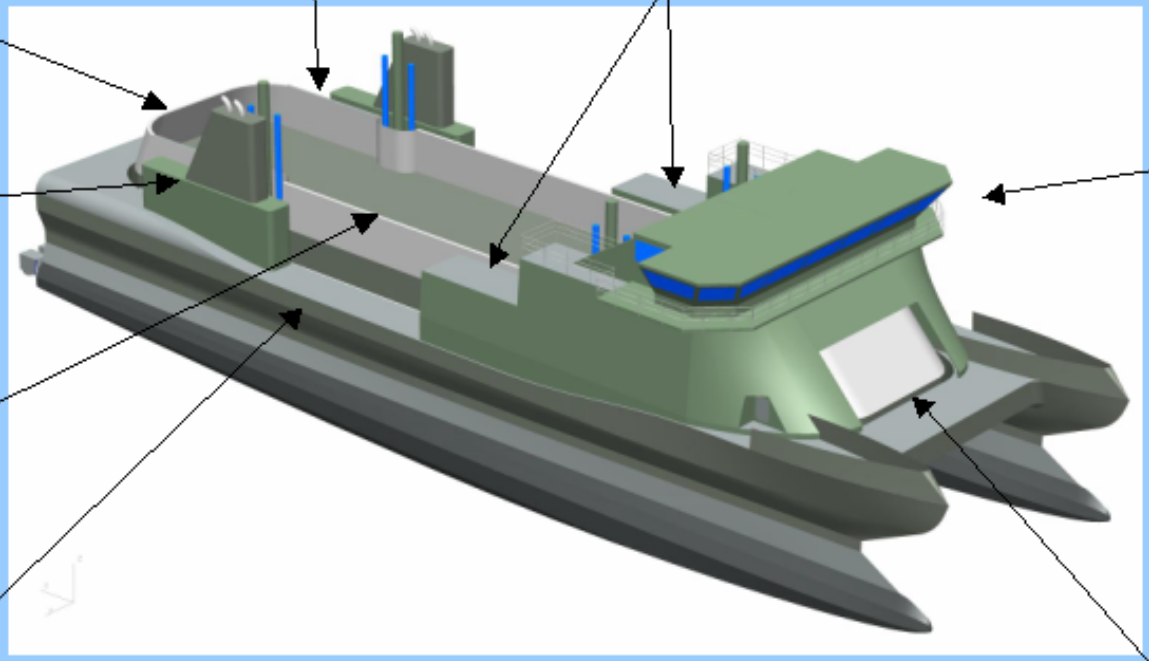
Rolling Bridge and Sea Basing Platform for US NAVY

E-Craft Vessel Arrangement

Single Stern Gate

Bulwarks for Open Vehicle Deck

Two Double Deck Compartments For 100 Total Passengers on Port and Starboard Outer Hulls



Pilothouse With Visibi Fore and A

Exhaust Stacks and Access to Lower Hulls

Single Level Vehicle Deck for 20 Cars

Lifesaving Equipment Area

Single Bow Ramp

Composite Army Bridge (CAB)

UCSD Approach (Kosmatka & Policelli, 1999)

- Aim: Lightweight composite bridge of better tactical mobility
- Prototype CAB:
  - Made of graphite design coupled with SCRIMP technique
  - A design failure load of 75,160 lb versus a proof test load of 116,000 lb
- Work in progress on launching mechanism at CFC-WVU

