LRFD DRIVEN PILE FOUNDATION DESIGN POLICY

North Carolina Department of Transportation
Geotechnical Engineering Unit

Policy Approval or Update	6th Update
Revision Details	Revise and Add New Sections:

- Revise Section 2.2.2 & C2.2.2 Prestressed Concrete Piles
- Revise C3.2.3 Dynamic Monitoring
- Revise C5.1.3 Scour Resistance
- Revise C9.2. Site Effects

This policy was originally developed by the Geotechnical Engineering Unit (GEU) in collaboration with the Structures Management Unit (SMU).

This policy is maintained by the Geotechnical Engineering Unit. Starting with the 4th update all future revisions will be approved and signed by the State Geotechnical Engineer only.

Approved by: ______________________ Date: May 5, 2014

John L. Pilipchuk, LG, PE
State Geotechnical Engineer

History of Policy Approval and Update

Name and Title	Date	Approval or Update
Njoroge W. Wainaina, P.E. State Geotechnical Engineer	May 10, 2012	5th Update
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Revision History

Revision Date	Sections Revised/Added	Comments
5/4/2014	• Revise Section 2.2.2 & C2.2.2 Prestressed Concrete Piles • Revise C3.2.3 Dynamic Monitoring • Revise C5.1.3 Scour Resistance • Revise C9.2. Site Effects	See the Section for details. C.9.2 created apparent conflict with Structures
05/10/2012	• Revise Section C2.3 Scour Resistance and Downdrag Load • Revise Section 4.1 Overburden Pressure Correction • Revise Section C5.1.1 Downdrag Load • Revise Section 5.1.3 Scour Resistance • Add a new Section 6 Downdrag • Original Sections 6 ~ 10 have been revised to Sections 7 ~ 11 • Revise Section 10.2.2 and C10.2.2 Required Driving Resistance • Revise Section 10.2.3 Estimated Pile Lengths • Revise Section 11 References	Compare the revised and added Sections with the previous policy for details
12/20/2011	• Section C3.2.3 PDA and WEAP – Option 2	See the Section for details
05/09/2011	• New Section 6.3 "Top-Down Construction"	See the Section for details
09/07/2010	• New Section 7 "End Bent Batter Piles" inserted after Section 6 • Sections C2.2.3 Timber Piles and 3.2.3 PDA and WEAP – Option 2	See the Sections for details
11/23/2009	• Section 5.1.3 Scour Resistance • Section C8.2.2 Required Driving Resistance	See the Sections for details

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Section 0 Definitions

AASHTO LRFD TERMINOLOGY	**DEFINITION**
P_n	Nominal compressive resistance, i.e., pile axial structural resistance
P_r	Factored structural resistance based on driving conditions for steel piles and tension or compression-controlled section for concrete piles
R_n	Nominal resistance, i.e., geotechnical resistance
R_r	Factored geotechnical resistance based on drivability analysis

NCDOT TERMINOLOGY	**DEFINITION**
Maximum Factored Resistance	R_r reduced for downdrag load, scour resistance and dead load of piles above the design scour elevation
Factored Resistance	Resistance equal to or larger than the maximum factored axial pile load
Required Driving Resistance	Factored resistance plus any additional resistance for downdrag and scour divided by a resistance factor
Point of Fixity	Elevation below which pile is considered fixed
Cored Slab Standard Bridge	Cored slab bridge designed per Structure standard bridge plans

Section 1 Factored Structural Resistance

POLICY

1.0 Factored Structural Resistance

1.1 Pile Axial Structural Resistance
Determine nominal compressive resistance based on AASHTO LRFD Specifications.

1.2 Prestressed Concrete Piles
- Resistance factor = 0.75 for compression-controlled sections
- Resistance factor = 1.00 for tension-controlled sections

1.3 Driving Conditions
Determine factored structural resistance based on driving conditions.

COMMENTARY

C1.0
See Section 0 Definitions for "Factored Structural Resistance".

