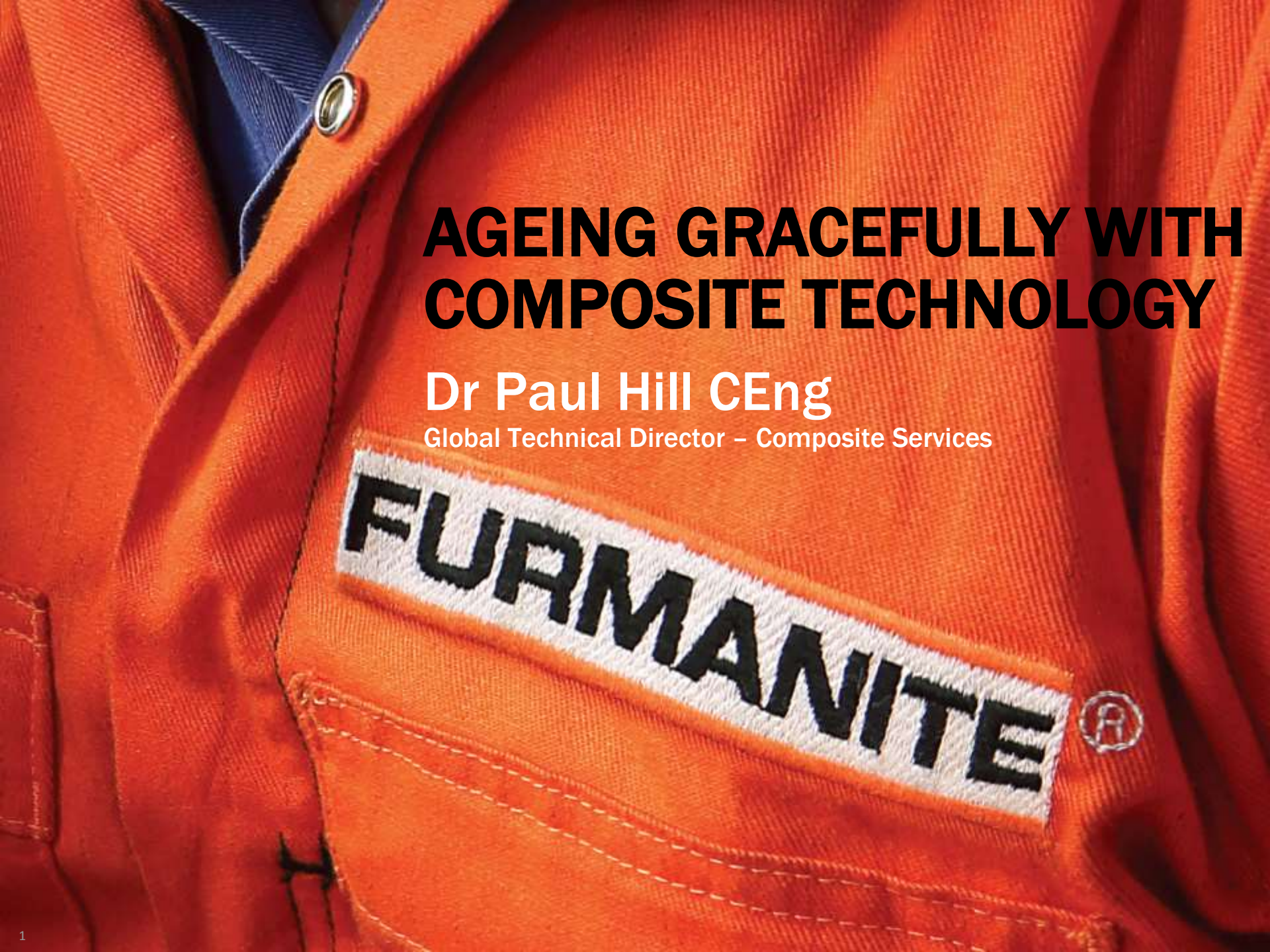

AGEING GRACEFULLY WITH COMPOSITE TECHNOLOGY

Dr Paul Hill CEng
Global Technical Director – Composite Services

FURMANITE®

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YOU THOUGHT YOU KNEW.

