Repair and upgrading of concrete structures with FRP materials

by

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Definitions

**Maintenance:** Keep a structure performance at original level

**Repair:** To upgrade a structures performance to its original level

**Upgrading:** To increase a structures performance

**Performance:**
- Durability
- Load Carrying Capacity
- Aesthetics
- Function
The environment changes

In the beginning of 1900

In the end of 1900

The built environment must be taken care of
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Increased Need of Rehabilitation

- 20 – 40 % New Investments
- 60 – 80 % Repair/Upgrading

- Historic Buildings
- Infrastructure
- Reconstruction

Importance of Infrastructure

- Roads
- Railways
- Airports
- Harbour
- Wharf
- Dams
- Power Stations
- Distribution lines
- Bridges
- Industry buildings
- Tunnels
- Waste water infrastructure

A majority of this infrastructure is constructed of reinforced concrete – which is our most important building material
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Possible Reasons for Deterioration

Steel Corrosion
- Freeze/Thaw
- Steel Corrosion
- Alkali-Silica Reaction
- Lime Leaching
- Sulphur reactions

Alkali-Silica Reaction

Synergy Effects?

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Deterioration process in general

Performance

Actual performance
Lowest acceptable performance
Remaining Life

Deterioration process
Last chance for measure

Time

A

B

I
Deterioration affects the load bearing capacity

The same deterioration process affects different parts of a structure differently

This means that considerations must be taken to where the deterioration process is most severe due to the load carrying capacity
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Infrastructure

Example from USA

2005 Report Card for America’s Infrastructure

Grade Definitions:
- A = Exceptional
- B = Good
- C = Mediocre
- D = Poor
- F = Failing
- I = Incomplete

Aviation
Bridges
Dams
Drinking Water
Energy
Hazardous Waste
Highways/Waterways
Public Parks & Recreation
Rail
Roads
Schools
Security
Solid Waste
Transport
Water/Sewer

America’s Infrastructure Report Card:

Total Investment Needs = $1.6 trillion
Approved 9 year $1.5 trillion

Ullasund bru – Norway – 30 years old –
demolished six years ago
Accidents: 1989 - Loma Prieta Earthquake

- Deficiencies due to:
  - Environmental Effects
    - Freeze-Thaw
    - Chloride Ingress
    - Wet-Dry
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**Infrastructure**

Strengthening due to: Increased traffic volumes

Then  |  Now
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Infrastructure

• Our infrastructure systems are deficient
• Neglect, deterioration, overuse, upgrade

Global Infrastructure Crisis

1. How can we prevent deterioration of infrastructure?
2. How can we prolong the lives of existing structures?

Future need for maintenance, repair and upgrading of reinforced concrete infrastructure – a prediction

• There exists a large, accumulated need for repair and strengthening of existing concrete structures (also for relatively new structures)
• We need to prepare oneself that deterioration of concrete structures will continue and that the future need for repair and strengthening will be demanding
• In the foreseeable future no simple or universal methods to eliminate the deterioration of concrete structures can be seen. Insufficient maintenance will intensify the problems.
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Need of Innovations

• "More – and better – for less!"

• Systems for cathodic protection

• Use of advanced composites

• Smart Structures

• Use of medical technology: ultrasound, X-ray etc.

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Repair and Upgrading of existing structures?

• New demands on existing structures
• Mistakes in the design or construction phase
• New user demands, reconstruction etc.
• Accidents
• Deterioration of existing structures/materials
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Complexity

Universities
Codes and Standards
Contractors
Consultants
Clients

- Design methods?
- Tests?
- Existing documentation?
- Non destructive testing?
- Condition of existing structure?
- Economy?
- Following up program?
- Type of Structure
- Original Design
- Materials
- Repair Methods
- Environment
- Aesthetics
- Life Cycle Analysis

Different principles to strengthen structures?

More accurate calculation models
Different principles to strengthen structures?

Increased cross section

Prestressing
Different principles to strengthen structures?

External bonding

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External Strengthening

1964
Steel Plates, *South Africa

1975-
Steel Plates
*France
*UK
*Japan
*Switzerland
*USA

1988
Steel Plates
*Sweden
FRP
*Japan

1990-
FRP
*Switzerland
*Canada
*USA

1993-
FRP
*UK
*Sweden
*Denmark
*etc.

etc…

FRP bridges

South Africa

Sweden

Japan

FRP

USA
Strengthening with Steel Plates

Strengthening with steel plates
Beams with springs for mounting the plates
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Strengthening with steel plates
After strengthening

Different ways to strengthening with FRP

- Hand-Lay Up
- Vacuum Infusion
- Winding
- Pre-manufactured Composites
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Different ways to strengthening with FRP

- NSMR
- CFRP Grids

What is FRP?

