Advancements in Non-metallic Reinforcements of Structures

January 2016

CompoSol®

INTRODUCTION

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

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OVERVIEW

- Introduction to composite materials
- History of structural repairs
- Development of CompoSol® Structure
- Case study (by R Thomson)
- HSL testing

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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

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Advantages of Composite Materials

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

Reinforcing Fibres

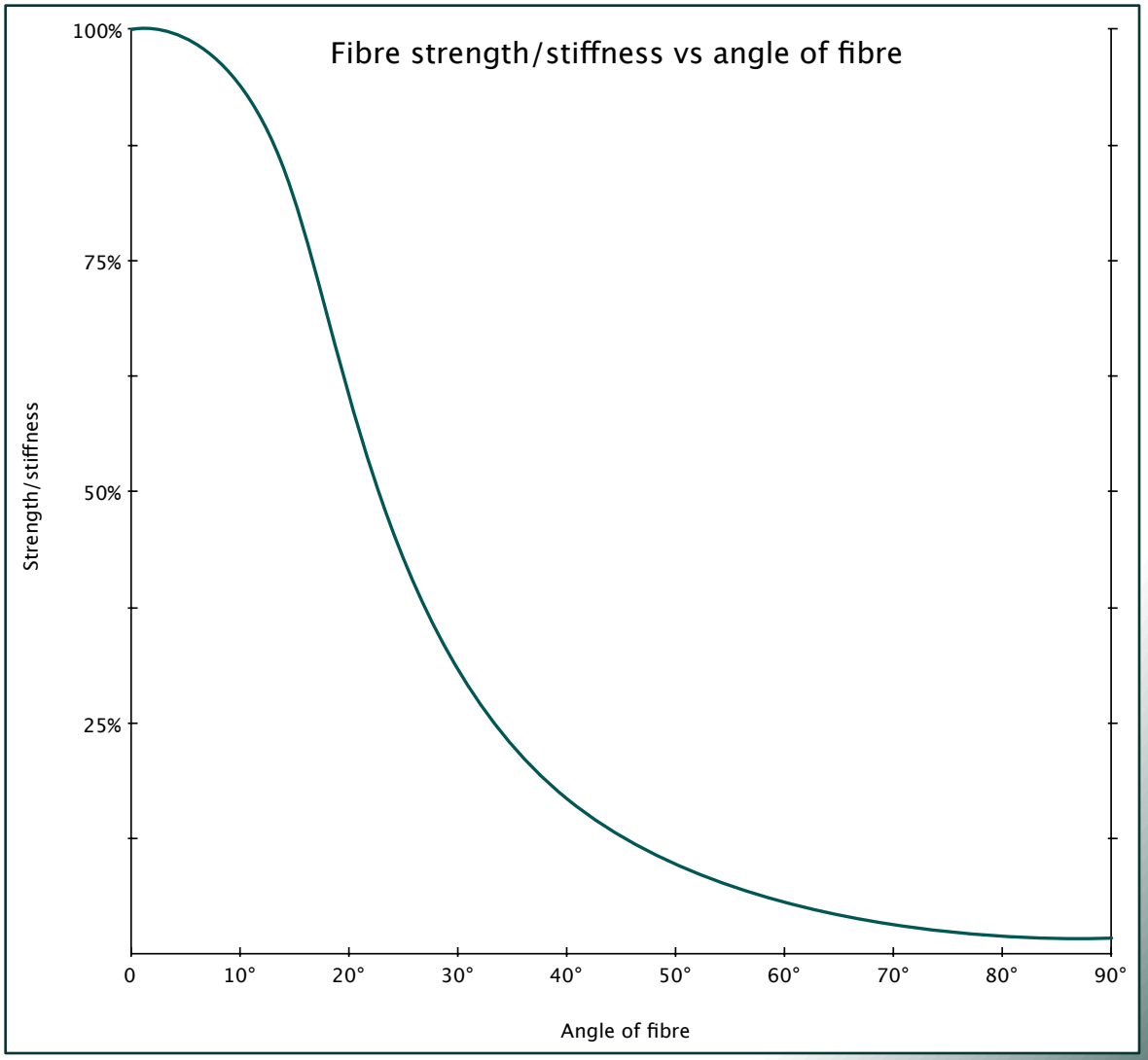
- Provide strength and stiffness to FRP

Property	Glass	Carbon	Aramid/ Kevlar	Steel (Typical)
Tensile Strength (MPa)	2400-3700	2000-5300	3100-3600	460
Stiffness (GPa)	69-86	160-440+	60-180	210