C1.1
For steel piles, see AASHTO LRFD 6.9.4.1 for details. For prestressed concrete piles, see AASHTO LRFD 5.7.4.4 and 4.5.3.2.2b for details.

The SMU developed charts to use for a preliminary estimate of pile axial structural resistance. Use the Nominal Compressive Resistance Chart for steel piles and the Interaction Diagrams for prestressed concrete piles. The charts account for buckling and are based on pile type, size and unbraced pile length.

Use Unbraced Length (L) as defined below.
- Pile bents not subject to scour:
  L = (BOC EL – GND EL) + 5 ft
- All bents subject to scour:
  L = BOC/BOF EL – Design Scour EL

where,
BOC = Bottom of Cap
BOF = Bottom of Footing
GND = Ground
EL = Elevation

C1.2
See AASHTO LRFD 5.5.4.2.1 for details.

These resistance factors are included in SMU's Interaction Diagrams.

C1.3
See AASHTO LRFD 10.7.3.2.3 for details.

Steel piles driven to rock might be considered a severe driving condition. Consider use of pile points to reduce potential damage during pile driving.

AASHTO LRFD does not specify resistance factors for prestressed concrete piles based on driving conditions.

1.3.1 Steel H Piles

- Resistance factor = 0.6 for good (normal) driving conditions
- Resistance factor = 0.5 for severe driving conditions

C1.3.1
See AASHTO LRFD 6.5.4.2 for details.

AASHTO LRFD C6.15.2 states that "Due to the nature of pile driving, additional factors must be considered in selection of resistance factors that are not normally accounted for in steel members." See AASHTO LRFD for more details.

These resistance factors are not included in SMU's Nominal Compressive Resistance Chart and should be applied to obtain factored structural resistance.

1.3.2 Steel Pipe Piles

- Resistance factor = 0.7 for good (normal) driving conditions
- Resistance factor = 0.6 for severe driving conditions

C1.3.2
See AASHTO LRFD 6.5.4.2 for details.

These resistance factors are not included in SMU's Nominal Compressive Resistance Chart and should be applied to obtain factored structural resistance.

Section 2 Maximum Factored Resistance

POLICY

2.0 Maximum Factored Resistance

2.1 Drivability Analysis
Determine factored geotechnical resistance based on drivability analysis.

2.1.1 Minimum Blow Count (at bearing)
Minimum blow count is defined as 30 BPF.

2.1.2 Maximum Blow Count (at bearing)
Maximum blow count is defined as 180 BPF.

2.1.3 Refusal (during driving)
Refusal blow count is defined as 240 BPF.

2.1.4 Piles Driven to Rock
Piles driven to rock are defined as 5 blows per ¼ inch of movement.

2.2 Pile Driving Stress Limit

2.2.1 Steel Piles
Driving resistance, φ_{da} = 1.00 (AASHTO LRFD 6.5.4.2 and Table 10.5.5.2.3-1)

- In compression and tension: AASHTO LRFD Eq. 10.7.8-1

$\sigma_{dr} = 0.9\varphi_{da} f_y = 45$ ksi for 50 ksi steel.

COMMENTARY

C2.0
See Section 0 Definitions for “Maximum Factored Resistance”.

C2.1
Use readily available hammers for drivability analysis and consult with GEU Operations Engineer for available hammers.

See AASHTO LRFD 10.7.8 and Section 2.2 below for details.

C2.1.1
Minimum BPF < 30 indicates that the selected hammer may be too big.

C2.1.2
Maximum BPF > 180 indicates that the selected hammer may be too small.

C2.1.3
In general, with an appropriate (approved) hammer, if blow counts exceed 240 BPF, then pile tip may have reached a very competent layer.

C2.2.1
Steel yield stress, f_y = 50 ksi

Based on judgment, stress limit may be lowered to a minimum of σ_{dr} = 0.8 φ_{da} f_y = 40 ksi.

