Large Diameter Open-End Pipe Piles for Transportation Structures

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Large diameter open ended piles (LDOEPs)

- Driven pile
  - Tubular steel
  - Prestressed concrete cylinder
- 36 inches outside diameter or larger
Typical LDOEP Applications

- High lateral load demands (often due to extreme event loading)
- High axial demand
- Deep weak soils
Typical LDOEP Applications

- Eliminate the need for a footing w/ single pile (pile bent)
- Marine construction - delivery, handling, and installation
- Significant unsupported length (scour, liquefaction, marine conditions)
Unique Challenges of LDOEPs

- Uncertainty of “plug” formation during installation
- Potential for installation difficulties and pile damage during driving is unlike other types of conventional bearing piles
Unique Challenges of LDOEPs

- Soil column within the pile may behave differently during driving or dynamic testing compared with static loading.

- Axial resistance from internal friction.

- Verification of nominal axial resistance is more challenging and expensive.
Steel Pipe Piles

- **Spiralweld:** Continuously welded spiral from coiled sheet

- **Rolled and welded:** Plate steel rolled and welded

*photos courtesy Skyline Steel*
Concrete Pipe Piles

- Spun Cast or Bed Cast
- Prestressed
- Post-tensioned

photo courtesy Gulf Coast Prestress
A Simplified Examination of the Dynamic Behavior of a Soil Plug

FIGURE 4  Schematic of a soil plug inside a pipe pile
Considerations Affecting Behavior of Steel LDOEPS

- Base Resistance of Steel LDOEPs on Rock and Driving Shoes
  - Shoe increases diameter – inside vs. outside
  - Shoe height and buckling of toe
  - Sloping rock
Considerations Affecting Behavior of Steel LDOEPS

- Vibratory Driving and Splicing
- Effect of Pile Length on Behavior and Axial Resistance
  - Reduced side resistance (remolding, friction fatigue, etc.)
  - Elastic compression enduring driving
- Time-Dependency of Axial Resistance
Considerations Affecting Behavior of Steel LDOEPS

- **Driving Resistance and Dynamic Load Testing**
  - Modeling inertial resistance of the soil plug/column
  - Inserts to promote plugging
  - Residual stresses
  - Limitations of hammer mobilizing resistance
  - Detection and avoidance of pile damage during installation
Considerations Affecting Behavior of Concrete LDOEPS

- Pile volume and prestressed concrete LDOEPs
  - Area ratio vs. steel piles – frictional resistance
  - Potential for plugging
  - Soil “bulking” in void
  - Hoop stress / water hammer
Considerations Affecting Behavior of Concrete LDOEPS

- Base resistance of concrete LDOEPs
  - Plugging vs mobilizing cross-section

- Driving Resistance and Dynamic Load Testing
  - Management of driving stresses
  - Splices rare
Design for Axial Loading

- Nominal axial resistance determined from driving resistance
- Static computations serve as guide for estimating length
Design for Axial Loading

- Axial Resistance in Clay Soils ("alpha")
- Axial Resistance in Sands ("beta")
- Methods Utilizing CPT Data (API RP2 GEO 2011)
- Methods Specific to Prestressed Concrete LDOEPs (FDOT)
Design for Axial Loading

- API RP2 GEO 2011
  - Current state of practice for design for offshore industry
  - Long history of use
  - Slight differences from FHWA “alpha” and “beta” based on offshore experience
  - Several CPT-based methods
    - ICP-05, UWA-05, NGI05, Fugro05
Resistance Factor Selection

- Current (2013) AASHTO guidelines do not specifically represent LDOEPs.

- Based largely on NCHRP Report 507 (Paikowsky (2004))
  - A very small number of open ended pipe piles.
  - LDOEPs are not documented separately from smaller piles.
Design for Lateral Loading and Serviceability

- Not different than for other deep foundations
- Consider contribution to lateral stiffness of concrete plug at top of pile (connection)
- Consider soil plug/column contribution to axial stiffness
Summary of Current State DOT Practices

- **Static Analysis Methods**
  - FHWA most common, a few use API
  - Nordlund (sands), alpha (clays) most common

- **Resistance Factors**
  - AASHTO recommended most common
  - Few states developed their own
Summary of Current State DOT Practices

- Driving Criteria and Testing
  - Majority use wave equation analysis and/or high strain dynamic testing
  - Static, Rapid, and Dynamic load tests very common
  - Concerns with analysis of high strain dynamic data, particularly with treatment of soil plug/column
Case Histories

- Hastings Bridge, Minnesota
- St. George Island Bridge, Florida
Case Histories – Hastings Bridge, MN

Key issues:

- Increased reliability through demonstrated pile resistance
- Vibrations on existing structures
Case Histories – Hastings Bridge, MN

Key issues:

- Limitations of dynamic tests to demonstrate fully mobilized pile resistance for piles driven to refusal on rock

- Use of lateral load test for design
Case Histories – Hastings Bridge, MN

- 42-in open-end pipe piles
  - $t_w = 1$ inch (for impact loads) or 7/8-in
  - Driven to bear on rock

- Axial Statnamic tests
  - 4,600 kips (1 in); 4,200 kips (7/8 in)
  - Maximum deflection about 2-½ inches; permanent sets of around ¼ in.

- Dynamic tests
  - 3,000 to 3,500 kips (Maximum hammer could mobilize)
Case Histories – Hastings Bridge, MN

- Statnamic tests used as basis of design
- Dynamic tests utilized on production piles to demonstrate:
  - that the piles were driven to a good seating on rock
  - that the piles were not damaged
  - that the hammer was performing as intended.
Case Histories – St. George Island, FL

Key issues:

- Assess nominal resistance of underlying Florida limestone
- Determining pile order lengths to meet schedule
- Comparison of axial load testing methods
- Control of longitudinal cracking
Case Histories – St. George Island, FL

Testing Program:

- 4 static load tests
- 6 Statnamic load tests
- 50 dynamic tests on production piles
Case Histories – St. George Island, FL

Summary of test results for St. George Island Bridge (Kemp and Muchard, 2007)

- Reasonable agreement between static and Statnamic
- Dynamic tests slightly under-predict vs. static
Longitudinal cracks were observed in 7% of piles, usually within three to four weeks after driving.

Determined to be “water hammer” from build-up of fluid soil inside the pile annulus.

Excess “hoop stresses” resulted in cracking.

Contractor elected to monitor and clean out plug/soil column – no further cracking.
Conclusions

- More LDOEP for transportation structures
- Advantages, limitations identified
- Some different engineering concepts required

Questions?