FURMANITE TECHNICAL SOLUTIONS KEY SERVICES

- Front-end engineering & design
- Life-cycle analysis
- Engineering
- Procurement
- Construction management
- Commissioning & start-up
- Project management
- Automation solutions
- Operations & maintenance
- Feasibility studies
- Staffing

Integrated Industrial Solutions. Seamless Implementation.

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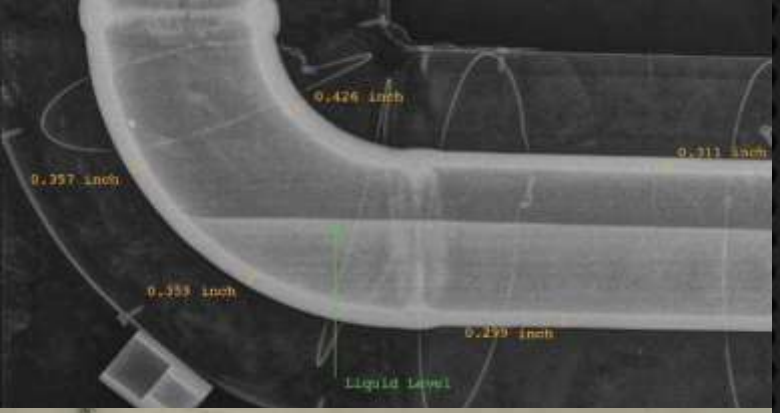


FURMANITE INSPECTION

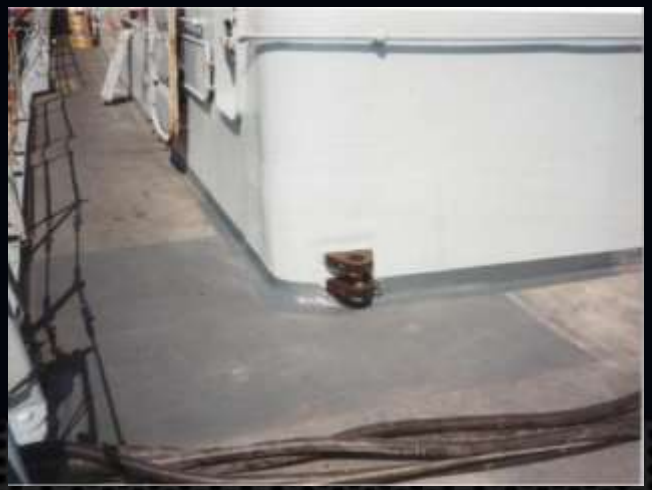
KEY SERVICES

- Traditional & Computed Radiography (RT/CRT)
- Magnetic Particle Testing (MT)
- Penetrant Testing (PT)
- UT Thickness and Flaw Detection
- Tube Inspection (ET/IRIS/RFT/ NFT)
- Phased Array (PAUT)
- Time of Flight Diffraction (ToFD)
- Electromagnetic Acoustic Emissions Testing (EMAT)
- Alternating Current Field Measurement (ACFM)
- Long Range UT Testing (Guided Wave)
- API Inspectors (510/570/653)

FURMANITE SPECIALITY MECHANICAL KEY SERVICES

- On-Line Leak Sealing
- Composite Repair
- Controlled Bolting
- On-Site Machining
- Heat Treatment
- Weld test & Isolation
- Hot Tapping & Line Stopping
- Valve Repair
- Trevitest

Ageing Gracefully



- Use of composite materials in managing ageing metal structures
- Examples
  - Bridges
  - Tunnels
  - Ships
  - Offshore

The history

- London Underground
  - Tunnel construction started in 1843 (by Marc Brunel and his son, Isambard)
  - First line (Metropolitan) started running in 1863
  - Subsequent development has led to significant changes in loading and access
    - Second photo shows Regent Street, rebuilt between 1895 and 1927

The challenge

- Tunnels built using the latest materials and techniques
  - “Cut and cover” tunnels
  - Cast Iron beams with brick jack arch infill
- Subsequent development has led to significant changes in loading and access
- Some of the structures are now over 160 years old
- This key infrastructure must continue to perform safely

Cast iron

- Cast iron known to be unreliable
  - Strong in compression
  - Weak in tension
  - Early QA - load tests on as-produced beams (up to 45 tonnes) followed collapse of Dee Rail Bridge in 1847 (built by Robert Stephenson, son of George, who is father of modern rail)
- Wrought iron even less suitable
  - Corrosion a longer term problem below ground (and higher cost)
- Blast furnace first patented in 1855 – too late for the tunnels