2.2.2 Prestressed Concrete Piles

Driving resistance, φ_{da} = 1.00 (AASHTO LRFD 5.5.4.2 and Table 10.5.5.2.3-1)

a) Normal Environments

- In compression: AASHTO LRFD Eq. 10.7.8-4

$$\sigma_{dr} = \varphi_{da}(0.85 f_c^{'} - f_{pe})$$

- In tension: AASHTO LRFD Eq. 10.7.8-5

$$\sigma_{dr} = \varphi_{da}(0.095\sqrt{f_c^{'}} + f_{pe})$$

b) Severe Corrosive Environments

- In compression: Same as normal environments

- In tension: AASHTO LRFD Eq. 10.7.8-6

$$\sigma_{dr} = \varphi_{da} f_{pe}$$

C2.2.2

In accordance with the SMU standard prestressed concrete pile details,

- f'_c = 7.5 ksi
- strand area = 0.153 in^2 (0.5 inch diameter) & 0.217 in^2 (0.6" diameter)
- strand yield strength = 270 ksi
- applied prestress (before loss) = 270 x 0.75 = 202.5 ksi
- f_{pe_strand} = 170 ksi , effective prestressing stress per strand (after loss)
- f_{pe} = (170 ksi × strand area × number of strands ÷ concrete area), where f_{pe} is effective prestressing stress in concrete

Number of strands depends upon pile & strand size (see Standard Prestressed Concrete Pile Sheets.)

2.2.3 Timber Piles

Driving resistance, φ_{da} = 1.15 (AASHTO LRFD 8.5.2.2 and Table 10.5.5.2.3-1)

- In compression and tension: AASHTO LRFD Eq. 10.7.8-7

$$\sigma_{dr} = \varphi_{da}(F_{co})$$

$$F_{co} = 0.9 \sim 1.25 \text{ ksi}$$

$\sigma_{dr} = 1.00 \sim 1.40$ ksi, recommended value

C2.2.3

AASHTO LRFD 2010 –

F_{co} : base resistance of wood in compression parallel to grain as specified in AASHTO LRFD 8.4.1.4

Reference Design Values for Piles (AASHTO LRFD Table 8.4.1.4-1)

Species	**F_{co} (ksi)**
Pacific Coast Douglas-Fir	1.25
Red Oak	1.10
Red Pine	0.90
Southern Pine	1.20

2.3 Scour Resistance and Downdrag Load

Determine maximum factored resistance by reducing the factored geotechnical resistance for downdrag load, scour resistance and dead load of piles above design scour elevation.

C2.3

See Section 5.1.1 and 5.1.2 for downdrag and dead load details.

For scour resistance, use static analysis to calculate skin resistance from existing ground line to design scour elevation. See Section 5.1 for static analysis methods.

Section 3 Resistance Factors

POLICY

COMMENTARY

3.0 Resistance Factors

3.1 Static Analysis
Use AASHTO LRFD Resistance Factors for all piles except steel H piles in the Coastal Plain.

C3.1
See AASHTO LRFD Table 10.5.5.2.3-1 for details.

3.1.1 Exception
Use NCDOT Resistance Factor of 0.7 for steel H piles in the Coastal Plain.

C3.1.1
NCDOT Resistance Factors are based on NCSU localized resistance factors calibration research. This factor applies to all soils and all static analysis methods for H piles in the Coastal Plain. This is an exception to AASHTO LRFD Specifications. See FHWA/NC (2002) for details.

See Subarticle 1018-2(B), (1) of the Standard Specifications for determining soils in the Coastal Plain. If in doubt, consult project geologic engineer.

3.2 Dynamic Monitoring
Use the same resistance factor for both drivability analysis and pile driving criteria.

C3.2
This is an exception to the AASHTO LRFD Specifications. These resistance factors are higher than the AASHTO LRFD Resistance Factors and were established based on NCDOT's pile driving experience.

