Large-Scale Shake-Table Test on a Low-Damage Concrete Wall Building: Numerical Modeling and Analysis

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1. Test building introduction
2. Wall simulation method
3. Method selection
4. Wall simulation
5. Conclusion and discussion
1. Test building introduction

- 2 storeys (5.4m × 8.95m × 8m)
- **Post-tensioned wall system**
- Gravity load resisting frames/columns
- Wall-to-floor connection
- Beam-to-column connection
- Floor system
- Energy dissipation devices
2. Wall simulation method

- Modelling the test building in two direction
- Wall behaviour is important for test building
- Predict the in-plane behaviour of post-tensioned wall
2. Wall simulation method

Rocking mechanism at wall base is a main feature of post-tensioned wall
2. Wall simulation method

Lumped plasticity model

Wall panel: Elastic beam column element

Wall base and PT tendons: Lumped rotational spring

Lumped rotational spring:
- Linear elastic rotational spring
- Hysteretic rotational spring
2. Wall simulation method

Multi truss model

Wall panel: Elastic beam column element
Unbonded PT tendon: Truss element
Wall base: A bed of concrete truss element
Number: depends on convergence and accuracy
Material: confined or unconfined concrete
Height: \( \min\{2t, 2c\} \)
2. Wall simulation method

Fiber element model

Assumption: smeared the rocking mechanism at wall base along the height of wall panel

Wall panel: Fiber beam column element

Unbonded PT tendon: Truss element
2. Wall simulation method

Fiber hinge model

Wall panel: Elastic beam column element
Unbonded PT tendon: Truss element
Wall base: Fiber-hinge element
Height: 2.5t
2. Wall simulation method

Solid element model

Wall panel: Brick element
Unbonded PT tendon: Truss element
Foundation: Brick element
Wall base: Contact behavior
3. Method selection

Selection simulation method for of post-tensioned wall

• Simulate the in-plane behaviour of wall panel and PT tendons
• Capture the hysteretic response
• Capture the interface behaviour at wall base
• Time efficiency for both static and dynamic analysis

Multi truss model and fiber hinge model are chosen
3. Method selection

Perez experiment

<table>
<thead>
<tr>
<th>Test wall</th>
<th>Loading</th>
<th>$A_p$ (cm$^2$)</th>
<th>$f_{pt}/f_{pu}$</th>
<th>$f_{ct,p}$ (MPa)</th>
<th>Confinement Type</th>
<th>PT bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>TW1</td>
<td>Monotonic</td>
<td>48.4</td>
<td>0.553</td>
<td>8.20</td>
<td>Spirals</td>
<td>xx xox xx</td>
</tr>
<tr>
<td>TW2</td>
<td>Cyclic</td>
<td>48.4</td>
<td>0.553</td>
<td>8.20</td>
<td>Spirals</td>
<td>xx xox xx</td>
</tr>
<tr>
<td>TW3</td>
<td>Cyclic</td>
<td>48.4</td>
<td>0.553</td>
<td>8.20</td>
<td>Hoops</td>
<td>xx xox xx</td>
</tr>
<tr>
<td>TW4</td>
<td>Cyclic</td>
<td>48.4</td>
<td>0.277</td>
<td>4.07</td>
<td>Hoops</td>
<td>xx xox xx</td>
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<tr>
<td>TW5</td>
<td>Cyclic</td>
<td>24.2</td>
<td>0.553</td>
<td>4.07</td>
<td>Hoops</td>
<td>xo o xo ox</td>
</tr>
</tbody>
</table>

*$_x$ = bar and $o$ = empty duct

Specimen information
3. Method selection

Multi truss model validate with Specimen TW2 in Perez experiment

Multi truss model compared with test results
3. Method selection

Establish fiber hinge model for TW2

Comparison between two simulation method
## 4. Wall simulation

### Design information

<table>
<thead>
<tr>
<th>Walls</th>
<th>Case</th>
<th>Design drift (%)</th>
<th>Damping (%)</th>
<th>PT bars (mm)</th>
<th>Axial ratio (%)</th>
<th>$f_{pl}/f_{py}$ (%)</th>
<th>Wall damper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PT1</td>
<td>PT3</td>
<td>PT2</td>
<td></td>
</tr>
<tr>
<td>Long span</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>25</td>
<td>0</td>
<td>25</td>
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<tr>
<td></td>
<td>1a</td>
<td>1</td>
<td>11</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>2.95</td>
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<tr>
<td>Short span</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>32</td>
<td>0</td>
<td>32</td>
<td>6.42</td>
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<tr>
<td></td>
<td>1a</td>
<td>1</td>
<td>11</td>
<td>25</td>
<td>0</td>
<td>25</td>
<td>4.11</td>
</tr>
</tbody>
</table>

### Material properties

- **Concrete**
  - Unconfined: $(0.0060, 56)$, $(0.0020, 40)$, $(0.0074, 0)$
  - Confined: $(0.0060, 56)$, $(0.0020, 40)$, $(0.0074, 0)$

- **PT tendon**
  - $f_{pl}=1080$ MPa
  - $f_{pt}=1230$ MPa
  - $E_p=200$ GPa

- **Dampers**
  - $f_c=450$ MPa
  - $E_f=300$ MPa
  - $E_f=200$ GPa
4. Wall simulation

Model establishment

Section of PT walls on Girds A & C
Short span direction

Multi truss model

Fiber hinge model
4. Wall simulation

Hysteresis response (in short span direction)

Case 1a

Wall uplift (in short span direction)

Case 2
4. Wall simulation

Tendon response (in short span direction)

Case 1a

Damper response (in short span direction)

Case 2
5. Conclusion and discussion

Conclusion

Both multi truss model and fiber hinge model can predict the behavior of the unbonded post-tensioned wall.

For further dynamic analysis, fiber hinge model is more appropriate:

- Less time consuming
- Simulate the out-plane behavior of low damage wall
- Easier to establish model
- Avoid convergence problem

Discussion

The height of wall base region for both multi truss model and fiber hinge model.

Validate the simulation result with test results.
Thank you for listening! Questions are welcomed!