Performance in Service

- Several beams have fractured but none have collapsed
  - Beams in highest risk locations have been replaced
- Cast iron covered-way roofs below roadways were rebuilt or underpinned in early 1960's
- **Cast iron tunnel roof remain a risk**
  - **in areas below buildings**
  - **in areas below footways and open spaces**

The challenge

- Covered way roofs below buildings
  - Only accessible from below when trains are not running
    (about 3 hours per night)
  - Need to maintain building support
  - Available space
    - Cast iron beams only just above trains
    - Only space available is in jack arch segmental void
- Can't lower the track
  - Large sewers pass immediately under tracks
  - Trackside retaining walls undermined (kick in at base unless restrained)

Current Solution

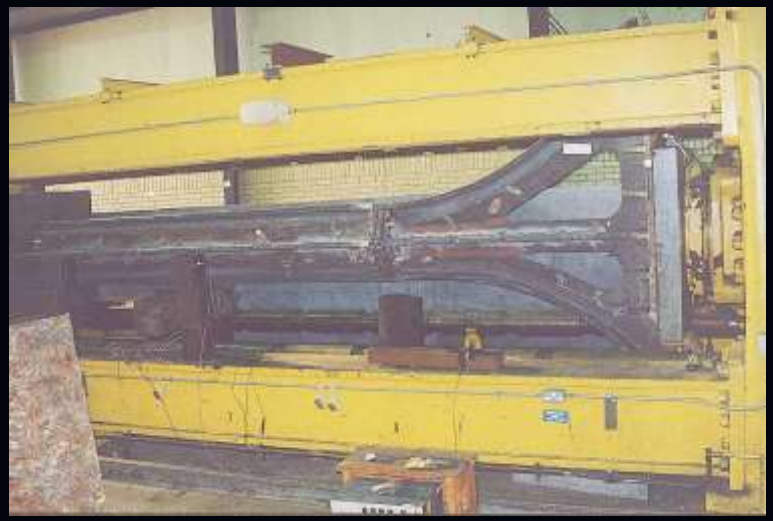
- Steel aerofoil beams
  - Each beam has a mass of 6½ tonnes
  - Loads in cast iron are unknown
  - Concern that installation may overload the cast iron in tension during installation
  - Solution required to strengthen tensile flange of CI beam

Composite Strengthening

- UHM carbon fibre validated as a strengthening option
  - High stiffness vs cast iron (360GPa vs 110-130GPa)
  - Pick up load quickly for small deflections
  - Use tensile strength of carbon and compression strength of cast iron
  - Only thin plates required