3.2.1 WEAP without PDA
Use a resistance factor of 0.60 for hammer approval.

3.2.2 PDA and WEAP – Option 1
Use a resistance factor of 0.60 for hammer approval with limited quantity of PDAs.

C3.2.2
PDA may be used without meeting AASHTO LRFD requirements in order to monitor stresses and resistance during pile driving.

3.2.3 PDA and WEAP – Option 2
Use a resistance factor of 0.75 for hammer approval with required quantity of PDAs.

C3.2.3
Minimum number of PDA tests required is two piles per site condition, but no less than 2% of the production piles. See AASHTO LRFD Section 10.5.5.2.3 for the definition of "site".

Section 4 Overburden Pressure and Hammer Efficiency Corrections

POLICY

4.0 Overburden Pressure and Hammer Efficiency Corrections

4.1 Overburden Pressure Correction
Correct SPT blow counts for overburden pressure.

4.2 Hammer Efficiency Correction
Correct SPT blow counts for hammer efficiency.

4.2.1 Hammer Efficiency Correction Exception
Hammer efficiency correction is not required for steel H piles in the Coastal Plain where NCDOT Resistance Factors apply.

4.2.2 Default Hammer Efficiency Correction Values
Use hammer efficiency from test results if available; otherwise use 60% for manual hammers and 80% for automatic hammers.

COMMENTARY

C4.1
See AASHTO LRFD 10.4.6.2.4 for details.

Software “Driven” and “APile” can automatically correct for overburden pressure. Both have different SPT $N1_{60}$ value versus internal friction angle tables to convert SPT $N1_{60}$ values to corresponding friction angles. See software manuals for details. Users can either enter N_{60} values or friction angles directly to the software programs.

C4.2
See AASHTO LRFD 10.4.6.2.4 for details.

C4.2.1
NCSU did not make hammer efficiency corrections for their research.

Section 5 Static Analysis

POLICY

5.0 Static Analysis

5.1 Static Analysis
Use AASHTO LRFD methods for static analysis.

5.1.1 Downdrag Load
To account for downdrag, add factored downdrag load to maximum factored axial load for static analysis.

5.1.2 Dead Load
To account for dead load of concrete piles above the design scour elevation, add factored dead load to maximum factored axial load for static analysis.

5.1.3 Scour Resistance
To account for scour, subtract scour resistance from nominal resistance calculated for static analysis.

COMMENTARY

C5.1
See AASHTO LRFD 10.7.3.8.6 for details.

Use software program Driven or APile with Nordlund/Tomlinson method or other AASHTO LRFD methods. Select a predominant soil type to determine analysis method and a corresponding resistance factor.

C5.1.1
See Section 6 for downdrag load analysis details.

C5.1.2
See AASHTO LRFD Table 3.4.1-2 for Component and Attachments factors.

Typically, dead load for steel piles may be neglected. However, if weight of steel piles is significant, dead load of steel piles above the design scour elevation may be considered.

C5.1.3
For analysis purposes, lower ground line to the contraction scour elevation (CSE) to account for contraction scour reported in the bridge survey report.

- Calculate overburden pressure according to the CSE, unless local scour is over 15 feet, in which case account for loss of overburden pressure due to local scour.
- If the CSE is lower than or equal to the design scour elevation (DSE), consider all scour as contraction scour.
- If the CSE is higher than the DSE, consider the difference between the CSE and the DSE as local scour.
- Assume zero shear force on pile in scour zone.

5.2 Steel H Pile Resistance Configuration

5.2.1 AASHTO LRFD Resistance Factors
Use box shape for skin resistance and H shape for tip resistance when AASHTO LRFD Resistance Factors are used.

C5.2.1
Consider rectangular perimeter defined by the soil plugged cross-section. Also, see AASHTO LRFD 10.7.3.8.6b for details.