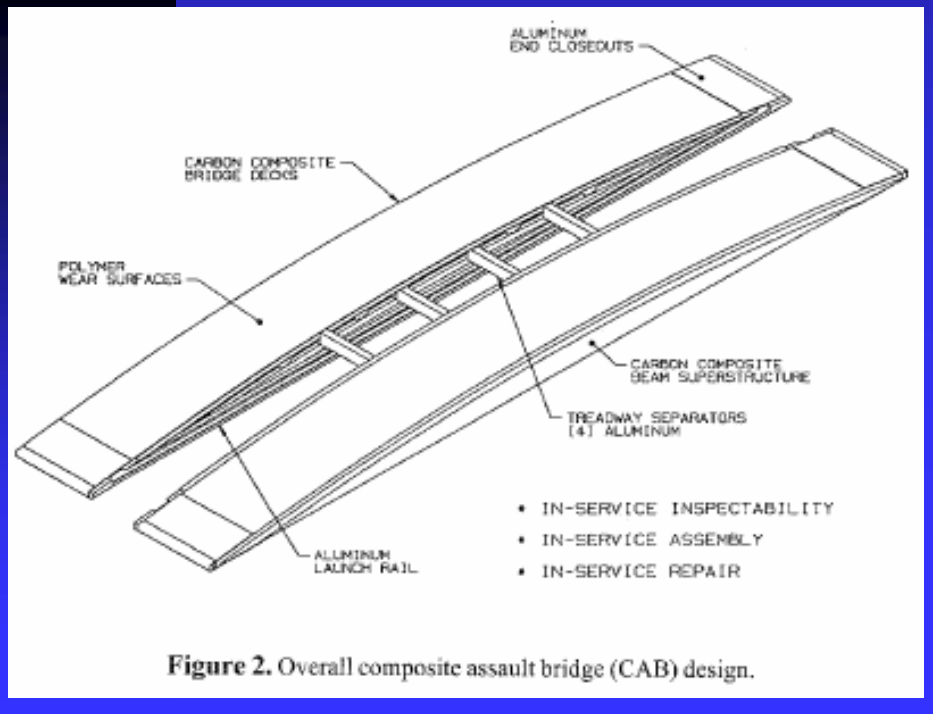


Figure 2. Overall composite assault bridge (CAB) design.

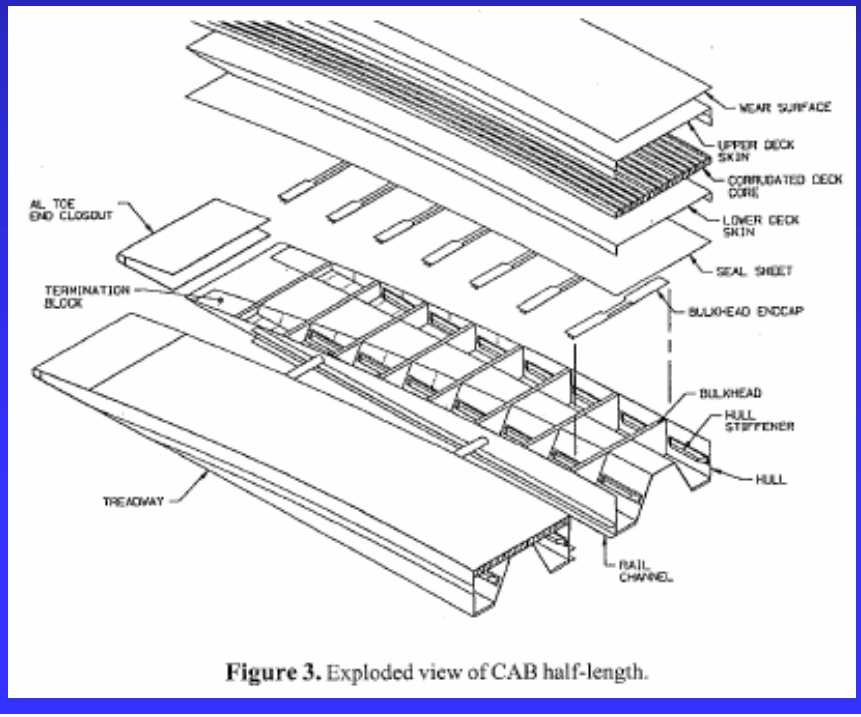


Figure 3. Exploded view of CAB half-length.

Light Duty Composite Tower (LDCT)

- LDCT in place of 60 ft metallic weather tower
- Operational in May 03
- Pilot Program No. 1

System Requirements

- A rectangular, non-tapered design (6'x4')
- Height 40-160' in repetitive 40' units
- Weight below 10 kips

Summary of Potential Market Impact

Applications	Annual market	Projected FRP market share	Projected FRP annual market
Highway signposts	$100-200 million	10%	$15 million
Guardrail posts	$50 million	5%	$2.5 million
Guardrail railing	$180 million	5%	$9 million
Bridge decks	$2-3 billion	2%	$50 million
Utility poles	$4 billion	5%	$200 million
Natural gas pipes	$8 billion	2%	$160 million
Marina decks	$3.4 billion	5%	$170 million
Army bridging	$40 million	10%	$4 million
Air Force towers	$40 million	10%	$4 million
Total	$18.36 billion	Overall 3.35%	$615 million