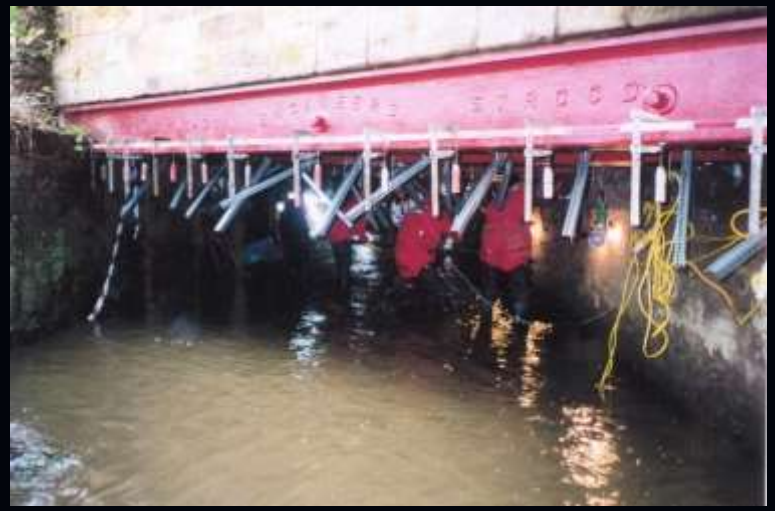
Verification

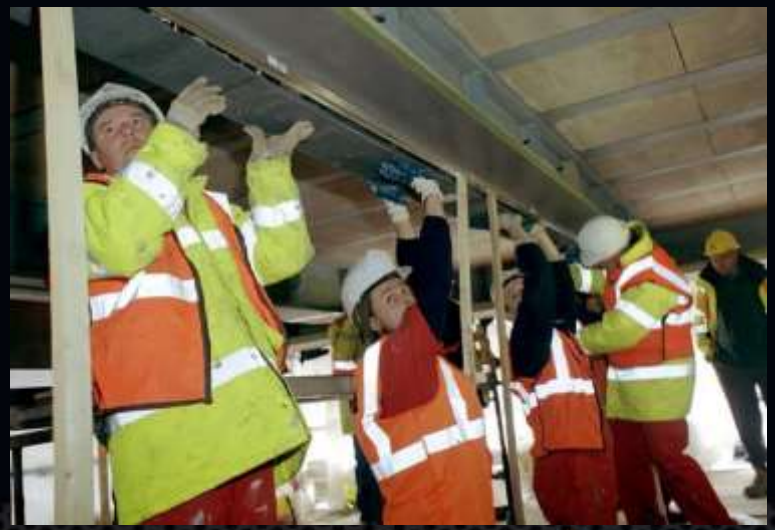
- Extensive test programme completed
- Component and materials scale testing
- Long term properties measured
- Application techniques verified
- Structural monitoring in-situ to confirm performance



Application Development

- Interest from wider industry in reinforcement of older bridge-stock
- Methodology standardised and published (ICE, CIRIA)
  - Wide range of projects completed
  - Pre-stressing techniques developed
  - Few older bridges in Europe post-1945



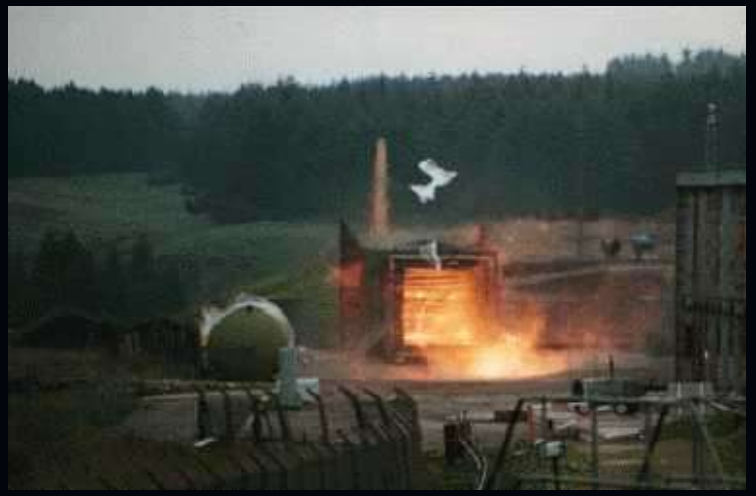


Other Structural Applications

- Materials also used to manage other cast iron structures
  - Tunnel pans
  - Struts
- Extended application to steel structures
  - Included webs and compression-side of beams

