Site Director: Dr. Antonio Nanni
Associate Director: Dr. Antonio De Luca
Date: February 1st, 2011
Status of the Site
List of Projects at Site

- **Project 01**: Durability Study of RC Seawalls Constructed with GFRP I-Bars and SIP Panels
- **Project 02**: Guide for Design and Use of Flexible Carbon Grid Reinforcement for the Repair and the Strengthening of Reinforced Concrete Slabs and of Masonry Walls
- **Project 03**: Large-Diameter Composite Hollow Rebars
List of Projects at Site

- **Project 04**: External Confinement of RC Columns by means of GFRP laminates
- **Project 05**: ICE Methodology for FRP Characterization
- **Project 06**: Safety Analysis of Composite Materials for Existing and New Construction
GFRP RC seawalls represent an economically competitive alternative to conventional solutions, such as steel RC or timber seawalls, because of its resistance to corrosion, high strength to weight ratio and excellent fatigue performance.

This research intends to investigate the long-term performance of concrete seawalls using structural SIP panels. The project tasks include design of a prototype, construction, accelerated ageing and deployment at a waterfront site, and laboratory testing.
Overview

The main problem for existing RC seawall is the concrete cover spalling due to the corrosion of the internal steel reinforcement, mainly visible at the head of the foundation piles.

Old Cutler by Mathesan Hammark Park, Miami (FL)
The main problem for existing RC seawall is the concrete cover spalling due to the corrosion of the internal steel reinforcement, mainly visible at the head of the foundation piles.
A combination of concrete and internal GFRP reinforcement represents a solution with high potential (no steel reinforcement corrosion) particularly when construction costs and completion time could be simultaneously reduced by introducing integrated GFRP structural reinforcement and stay-in-place (SIP) formwork.
Objectives

- Investigate the longevity of concrete seawalls reinforced with GFRP SIP panels
- Provide the scientific community and practitioners with experimental data on the long term performance of GFRP SIP panels when exposed to harsh environment
- Provide the engineering community with new design tools to build long-lasting RC seawalls
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57 total samples are aged in the experiment. 36 samples are subjected to accelerated aging. They are separated into groups of three and aged for 3 months, 6 months, 9 months, and 12 months at room temperature, 104° F, and 140° F. In addition, 18 GFRP-RC beams are aged in a natural marine environment for 6 months, 12 months, two years, three years, four years, and five years.
Expected outcomes

The graph shows the expected outcomes of natural and accelerated aging processes. The x-axis represents time in hours, ranging from $10^2$ to $10^6$. The y-axis represents $\log \frac{M_{\text{aged}}}{M_{\text{bench}}}$.

Key points:
- Natural ageing at waterfront site
- Accelerated ageing at room temperature
- Accelerated ageing at $T=104^\circ F$
- Accelerated ageing at $T=140^\circ F$

Time milestones are indicated:
- 3 months
- 6 months
- 9 months
- 12 months

The graph illustrates how the ratio of aged to bench material changes over time for different conditions.
Specimen preparation

60 inches

5-½ inches

96 inches
Specimen preparation

- 3/8-inch max size coarse aggregate
- 5-inch slump
- 3.3% air content
- 140-pcf density
This document offers general information on the use of a specific product, named C-GRID and developed by Chomarat North America, for the repair and strengthening of reinforced concrete (RC) slabs and unreinforced masonry (URM) walls.
The document aims at providing a design guide with solved examples to assist designers and practitioners.
Large-Diameter Composite Hollow Rebars
Project Number: 03

Overview: The hollow core eliminates the inefficient solid core and, potentially, enables the rebar to carry data or electrical wiring, radiant heating, or sensors to make smart structures. Large-diameter, hollow composite rebar can provide distinct advantages for concrete construction application.

Experimental Plan: Hollow rebar specimens will be subjected to tensile tests. The experimental results will be used to validate an FE model.

Objectives: This project aims at investigating the mechanical behavior of hollow-core CFRP rebars.
External Confinement of RC Columns by means of GFRP laminates
Project Number: 04


Specimens were intended to represent real size building columns designed according to a dated ACI 318 code (i.e., prior to 1970) for gravity loads only.
Research outcomes

![Graph showing normalized axial stress vs. axial deformation for specimens S-1-5GA, S-1-2GB, S-1-control, and S-1-8H. The graph includes a scale for axial deformation in inches and a normalized stress axis.]

- S-1-5GA
- S-1-2GB
- S-1-control
- S-1-8H

24 in.
Research outcomes

Circular vs. prismatic cross-sections
Change in volume of a representative one-quarter unit element.

peak load

failure
Research outcomes

square

rectangular

Axial strain

Volumetric strain

S-1-control

S-1-2GB

S-1-8H

R-0.5-control

R-0.5-GB

R-0.5-8H

(1-2ν)

(1-2ν)
In prismatic columns, the FRP confinement effectiveness is more significant in terms of enhancement of concrete axial deformation rather than increment in axial strength.

