Polymer Composites Conference III 2004 –
Transportation Infrastructure, Defense and Novel Applications of Composites
(March 30-April 1, 2004, Radisson Hotel, Morgantown, West Virginia, USA)
R.C. Creese and H. GangaRao, ed., DEStech Publications, pp.173-187

APPLICATIONS OF FIBER REINFORCED POLYMER COMPOSITES

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CONSTRUCTED FACILITIES CENTER

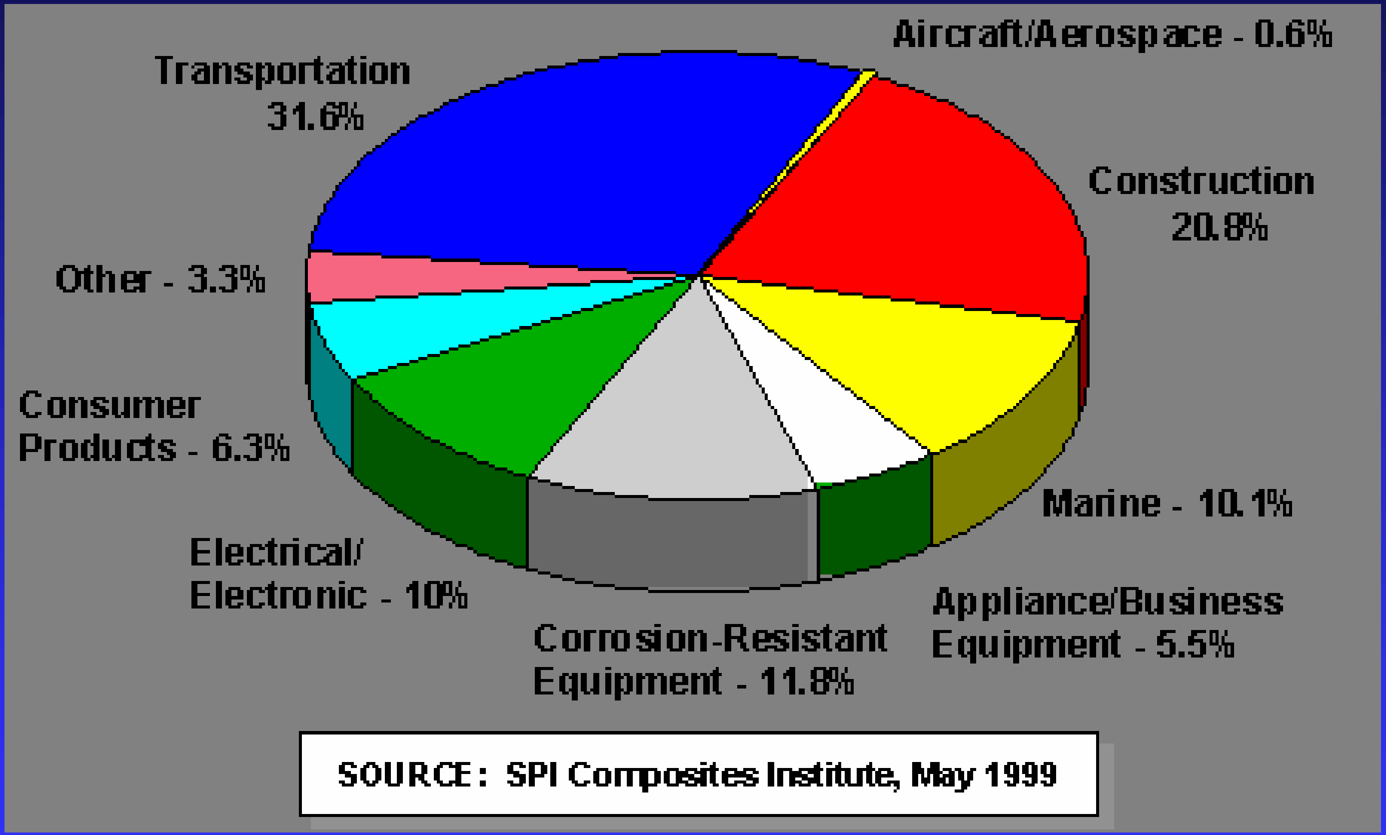
West Virginia University
Where Greatness is Learned

April 1, 2004

Presentation Overview

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

Current Markets and Applications



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

R & D Areas on FRP at CFC-WVU

- Materials innovation and characterization
- Product design and development
- Prototype and advanced manufacturing
- Destructive /nondestructive evaluation
- Field monitoring & performance studies
- Technology training
  - **FRP training school**
  - **Short courses**
  - **Conferences**

Opportunities and Challenges- New Products and Applications

- Highway Structures
  - Prodeck Bridge System
  - Auto Skyway
- Utility Poles
- Pipes
- Decking for Navy and Marina
- 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**

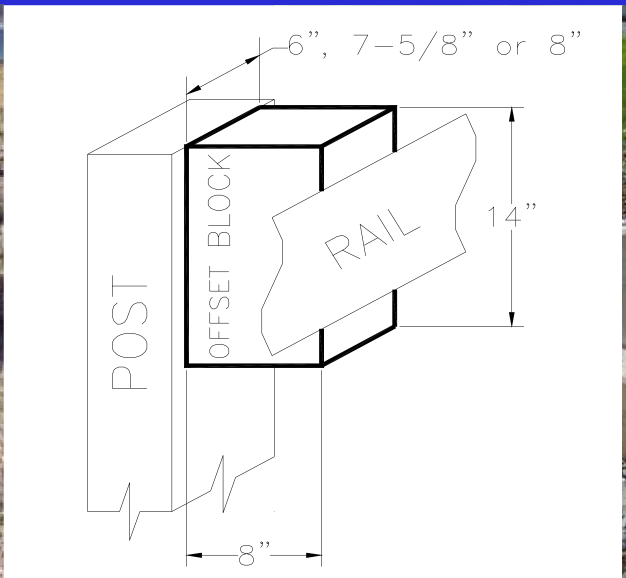
The Lions Gate Bridge (Vancouver, British Columbia, Canada) truss and deck sections were replaced during 10-hour night closures.

