Lateral pre-tensioning of RC columns with FRP jackets

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| • Pre-tensioning method description |
| • Experimental program    |
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Why Pre-tensioning?

• Better utilisation of confinement materials (FRP)

What are the results of better utilisation of FRP?

• Enhancement in column load capacity
• Increase of service load capacity
• Enhancement of ductility
• Improvement of concrete stress-strain characteristics
For pre-tensioning:

- An Expansive Agent (EA) is employed

Application of pre-tensioning?

- By casting the EG into the gap

How to control pre-tensioning stress?

- Stiffness of jacket material \( \frac{E_{j_t}}{r_j} \)
- Ratio of EA in Expansive Grout (EG)
- Volume of EG
Effect of Confinement Stiffness

Confinement stiffness (MPa) vs. MEP (MPa)

- 20% EA
- 10% EA

Lateral microstrain vs. Time (hour)

- Cop.
- An.L
- Bl.S

- 20% EA
Prediction of Expansion Strain

\[ \varepsilon_{\text{pre}} = \frac{0.0795}{k_{jn}} \left[ k_{jn}^{0.566} EA^{1.132} \right] \]
Prediction of Expansion Stress

\[ f_{lpren} = 0.0795 (k_{jn} (EA)^2)^{0.5659} \]
## Confinement Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus</th>
<th>Ultimate Stress</th>
<th>Ultimate Strain</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>$E_{su} = 200 \text{KN/mm}^2$</td>
<td>$F_{su} = 400 \text{N/mm}^2$</td>
<td>$\varepsilon_{sy} = 0.2%$</td>
<td>$\varepsilon_{su} = 2.25%$</td>
</tr>
<tr>
<td>GFRP</td>
<td>$E_{gu} = 64 \text{KN/mm}^2$</td>
<td>$F_{gu} = 1700 \text{N/mm}^2$</td>
<td>$\varepsilon_{gu} = 2.8%$</td>
<td>$t = 0.135 \text{mm}$</td>
</tr>
<tr>
<td>CFRP</td>
<td>$E_{cu} = 240\text{KN/mm}^2$</td>
<td>$f_{cu} = 3900 \text{N/mm}^2$</td>
<td>$\varepsilon_{cu} = 1.55%$</td>
<td>$t = 0.117 \text{mm}$</td>
</tr>
</tbody>
</table>

- 18 specimens
- 25 specimens
- 25 specimens
- 68 specimens
Steel Confinement

Non-pre-tensioned
(Cast in Concrete)

- t = 1 mm
  - CS0101
  - CS0102
- t = 1.5 mm
  - CS0201
  - CS0202
- t = 2.0 mm
  - CS0301
  - CS0302

Pre-tensioned
(Laterally pressure applied)

- t = 1.0 mm
  - 10% Beto.
    - PS71101
    - PS71102
  - 20% Beto.
    - PS71101
    - PS71102
  - 20% Beto.
    - PS72201
    - PS72202
  - 30% Beto.
    - PS72301
    - PS72302
- t = 1.5 mm
  - 20% Beto.
    - PS73201
    - PS73202
  - 30% Beto.
    - PS73301
    - PS73302
- t = 2.0 mm
  - 20% Beto.
    - PS73201
    - PS73202
  - 30% Beto.
    - PS73301
    - PS73302
GFRP Confinement

Glass

Non-pre-tensioned
(Cast in concrete/wrapping)

- Two layers
  - Cast in
    - CG0201
    - CG0102
  - Wrapping
    - CG0301
    - CG0302

- Three layers
  - Cast in
    - CG0401
    - CG0402
    - CG040ex
  - Wrapping
    - PG72101
    - PG72102

- Four layers
  - Cast in
    - PG73201
    - PG73202
  - Wrapping
    - PG74201
    - PG74202

Pre-stressed
(Laterally pressure applied)

- Two layers
  - 10% Beto.
    - CG0201
    - CG0102
  - 20% Beto.
    - CG0301
    - CG0302

- Three layers
  - 20% Beto.
    - CG0401
    - CG0402
    - CG040ex
  - 20% Beto.
    - PG72101
    - PG72102

- Four layers
  - 30% Beto.
    - CG040ex
  - 20% Beto.
    - PG73201
    - PG73202
  - 30% Beto.
    - PG74201
    - PG74202