- Glass: Cost, toughness, impact
- Anisotropic

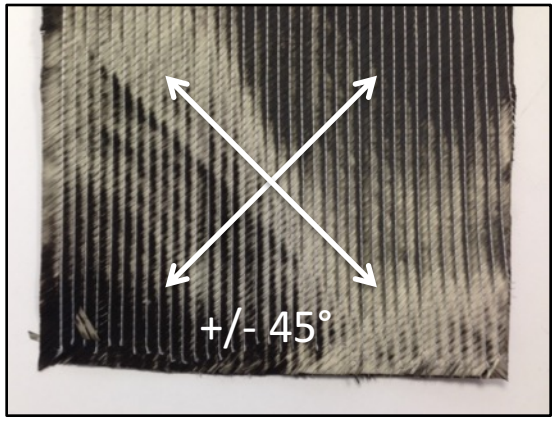
Reinforcing Fibres

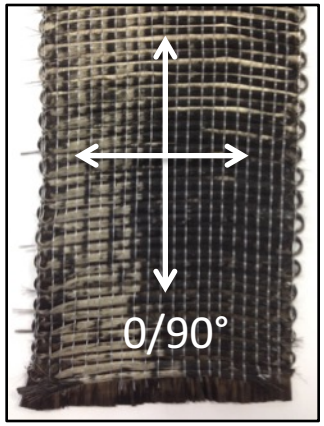
- Anisotropic

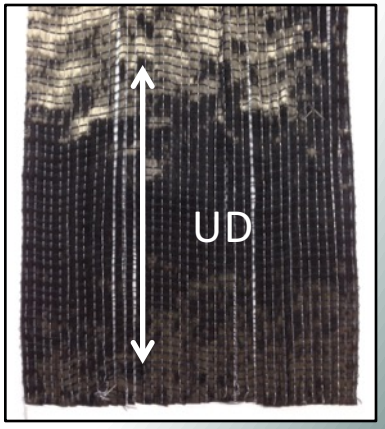


Reinforcing Fibres

- +/- 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

Resin	Pros	Cons
Epoxy (such as CompoSol® CRC)	Best mechanical properties (strength, stiffness, adhesion, toughness)	Higher costs
Polyurethane	Easy to apply (especially in water), good impact resistance	Poor compressive strength
Polyester	Low cost	Poor mechanical properties (particularly adhesion)
Vinyl-ester	Improved adhesion compared to polyester, chemical resistance	Poor mechanical properties relative to epoxies

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

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EXAMPLES: FPSO MIDDLE EAST

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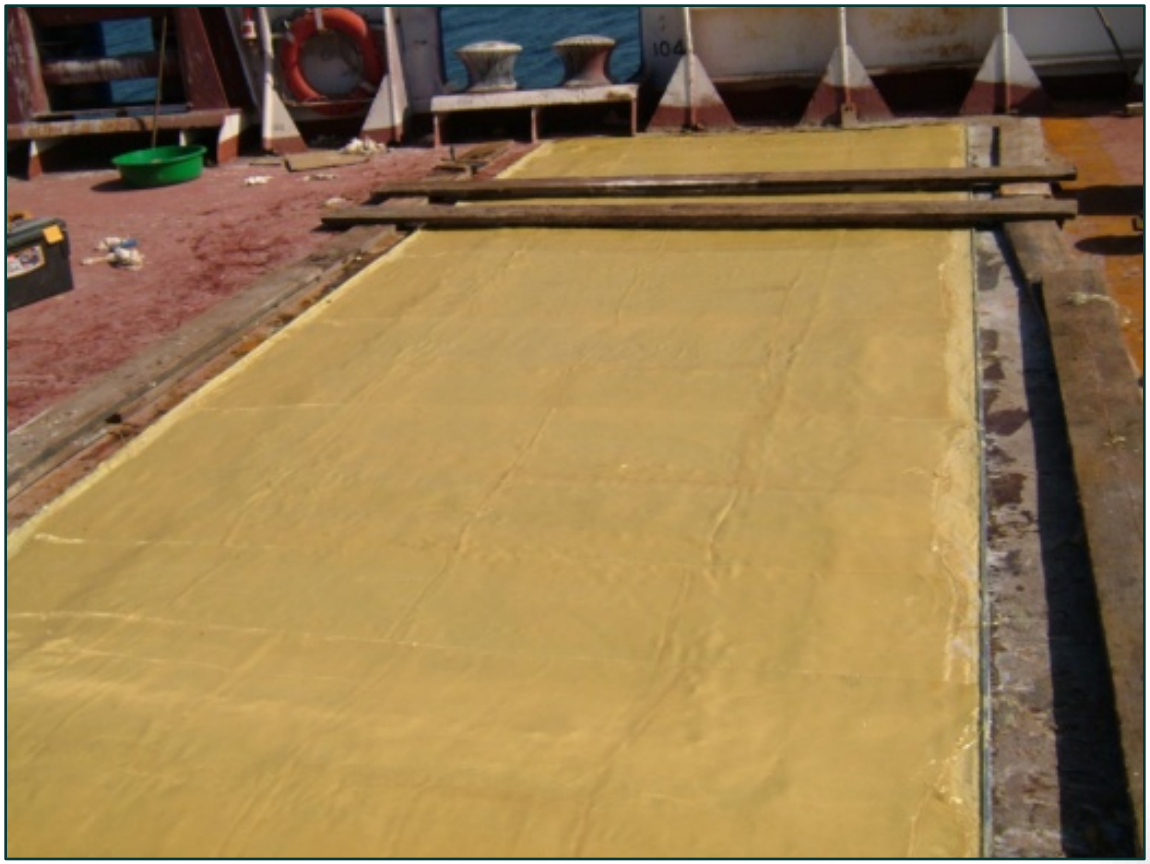