Note: U.S. FRPs shipment total 4.2 B lbs in 2002 (over $24 B)

Technical Solutions

Integration of the state-of-the-art of composites technologies for more durable, lower cost and better performance of FRP products

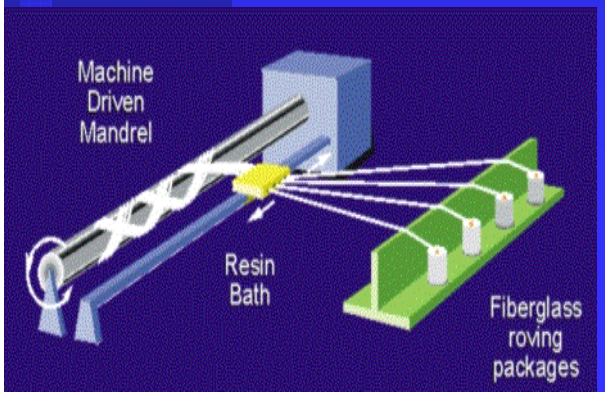
Pultrusion process integrated with patented technological innovations developed at CFC-WVU:

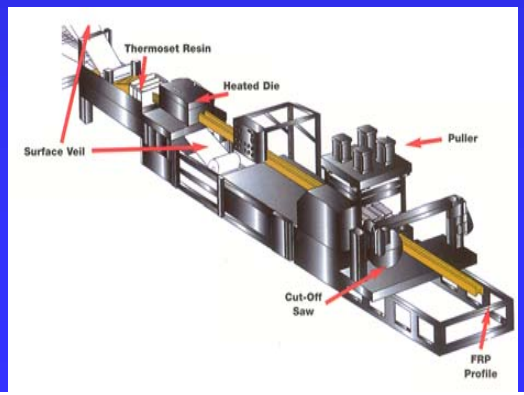
- **3-D stitching of fabrics**
- **Nano-resins (resin systems with nanoadditives)**
- **Urethane modified vinyl ester hybrid resin**
- **Advanced manufacturing**
- **Structurally more efficient optimized designs**

Manufacturing Methods for FRP

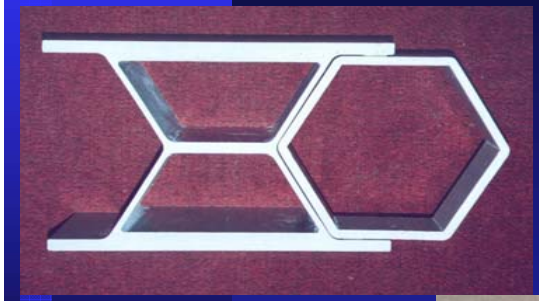
- Spray / wet hand lay-up (~50%)
- Compression molding (~20%)
- Filament winding (~15%)
- Pultrusion (~10%)
- Resin transfer molding (<5%)

