ADVANCEMENTS IN NON-METALLIC REINFORCEMENTS OF STRUCTURES

January 2016
INTRODUCTION

- IMG Composites formed in 1998
- CompoSol® range of services
- Provide bespoke materials
- ISO9001
- F-Pal verified
OVERVIEW

• Introduction to composite materials

• History of structural repairs

• Development of CompoSol® Structure

• Case study (by R Thomson)

• HSL testing
COMPOSITE MATERIALS

• IMG Composites specialise in Fibre Reinforced Polymers (FRP)

• Pipe repairs
  – ISO24817 compliant
  – Prevents further corrosion
  – Reinstates the strength of the pipe
  – Seals leaks
ADVANTAGES OF COMPOSITE MATERIALS

- Lightweight
- Strong
- Do not degrade
- Prevents corrosion
- Applied in-situ
- No downtime
- Cost (local repairs vs replacement)
REINFORCING FIBRES

• Provide strength and stiffness to FRP

<table>
<thead>
<tr>
<th>Property</th>
<th>Glass</th>
<th>Carbon</th>
<th>Aramid/Kevlar</th>
<th>Steel (Typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength (MPa)</td>
<td>2400-3700</td>
<td>2000-5300</td>
<td>3100-3600</td>
<td>460</td>
</tr>
<tr>
<td>Stiffness (GPa)</td>
<td>69-86</td>
<td>160-440+</td>
<td>60-180</td>
<td>210</td>
</tr>
</tbody>
</table>

• Glass: Cost, toughness, impact
• Anisotropic
REINFORCING FIBRES

- Anisotropic

Fibre strength/stiffness vs angle of fibre
REINFORCING FIBRES

• +/- 45° for shear
  – Webs of I-beams
  – Pre-fabrication

• 0° UD
  – Most common
  – Fatigue

• 0/90°
  – Pre-fabrication
  – Pipes
# Resin Matrix

- Stress transfer between fibres
- Protects fibres
- Vital for compression, impact, fatigue resistance

<table>
<thead>
<tr>
<th>Resin</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy (such as CompoSol® CRC)</td>
<td>Best mechanical properties (strength, stiffness, adhesion, toughness)</td>
<td>Higher costs</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>Easy to apply (especially in water), good impact resistance</td>
<td>Poor compressive strength</td>
</tr>
<tr>
<td>Polyester</td>
<td>Low cost</td>
<td>Poor mechanical properties (particularly adhesion)</td>
</tr>
<tr>
<td>Vinyl-ester</td>
<td>Improved adhesion compared to polyester, chemical resistance</td>
<td>Poor mechanical properties relative to epoxies</td>
</tr>
</tbody>
</table>
HISTORY OF STRUCTURAL REPAIRS

• Designed for incidental loading

• Were not designed or required to take structural loads

• Repairs to bulkheads and other vertical surfaces

• Numerous deck repairs in the UKNS and ME
  – FPSO in Middle East
EXAMPLES: FPSO MIDDLE EAST
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EXAMPLES: SWITCH ROOM BULKHEAD
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COMPOSITE STRUCTURAL REPAIRS

- Retrofitted
- Corrosion protection
- Contour to different geometries
- Anisotropic - Efficient design
- Localised repair
COMPOSol® STRUCTURE REPAIRS

• Designed to restore or upgrade capacity

• Applied to a variety of structures
  – Decks
  – Caissons
  – I-beams
  – Hollow sections

• Fully integrated composite design
STAGES OF A COMPOSOL® REPAIR

- Information gathering
- Design
- Planning & Application
COMPOSol® STRUCTURE: INFORMATION

- Classification of repair
  - Extent of damage
- Type and size of loads
- Geometry
- Operational restrictions
**COMPOSol® STRUCTURE: INFORMATION**

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COMPOSOL® STRUCTURE: INFORMATION

• Classification of repair
  – Extent of damage

• Type and size of loads

• Geometry

• Operational restrictions
COMPOSol® STRUCTURE: DESIGN

• No governing standard – conservative approach
  – Published guidelines
  – Research papers (Empirical)
  – Engineering first principles

• Load capacity & bond analysis

• Iterative process with client
  – Safety factors
**CompoSol® Structure: FEA**

- Finite element analysis used to supplement design process
- Steel and composite interaction modelled
- Stress and deflection checks
- Study the structure holistically
  - Ensure there are no unaccounted stresses
COMPOSol® STRUCTURE: APPLICATION