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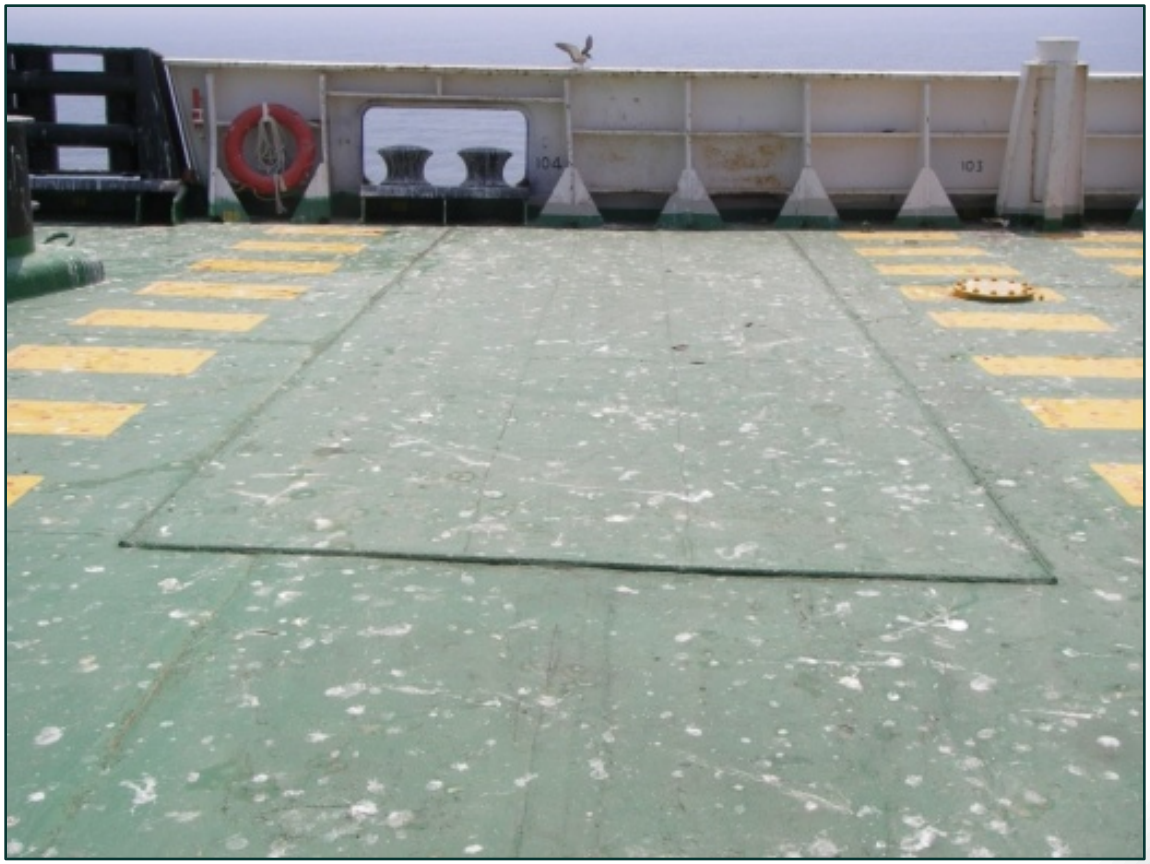
EXAMPLES: FPSO MIDDLE EAST



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EXAMPLES: SWITCH ROOM BULKHEAD

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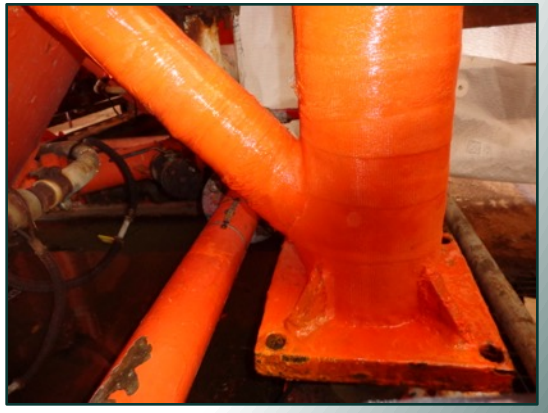
Composite Structural Repairs

- Retrofitted
- Corrosion protection
- Contour to different geometries
- Anisotropic - Efficient design
- Localised repair



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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

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Stages of a CompoSol® Repair

- Information gathering
- Design
- Planning & Application

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CompoSol® Structure: Information

- **Classification of repair**
  - **Extent of damage**
- Type and size of loads
- Geometry
- Operational restrictions

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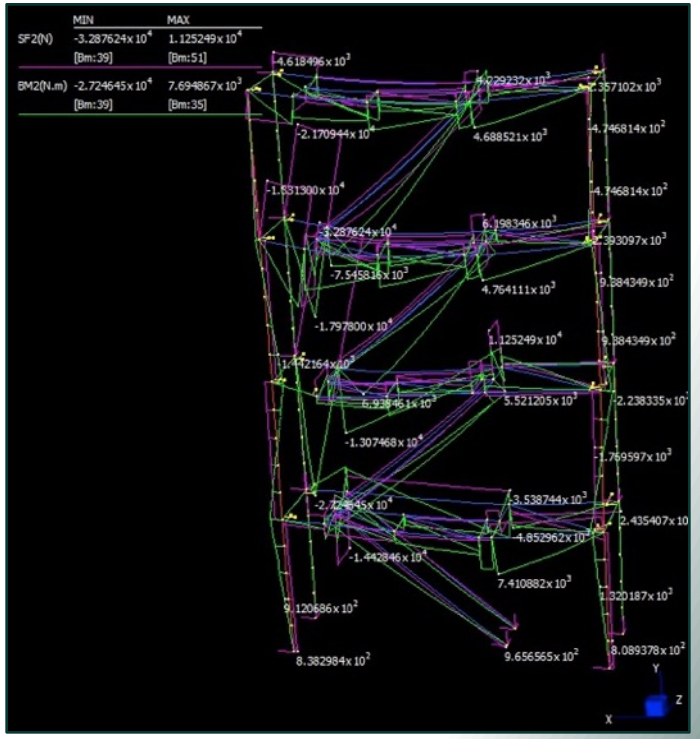