  (RTM, VARTM, RIM, SCRIMP)
- Others, e.g. centrifugal casting





Cost Improvement via Pultrusion for FRP Bridge Decks by CFC-WVU



1. Double trapezoid and hexagonal deck

2. Revised trapezoidal deck

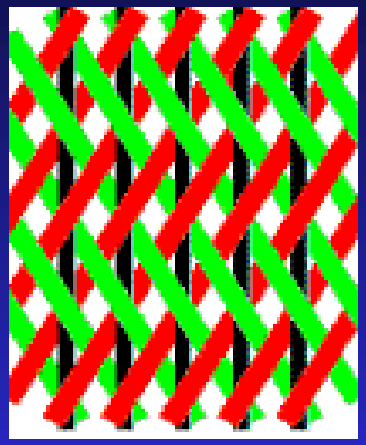
3. Lightweight composite bridge deck

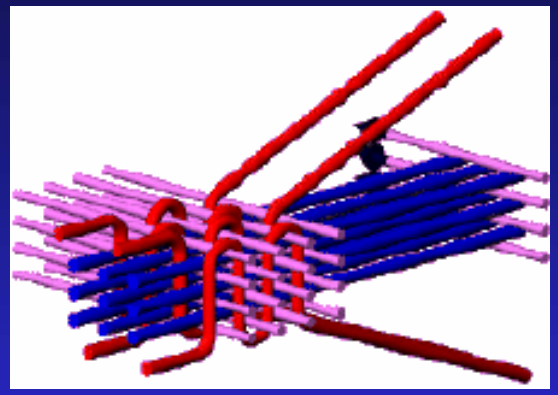
4. Low profile bridge deck

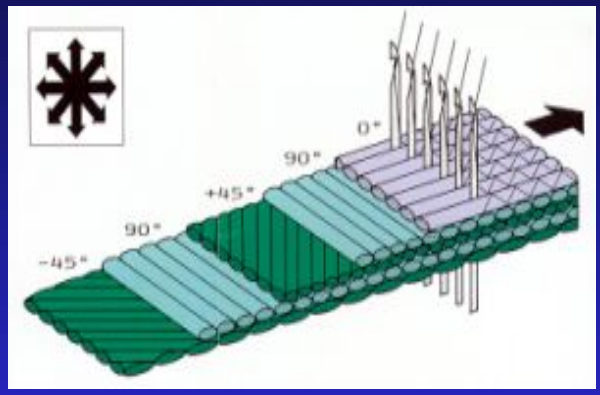
Deck type	Weight per unit area lbs/sq ft	Cost per unit area $/sq ft	Cost per unit weight $/lb	Failure stress ksi
1# FRP 1998	22	~80	3.64	10
2# FRP 2000	19	~58	3.05	30
3# FRP 2002	15	~34	2.27	30
4# FRP 2003	10	~25	2.5	35-40
Current FRP *	18-24	65-100	3.6-5	25-30
Concrete	90-120	~30	0.29-0.35	4-6 (C)* < 1 (T)

*** Currently used FRP decks.**
C: Compression T: Tension

Three-dimensional (3-D) Fabrics







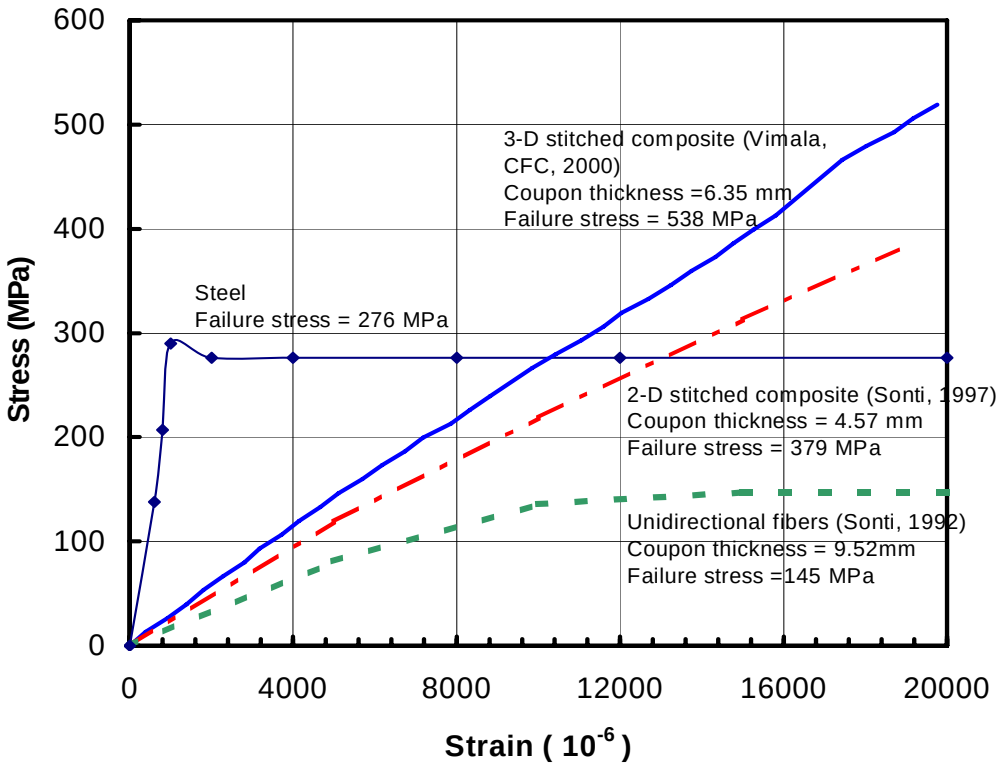
Left: braiding of fibers into a specified shape

Middle: specific weaving pattern which a fabric is formed into from interlacing yarns;

Right: stitching- a series of stitches embodied in woven fabric through-the thickness

