NUMERICAL MODELING OF REINFORCED CONCRETE COLUMNS
STRENGTHENED WITH COMPOSITE MATERIALS

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Presented by:
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SUMMARY

- Abstract.
- Geometry of the column.
- Materials properties.
- Experimental tests.
- Numerical modeling using ATENA software 2D.
- Results.
- Conclusion.
1. ABSTRACT

NUMERICAL MODELS

BEHAVIOR UNDER CYCLIC LOADING

STRENGTHENING MATERIALS USED

- Experimental RC columns strengthened with composite materials
- Modeled RC columns strengthened with composite materials

- Glass Fiber Reinforced Polymers (GFRP)
- BARS METALLIC (BM)
2. GEOMETRY OF THE COLUMN

Square cross section

- Area of the column: 25x25 cm²
- Height of the column: 150 cm
- Diameters of the steel bars: 8, 10, 12 and 16 mm
2. GEOMETRY OF THE COLUMN

Figure 2.1 : Plan of reinforcement elements [1].

Figure 2.2 : Bars deformed [1].

Bars deformed before test
### 3. MATERIALS PROPERTIES

**CONCRETE C16/20**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength [MPa]</td>
<td>$f_{ck,cube} = 27.5$ MPa</td>
</tr>
<tr>
<td>Elastic modulus [MPa]</td>
<td>$Ec = 34500$ MPa</td>
</tr>
<tr>
<td>Tensile strength [MPa]</td>
<td>$Ft = 2.187$ MPa</td>
</tr>
</tbody>
</table>
3. MATERIALS PROPERTIES

Steel bars Ø8, Ø10, Ø12, Ø16

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength [MPa]</td>
<td>ft = 560 MPa</td>
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<tr>
<td>Elastic modulus [MPa]</td>
<td>Es = 200000 MPa</td>
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<tr>
<td>Density [Kg/m³]</td>
<td>P = 7850 Kg/m³</td>
</tr>
</tbody>
</table>
### 3. MATERIALS PROPERTIES

#### Glass Fiber Reinforced Polymers (GFRP)

<table>
<thead>
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<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>$f_t = 2250$ MPa</td>
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<tr>
<td>Elastic modulus</td>
<td>$E = 70000$ MPa</td>
</tr>
<tr>
<td>Density</td>
<td>$P = 2530$ Kg/m³</td>
</tr>
<tr>
<td>Thickness</td>
<td>$\varnothing = 0.17$ mm</td>
</tr>
</tbody>
</table>
13 attempts was performed under cyclic loading [1]

For this article we study 02 attempts under cyclic loading BM - GW

Hydraulic pump

Figure 4.1: Elements of the test bench [1].
4. EXPERIMENTAL TESTS

Determination of the limit of elastic behavior 25 kN – 24 mm

Figure 4.2 : Reference model C1C [1].

Compression test on concrete

Tensile test on steel bars
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.1. Definition of the materials

- **Material type in ATENA**
  - **Material**
    - SBeta Material • Concrete
    - Cycling Reinforcement • Steel bars
    - Reinforcement • GFRP
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.2. Definition of the geometry

- Joints
- Lines
- Macro-elements
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.3. Definition of loading and support

- Imposed force
- Imposed displacement
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.3. Definition of loading and support

Support
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.4. Application of loading and support

- Selection of the load case of support
- Application of the support
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.4. Application of loading and support

- Selection of the load case of loading
- Application of the imposed forces (1 kN)
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.4. Application of loading and support

Application of the imposed displacement (1 mm)
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5.5. Monitoring points

- Control of displacement (D1)
- Control of force
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.6. Column strengthened with BM

Plan of the column C3C-BM-AF

Detail of strengthening
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.7. Column strengthened with GFRP

Plan of the column C6C1-GW-BC

Detail of strengthening
5. NUMERICAL MODELING USING ATENA SOFTWARE 2D

5.8. Models used for materials

- **Concrete**
  - Non linear model for concrete.
  - Strain softening in compression: softening law defined by means of the softening modulus.
  - Strain softening in tension: Exponential crack opening law (Bazant 1983) [6].
  - Rotated crack model for cracks.

- **Steel bars**
  - Perfect elastoplastic model.

- **GFRP**
  - Bilinear model.
6. RESULTS

6.1. C3C-BM-AF

Figure 6.1: Curve of comparison between the numerical and experimental test for the column C3C-BM-AF.
6. RESULTS

6.1. C3C-BM-AF

Maximum load

Experimental : 38.15 kN  
Numerical : 49.24 kN

Maximum displacement

Experimental : 55.00 mm  
Numerical : 54.04 mm

Figure 6.2 : Observed failure mechanism in experimental.

Figure 6.3 : Observed failure mechanism in numerical.
6. RESULTS

6.2. C6C1-GW-BC

Figure 6.4: Curve of comparison between the numerical and experimental test for the column C6C1-GW-BC.
6. RESULTS

6.2. C6C1-GW-BC

Maximum load

- Experimental: 32.83 kN
- Numerical: 28.01 kN

Maximum displacement

- Experimental: 78.34 mm
- Numerical: 77.82 mm

Figure 6.5: Observed failure mechanism in experimental.

Figure 6.6: Observed failure mechanism in numerical.
Both numerical models for the columns strengthened with BM and GFRP show a behavior similar to the experimentally tested ones.

- **For C3C-BM-AF**: the numerical model is slightly more rigid compared to the experimental one. This can be partially due to the difference of the concrete constitutive model in the ATENA modeling and in the experimental test.

- **For C6C1-GW-BC**: The numerical behavior of the column is similar to the behavior of the experimental tested one.

This gives confidence to the design engineers and researchers in using finite element modeling for evaluating the cyclic behavior of RC columns strengthened with different types of composite materials.

To describe the real behavior of concrete elements strengthened with composite materials it is necessary to take into account all the parameters which can influence their behavior (thermal conditions, initial state of concrete, contact surfaces, boundary conditions . . . etc). This point is a subject for a future work.
Bibliography


THANK YOU FOR YOUR ATTENTION