• Access

• Habitat provision

• Surface preparation
  – Practical
  – Technical

• Condition of substrate
  – Pre-fabrication necessary?
COMPOSol® STRUCTURE: APPLICATION

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**CompoSol® Structure: Application**

1. CompoSol® REP – level surface
2. CompoSol® Carbon Reinforcement/CRC – main reinforcement
3. CompoSol® Glass Reinforcement/CRC – impact protection
4. Top coat, e.g. paint, anti-slip, etc.
COMPOSOL® STRUCTURE: OTHER ISSUES

• Fire resistance
  – Loss of properties at high temperatures

• Maintenance over lifetime
  – Inspection Regimes
    • Composite – Visual
    • Substrate

• Temperature
  – High temperatures
  – Thermal mismatch
CASE STUDY

• Rorie Thomson
CASE STUDY: NOTIFICATION OF DEFECT
CASE STUDY: REPAIR OPTIONS

1. No repair
2. Localised repair
3. Full replacement
4. Composite
OPTION 1: NO REPAIR

- Over design?
  - UT 0.20
- Redundant steel
- Braces unnecessary
OPTION 2: LOCALISED REPAIR
OPTION 3: TOTAL REPLACEMENT

• Surveys
• Decommissioning studies
• Calculations, drawings & fabrication
• Installation of new stair tower
• Operational impacts
OPTION 4: COMPOSITE REPAIR

- New and unknown
- £89k
- 21 days
- Local repair only
# Design Choice

<table>
<thead>
<tr>
<th>Design</th>
<th>Estimate Cost</th>
<th>Bedding Requirement</th>
<th>Operational Impact</th>
<th>Constructability</th>
<th>Duration</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Replacement</td>
<td>£80k - £120k</td>
<td>High</td>
<td>High Impact</td>
<td>Difficult</td>
<td>Months</td>
<td>Known &amp; trusted</td>
</tr>
<tr>
<td>Composite</td>
<td>£89k</td>
<td>Low</td>
<td>Low Impact</td>
<td>Easy</td>
<td>Days</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

| Driving Factor       | ✓              | ✓                   | ✓                 |                   |          |                        |
DESIGN AND RATIONALISTION

Buckled shape of column is shown by dashed line

<table>
<thead>
<tr>
<th>Theoretical $K$ value</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
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<td></td>
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<tr>
<td>1.0</td>
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<tr>
<td>1.0</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
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Recommended design value when ideal conditions are approximated

| 0.65 | 0.80 | 1.2 | 1.0 | 2.10 | 2.0 |
**End Result**

- £53k
- 16 days
HSL TESTING

• Links between HSL and HSE

“The research and incident investigation conducted on a daily basis by our scientists and health and safety experts underpins and informs the regulatory activities of the Health and Safety Executive (HSE).

Our unique relationship with the regulator means that no-one is better placed than HSL to advise high hazard industries on risk management and the organisation-wide adoption of a strong safety culture.”
HSL Testing

- Links between HSL and HSE
- Verification of design methodologies
  - Decks initially
**CompoSol® Structure: Testing**

- Repairs to steel decks tested
- Samples subjected to 3-point bending tests
COMPOSOL® STRUCTURE: TESTING

- Repairs to steel decks tested
- Samples subjected to 3-point bending tests
- Samples consisted of:
  - 2mm steel plate (approx. moment capacity 0.12kNm)
  - Min. 5mm CompoSol® REP (core material)
  - Carbon Reinforcement
  - Glass Reinforcement
  - Anti-slip
**COMPOSOL® STRUCTURE: TESTING**

- Test results are as follows:

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<th>BM Capacity (Yield)</th>
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<tr>
<td>2.10 kNm</td>
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**CompoSol® Structure: Testing**

- Comparison with design calculations
  
<table>
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<th>BM Capacity (Yield)</th>
<th>BM Capacity (Ultimate)</th>
<th>Predicted BM Capacity</th>
<th>Ratio of Actual/Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.10 kNm</td>
<td>3.18 kNm</td>
<td>1.81 kNm</td>
<td>1.164</td>
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- More tests planned for the future
CONCLUSIONS

- Development from super-coating to viable structural reinforcement
- Cost-effective
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• Cost-effective