Introduction to FRP Composites for road, rail and building applications

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What are fibre reinforced polymer composites?

- Modern high strength, lightweight, durable materials
- Extensively used in the aeronautical, automotive and sports goods industries
- External reinforcement for strengthening structures
- New bridge decks and components
Composite Materials

Military Aircraft

Commercial Aircraft

Spacecraft
Engineering Applications

Automotive Engineering

Monocoque

Brake Discs
Suspension Struts
Engineering Applications

New Structures

Carbon Fibre Cables

FRP Deck and beams
Engineering Applications

New Structures

Concrete Slab

FRP Beams
Engineering Applications

Structural Strengthening

Streatham Station Bridge

London Stakis Metropole Hotel
Why do structures need strengthening?

- Change of use giving an increased loading
- Inadequate design or construction
- Structural modification
- Structural and fire damage
- Seismic loading
- Reinforcement corrosion (if cause treated)
- Loss of pre-stress force
- Impact and blast protection
Externally Bonded Reinforcement

*The Background*

- Widely accepted practice world-wide and in the UK over the last 50 years
- More cost effective than demolition and rebuild
- Involves the bonding of additional reinforcement to the external faces of a structural member
- Incorporates either steel plates, composite plates or composite wrapping systems
- Extensive track record in UK and Europe
What can be achieved by adopting FRP strengthening?

Technical

• Increase load carrying capacity of structure
• Redistribute loads around openings
• Increase impact and fatigue resistance
What can be achieved by adopting the technique?

Practical

- Reduce the visual impact of strengthening
- Accelerate project times
- Overcome access problems
- Minimise disruption to existing services
- Resolve difficult detailing problems
Why use composites?

• Composites were developed to RESIST the normal deterioration processes that affect wood, steel and concrete.

• Composites do not readily dissolve, oxidise or reduce when exposed to atmospheric gases, liquids, fungi or bacteria. They are generally inert.

• Day to day environmental actions are hostile to traditional construction materials.

They are light, strong, stiff and durable!
FRP vs. Conventional upgrade
simply supported beam; 35% upgrade in live load

Bonded steel plate
- 6mm bolted plate
- 110 kg. dead load
- placed by lift truck
- Labour intensive

Member enlargement
- 2 16mm rebar
- 100mm. grout
- 1110 kg. dead load
- formed and cured

FRP sheet
- 1 layer resin bonded
- 1.5 kg. dead load
- placed by hand
- Cured within 12 hrs
What are composites?

- Composites are a mixture of a hardened matrix and a reinforcement.
- In **traditional construction** the matrix is concrete and the reinforcement is steel.
- With **fibre reinforced composites** the matrix is a resin (like epoxy) and a **fibre or fabric** (like carbon, aramid, basalt or glass).
- Different composites have different properties.
What do composite materials consist of?

- Fibers
- Matrix

Image:
- Acceleration Voltage: 15.0 kV
- Spot Size: 3.0
- Magnification: 5000x
- Detector: SE
- Working Distance: 9.9 µm
- Scale: 5 µm
Resins

• There are five basic resin types used in FRP composites.
  
  • **Phenolics** - good fire resistance - poor mechanicals
  
  • **Polyurethanes** - good abrasion resistance - poor temperature performance, toxicity problems
  
  • **Polyesters** - workhorse of the trade - inexpensive - good general properties - VOC and odour problems
  
  • **Vinylesters** - good fatigue, moderate price, good chemical resistance, VOC and odour problems
  
  • **Epoxies** - best resistance, adhesion, fatigue - more expensive, low odour and VOC
Potential Uses

**Bridges**
- Bridges – increased axle/dynamic loads

**Buildings and Bridges**
- Beams/slabs – increases in loading
- Columns – impact and axial loads

**Buildings**
- Walls – blast and seismic loading
- Openings in slabs/walls – redistribution
- Fire damage – capacity restoration
Strengthening Design

Why?
What?
How?
Why?

To strengthen existing structures in a quick and economic manner.

• Increased loading
• Deterioration
  – Structural damage
  – Fire damage
  – Corrosion
• Inadequate design
Why Composites?

- Easy access / minimal disruption
  - Minimal plant or temporary works
  - Light weight - manually delivered etc.
  - Flexible - work around services etc.
- Aesthetic
  - Small section - easily concealed
- Durable

= Cost Savings & Best Value
Minimal Plant
Light Weight

(Equivalent stiffness steel plate: 536kg)
Flexible
Aesthetic
Durable

Installed 1998

September 2005
What?

- Concrete
  - Flexural
  - Shear
  - Axial
- Metallic
  - Flexural
  - (shear, axial, stiffness, fatigue)
How?

