

Steel Pipe Pile/Concrete Pile Cap Bridge Support Systems: Confirmation of Connection Performance

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Background

Typical Bent Configuration and Advantages:

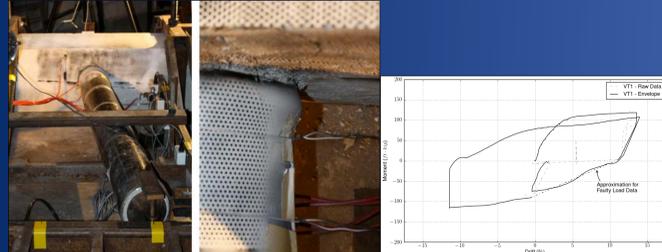
- Series of concrete-filled steel pipe piles embedded in a concrete pile cap
- Fast and efficient to construct
- With proper design, improves the ductile response and overall strength of the structure



Typical MDT Concrete-Filled Steel Pile and Concrete Pile Cap Bridge Substructure

Benefits of Concrete-Filled Steel Tube (CFT):

- Concrete inside steel tube has several advantages:
 - Increases flexural capacity and ductility, and delays buckling of the steel tube
 - Compression strength of column is increased
 - Plastic hinging of the CFT is a preferable failure (opposed to deterioration of the cap)
- Proper design of the connection between CFT and concrete cap is necessary for benefits



Example of test specimen VT1 with plastic hinge in CFT – Ductile Behavior with full hysteresis response

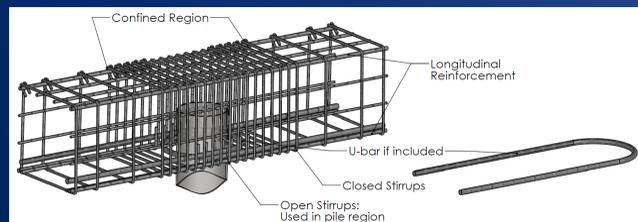


Example of test specimen VT2.5 with degraded concrete cap – Non-Ductile Behavior with pinched hysteresis response

Research Objective and Scope

Focus of Research:

- Establish/verify design methodologies
- Gain further insights on connection behavior under monotonic and cyclic loads
- Determine possible design improvements
- Develop and implement efficient steel reinforcement methods for connection design

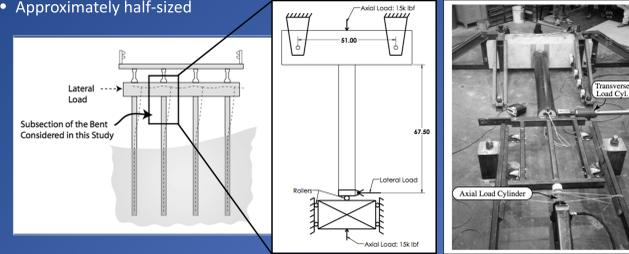


Example of improved connection reinforcement scheme with U-bars

Approach Methodology

Test Setup:

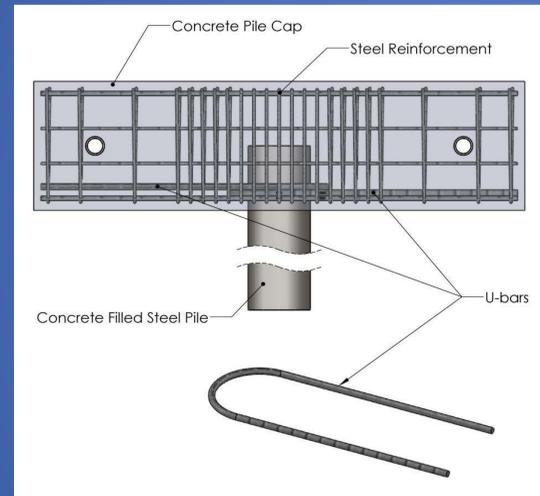
- Test specimens based on a subsection of a typical bridge bent
- Approximately half-sized



General test setup layout (all lengths in units of inches)

Overall:

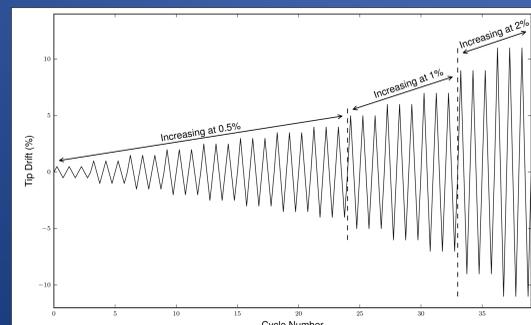
- 9 monotonic test specimens –
 - 4 without U-bars encircling the embedded pile
 - 5 with U-bars encircling the embedded pile
- 2 cyclic test specimens
 - Both include U-bar reinforcement