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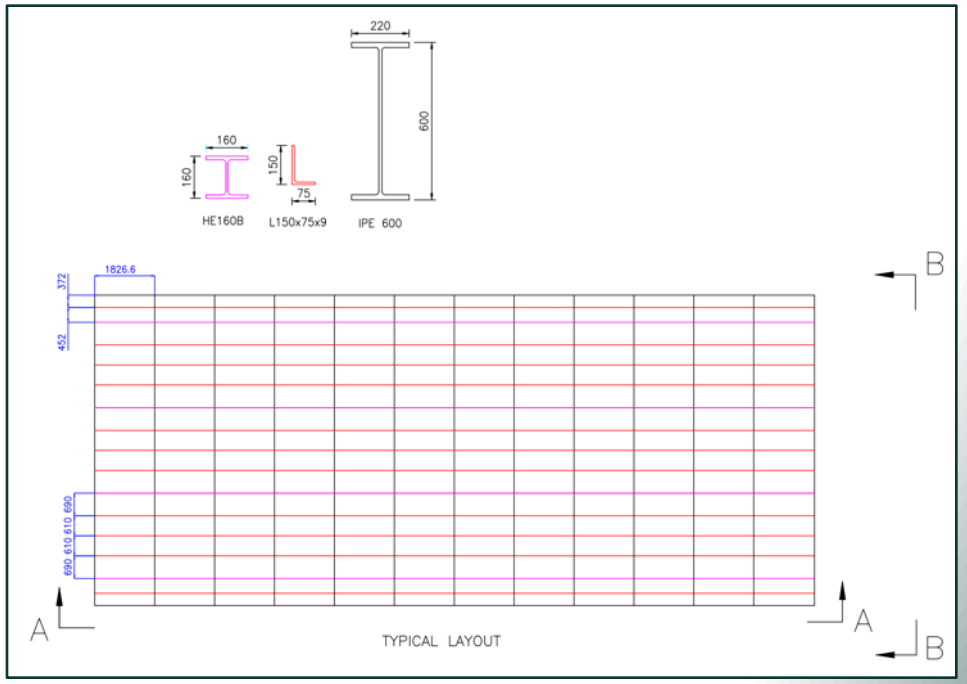

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CompoSol® Structure: Information

- 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

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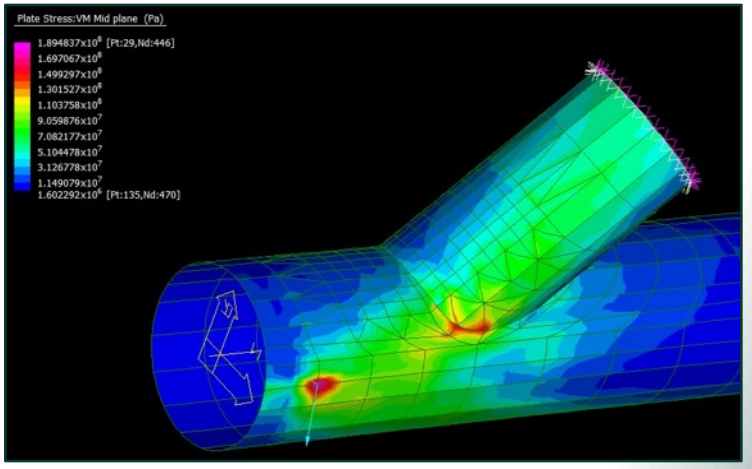
CompoSol® Structure: FEA

- 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?

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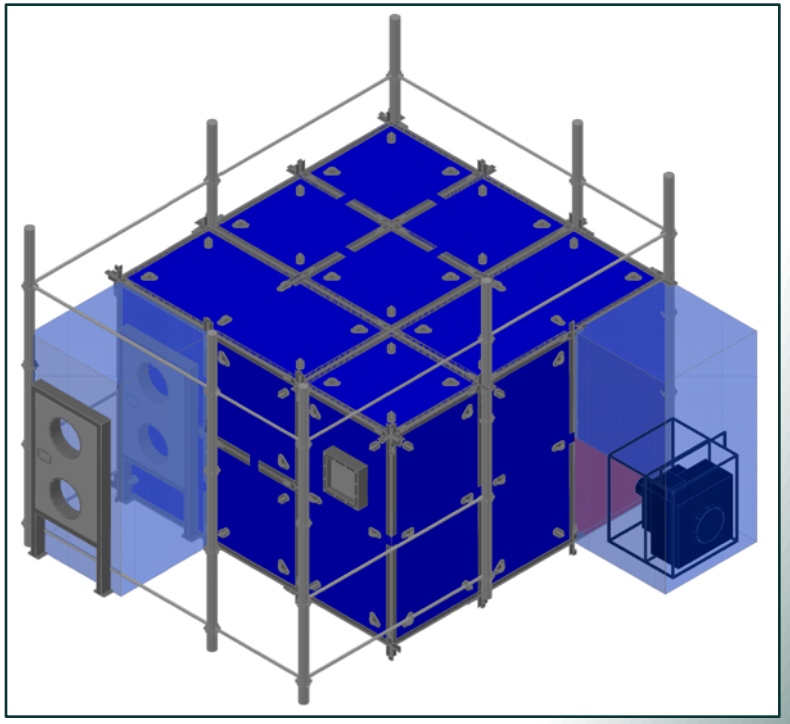

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CompoSol® Structure: Application

- Access
- Habitat provision
- **Surface preparation**
  - **Practical**
  - **Technical**
- Condition of substrate
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CompoSol® Structure: Application

- Access
- Habitat provision
- Surface preparation
  - Practical
  - Technical
- **Condition of substrate**
  - **Pre-fabrication necessary?**