• Concrete
  – Flexural
  – Shear
  – Axial
• Metallic
  – Flexural
  – (shear, axial, stiffness, fatigue)

A combination of theoretical and experimental results giving a proven technique
Concrete – Flexural
Reinforcement Configuration

Typically 4mm loss clearance
NSM Reinforcement

Epoxy resin adhesive in 20mm square groove

Carbon fibre bar embedded in adhesive

Steel bars

Deck slab

Section through slab
Reinforcement Configuration
## CFRP vs Steel Plates

<table>
<thead>
<tr>
<th>Criteria</th>
<th>CFRP</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Self weight</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Tensile Strength</strong></td>
<td>Very High</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Thickness</strong></td>
<td>Very Low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Length of plate</strong></td>
<td>Any</td>
<td>Limited</td>
</tr>
<tr>
<td><strong>Corrosion</strong></td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Handling</strong></td>
<td>Flexible, easy</td>
<td>Difficult, rigid</td>
</tr>
<tr>
<td><strong>Lap joints</strong></td>
<td>Easy</td>
<td>Complex</td>
</tr>
<tr>
<td><strong>Load Bearing</strong></td>
<td>Longitudinal</td>
<td><strong>Any Direction</strong></td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>No tools</td>
<td>Lifting gear, clamps</td>
</tr>
<tr>
<td><strong>Fatigue</strong></td>
<td>Outstanding</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Installation Costs</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Material Costs</strong></td>
<td>Medium/High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td>Light</td>
<td>Heavy</td>
</tr>
<tr>
<td><strong>Plate preparation</strong></td>
<td>Minimal</td>
<td>Considerable</td>
</tr>
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</table>
QAFCO Prill Tower

- 65m tall, 11m diameter RC urea prill tower
- Client: Qatar Fertiliser Company (QAFCO), Qatar
- Tower produces urea fertiliser 365 days per year
  - Cost of production per day - £600,000
- Internal surface temperatures - 70 degs
- Tower built over 30 years ago
- Big problems with vertical/horizontal cracking of concrete
- Loss of section on internal face of tower
Strengthening options

- CFRP plate bonding in hoop direction
  - 2 no 160mm x 1.8mm thick plates per m
- Steel plate bonding
  - 2 no 300mm x 7mm thick plates per m
- Concrete rings
  - 10 very large rings spaced equally over length of tower
- Mouchel recommendation
  - CFRP plate bonding option
CFRP strengthening

• Whole tower scaffolded
  – Carry out works quickly on all lifts
  – Provide tented area for bonding
  – Good working conditions
CFRP strengthening

2 crews of 12 men
12 hour shifts per day
38 - 42 deg ambient temp
32 - 36 deg temp in scaffold tent
CFRP strengthening

Plates supported by timbers and steel plates for 24 hours (300 centres)
Plates tap tested thereafter to check for voids
Refurbished Tower
Hammersmith Road Bridge – Background

• NR Southern Territory/London Underground
  – District/Circle Line, London underground

• Client: London Borough of Hammersmith and Fulham

• 3 Span Road over Rail bridge
  – 2 spans NR, one span LUL
  – Constructed c. 1860
Hammersmith Road Bridge

- Required capacity 40 tonnes
- Feasibility study of conventional options – service diversion too costly
- Supplementary feasibility for CFRP plating – Chosen option
- Detailed design including 3D Finite Element Model for lateral arch thrust, thermal stress calculation and deck plate strength
Hammersmith Road Bridge – Solution

• Strengthening Solution

– Longitudinal strengthening of main beams (flexure) – UHM Laminates (440GPa)
– Main span
  • 3No. 140mm wide, 24 mm thick CFRP Laminates
– Side spans
  • 3No. 140mm wide, 16 mm thick CFRP Laminates
Hammersmith Road Bridge – Solution

- Deck plates strengthening
  - 4No. 30mm wide tapered multi-layered pultruded plating to transverse stiffeners
  - Pultruded CFRP Cruciform to diagonal stiffeners
Hammersmith Road Bridge
– LUL Span

- Works completed in New Year
- 96 hour Possession:
  - Erection of birdcage scaffold
  - Work completed in 75 hrs
Hammersmith Road Bridge
LUL Span

- Adhesive application to soffit of structure and plates
- Fitting of plates into temporary support system hangers
Hammersmith Road Bridge

Before

After
Summary -
Key benefits of composites

- Weight
- Fast and lower cost installation
- Reduced life cycle maintenance costs
- Minimal business interruption
- Reduced new works capital costs
- Increased refurbishment opportunities
  - To extend existing asset life
- New product development opportunities (Mapewrap EQ)
Conclusions

- Proven technology
  - On concrete structures
  - On metal structures, except Wrought iron, riveted
- Value for money
  - Fast and low cost installation
  - Lightweight access needs compared to other methods
- Specialists play key role in economics
  - Designers, contractors with the right skills.
  - Quality control, Proper specifications, Site supervision
- Operational benefits
  - Reduction in number/length of possessions or road closures
- Greater options in structures management
  - Bridge life spans extended to suit wider business decisions
“Fibre composite strengthening is proving to be a cost-effective technique, which can bring great benefits to the owners of structures, chiefly because of the speed of installation, leading to less disruption ... “
“Whilst the approach is simple, composite strengthening is highly dependent on quality of workmanship. It is vital that an experienced repair contractor, using suitably trained and supervised staff, carries out the work. This is one of the key points identified in the Concrete Society Technical Report, TR57 ... “