Strengthening of Existing Buildings to Resist Earthquakes

Eng. Ghassan G. Hachem (ESIB-CHEBAP)
What is FRP Technology?

- FRP = Fiber Reinforced Polymers
- High-Strength, Light-Weight system for the external reinforcement of concrete, steel and wood
- Aerospace technology adapted for structural engineering
- Low profile, when installed typically 6mm thick
- Cost effective solution for structural strengthening and protection against environmental actions
In most countries of the world, the building stock is ageing and needs continuous maintenance or repair. The majority of existing constructions are deficient in the light of current knowledge and design codes. Structural deficiency of existing constructions is especially acute in seismic regions. The direct and indirect costs of demolition and reconstruction of structurally deficient constructions are relatively high and often prohibitive. FRP’s are cleaner and easier to apply than conventional retrofitting techniques. There’s reduction in disruption to the occupancy and operation of the facility. FRP do not generate debris or waste, and reduce health and accident hazards at the construction site as well as noise and air pollution in the surroundings. Externally bonded Fiber Reinforced Polymers (FRPs) are rapidly becoming the technique of choice for structural retrofitting.
APPLICATIONS

- Change of use (increase of Dead Load or Live Load) : زيادة أحمال
- Seismic upgrade : تدعيم للزلازل
- General structural upgrade : تدعيم أبنية
- Low in-situ concrete compressive strength vis-à-vis design strength requirement : ضعف البeton
- Inadequate or erroneous steel reinforcement placement in reinforced concrete members : أخطاء هندسية
- Temporary construction loading with heavy equipment on elements not designed to cater to such loads.
TYPES OF COMPOSITES - CARBON

➢ CFRP (Carbon)

- Tyfo® SCH Composite
  Uni-directional carbon fabric

- Tyfo® BCC Composite
  ±45° Bi-directional carbon fabric

- Tyfo® UC Composite Laminate Strips
  Pre-impregnated carbon plates
**TYPES OF COMPOSITES – GLASS / ARAMID**

- **GFRP (Glass)**
  - Tyfo® SEH Composite
    - Uni-directional glass fabric
  - Tyfo® WEB Composite
    - 0°/90° Bi-directional glass fabric
  - Tyfo® BC Composite
    - ±45° Bi-directional glass fabric

- **AFRP (Aramid)**
  - Tyfo® WAB Composite
    - 0°/90° Bi-directional aramid fabric

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International FRP design guidelines and codes

- International Code Council material and design guidelines - ICC AC125.
- The American Concrete Institute Committee Report - ACI440.
- The United Kingdom Concrete Society Technical Report - TR55.
- The International Federation for Structural Concrete - fib bulletin14.
APPLICATIONS in BUILDINGS (UPGRADING OF COLUMNS)

- **COLUMNS**
  - Axial Enhancement
  - Flexural Upgrading
  - Shear Upgrading

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APPLICATIONS in BUILDINGS (UPGRADING OF COLUMNS)

Seismic Upgrade by improving ductility of RC Columns

Stress, $f_c$

- Confined Concrete
- Unconfined Concrete

Strain, $\varepsilon_c$

- $\varepsilon_0$
- $\varepsilon_{cc}$
APPLICATIONS in BUILDINGS (UPGRADING OF COLUMNS)
APPLICATIONS in BUILDINGS (UPGRADING OF COLUMNS)

High-ratio rectangular wall-like columns

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APPLICATIONS in BUILDINGS (SHEAR UPGRADING)

BEAMS / SLABS

Poor Concrete Quality

Flexural Upgrading

Shear Upgrading

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APPLICATIONS in BUILDINGS (SHEAR UPGRADING)

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APPLICATIONS in BUILDINGS (FLEXURAL UPGRADING)
APPLICATIONS in BUILDINGS ( FLEXURAL UPGRADING )

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The church was constructed in 1907.

Cracks were found in the main beams due to differential settlement of the structure.
APPLICATIONS in Masonry Walls

Cracks were taken by fabrics

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APPLICATION PROCEDURE

STEP 1: SURFACE PREPARATION

STEP 2: FABRICS PREPARATION

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STEP 1: SURFACE PREPARATION  ➔  STEP 2: FABRICS PREPARATION
APPLICATION PROCEDURE

STEP 3: SURFACE IMPREGNATION

STEP 4: FABRICS APPLICATION
APPLICATION PROCEDURE

GALVANIC CORROSION!

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QUALITY CONTROL

ASTM D3039

Pull-off bond testing
Projects Briefs: Columns Upgrading for Seismic Loads

Upgrading of 12Nb Storeys Building using Push Over Analysis

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PROJECTS BRIEFS: Cimenterie Nationale Chekka – Shear Upgrading

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Circular Opening upgraded with Carbon Fabrics SCH-7UP
Project Description

Upgrading and retrofitting of a solid slab (30cm thick PT) in addition to a Post Tensioned beam (PT beam) that showed signs of distress (vertical cracks and inclined cracks).