5.2.2 NCDOT Resistance Factors
Use H shape for both skin and tip resistance when NCDOT Resistance Factors are used. This applies to steel H piles used in the Coastal Plain.

C5.2.2
Consider the unplugged cross-section. Also, see Section 3.1.1.

Section 6 Downdrag

POLICY

6.0 Downdrag

6.1 Downdrag Load Criteria

AASHTO LRFD 3.11.8 states "If the settlement in the soil layer is 0.4 in. or greater relative to the pile or shaft, downdrag can be assumed to fully develop."

6.2 Downdrag Load Factors

Use AASHTO LRFD Downdrag load factors.

For Nordlund Method

- Load factor = 1.25

COMMENTARY

C6.1

See AASHTO LRFD 3.11.8, 10.6.2.4 and 10.7.3.7 for downdrag and settlement analyses details.

Downdrag load developed when:

$S \geq \Delta H + \delta$

where,

- S = embankment settlement
- ΔH = 0.4 inches
- δ = elastic deformation of the pile subject to service dead loads

For δ calculation:

- Obtain service dead load from the structures design engineer. In absence of service dead load, engineer may use a simple conversion listed below (assume Strength Limit I, Span Length ≅ 90ft, and DL/LL = 1.5.)
    - Dead load = factored load / 2.4

C6.2

See AASHTO LRFD Table 3.4.1-2 for details.

This is an exception to AASHTO LRFD. The resistance factor was chosen based on a factor of safety of 2.75 (Table 4.5.6.2A, AASHTO ASD) and a resistance factor of 0.45 for Nordlund Method (Table 10.5.5.2.3-1, AASHTO LRFD).

Load factor = 2.75 x 0.45 ≅ 1.25.

6.3 Embankment Settlement Analyses

Use AASHTO LRFD Eq. 10.6.2.4.1-1 for settlement analyses.

Treat embankment as a spread footing for settlement analyses.

C6.3

Total settlement includes elastic (immediate, short-term), primary consolidation and secondary settlements.

Treat it as a rectangular, square, or strip spread footing depending upon engineering judgment.

Assume the footing width equals the embankment width measured from hinge point to hinge point (outside edge of shoulder.)

As a general guideline, assume footing length equals abutment cap width plus the greater of the following two numbers.

1. 15 feet, or
2. Height of embankment fill (measured from existing ground to grade elevation)

If necessary, use numerical analysis to acquire more accurate embankment settlement.

6.3.1 Elastic/Immediate Settlement

The elastic properties (elastic modulus and Poisson’s ratio) of a soil may be estimated from empirical relationships presented in AASHTO LRFD Table C10.4.6.3-1.

6.3.2 Settlement on Cohesive Soils

Use AASHTO LRFD 10.6.2.4.3 for settlement analysis on cohesive soils.

C6.3.2

Based on engineering judgment, primary and secondary settlements for piles driven to refusal through over consolidated clays (i.e. residual soils) may be neglected. However, it is still necessary to calculate elastic settlement.

As a general guideline, over consolidated clays is defined as OCR $\geq$ 2.0, approximately.

6.3.3 Settlement on Cohesionless Soils
Use Schmertmann Method for immediate (elastic) settlement analysis on cohesionless soils.

C6.3.3
Do not use Hough Method. AASHTO 10.6.2.4.2 refers to the Hough Method but FHWA recommends the Schmertmann Method. See FHWA (2006b, 2010) for details.