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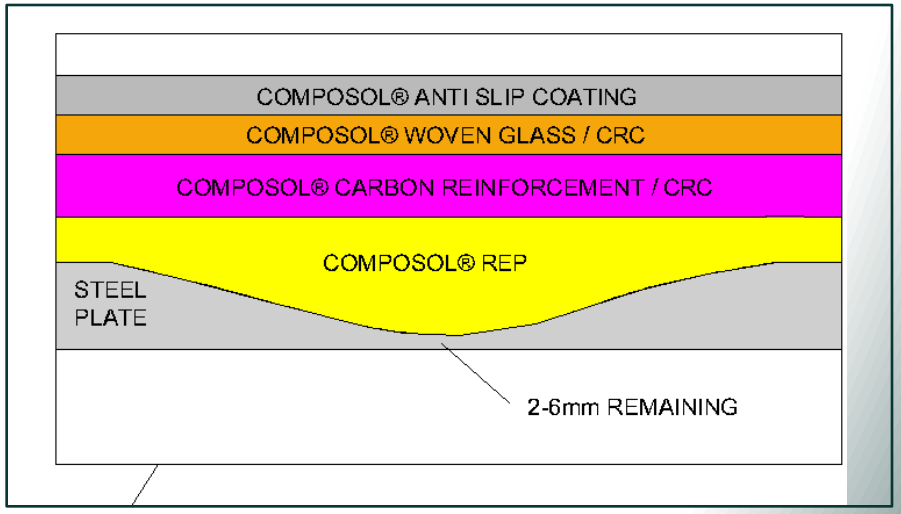
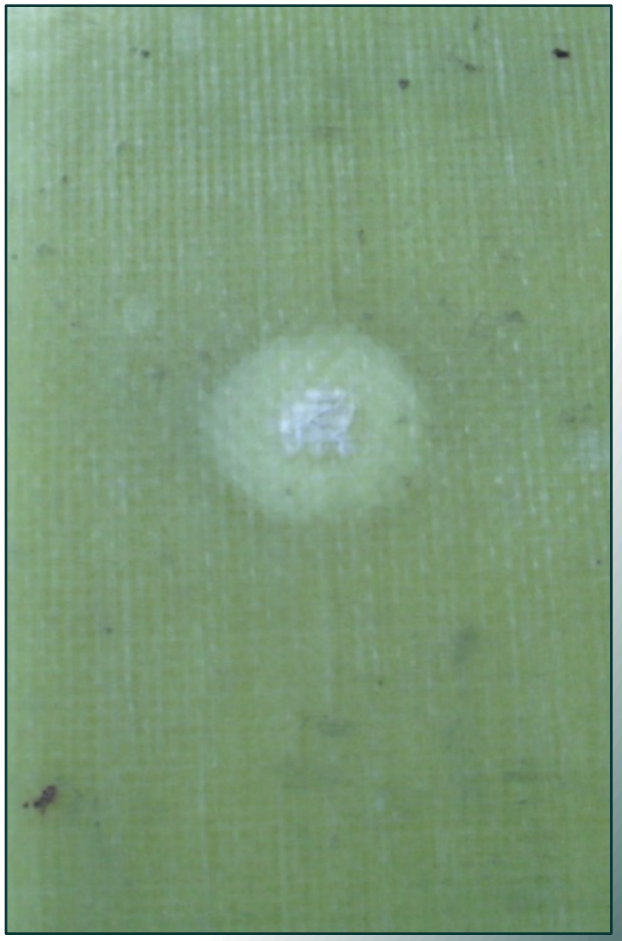
CompoSol® Structure: Application

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



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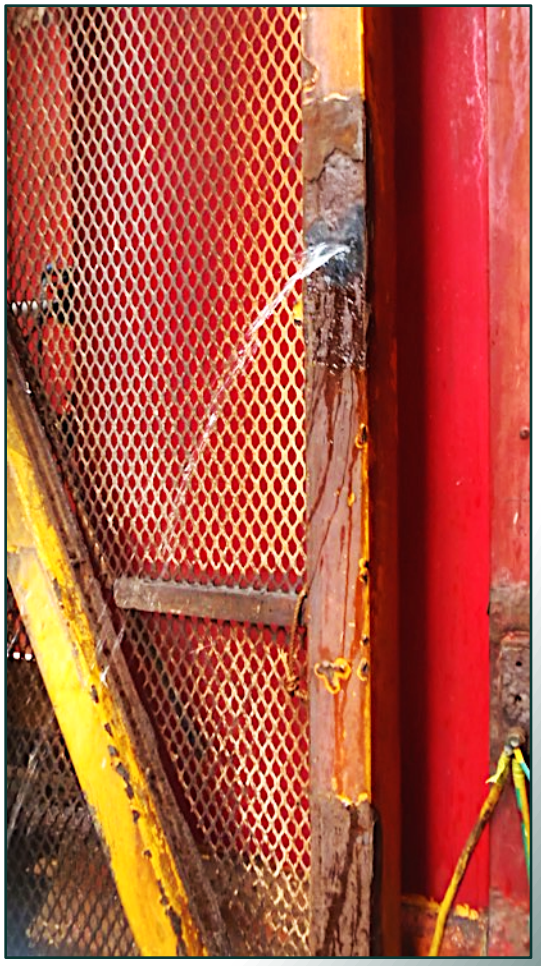
CASE STUDY