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**

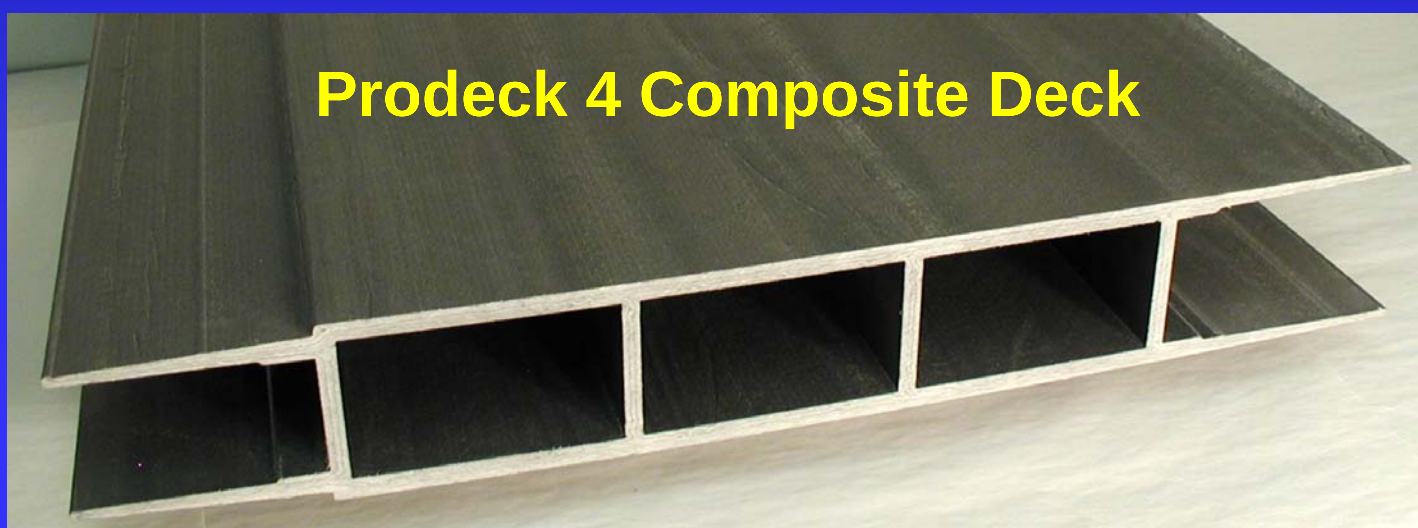
Prospective Market: Guardrail Systems

- 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



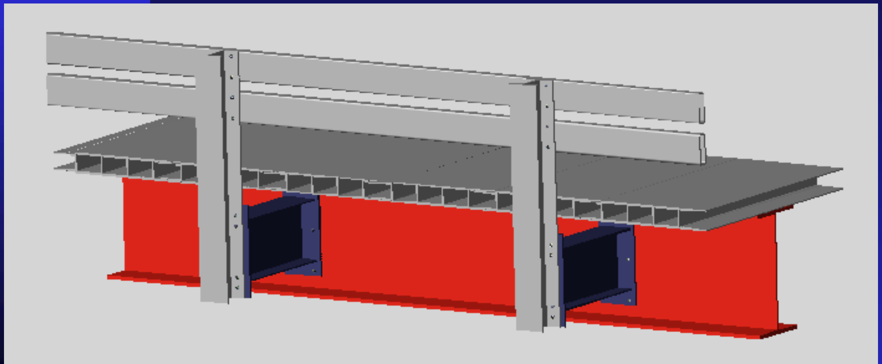
Prodeck Bridge Systems

Prodeck 8 Composite Deck

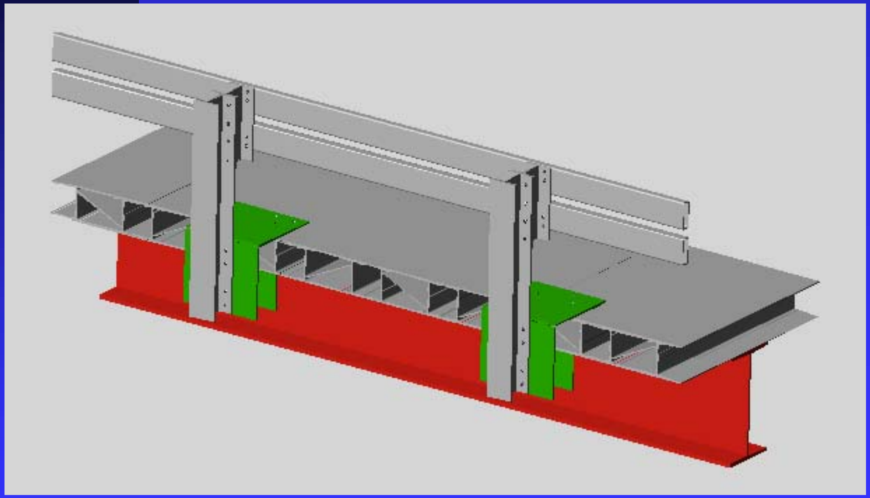


Prodeck 4 Composite Deck