Schmertmann Method (Eq. 8-16, FHWA 2006b) for immediate settlement, S_i, of spread footings:

$$S_i = C_1 C_2 \, \Delta \mathrm{p} \sum_{i=1}^{n} \Delta H_i$$

where,

- C_1 = depth (embedment) correction factor, not applicable where consolidation settlements occurs
- C_2 = creep correction factor

Recommended values:
(Section 8.5.1.2, FHWA 2006b)

- C_1 = 1.0 (consolidation settlement occurs)
- C_2 = 0.1 years for cohesionless soils
- C_2 = 1.0 year for undrained fine-grained cohesive soils with low plasticity

Section 7 Pile Bents

POLICY

7.0 Pile Bents

7.1 Lateral Deflection & Pile Stresses
The SMU will check bent deflections and structural adequacy of piles.

7.2 Point of Fixity (POF)
This is a strength limit analysis. Use factored loads for POF analyses.

7.2.1 Preliminary POF
For preliminary POF analysis, use the maximum factored resistance and a shear load of 3 kips per pile (no moment). Also, use the following lateral deflection limits for a single pile with a free head condition for selecting pile type and size.

- Steel Piles 6”
- Prestressed Concrete Piles 3”

7.2.2 Iteration Limit for POF Analysis
Terminate POF analysis if either one of the following conditions are met.

- new POF is less than **3** ft higher than the previous POF, or
- new POF is less than **2** ft below the previous POF.

Otherwise, provide the SMU the new POF and continue the iteration process or change the pile design.

7.3 Point of Fixity (POF)
Refer to the Structure Design Manual – Sections 6.4.2 or 6.5.2 for span length limits for top-down construction. For projects where pile driving operations may establish the size of the crane used, develop a preliminary estimate of the pile driving hammer energy range required to construct the foundation. When the estimated energy range is greater than 40 ft.-kips or other factors that may influence the required crane size are present, coordinate with the Structures Management Unit to assess whether the proposed span lengths are attainable.

COMMENTARY

C7.2
Other methods such as cantilever beam may be used to supplement L-Pile in determining POF.

Point of fixity should be selected from between where the deflection curve first intercepts the “point of the first zero deflection” and the “maximum negative deflection point.”

C7.3
Structure Design Manual – Section 6.1.2 does not recommend use of cored slab or box beams superstructures for bridges with more than 4 spans. The attainable span lengths may be reduced by the size of the crane required to construct the foundation. Factors that influence the size of the crane include pile type (e.g. prestressed concrete piles), design pile tonnages (maximum factored load) in excess of 130 tons, and pile driving equipment with high energy ranges (≥ 40 foot-kips).

Section 8 End Bent Batter Piles

POLICY

8.0 End Bent Batter Piles

8.1 General

Batter piles are required if vertical piles will not provide sufficient lateral earth pressure resistance or overturning resistance at end bents. This situation may occur when there is not sufficient pile embedment.

8.2 Batter Piles Design Guidelines

- Design a minimum of two battered piles for pile embedment depth equal or less than 15 feet for all bridges except Cored Slab Standard Bridges.
- No battered piles for Cored Slab Standard Bridges.

COMMENTARY

C8.1

Active lateral earth pressure developed from the bottom of the end bent cap to the finished grade (except for integral abutments) shall be resisted by piles to prevent the transfer of excessive lateral earth pressure applied to the bridge superstructures.

Section 9 Seismic Design

POLICY

9.0 Seismic Design

9.1 General

The SMU will use a map showing general seismic zones in NC to determine whether or not a bridge will be designed for seismic loads. This will be reflected in SMU's Request for Foundation Recommendations. For seismic design, the SMU may request bridge site classification per definition in AASHTO LRFD 3.10.3.

9.2 Site Effects

The SMU will characterize the seismic hazard in accordance with AASHTO LRFD 3.10.2.

COMMENTARY

C9.1

A map showing general seismic zones in NC is available in the SMU Design Manual.

C9.2

See AASHTO LRFD 3.10.3 for details.

In Seismic Zone 2, provide Structures with the Site Class according to Table 3.10.3.1-1. In Seismic Zone 1, if the Horizontal Response Spectral Acceleration Coefficient according to Figure 3.10.1.1-3 is greater than 5%, provide Structures with the Site Class if the Site Class is known to be E.