Typical Test Specimen – Reinforcement, concrete strength, embedment length of pile, and reinforcement were varied between tests

Test Methods:

- Initial monotonic testing without U-bars (Labeled PC1, PC2, PC3, PC3a)
- Remaining monotonic testing included U-bars (Labeled PC4, VT1, VT2, VT2.5, VT3):
 - 3 unique cap reinforcement configurations (VT1 cap was reused for VT2.5)
 - Loaded in a single direction until failure, with extensive cap deterioration observed
 - The loading was reversed and increased until the tip of the pile reached the same displacement as the initial loading
 - CFT tip deflection, applied CFT tip deflection and reinforcement strains were recorded
- Cyclic testing included U-bars (Labeled CT1, CT2):
 - 2 different cap reinforcements configurations (one was similar to VT2, second was enhanced)



Cyclic Loading History (CT1 and CT2)

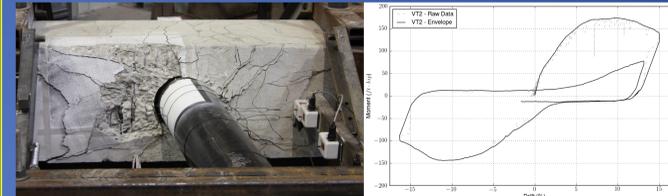
Test Results

Observed Limit States:

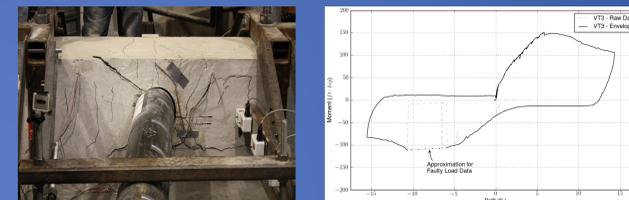
- Initial Cracking
- Yielding of the CFT
- Concrete degradation/crushing
- Yielding of the steel reinforcement
- Splitting of the cap

Results Focus:

- Test results presented herein focus on VT and CT test series with U-bar



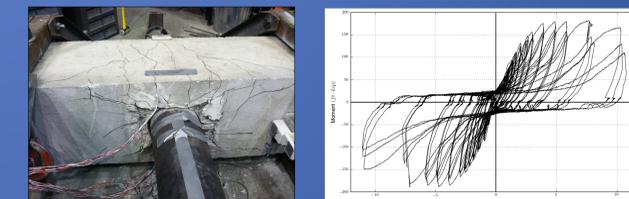
VT2 - oversized pile with significant cap deterioration



VT3 - oversized pile with significant cap deterioration



CT1 - oversized pile with significant cap deterioration



CT2 - oversized pile with significant cap deterioration

Summary of Results For All Tests:

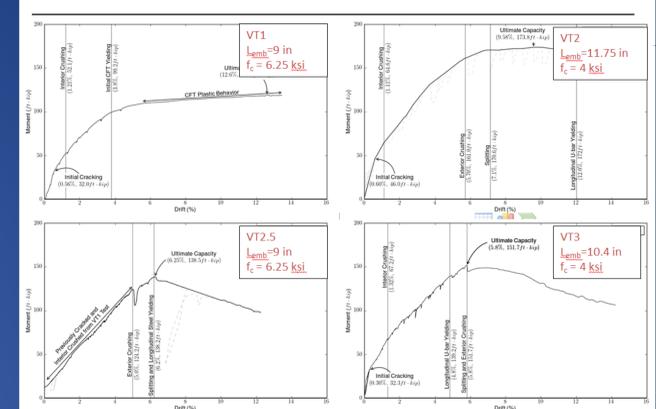
Test	U-bar Configuration	U-bar Location	Pile Embedment Length	Concrete Strength	Failure Mechanism	Maximum Moment at Failure
PC-1	None	NA	9.0 in	4832 psi	Fracture/Cracking of the concrete pile cap	82 ft-kip
PC-2	None	NA	9.0 in	5326 psi	Fracture/Cracking of the concrete pile cap	74 ft-kip
PC-3	None	NA	9.0 in	3150 psi	Fracture/Cracking of the concrete pile cap	76 ft-kip
PC-3a	None	NA	9.0 in	3945 psi	Fracture/Cracking of the concrete pile cap	102 ft-kip
PC-4	Single #7 U-bar in each direction	Exterior Only	9.0 in	4682 psi	Plastic hinge in steel pile pile	121 ft-kip
VT1	Single #7 U-bar in each direction	Exterior Only	9.0 in	6250 psi	Plastic hinge in steel pile pile	119.2 ft-kip
VT2	Single #4 and #5 U-bar in each direction	Exterior Only	11.75 in	3800 psi	Fracture/Cracking of the concrete pile cap	173.8 ft-kip
VT2.5	Single #7 U-bar in each direction	Exterior Only	9.0 in	6250 psi	Fracture/Cracking of the concrete pile cap	138.5 ft-kip
VT3	Single #7 U-bar in each direction	Exterior Only	10.375 in	4100 psi	Fracture/Cracking of the concrete pile cap	151.7 ft-kip
CT1	Single #4 and #5 U-bar in each direction	Exterior Only	11.75 in	4200 psi	Fracture/Cracking of the concrete pile cap	172.4 ft-kip
CT2	Single #4 and #5 U-bar in each direction	Interior and Exterior	11.75 in	4200 psi	Fracture/Cracking of the concrete pile cap	181.8 ft-kip