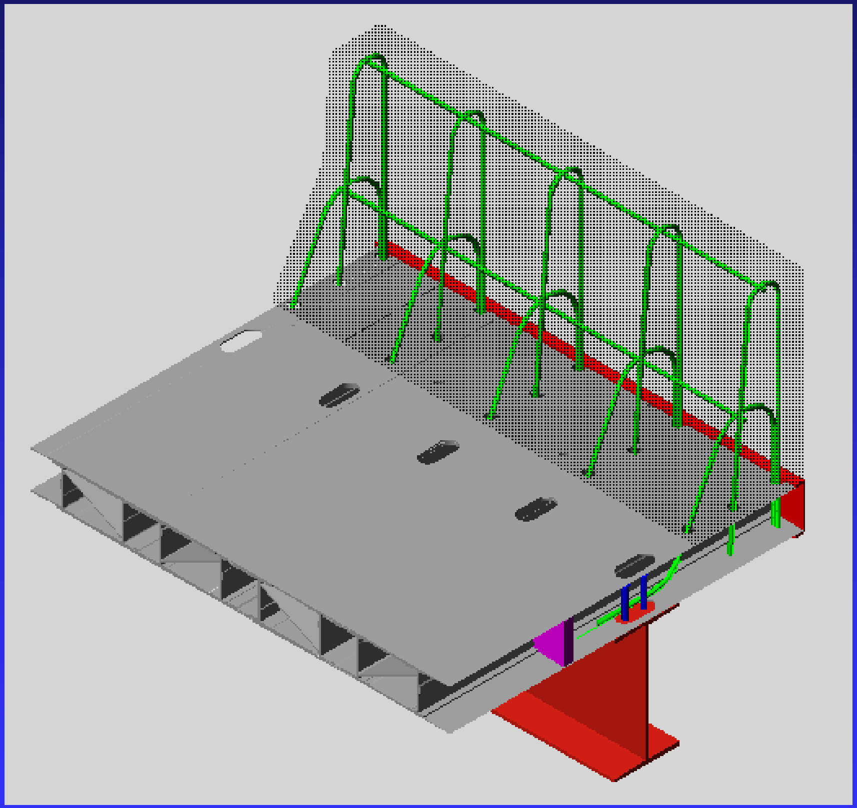
Prodeck Railing Details



Railing Cantilevered From Girders



Railing Attached to Deck

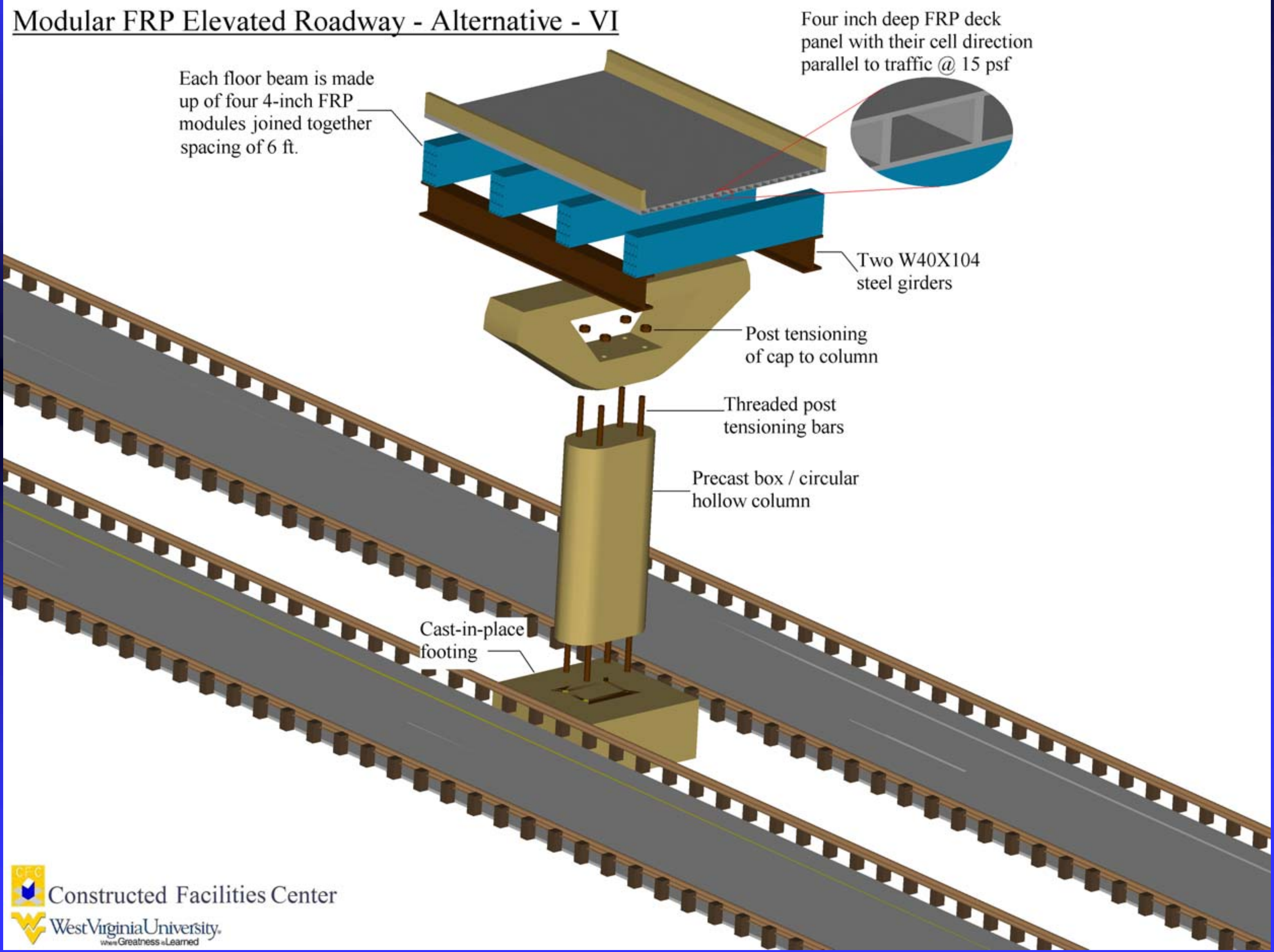


Concrete Barrier Attached to Deck

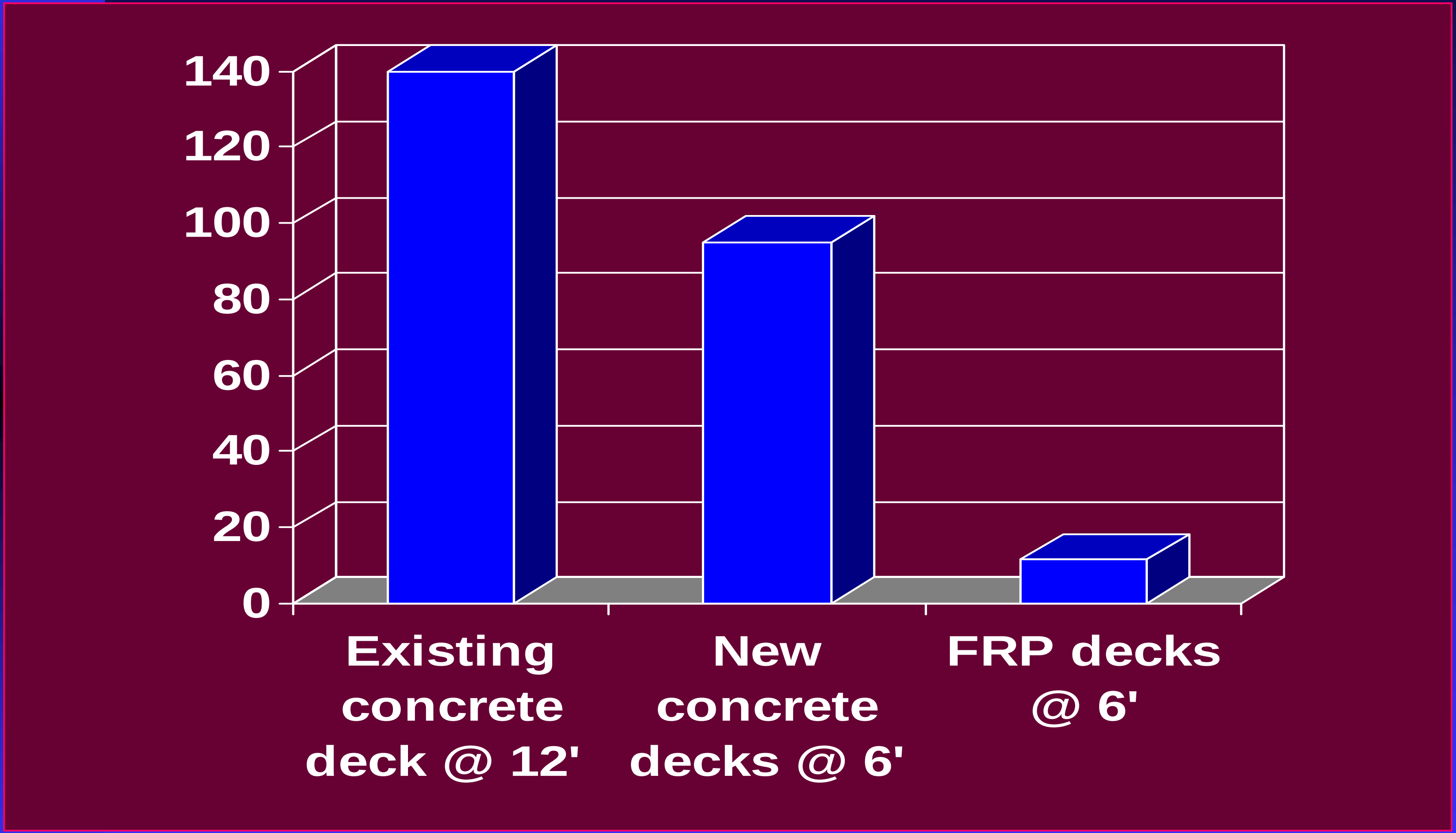
ANOTHER APPLICATION
Auto Skyway
- Needs -

- 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.