3-D Stitched Fabric Composite

Strength /stiffness of composites with different types of fabrics



- √ 3-D stitched composites have enhanced strength & stiffness by 30-50%, and interlaminar shear strength by about 250% over 2-D composites
- √ Ultimate stress of 3-D stitched composite (75-80 ksi) was 95% more than that of conventional steel (40 ksi)

Nanoresin Systems

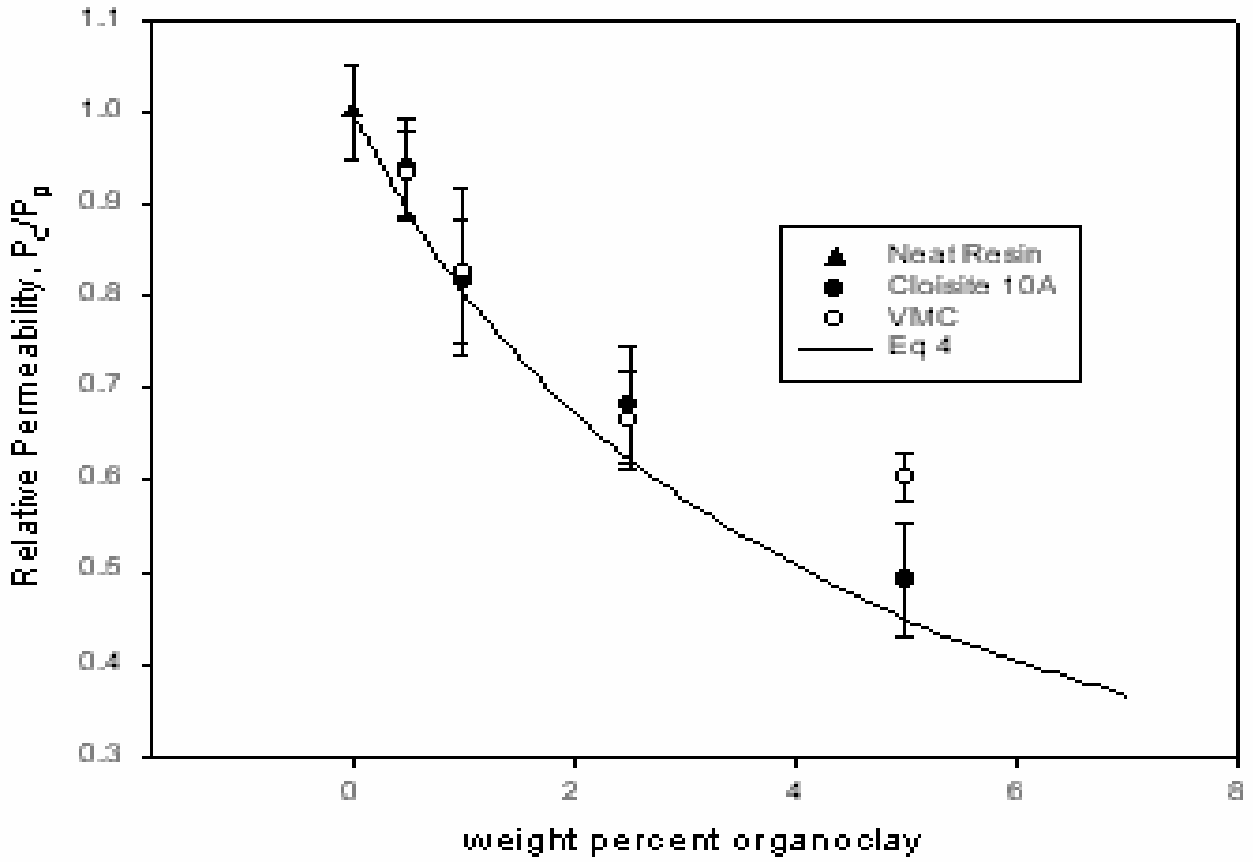
Made of nanoparticles of the following features dispersed in a polymer resin:

- at least one dimension in the nanometer regime
- a large aspect ratio with a large surface area per unit volume

e.g. vinyl ester resin modified with nanoclay fillers

Nanoclay particles as moisture barriers to improve durability of fiber-reinforced polymer composites