A composite is a material of which attribute is superior to the individual components.
Fibre Reinforced Polymers (FRP)

- Fiber
  - Carbon
  - Aramid
  - Glass

- Matrix
  - Epoxy
  - Vinylester
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Manufacturing Process (Laminates)

Pultrusion

[Diagram of the pultrusion process]

Manufacturing Process

[Images of the manufacturing process]
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Manufacturing Process

FRP Strengthening systems

- FRP Sheet
- FRP Plate
- FRP Bar
- FRP Grid
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FRP Plate - laminat

Are for use
- Suitable for flat surfaces, but can also be used on curved surfaces with a sufficient large radius.
- Suitable for strengthening for flexure (bending).
- Can also be used for shear strengthening

Laminate
- Width: 50/80/100/120/150 mm
- E-modulus: 150/170/260 GPa
- Peel-ply on both sides

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FRP Plate - laminate

The strengthening system consists of
- XXX Primer 50 Super
- XXX Spackel 205
- XXX Lim 567
- XXX Plate
- Possible with post treatment
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**FRP Bar-rod system**

- **Arera for use**
  - Suitable for flat and uneven surfaces
  - Suitable for increased flexural/bedding strengthening
  - Protected against impact

- **NSMR**
  - Dimensions: 10 x 10 mm
  - E-modulus: 150/250 GPa
  - Peel-ply
  - Sanded surface for grouting
StoFRP Bar-rod system

The strengthening system consists of:
- XXX Primer 50 Super
- XXX Lim 465
- XXX Bar
- Possible with post treatment
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FRP Sheet – sheet system

Areas for use
- Suitable for curved surfaces, in relation to openings and shear strengthening.
- Torsional strengthening, flexure

Väv
- Weight: 200/300 g/m²
- E-modulus: 228/377 GPa
- One directional, bi-directional

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FRP Sheet - vävsystem

Förstärkningssystemet består av:
- XXX Primer 50 Super
- XXX Spackel 205
- XXX Lim 417
- XXX FRP Sheet
- Möjlighet till efterbehandling med StoCretec produkt
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Area for use
- Crack reinforcement
- Traditional reinforcement for new construction
- Decrease concrete cover

Grid
- Grid size 40 x 30 mm / other sizes available
FRP Grid

The strengthening system consists of:
- StoCrete TH
- StoCrete GM1
- StoFRP Grid
- Possible with post treatment
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**Fibre**

![Graph showing stress-strain relationship for different fibres](image)

<table>
<thead>
<tr>
<th>Fibre</th>
<th>E, (GPa)</th>
<th>σ, (MPa)</th>
<th>ε, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aramid</td>
<td>70 - 160</td>
<td>3 300 - 2 400</td>
<td>1.5 - 4.0</td>
</tr>
<tr>
<td>Glass</td>
<td>70-80</td>
<td>3 000 - 5 000</td>
<td>4.0</td>
</tr>
<tr>
<td>Carbon</td>
<td>200-600</td>
<td>4 500 - 1 500</td>
<td>0.4 - 2.0</td>
</tr>
</tbody>
</table>

**Matrix**

<table>
<thead>
<tr>
<th>Property</th>
<th>Epoxy</th>
<th>Vinylester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, (kg/m³)</td>
<td>1 100 - 1 400</td>
<td>1 200 - 1 500</td>
</tr>
<tr>
<td>Young’s modulus, (GPa)</td>
<td>3 - 6</td>
<td>2 - 4.5</td>
</tr>
<tr>
<td>Tensile Strength, (MPa)</td>
<td>35 - 100</td>
<td>40 - 90</td>
</tr>
<tr>
<td>Compressive Strength, (MPa)</td>
<td>100 - 200</td>
<td>90 - 250</td>
</tr>
<tr>
<td>Elongation to break, tension, (%)</td>
<td>1 - 6</td>
<td>2</td>
</tr>
<tr>
<td>Coefficient of thermal expansion, (10⁻⁶/°C)</td>
<td>60</td>
<td>100 - 200</td>
</tr>
<tr>
<td>Shrinkage on curing (%)</td>
<td>1 - 2</td>
<td>4 - 8</td>
</tr>
<tr>
<td>Water absorption 24h to 20 h to 20 °C</td>
<td>0.08 - 0.15</td>
<td>0.10 - 0.30</td>
</tr>
</tbody>
</table>
**FRP Composites to Retrofit Concrete Structures**