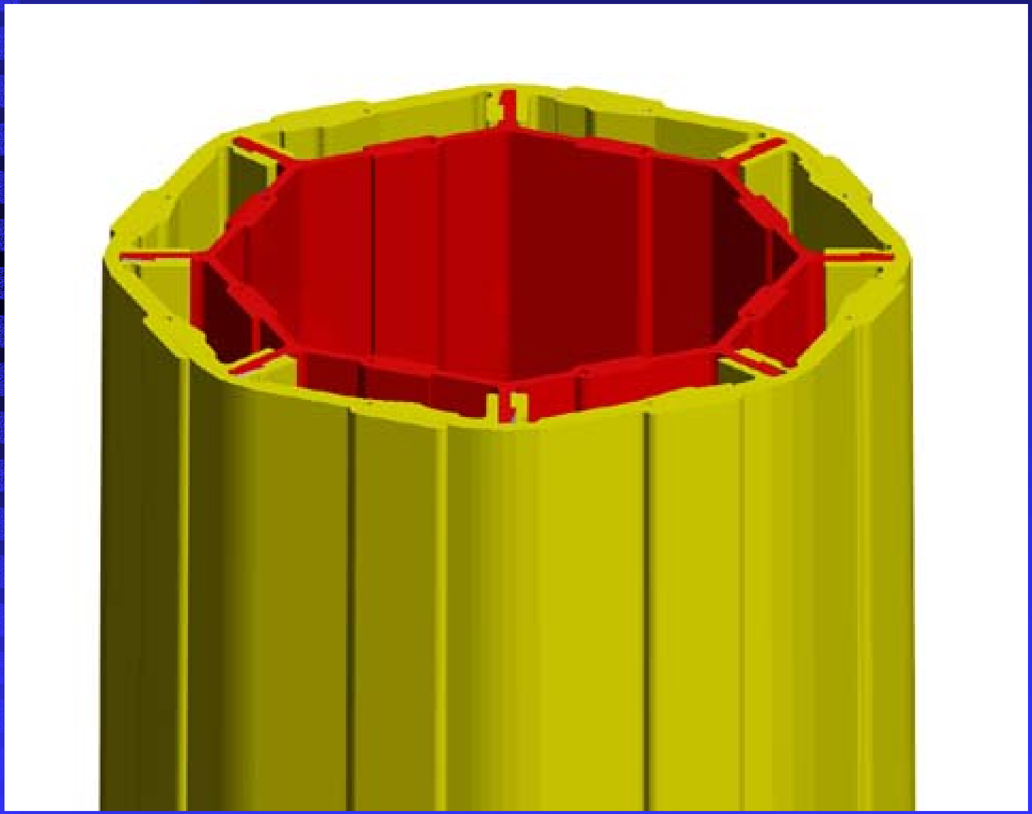
Prospective Market: Utility Poles

- 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

Pros & Cons of Alternatives to Wood Poles

Wood Poles	Concrete Poles	Steel Poles	FRP Poles
Pros	***Pros***	***Pros***	***Pros***
• Low Cost	• Low cost	• Long life	• Lightest Weight
• 70 years experience	• Long life	• Lighter weight	• Field Repair
• Field Framing/Repair	• Less vibration	• No Defects	• Non-Conductive
• Non-Conductive		• Low Maintenance	• Longer life
Cons	***Cons***	***Cons***	***Cons***
• Decay	• Heavy	• Conductivity	• Higher Init. Cost
• Disposal	• Transport. difficulty	• Energy Intensive	• Surface Abrasion
• Toxic Treatment	• Excessive Cracking	• Hard to Field Drill	
• Not a safe roadsides		• Corrosion prone	

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

FRP Composites for More Durable Pipes

- FRP composites having many positive attributes are ideal for pipeline applications with enhanced durability, long-term integrity and safety under corrosive environments.
- Refer to: Current and Potential Use of FRP Composite Pipe in the Natural Gas and Petroleum Pipeline Industries (Laney, 2002)

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

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

Opportunities for Composites in Marina Applications

-ONR Survey Report, Dec. 2000

- 62% of 11,045 U.S. Marinas w/construction activity, costing $100 million /year (materials only)
- Use of composites: about 2% (over last 5 years)
- User knowledge of composites:

37%	little to none
35%	average
28%	above average

- Receptivity to composites: 80% of surveyed personnel either receptive or very receptive

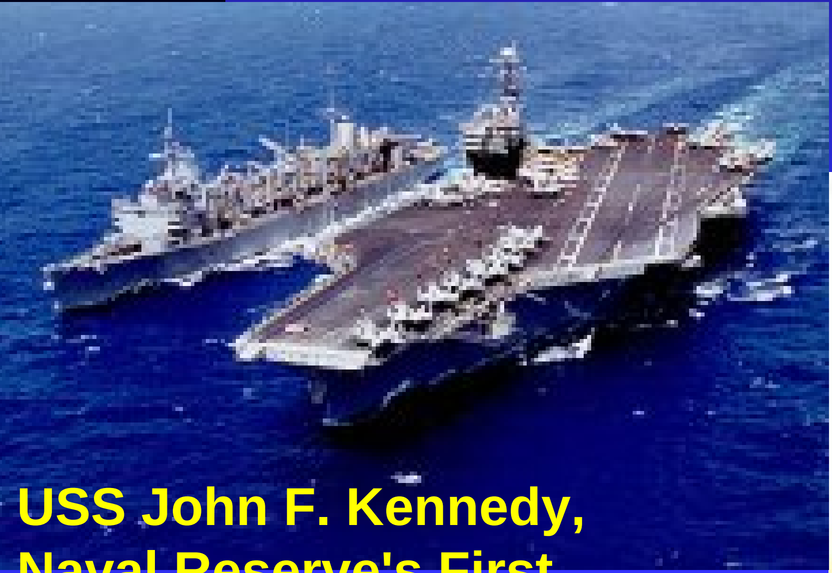
Prospective Market: Waterfront Structures