- Rorie Thomson

Case Study: Notification of Defect



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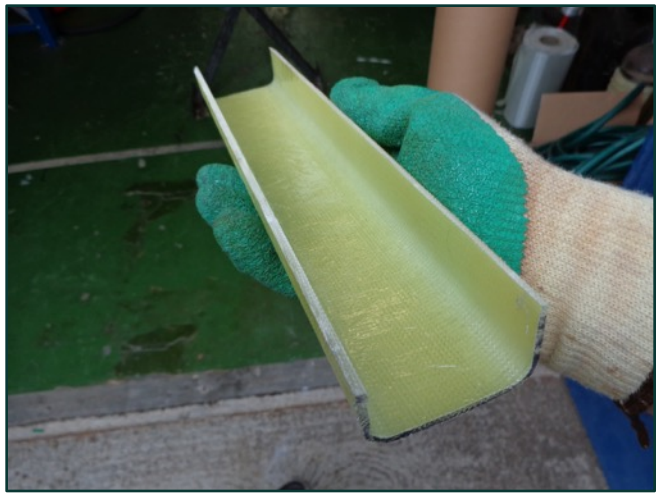
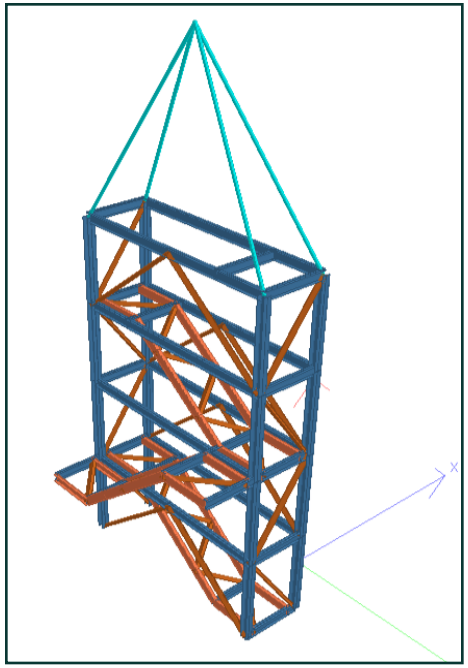
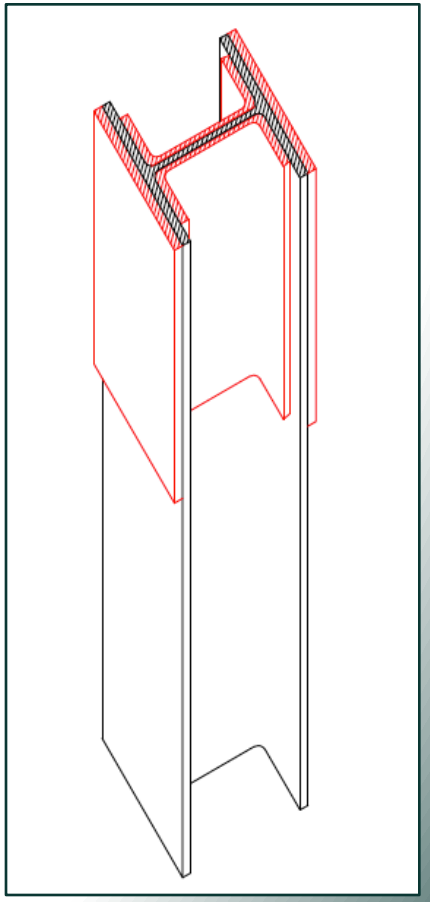
Case Study: Repair Options

