Ductility Improvement of High Strength Concrete Columns using Hybrid Confinement

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Outline

• Motivation
• Hybrid Confinement
• Experimental Test
• Practical Implementation
• Conclusions
Motivation

1) Retrofitting of old columns

- Diagonal cracking – shear failure
- Flexural ductility failure – insufficient confinement
Shape Memory Alloy (SMA) retrofit

Passive confinement (FRP, Steel jackets)
Active confinement (Shape Memory Alloy)

High temperature phase (Austenite)
Low temperature phase (Martensite)

Deformation
Heating

Concrete core
SMA spirals

1) loading in martensite
2) Unloading in martensite creates pre-strain
3) Heating to trigger shape memory effect

σ
ε
Prestrain in Martensite
Austenite (zero strain)
Martensite (prestrain)
Column Tests

As built column at 5% drift

SMA retrofit column at 14% drift

SMA/GFRP column at 14% drift
Motivation

2) Hybrid confinement of new high strength concrete (HSC) columns

High Strength Concrete
✔ High Strength
✔ High Stiffness
✖ Lower ultimate strain
✖ Lower lateral dilation
✖ Reinforcement congestion

Concrete Filled Fiber tube (CFFT)
✔ Avoids reinforcement congestion
✖ Passive confinement – thick FRP

CFFT + SMA (plastic hinge)
✔ Thickness of FRP shell reduced
Hybrid Confinement Technique

- a) Concrete core
- b) FRP confinement
- c) Hybrid confinement

Graphs showing:
- Concrete core: Strength = 46.2 ksi
- FRP confinement: Young's Modulus = 2620 ksi
- Hybrid confinement: Stress-strain properties
- SMA: Diameter = 0.072
  - Recovery Stress = 80 ksi
<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>Specimen Designation</th>
<th>Unconfined Concrete Strength (ksi)</th>
<th>Passive Component</th>
<th>Active Component</th>
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<tbody>
<tr>
<td></td>
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<td>Number of FRP layers</td>
<td>% volumetric ratio of FRP</td>
<td>Passive confinement (psi)</td>
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<td>Unconfined NSC</td>
<td>N-UC</td>
<td>5.22</td>
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<tr>
<td>Unconfined HSC</td>
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<td>FRP confined NSC</td>
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<td>H-C-11-SMA2</td>
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</table>

Caltrans recommended lateral confinement for FRP is 300 psi
Test Instrumentation

- Uniaxial cyclic compression testing
- Strain rate of 0.0025/min
- Strain increment in each cycle = 0.0075
- Lateral and axial strain monitored
Cyclic Axial Stress Strain
Unconfined NSC vs Unconfined HSC

- **NSC**
  - Limited vertical cracking at failure
  - Stress plateau before failure

- **HSC**
  - Explosive failure
  - No distinct stress plateau
FRP confinement – NSC vs HSC

- ✔ FRP introduces a stress plateau in HSC
- ✗ No significant improvement in ultimate strain in HSC
- ✗ Sudden failure of FRP without warning signs
FRP vs Hybrid Confinement

✔ SMA provides second line of defense
✔ FRP rupture provides clear visual warning
✔ SMA improves ultimate strain and residual stress
Lateral Strain at FRP rupture

- Efficiency of FRP confinement increases with number of layers
- Larger lateral strain at FRP rupture for hybrid confined cylinders

Prestressing of FRP jacket by SMA!
## Pushover Analysis of CFFT columns

<table>
<thead>
<tr>
<th>Column Designation</th>
<th>Material Stress Strain Behavior</th>
<th>Unconfined Concrete Strength (ksi)</th>
<th>CFFT Passive Confinement (psi)</th>
<th>SMA Active Confinement (psi)</th>
<th>Yield Strength (kips)</th>
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<tbody>
<tr>
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<td>200</td>
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</tbody>
</table>
Pushover Results

- Loss of lateral strength at failure is less than 20% for hybrid confined CFFTs

Drift capacity comparison
- H-CFFT-SMA-2 > H-CFFT-SMA-1 > N-CFFT-1
Conclusions

• FRP confinement is not an effective means of improving HSC ductility.

• Hybrid confinement results in significant improvement in ultimate strain and retains sufficient strength till failure.

• Rupture of FRP provides visual signs before actual failure.

• SMA prestresses the FRP jacket and delays its rupture.

• SMA spirals in the plastic hinge region of CFFT improve ultimate drift without significant loss in lateral strength.