Wrap

- Two layers
  - Cast in
    - CG0201
    - CG0102
  - Wrapping
    - CG0301
    - CG0302

- Three layers
  - Cast in
    - CG0401
    - CG0402
    - CG040ex
  - Wrapping
    - PG72101
    - PG72102

- Four layers
  - Cast in
    - PG73201
    - PG73202
  - Wrapping
    - PG74201
    - PG74202

Beto.
CFRP Confinement

Carbon

Non-pre-tensioned (Cast in concrete/wrapping)
- One layer
  - Cast in
    - CC0101
    - CC0102
  - Wrap ping
    - CC0201
    - CC0202
- Two layers
  - Cast in
    - CC0301
    - CC0302
  - Wrap ping
    - PC71101
    - PC71102
- Three layers
  - Cast in
    - WC0101
    - WC0102
  - Wrap ping
    - WC0201
    - WC0202
  - 10% Beto.
    - PC71201
    - PC71202
    - PC72201
    - PC72202
  - 20% Beto.
    - PC71301
    - PC71302
    - PC72301
    - PC72302
    - PC73401
    - PC73402
    - PC7330ex

Pre-tensioned (Laterally pressure applied)
- One layer
  - Cast in
    - CC0201
    - CC0202
  - WRAP ping
    - PC7201
    - PC7202
  - 10% Beto.
    - PC71101
    - PC71102
  - 20% Beto.
    - PC72201
    - PC72202
  - 30% Beto.
    - PC73201
    - PC73202
  - 20% Beto.
    - PC7330ex
  - 40% Beto.
DV2 measures the longitudinal displacement over 73 mm (middle one-third) using three LVDT transducers
Instrumentation

DV1 integrates the strains over the perimeter of the cylinder.

For very low lateral strains it is not so accurate, but for large strains, it shows good agreement with strain-gauge results.
Failure mode
Experimental results

WC-1 Vs. PC1-20

![Diagram showing normalised axial stress vs. microstrain for WC-1 and PC1-20 samples. The graph compares lateral and axial stress responses.]
Experimental results

WC-2 Vs. PC2-20

Ave. microstrain vs. Load (kN)

Non-prestressed
Prestressed
Unconfined
Experimental results

WG-3 Vs. PG3-20

Load (kN)

Non-prestressed

Prestressed

unconfined

Ave. microstrain

-14000 -12000 -10000 -8000 -6000 -4000 -2000 0 2000 4000 6000
Experimental results

WG-4 Vs. PG4-30

![Graph showing Normalised axial stress vs Microstrain for PG4-30-lateral, PG4-30-axial, WG4-lateral, and WG4-axial. The graph includes points for ε_{cr} and ε_{cl}.]
Experimental results

WC-1 Vs. PC1-20- volumetric strain

Critical stress

Volumetric strain (V-V0)/V0

Normalised axial stress

-0.0025 0.0005 0.0035 0.0065 0.0095

PC1-20

WC1
Experimental results

WG-4 Vs. PG4-30 - volumetric strain

Critical stress

Volumetric strain (V-V0)/V0

Normalised axial stress

Experimental results

Critical stress
VLC Model Comparisons

Normalised ultimate axial strain

New equation

\( \varepsilon_{\text{ccl}} / \varepsilon_{\text{co}} - \text{Experiment} \)
VLC Model Comparisons

![Graph showing VLC model comparisons with different stress-strain curves for WC1 and PC120.](image-url)
VLC Model Comparisons

The diagram illustrates the comparison of VLC models with experimental data for two different materials, WG3 and PG320. The x-axis represents microstrain, while the y-axis represents normalised stress. The plots show the stress-strain behavior under different conditions, with the VLC models (solid lines) compared against the experimental data (dotted lines).

Key observations:
- The VLC model for WG3 (black line) is compared with the experimental data (green line).
- The VLC model for PG320 (blue line) is compared with the experimental data (red line).

The diagram highlights the accuracy of the VLC models in predicting the stress-strain behavior, with close alignment to the experimental results.
Conclusions

Pre-tensioned External Lateral Confinement

• increases the effectiveness of the composite confinement

• further increases concrete strength and ductility

• increases energy dissipation during cyclic loading