1. No repair
2. Localised repair
3. Full replacement
4. Composite

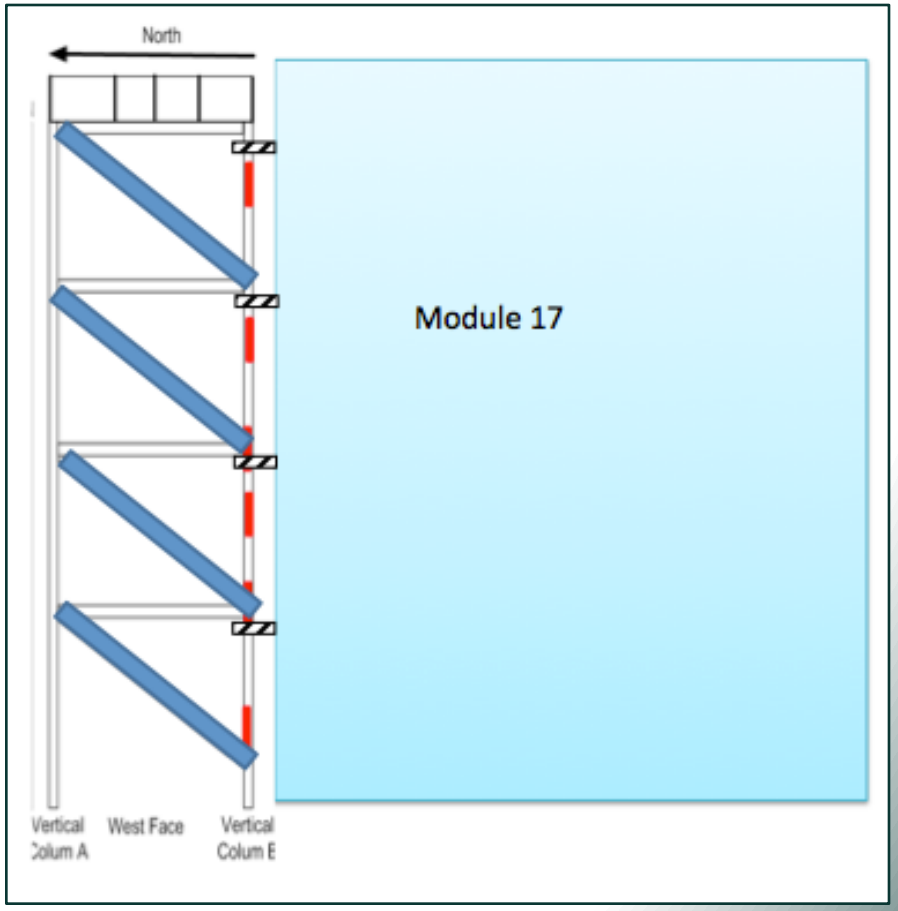




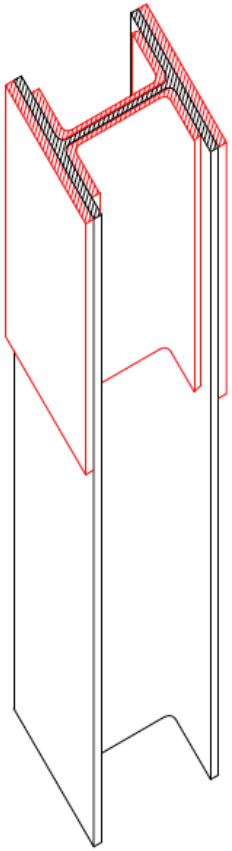


Option 1: No Repair

- Over design?
  - UT 0.20
- Redundant steel
- Braces unnecessary

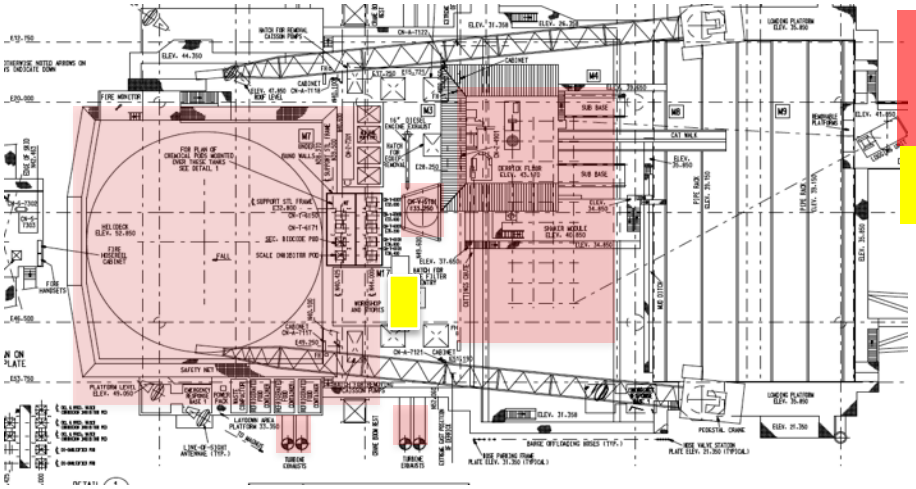


Option 2: Localised Repair



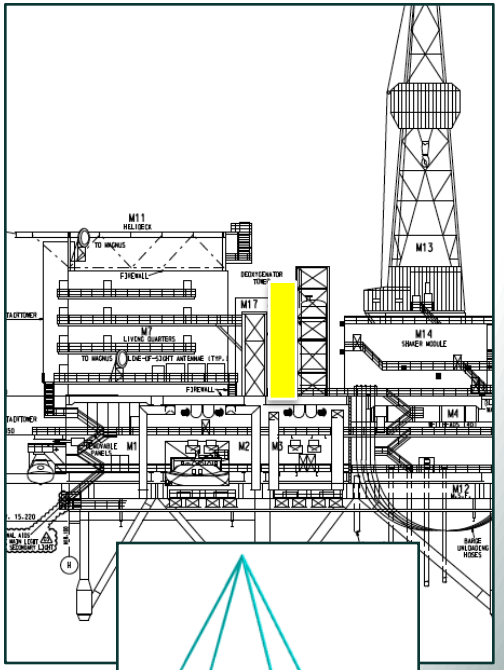
Option 3: Total Replacement

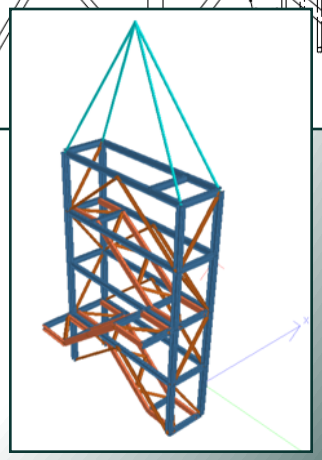
- Surveys
- Decommissioning studies
- Calculations, drawings & fabrication
- Installation of new stair tower
- Operational impacts



Obstacles / Hazards

Stair Tower





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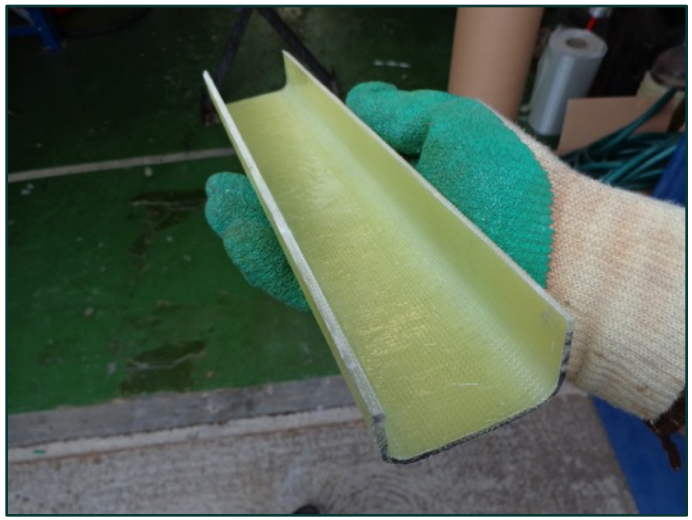
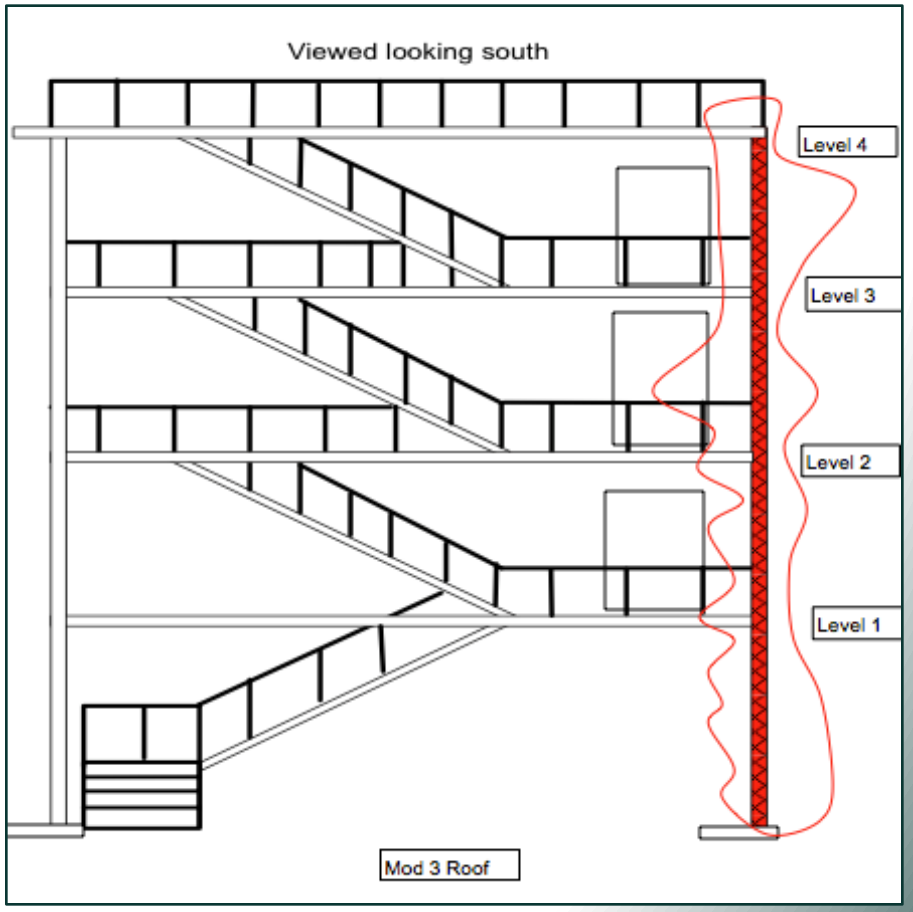
Option 4: Composite Repair