- $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

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

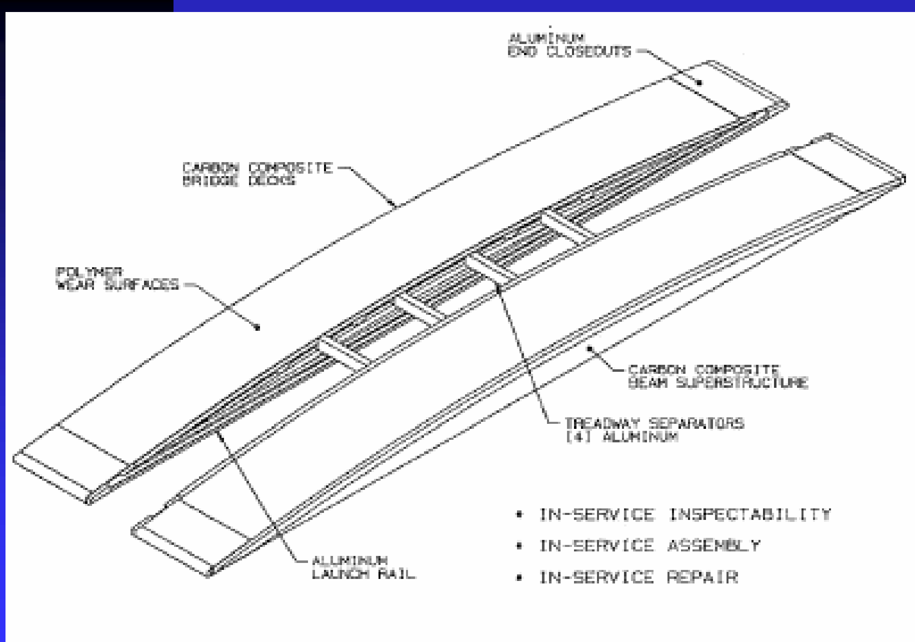


Figure 2. Overall composite assault bridge (CAB) design.

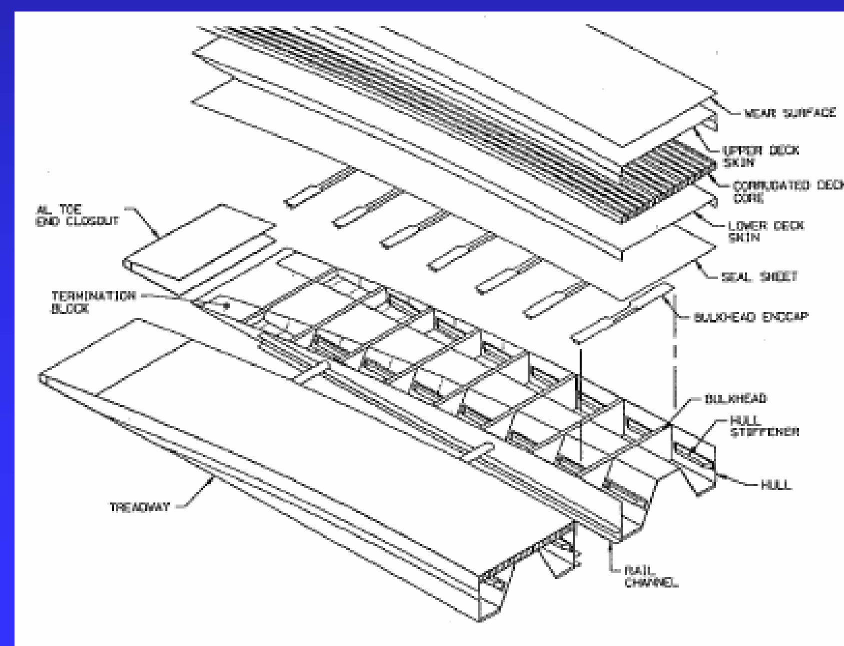


Figure 3. Exploded view of CAB half-length.

Air Force Towers

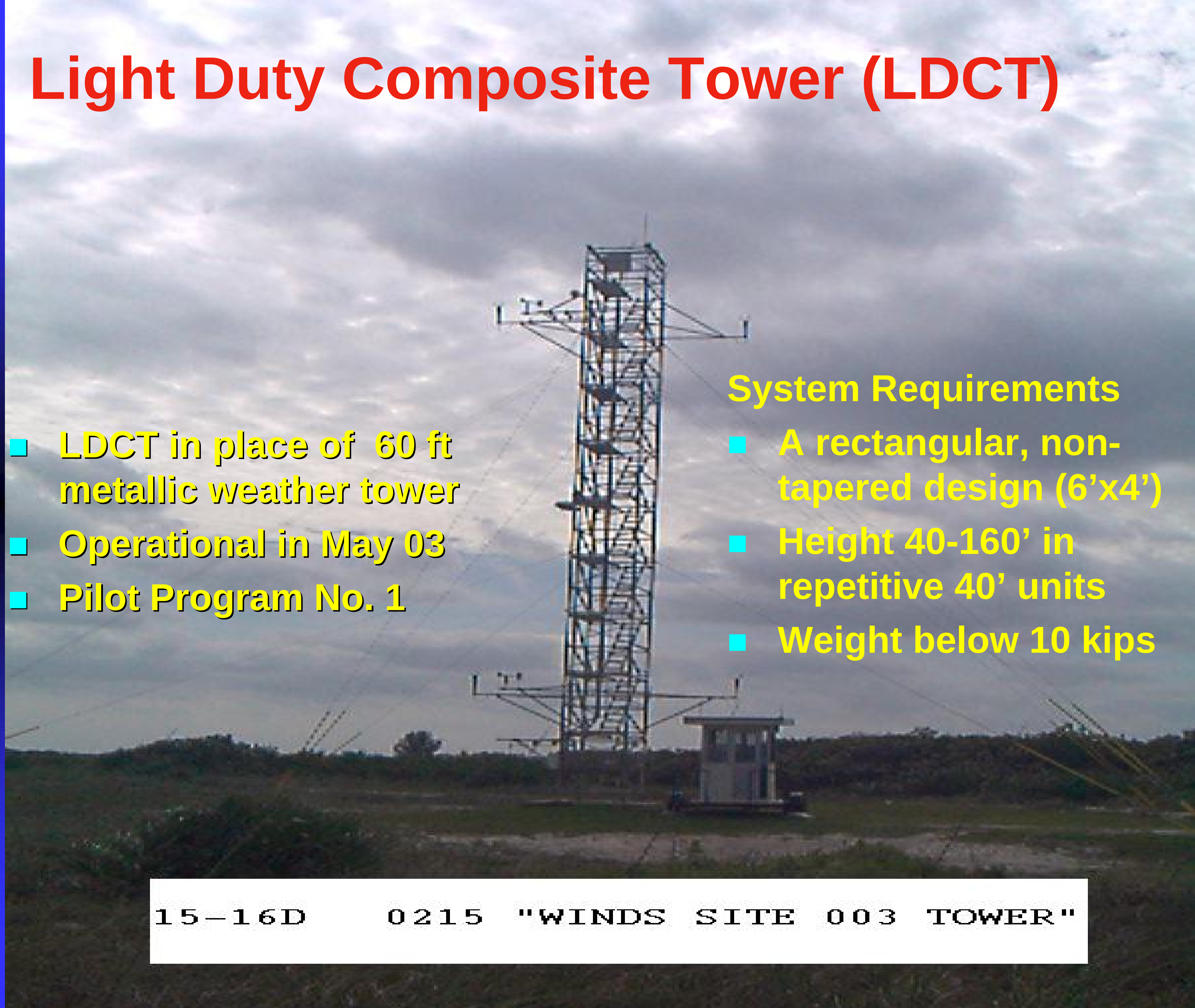
- 1000s of metal towers suffer from corrosion & poor maintenance and are in advanced states of disrepair
- Office at Ogden Air Logistics Center (OO-ALC/LHH) is intending to employ FRPs towers as “functional” replacements
- Expected benefits: lower life-cycle costs, maintenance free, lower self-weight, and better assembly efficiency
- A low cost structural composite tubing product is required with significantly improved stiffness
- Composites for shelters (4000+) and radomes (305+)

