Rapid Construction of Bridges with Concrete Filled Tubes

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Overview of Presentation

- Introduction and overview of research
- Component tests and member behavior
- Column-to-foundation connection
  - Fully restrained connection
  - Design requirements
- Current Research
CFT is a Composite Solution

Advantages
- Reduced labor
- Large strength
- Large stiffness
- Inherent stability

Disadvantages
- Unknown deformation capacity
- Unverified design expressions
- No standard connections
  - Connections should be capable of transferring full strength of CFT

* A CFT is not a jacketed RC member

Laguna De Santa Rosa Column Re-designed using CFT
Objective

Develop design expressions such that CFT’s can be widely implemented in bridge construction.

Cap Beam Connection:
standard cap detail capable of achieving strength and ductility requirements

CFT Component:
expressions for stiffness and strength

Foundation Connection:
standard foundation detail capable of achieving strength and ductility requirements
Component Evaluation
Component Evaluation Summary

- 13 circular CFT tests conducted
- 122 circular CFT tests surveyed
- Strength and stiffness recommendations provided
Design Expressions

- Design expressions verified and developed using experimental survey
  - Geometric limits
  - Column buckling
    - Moment strength
    - Effective stiffness
- Expressions currently being considered by AASHTO T-14
Plastic Stress Distribution Method

- Method of choice for flexural strength calculation
- Equilibrium based approach

Assumptions

- Steel is at yield in tension and compression
- Concrete stress block at $0.95f'_c$
- External axial load is applied at centroid
Comparison with Test Data
Effective Stiffness of Circular CFT

\[ E_{I_{\text{eff,PROPOSED}}} = E_S I_S + C_3 E_C I_C \]

\[ C_3 = 0.15 + \frac{P}{P_0} + \frac{A_S}{A_S + A_C} < 0.9 \]

Experimental Stiffness Comparison of All Specimens

<table>
<thead>
<tr>
<th>Research Data Set</th>
<th>Mean</th>
<th>Min.</th>
<th>Max.</th>
<th>Std. Dev.</th>
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<tr>
<td>AISC</td>
<td>0.81</td>
<td>0.50</td>
<td>1.23</td>
<td>0.20</td>
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<tr>
<td>ACI</td>
<td>1.27</td>
<td>0.76</td>
<td>2.00</td>
<td>0.33</td>
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<tr>
<td>Combined AISC-ACI</td>
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<td>0.71</td>
<td>1.81</td>
<td>0.27</td>
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<td>Proposed Expression</td>
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<td>0.70</td>
<td>1.57</td>
<td>0.22</td>
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</tbody>
</table>

Measured-to-Predicted Average is 1.0
Foundation Connection Types

- Fully restrained moment connection
- Tube embedded in foundation concrete
- Annular ring used to transfer overturning forces
- Two connections evaluated
  - Monolithic connection
  - Isolated connection
Monolithic Connection

1. Temporarily support CFT
2. Build foundation cage
3. Cast CFT and foundation

- embedded tube
- concrete filled steel tube
- steel flange welded to base of the tube
- annular ring to transfer overturning
- reinforcing cage
- foundation concrete
- concrete fill
- steel tube
Connection Types

Isolated Connection

1. Built foundation cage
2. Insert corrugated metal pipe
3. Cast foundation
4. Install and grout tube
5. Cast column

- void created using corrugated pipe
- tube grouted into position with fiber reinforced grout
- annular ring to transfer overturning (not shown)
- fiber reinforced grout
- concrete fill
- steel tube
- reinforcing cage
- foundation concrete
Specimen Overview

- Varying shear reinforcing ratio
- Varying embedment depth, $t_e$
- Concrete filled tube column
- 72-in. (1.83-m) in loading direction
- 24-in. (610-mm)
- 76-in. (1.93-m)
- 68-in. (1.73-m)
- Transverse and longitudinal reinforcing
- $D = 20$-in. (508-mm)
- $t = 0.25$-in. (6.3-mm)
Study Parameters

- Type of connection: monolithic and isolated
- Type of tube: spiral welded and straight seam weld
- Tube strength
- Tube geometry (D/t ratio)
- Foundation boundary conditions
- Shear reinforcing ratio
- Axial load ratio
- Embedment depth
Test Configuration

- CFT-column
- Foundation
- Constant axial load applied via Baldwin test machine ($P = 10\% P_0$)
- Cyclic load applied via horizontal actuator
- Anchor rods
Experimental Summary

- Total of 19 tests conducted
- Embedment depth very important
  - Drifts of 7-10% for adequate embedment
- Failure mechanism is tearing
- Initial buckling does not reduce capacity
- Lower strength steel tubes achieved higher drifts
Observed Behavior with Inadequate Embedment (0.6D)

- bisecting cracks: 0.75% drift
- interface gap: 2.5% drift
- footing uplift: 4% drift
- final state: 8% drift
Observed Behavior with Adequate Embedment (0.9D)

- limited footing damage: 2.5% drift
- tube buckles: 4% drift
- initiation of tearing: 6% drift
- final state: 7.2% drift
Hysteretic Response

\[ \frac{M}{M_{P,SD}} = 1 \]

\[ \frac{M}{M_{P,CFT}} \]

- Drift (%)
Requirements for Fully Restrained Connection to a Cap Beam or Foundation

detailing of annular ring

embedment depth

foundation reinforcement

punching shear
Embedment Depth

- Required embedment to prevent cone pullout
- Expression derived using single strut model and experimental results
- Shear strength coefficient, $n$, of 6. ($f'_{cf}$ in psi)

$$L_e \geq \sqrt{\frac{D_o^2}{4}} + \frac{D t F_u}{6 \sqrt{f'_{cf}}} - \frac{D_o}{2} (\text{psi})$$
Current Research
Connection Alternatives

CFT Connection

Reinforced Concrete Connection

- longitudinal direction
- transverse direction
- cap
- Beam
- precast inverted-t
- CIP for integral connection
- annular ring
- grout
- corrugated pipe
- CFT column
- ring of grouted headed bars
- soffit
- bars welded to tube
Numerical Analysis

FE model in ABAQUS

- End nodes pinned, $\Delta_x = \Delta_z = 0$
- Axial load, $P$, applied under column
- Symmetry face, $\Delta_y = \theta_x = \theta_z$
- Contact interaction between precast girder and bearing pad
- Gap elements
- Embedded reinforcing
- Axial load, $P$, deformation applied, $\Delta_x$
Reinforced Concrete Connection

- Maximum reinforcing ratio, $\rho = 3\%$
- Reinforcing de-bonded in connection region
- Inelastic deformation isolated to connection reinforcing

$M = 0.10P_o$
CFT Connection

- Inelastic behavior concentrated in CFT
- No yielding in cap beam reinforcing
Welded Reinforcing Experiments

- Welded connection detail evaluated using pullout tests
- Primary variables
  - Weld strength
  - Effects of debonding
- Failure mode of all bars characterized by bar yield and fracture
Ongoing Research

- Large scale experiments
  - Range of Connections
  - Target Design Parameters
Final Points

- CFT design expressions validated using a large database (122 specimens). Specification language developed.
- CFT foundation connection expressions validated using experimental and analytical results.
- CFT cap beam connections analytically evaluated.
- Large scale cap beam tests planned to validate numerical results and develop design expressions.
Thank You