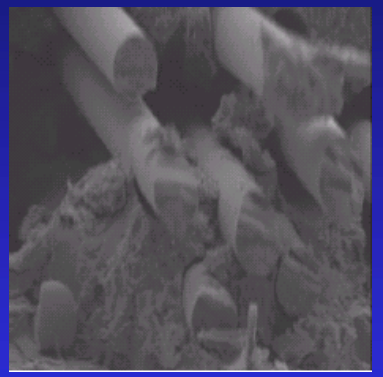
Relative Permeability as a Function of Clay Loading

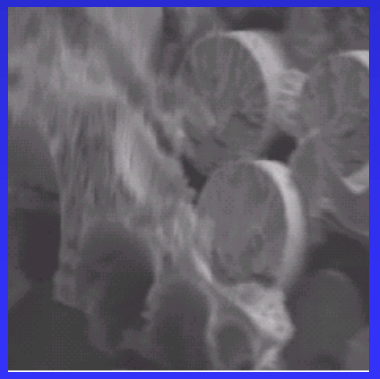


No Fiber Degradation in Matrix with 5 wt% Nano-Clay

SEM of freshly prepared GFRP (vinyl ester) film

SEM taken after 2 months of immersion in Distilled Water





FIELD DEMONSTRATIONS

Market Street Bridge, Wheeling, WV – Jointless Bridge

GENERAL INFORMATION

Location: Ohio County, Wheeling, WV
State District Number: 6
Owner: West Virginia Division of Highways
Contractor: JD & E Associates; Wheeling, WV
Date of Construction Completion: July 2001
Superstructure: Steel plate girders
Deck Type: FRP- Creative Pultrusion: Superdeck™