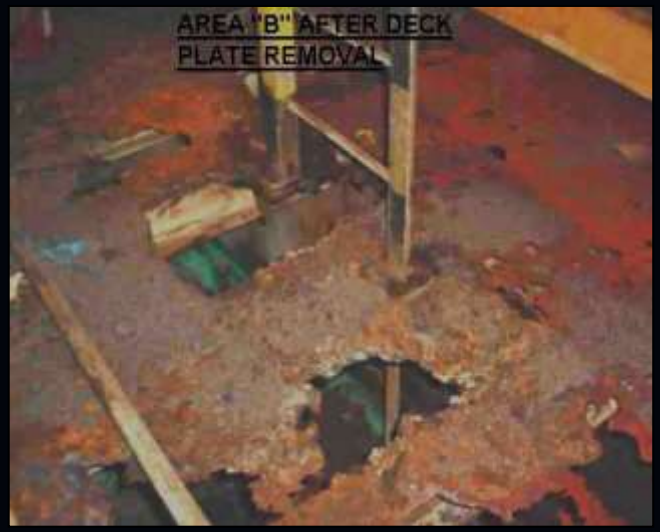
Other Structural Applications

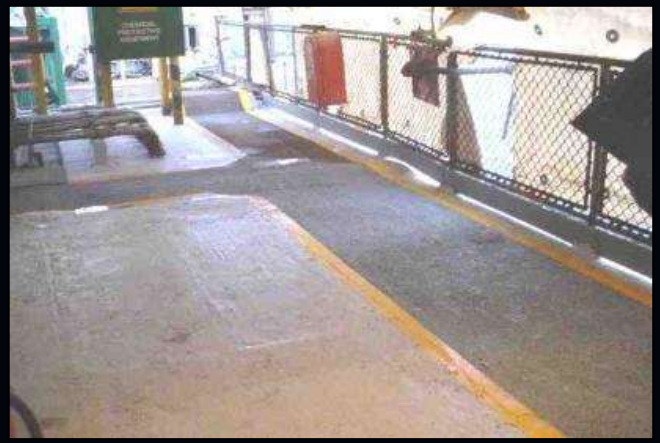
- Blast wall strengthening
- Testing completed to determine:
  - Short term mechanical properties
    - Tension and compression
    - Temperature and strain rate effects
  - Bond strength
    - Surface preparation
    - Temperature and strain rate effects
  - Representative blast tests completed to verify performance



Other Structural Applications

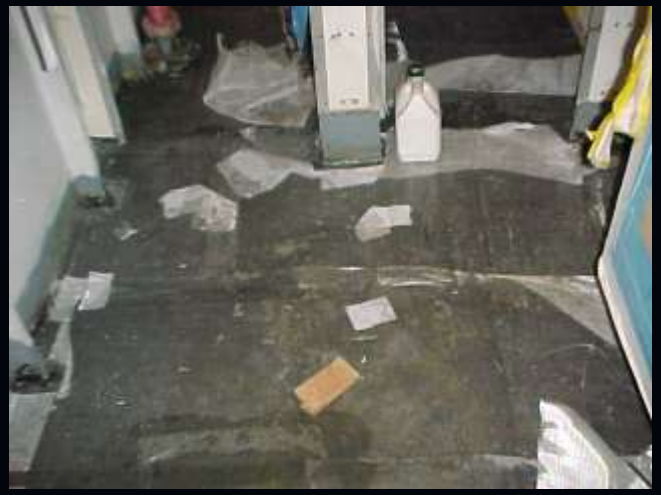
- Wide range of applications for repair of degraded metal structures pioneered using data, design methodolgy and test results developed
  - Cold work application process
  - Easy to apply and cost-effective
  - Add little extra weight to structure
- For example, Offshore Deck repair (up to 400m^2/4000sqft)

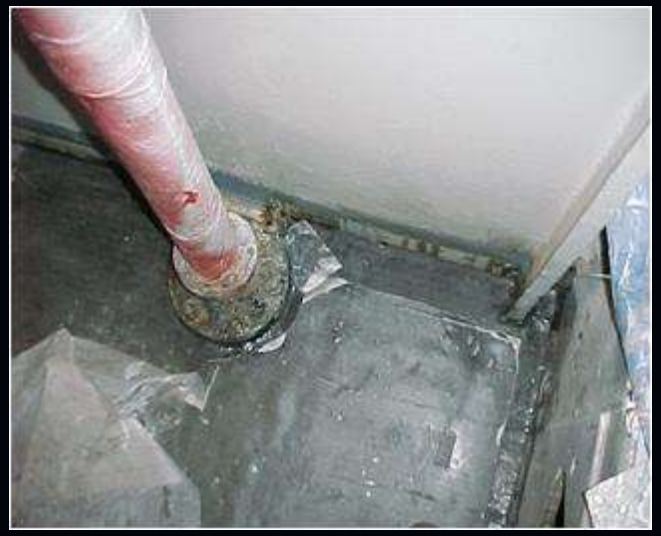




Other Structural Applications

- Repair of corroded steel decks in ships
- Cold-work application process meant work could be completed without disrupting other activities
- Programme was compressed, leading to significant cost savings





Other Structural Applications

- Use of composites for crack reinforcement studied
- JIP led by DNV in Norway
- Trial applications of crack repair and deck repair completed on FPSO's in Europe and Asia
- Performance in line with expectations

Ageing Gracefully

- Composite materials can ensure help ageing structures continue in service
- Plastic surgery that does more than make you look younger!

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