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

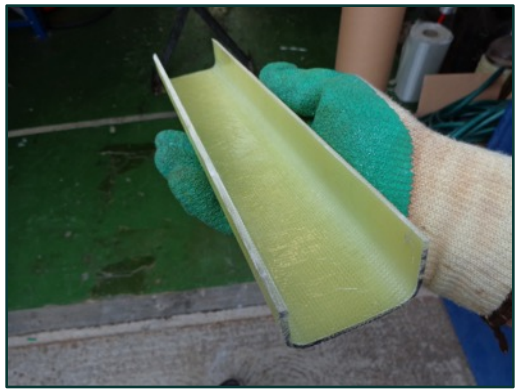


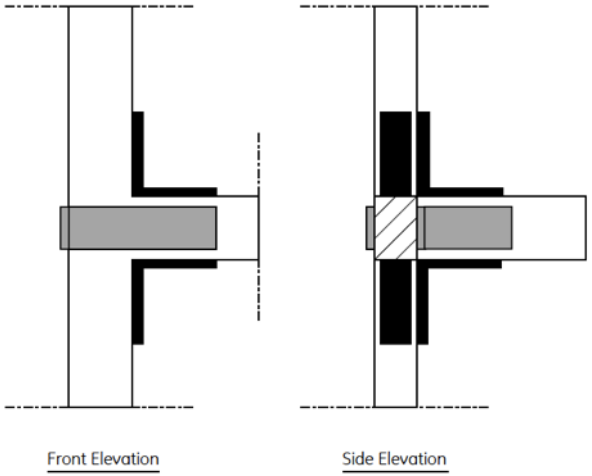


Design Choice

Design	Estimate Cost	Bedding Requirement	Operational Impact	Constructability	Duration	Technology
Full Replacement	£80k - £120k	High	High impact	Difficult	Months	Known & trusted
Composite	£89k	Low	Low Impact	Easy	Days	Unknown
Driving Factor		✔	✔		✔	

DESIGN AND RATIONALISTION





Buckled shape of column is shown by dashed line	(a)	(b)	(c)	(d)	(e)	(f)
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0

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End Result

- £53k
- 16 days

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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."

HEALTH & SAFETY LABORATORY

HSL Testing

- Links between HSL and HSE
- Verification of design methodologies
  - Decks initially

HEALTH & SAFETY LABORATORY

CompoSol® Structure: Testing

- Repairs to steel decks tested
- Samples subjected to 3-point bending tests

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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:

BM Capacity (Yield)	BM Capacity (Ultimate)	Steel only	Increase in BM Capacity
2.10 kNm	3.18 kNm	0.12 kNm	**1.98 kNm** *(>16x)*

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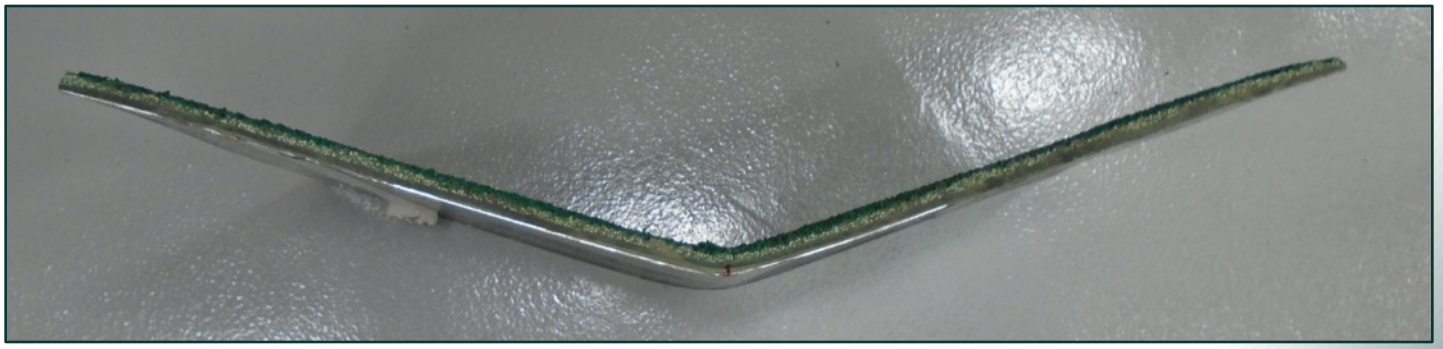

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CompoSol® Structure: Testing

- Comparison with design calculations

BM Capacity (Yield)	BM Capacity (Ultimate)	Predicted BM Capacity	Ratio of Actual/Predicted
2.10 kNm	3.18 kNm	**1.81 kNm**	1.164

- More tests planned for the future

CONCLUSIONS

- **Development from super-coating to viable structural reinforcement**

- Cost-effective

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