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

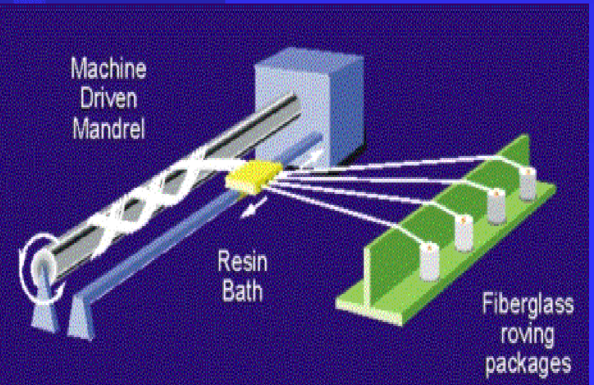
Integration of the state-of-the-art of composites technologies for more durable, lower cost and better performance of FRP products

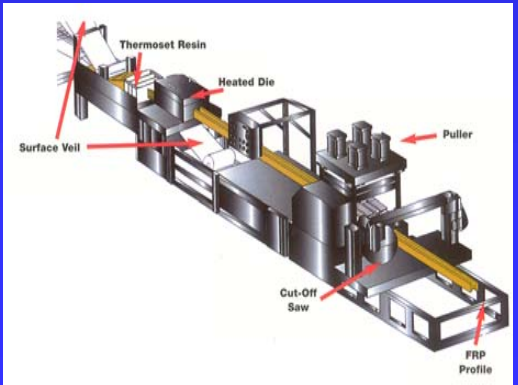
Pultrusion process integrated with patented technological innovations developed at CFC-WVU:

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

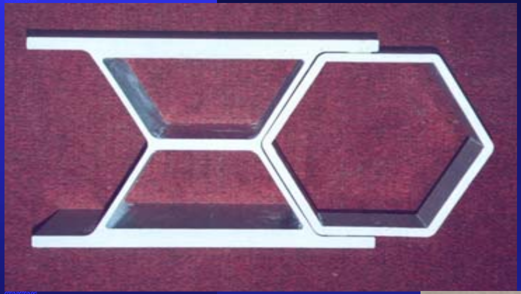
Manufacturing Methods for FRP

- 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

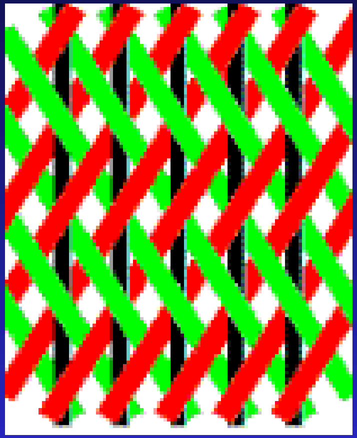
Pultrusion vs. RTM:
Cost Effectiveness Improvement

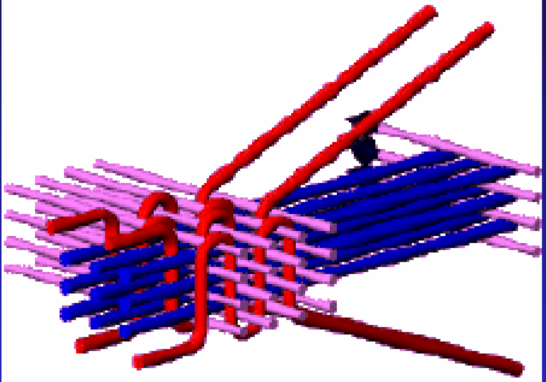
Manufacturing process	Cost per unit weight ** $/lb GFRP
Pultrusion	~2.5 – 4
VARTM	~5
Compression molding (Closed molding)	3 – 4
Filament winding	~5 – 8
Wet lay- up (Open molding)	~8-10