**Benefits with FRP**

- High tensile strength and stiffness ratio
- Superb durability/stiffness properties
- Chemical resistant
- Thin strengthening layers
- Short time for application on site
- Easy to handle and transport
- Possibility with prestressing
- Design
- Project costs

**Challenges with FRP**

- Temperature and moisture
- Fire
- Long-time properties
- Material cost
Properties of FRP in comparison with steel

- Linear elastic behaviour to failure
- No yielding
- Higher ultimate strength
- Lower strain at failure
- Comparable modulus (or higher, carbon)
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Guidelines

Guidelines are essential for proper design

In Europe a few guidelines exist e.g. in Switzerland, Germany, The UK, Sweden

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Laboratory tests

Prestressing

![Graph showing load vs. midpoint deflection with three curves: Strengthened prestress, Strengthened, and Reference. The curves indicate early cracking and yielding.](image)
External Prestressing

[Image of prestressing in a concrete structure]

External Prestressing

[Image of prestressing in a concrete structure]
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Laboratory tests Mineral Based Strengthening

Stirrups at supports \( \phi 10 \)

Stirrups in one shear span. \( \phi 12 \times 100 \)

Reinforced Area

Speckle Analysis

Laboratory tests Mineral Based Strengthening

Epoxy Bonded

MBC Strengthened
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Field Applications

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Strengthening of slabs
Strengthening of slabs

NSMR to strengthen the slab from above

Strengthening of a concrete beam - outside
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Strengthening of a concrete beam - inside

Object data
- Parking garage
- 88 no. of columns

Reason for strengthening
- Increased loading
- Chlorides
- Steel corrosion

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Strengthening of columns
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Strengthening of columns
Mounting of sheets and NSMR rod

After strengthening the columns are painted with a diffusion open paint.
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Pre-treatment

Making of an opening

Strengthening
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**Strengthening of Bridges - NSMR**

![Image of workers applying FRP composites to a bridge]

**NSMR Parking garage**

![Image of the NSMR parking garage]

![Image of another angle of the NSMR parking garage]

![Image of a close-up of the NSMR parking garage]

![Image of another angle of the NSMR parking garage]
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NSMR Parking garage

Sawing of grooves in the underside of the beams
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Strengthening of Silos

Extensive Cracking
Wrong design
Strengthening of Silos

Mounting of CFRP Sheets

One silo is strengthened on the outside and one on the inside.
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Strengthening of Silos

Final result

Strengthening of Road Bridges
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Strengthening for shear
Parking Garage

Guidelines
The work with the guideline started 1998 in relation to a strengthening work of a rail road bridge

It was felt from the Rail Road authorities that a guideline was needed if the techniques should be accepted to be used on railroad and the like

Today the guideline is used both by the Swedish National Road Authorities and the Rail Road Authorities.
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Guidelines

The most essential in the codes considered to be:

- Strengthening for bending
- Strengthening for shear
- Safety factors
  \[ f_d = \frac{f_k}{\eta \gamma_n \gamma_s} \]

But shear, fatigue, torsion and confinement are also considered.

Execution and quality control

Two large bridges in Stockholm

Strengthening with CFRP and Steel Stays

Monitoring with Fibre Optic Sensors
The bridge type

- 1999, Open for traffic
- 2001, April: Cracks found at inspection
- 2001, Number and size of cracks increases
- 2001, November: Closed for traffic, temporary strengthening
- 2002, Mars: Open again for traffic
- Permanent strengthening and monitoring
Application of adhesive

Mounting of plates
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The Gröndals Bridge

CFRP Laminates in the service limit state. Bonded to the bridge on the inside of the box girder.

Final Result
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Media coverage

Conclusions

• External strengthening with CFRP materials has a wide range of applications.

• Laboratory and full-scale tests have shown that the strengthening methods work in reality.

• Strengthening can be carried out during structural use.

• The methods are cost effective compared to traditional methods.