The original design was based on 30MPa concrete strength, actual strength was 17MPa.
PROJECTS BRIEFS: PT SLAB AND BEAM

Cracks Inclined at 45° due to Shear forces

Vertical Cracks due to Bending Moment

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PROJECTS BRIEFS: PT SLAB AND BEAM

DIAGRAM USED FOR SLAB RETRO FITTING

Bottom Stress

Positive for Tension Stress
Negative for Compression Stress
Clouded zones are where stresses exceed allowable values

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Worldwide Specialized Contractors

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Application of Fabrics for Bending Moment
Application of Fabrics for Shear Loads
PROJECTS BRIEFS : PT SLAB AND BEAM

Load Test in Progress

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Loads Test Completed

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# Reading a Data Sheet

## Typical Fabric Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Test Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>550,000 psi (3.79 GPa)</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>$33.4 \times 10^6$ psi (230 GPa)</td>
</tr>
<tr>
<td>Ultimate Elongation</td>
<td>1.7%</td>
</tr>
<tr>
<td>Density</td>
<td>0.063 lbs./ft.$^2$ (1.74 g/cm$^2$)</td>
</tr>
<tr>
<td>Weight per sq. yd.</td>
<td>19 oz. (644 g/m$^2$)</td>
</tr>
</tbody>
</table>

## Composite Gross Laminate Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Method</th>
<th>Typical Test Value</th>
<th>Design Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>D-3039</td>
<td>143,000 psi (986 MPa)</td>
<td>121,000 psi (834 MPa)</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>D-3039</td>
<td>1.9%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>D-3039</td>
<td>$13.9 \times 10^6$ psi (95.8 GPa)</td>
<td>$11.9 \times 10^6$ psi (82 GPa)</td>
</tr>
<tr>
<td>Laminate Thickness</td>
<td></td>
<td>0.04 in. (1.0mm)</td>
<td>0.04 in. (1.0mm)</td>
</tr>
</tbody>
</table>

Note: Tension properties are tested in primary fiber direction.

* Gross laminate design properties based on ACI 440 suggested guidelines will vary slightly. Contact Fyfe Company engineers to confirm project specification values and design methodology.

## Elevated Temperature Performance Characteristics

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Method</th>
<th>Typical Test Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Transition Temp. ($T_g$)</td>
<td>E-1366</td>
<td>214°F (101°C)</td>
</tr>
<tr>
<td>Critical Temp. ($T_c$)**</td>
<td></td>
<td>500°F (260°C)</td>
</tr>
</tbody>
</table>

** Critical temperature is defined as the temperature at which the composite loses 50% of its design values.
Tyfo® Fibr™ Anchors

- Tyfo® SEH Fibr™ Anchors
  
  Uni-directional glass roving for improved end details & force transfer

- Tyfo® SCH Fibr™ Anchors
  
  Uni-directional carbon roving for improved end details & force transfer
Anchors in Foundation

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Anchoring Procedure
2 layers TYFO SCH-41-2X, TYFO SCH Composite Anchors
Concrete strength ≈ 20 MPa
Specimen:

12 mm
8 mm
800 mm
150 mm
Specimen preparation

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Specimen preparation

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Resultats : النتائج

![Graphs showing stress-strain relationship for various materials.](image-url)
Resultats: 

- Rebar buckling
- Light anchors ruptured
- Heavy anchors did not fail

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• The new Tyfo® EP-B Basalt and Tyfo® EP-C Carbon systems consist of open weaved fabrics. The fabric is covered with a high temperature resistant special coating for joints stability

• The matrix environment is mortar, either Tyfo® C-Matrix (1-component dry cement with polymers), or Tyfo® C-Matrix Type F (w/o polymers) – fire resistant mortar

• Cement free natural hydraulic lime mortar Tyfo® NHL-Matrix or local lime mortars can also be used to meet the restoration requirements.

• Tyfo® Fiber Anchors can be also installed for improved bonding
• Masonry is a weak material as compared to RC and steel.

• Historical masonry, on the other hand, has its own difficulties regarding the reversibility and compatibility.

• Existing FRP solutions with epoxy bonding are not compatible with Historic Masonry structures.

- Compatibility
- Reversibility
- Fire Resistance
- Environmental friendly
- Texture and colors consistency
Structural elements Testing

← Static studies

Cyclic studies →
Tyfo® RM System Design Guidelines

Out-of-plane

In-plane Flexure & Shear

(a)  (b)
Application procedure:

التطبيقات:
Thank You

شكرًا للحضور

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ESIB-CHEBAP

MAY-2020

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