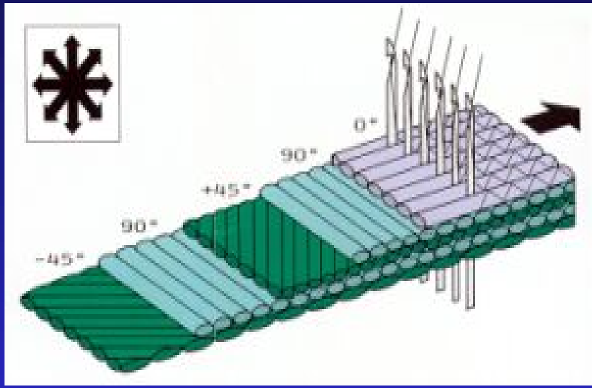
*   Figure for bridge decks only

** Average cost is $5.7/lb (total 4.2 billion lbs for $24 billion in US)

Three-dimensional (3-D) Fabrics







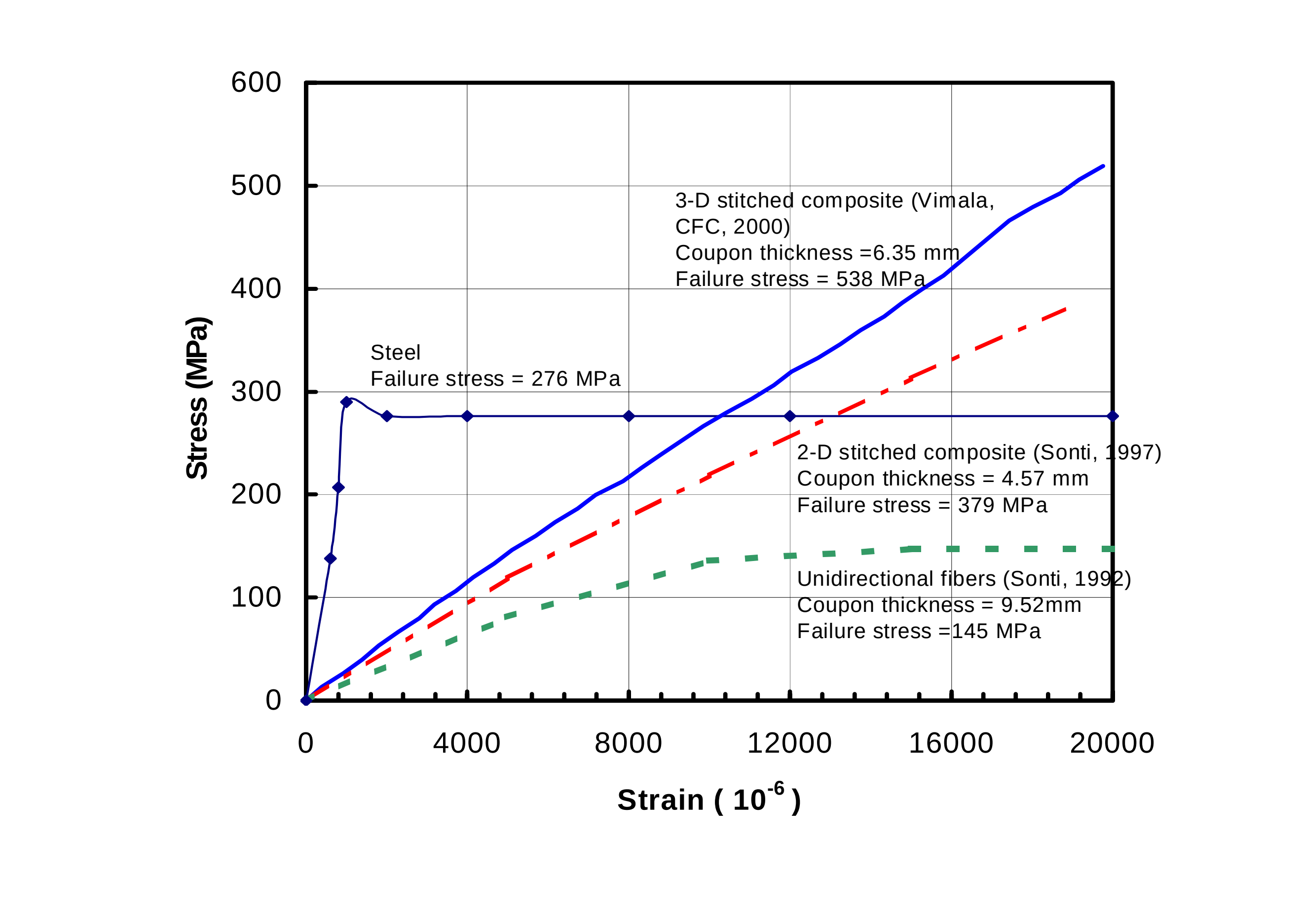
Left: braiding of fibers into a specified shape

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

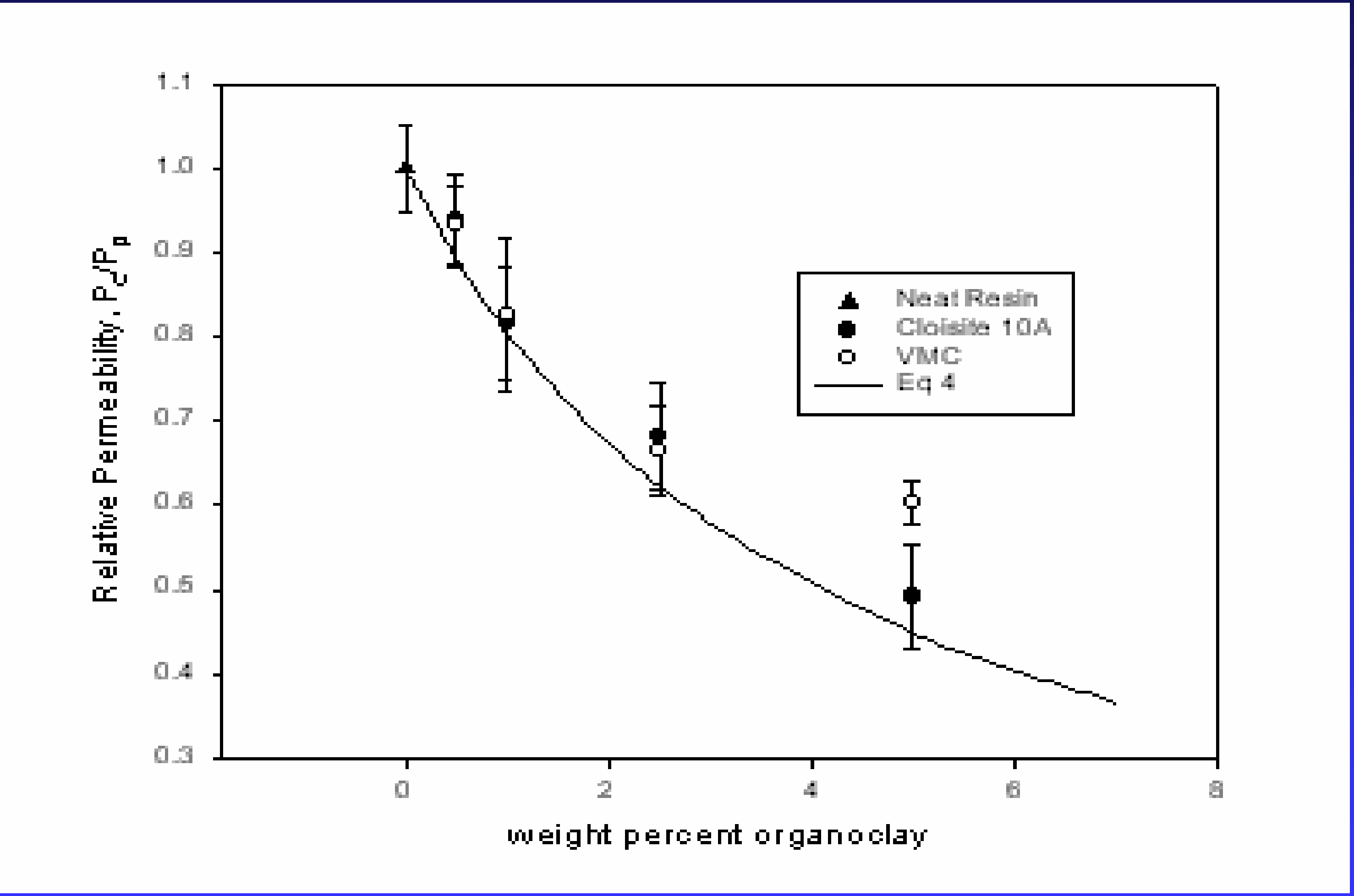
Made of nanoparticles of the following features dispersed in a polymer resin:

- 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

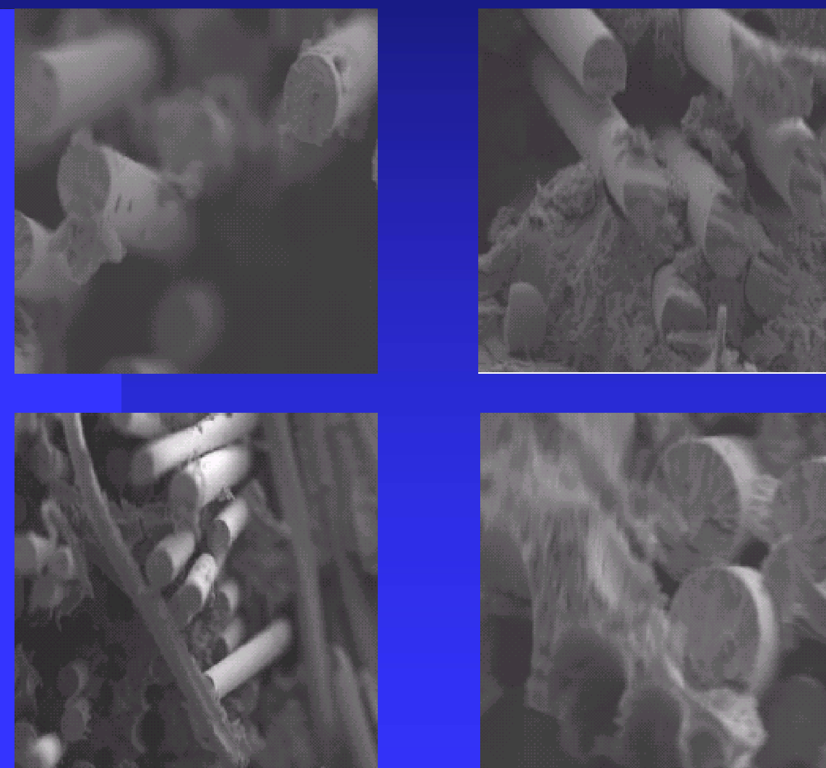
Relative Permeability as a Function of Clay Loading



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



Manufacturing at West Virginia

- The vision – R & D and demonstration through partnerships with commercialization initiative will result in regional economic development in the order of $1 billion annually by the year 2010.

- The goal – cost-effective production and application of advanced FRP composite materials to meet global market needs in the form of Poles, Posts, Pipes and Panels.

Composite Manufacturing Facility in West Virginia

- Recent market acceptance and advances
- Strong presence of chemical industries in and around WV
- Limited production of FRP composites in WV for high volume structural products
- R & D support from WVU and other major resin/fiber industries

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^{TM}

GEOMETRY

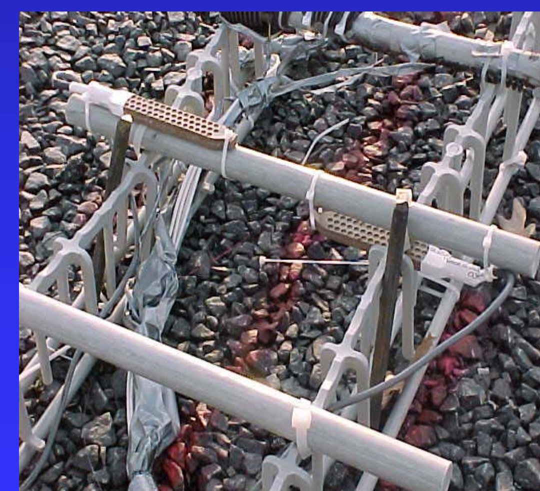
Number of Spans: 1
Out-to-Out Length: ~180’
Center-to-Center Bearing Length: 177’
Skew: 0^0
Number of Lanes: 2
Deck Width: 56’
No. of Steel Girders and Spacing: 7 at 8’-6”

Pleasant Plain Road Bridge (Montgomery County, OH)

FRP Dowels

Field installation of FRP dowels at Elkins Corridor H-Project

Close-up of instrumented FRP dowel bars



Multi-purpose FRP Building

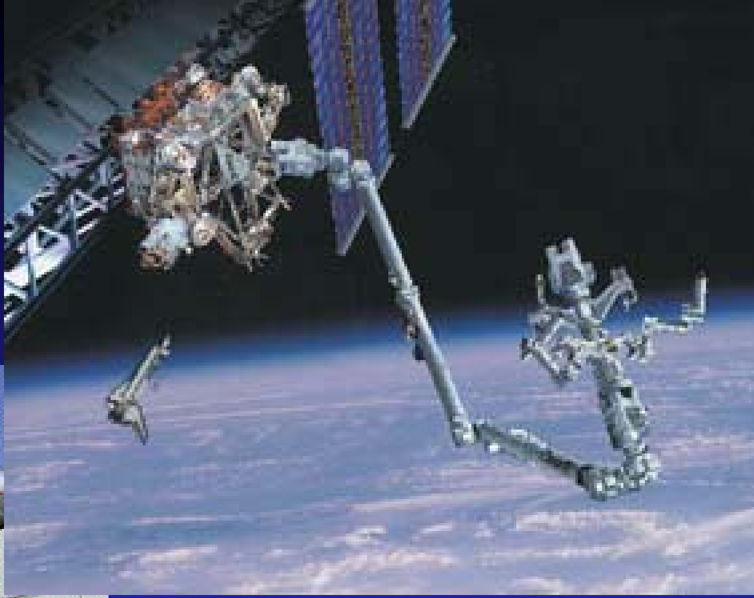
Located in Weston, WV and Constructed with FRP Panels

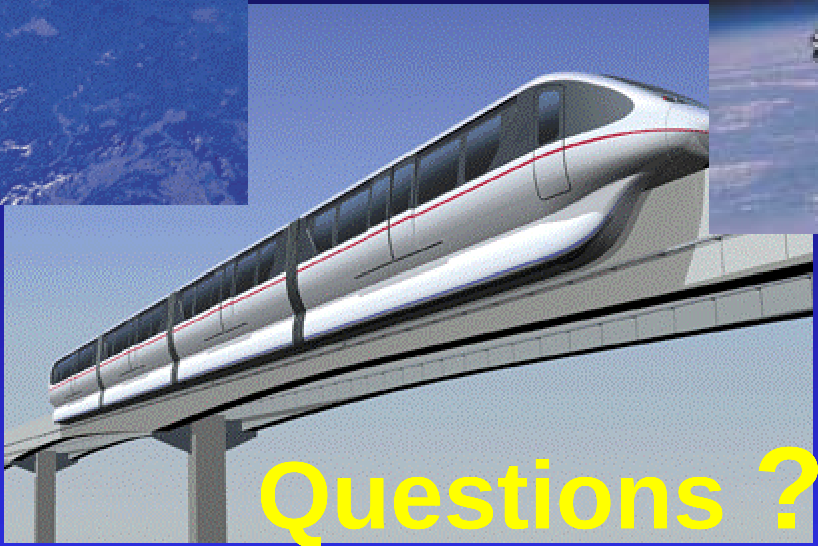
“The advantages of this building material are its relative lightweight, its ease in handling, and maintenance free” - WVDOT/DOH

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.
- However, 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 ?


TELLUS
DONSÖ


DENT-RESISTANT
SHEET MOLDED
COMPOSITE HULL

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Hota GangaRao, Ph.D. P.E., director of the Constructed Facilities Center and professor of civil engineering, West Virginia University, has over 300 technical papers and several U.S. patents, supervised 250 M.S. and Ph.D. students, organized and chaired several technical conferences and sessions at national and international conferences