The presence of the FRP jacket allows a “growth” in volume of the concrete core by offsetting buckling of the longitudinal bars and by delaying unstable crack propagation.

The shape of the cross-section influences the effectiveness of the confinement.

The maximum stress reached by concrete in columns is only about 85% of the cylinder strength, therefore, theoretical models should use $0.85 \cdot f'_{c}$, not just $f'_{c}$. 
Future work

Full scale
Future work

Full scale

Small scale
Future work

Full scale

Small scale

1:5
Future work

- Size effect
- More experimental evidence
ICE Methodology for FRP Characterization

Project Number: 05

- Current ultimate strain of FRP flat coupons based on direct tensile tests ($\varepsilon_{fu}$) do not correspond to experimental results of FRP jackets in the hoop direction ($\varepsilon_{\theta u}$).

- Develop a new test methodology to determine the ultimate circumferential properties of FRPs.

- Use the natural expansion of ice to apply an internal hydrostatic pressure to FRP cylindrical jackets for characterization.

**Direct tensile testing:**

$\varepsilon_{fu}$

**VS**

**“Hoop” tensile testing:**

$\varepsilon_{\theta u}$
Novelty originates from the lack of moving parts or complex fixtures to transfer load to the specimen, while applying a hydrostatic load...

...using the property of water that expands when it changes state of matter from liquid to solid, resulting on an applied load to test specimens.
Objectives

1. To develop an efficient and reliable experimental technique to measure the ultimate circumferential (hoop) strain of FRP laminates, including specimens with different jacket diameters and laminate thicknesses.

2. To determine the effect of cylindrical FRP shell curvature and laminate thickness on the strain efficiency.
Experimental matrix

2 PARAMETERS

LAMINATE THICKNESS

SHELL DIAMETER

1-PLY

2-PLY

3-PLY

115 mm

171 mm

60 mm

32
Specimen preparation
Experimental results

- **Behavior:**
  - Linear elastic to failure, constant gradient.
  - Increasing ultimate strain with increased diameter.
Experimental results

- Sudden brittle failure with rupture of the GFRP, in the middle third of the specimen height.
- With increasing reinforcement ratio, the failure occurred through the entire cross-section.
- Rupture zipped through the cross-section and migrated longitudinally in both directions.
GFRP cylinders followed a linear elastic behavior till failure, where specimens failed in the middle third section in pure tension.

The loading mode was successfully confirmed to be hydrostatic with video footage, as water busted out through the GFRP jacket at the instant of failure.

Ultimate circumferential strain values increased with increasing diameter, while being consistently lower when compared to similar GFRP flat coupon specimens under the same environmental conditions.
This project aims at calibration of the safety factors of ACI 440 Code, particularly those pertinent to columns, by the process of reliability analysis. Furthermore this is an attempt to incorporate the expected life-time of a structure into design by introducing a methodology that relates life-time to safety factors. The latter goal is, of course, applicable to both existing (ACI 440.2) and new construction (ACI 318 and 440.1).

The structural types considered in this study include columns subject to pure axial load or shear and beams subject to shear.
Knowing the suddenness of the failure of an FRP reinforced member they should be designed to be safer than steel reinforced members, but how much safer are they in reality?

Most rehabilitated structures have a shorter expected life-time than new structures, can we relax the safety rules for them?

Reliability Analysis is the methodology to address such questions...
Reliability Index, $\beta$, is a function of:

1. Safety factors
2. Load factors
3. Statistical parameters of resistance
4. Statistical parameters of loads
5. And is related to probability of failure
Overview

Development of safety factors:

- Safety factors
- Load and Resistance factors
- Time dependent factors
How life-time can play a role in design:

Live load statistical distribution is Type I Extreme Value Distribution (EVD)

<table>
<thead>
<tr>
<th>Life time (years)</th>
<th>Maximum/Nominal</th>
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</thead>
<tbody>
<tr>
<td>25</td>
<td>0.86</td>
</tr>
<tr>
<td>50</td>
<td>1.0</td>
</tr>
<tr>
<td>100</td>
<td>1.13</td>
</tr>
</tbody>
</table>
Preliminary results

Incorporating Expected Life Time Into Design Procedure

Live Load Factor vs. Life-Time (years)
Scope of work

Calibration Procedure:

1. Focus is on columns under axial or shear force.
2. Statistical model of resistance is selected.
3. Statistical model of load is selected, live load is modeled as a time dependent random variable.
4 The model is analyzed: Analytically or numerically.

5 Reliability is then compared to the target reliability.

6 The safety and load factors are then modified if needed so that the desirable reliability is achieved.
Thank U