Test Observations:

- Connection capacity increases with increased CFT embedment, increased concrete strength, the addition of U-bar reinforcement, etc.
- CT1 was designed similar to VT2 - strength remained similar between monotonic and cyclic tests
- CT2 included interior U-bars – provided highest capacity and delayed concrete deterioration

Summary and Conclusions

Pushover Results



U-bar Benefits:

- Provide local concrete confinement around CFT
- Direct steel reinforcement capable of resisting CFT rotation
- Carry load away from compression region(s)

Yielding of the CFT:

- Plastic-hinging of the CFT provides ductile behavior when compared to cracking/fracturing of the cap
- Important to consider upper bound for CFT strength in design
- Choose a design that includes over strength considerations

Concrete degradation/crushing:

- Two crushing regions – interior and exterior compression zones around the embedded CFT
- When U-bars are only placed in exterior compression zone, interior may unknowingly deteriorate
- Inclusion of interior U-bars delayed degradation.

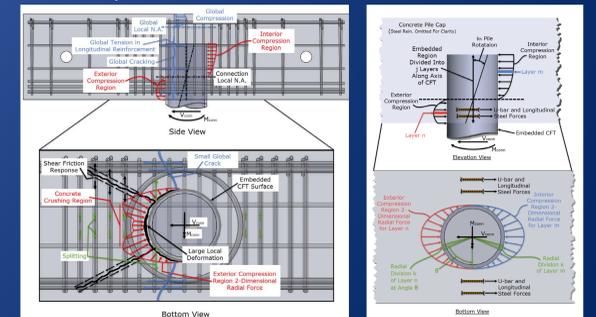
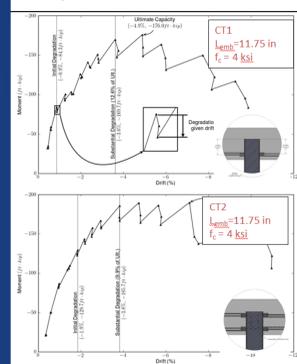
Yielding of the steel reinforcement:

- Both longitudinal steel and U-bar steel may yield
- Longitudinal steel is likely to be adequate using conventional design
- Development of a more detailed mechanics model is in progress for U-bar design

Splitting of the cap:

- Round geometry of CFT creates transverse forces that may cause the cap to split
- Transverse steel resists these forces and provides concrete confinement for the compression regions resisting the pile rotation
- Possibly rely on empirical relationship for transverse reinforcement or use forces from a more robust analytical model

Cyclic Test Results



Supporting Documents

- Kappes, L., M. Berry, and J. Stephens. 2013. Performance of Steel Pipe Pile-to-Concrete Cap Connections Subject to Seismic or High Transverse Loading: Phase III Confirmation of Connection Performance. Montana Department of Transportation. (Accepted by MDT in 2013)
- Stephens, Jerry, and Ladean McKittrick. 2005. Final Report: Performance Of Steel Pipe Pile-To-Concrete Bent Cap Connections Subject To Seismic Or High Transverse Loading. Montana Department of Transportation. (Accepted by MDT in 2005)