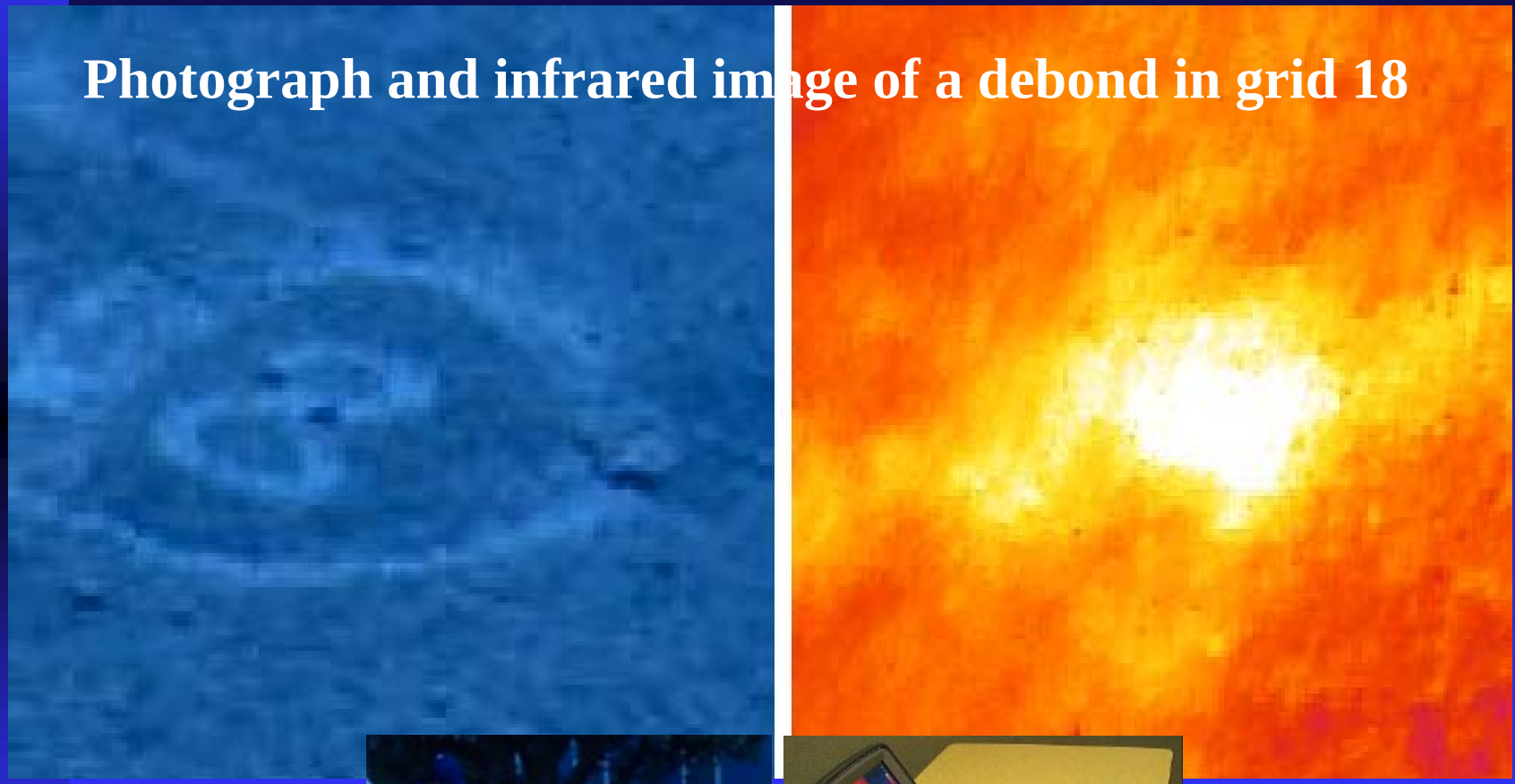
GEOMETRY

Number of Spans: 1
Out-to-Out Length: ~180'
Center-to-Center Bearing Length: 177'
Skew: 0^0
Number of Lanes: 2
Deck Width: 56'
No. of Steel Girders and Spacing: 7 at 8'-6"

Pleasant Plain Road Bridge (Montgomery County, OH)

Field Testing of FRP Bridges Using IR Thermography

Photograph and infrared image of a debond in grid 18



Field setup

Digital infrared camera

FRP Dowels

Field installation of FRP dowels at Elkins Corridor H-Project

Close-up of instrumented FRP dowel bars

Multi-purpose FRP Building

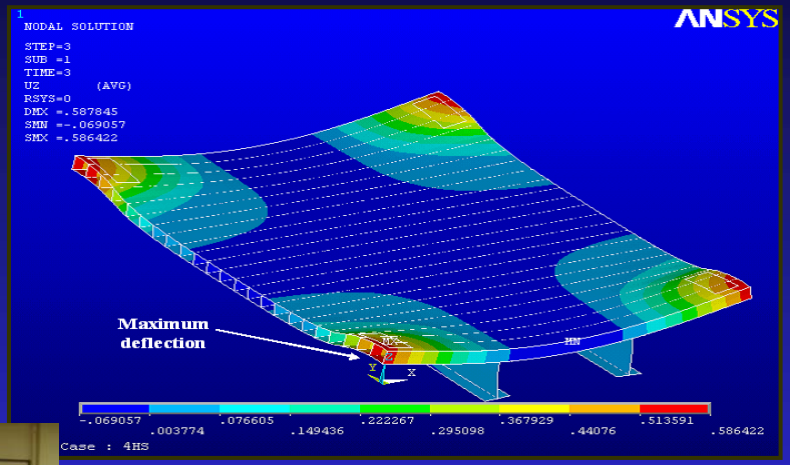
Located in Weston, WV and Constructed with FRP Panels

"The advantages of this building material are its relative lightweight, its ease in handling, and maintenance free" - WVDOT/DOH

Rapid Housing

FRP composite home being erected at BRP Inc. manufacturing facility

FRP DECKS FOR MILITARY APPLICATIONS



Systems & Electronics Inc.
An ESSI Company

WestVirginiaUniversity.
WhereGreatnessisLearned

Gel-Coated Composite Panels For Trailer Siding

FIBER-TECH INDUSTRIES, INC
Another Celstar Company

Cost Analysis

- Two cost analysis approaches common in practice:
  - Initial cost approach: the constituents, manufacturing, fabrication and testing (QA/QC) costs.
  - Life cycle cost approach: additional costs associated with transportation, installation, inspection, maintenance, disposal, and others.
- Initial future cost can be made more favorable by purchasing higher volume of a composite product.
- Composites are more cost effective for most applications than conventional materials such as wood, steel, or concrete in terms of life cycle costs.

Conclusions

- The wide range of potential applications as described in this presentation, need technological innovations and breakthroughs to arrive at economical and durable FRP composite products.

- A number of R&D issues need to be addressed in the areas of material sciences of resins and fibers/fabrics, structural designs, joining mechanisms, and manufacturing techniques in order to make FRP composites the material of choice.


X-34
Orbital
Questions ?
DENT-RESISTANT
SHEET MOLDED
COMPOSITE HULL
TELLUS
DONSÖ