Section 10 Foundation Recommendations

POLICY

10.0 Foundation Recommendations

10.1 Preliminary Foundation Recommendations
Determine if PDA will be used for the project. If PDA will be used, determine appropriate resistance factor based on the purpose of the PDA.

GEU will provide the SMU with the following:

- Proposed pile type, size and Maximum Factored Resistance.
- Preliminary POF for interior bents.

10.2 Final Foundation Recommendations

10.2.1 Factored Resistance
Provide proposed pile type, size and Factored Resistance. Provide factored resistance equal to maximum factored axial load rounded up to the nearest 5 tons.

10.2.2 Required Driving Resistance
Provide a standard foundation note on plans with Required Driving Resistance.

Required Driving Resistance =
[(Factored Resistance + Factored Downdrag Load + Factored Dead Load) / Resistance Factor] + (Unfactored Downdrag Resistance) + (Unfactored Scour Resistance / Scour Resistance Factor)

COMMENTARY

C10.1
See Section 3.2 for details.

See Section 0 Definitions for "Maximum Factored Resistance". Use standard form to request structure information. The SMU will provide controlling factored loads, pile configurations (number of piles and spacing) and bottom of cap elevations for each bent.

C10.2.1
See Section 0 Definitions for "Factored Resistance".

C10.2.2

Factored Dead Load is defined as factored pile dead load above ground line.

Unfactored Downdrag/Scour Resistance is "side resistance which must be overcome during driving through downdrag/scour zone" (AASHTO C10.7.3.7.)

See AASHTO 10.7.3.7 and Equations C10.7.3.7-1 and C10.7.3.7-2 for downdrag details. See AASHTO 10.7.3.6 for scour details.

Default scour resistance factor = 1.0.

In case of severe scour, handle it case by case such as use of test piles or predrilling.

10.2.3 Estimated Pile Lengths and Minimum Tip Elevation

10.2.3.1 Estimated Pile Length

Estimate pile lengths based on static analysis and minimum pile penetration.

C10.2.3.1

See AASHTO 10.7.3.3 for details.

10.2.3.2 Minimum Tip Elevation

Minimum tip elevation (i.e., tip elevation no higher than) should meet all of the following conditions.

1. Minimum penetration of 10 ft into natural ground.
2. Minimum penetration of 5 ft below design scour elevation.
3. For pile bents with plumb piles, elevation where piles achieve fixity.

C10.2.3.2

Minimum tip elevation is primarily for lateral stability. However, AASHTO 10.7.6 has in-depth guidance for minimum pile penetration. In addition, AASHTO C10.7.6 specifies that "A minimum pile penetration should not be specified solely to meet axial compression resistance, …"

10.2.4 Point of Fixity

For pile bent, provide final POF elevation.

10.2.5 Hammer Energy

If it is determined that a Delmag D19-32 (or D19-42) or an equivalent hammer is not sufficient to drive piles to the Required Driving Resistance, include a standard foundation note on plans with the "Estimated Hammer Energy Range".

10.2.6 Scour Critical Elevation (SCE)

1. Use 500 year hydraulics scour elevation, if available, as SCE.

2. Otherwise, use 2 ~ 3 ft below design scour elevation as SCE.

3. In all cases, at least 5 ft embedment is required below SCE.

Section 11 References

AASHTO ASD (2002). *AASHTO Standard Specifications for Highway Bridges*. 17th (2002) Edition with 2003 and 2005 Erratas.

AASHTO LRFD (2012). *AASHTO LRFD Bridge Design Specifications*, 6th (2012) Edition.

FHWA/NC (2002). *Load and Resistance Factor Design (LRFD) for Analysis/Design of Piles Axial Capacity*, Rahman, M.S., M.A. Gabr, R.Z. Sarica and M.S. Hossain, NCSU Research Report No. FHWA/NC/2005-8, July 2002.

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NCDOT (2006). *Standard Specifications for Roads and Structures,* North Carolina Department of Transportation, July 2006.