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Design and Evaluation of Scour for Bridges Using HEC-18
(Volume 3 of 3)

FINAL REPORT
July 2017

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<tr><td colspan="6">16. Abstract
The overall objective of this research is the development of a new approach for evaluating bridge scour for New Jersey's bridges on non-tidal waterways. The study commenced with a web-based survey of scour practice within the U.S. and a literature review of predictive scour models. The major project deliverable is a new Scour Evaluation Model (SEM), which is a tiered, parametric, risk-based decision tool. A variety of geo-technical, hydrologic, and hydraulic data are analyzed to generate risk ratings for a particular bridge. These ratings are then inputted into a Risk Decision Matrix to generate a scour priority level and recommended actions, which may range from expedited installation of countermeasures to removal from scour critical status. Bridge importance is also factored into the final priority level. In addition, the New Jersey SEM provides standard protocols for: (1) erosion classification of sediments; (2) application of scour envelope curves; and (3) analysis of hydrologic data. The model was validated and calibrated by inspecting scour critical bridges and comparing actual field observations with model results. While the current model reflects New Jersey's geology and hydrology, it can be recalibrated to other regions or states. The model is principally designed to evaluate scour risk of existing bridges, but many model components are useful for designing new bridges as well. Included are example SEM applications for 12 bridges and two detailed example problems.</td></tr>
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Appendix C: Example Investigative Reports

SEM analyses require that three kinds of reports be generated for each bridge studied: (1) Geotechnical Reconnaissance Study; (2) Field Scour Investigation; and (3) Reconnaissance Hydrologic Analysis. These reports are not included in this document due to length restrictions. However, examples of each are available upon request from the Department of Civil and Environmental Engineering at the New Jersey Institute of Technology. Contact: Dr. John Schuring at schuring@njit.edu.

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LIST OF ACRONYMS

AASHTO – American Association of State Highway and Transportation
ACBs – Articulated Concrete Blocks
ADT – Average Daily Traffic
ARF – Average Risk Failure
ASTM – American Society for Testing and Materials
BIM – Bridge Importance Matrix
COF – Consequence of Failure
CSU – Colorado State University
DOT – Department of Transportation
DR – Detour Risk
EFA – Erosion Function Apparatus
FDOT – Florida Department of Transportation
FEMA – Federal Emergency Management Agency
FHWA – Federal Highway Administration
HEC-18 – Hydraulic Engineering Circular No. 18
ICSE-5 – 5th International Conference on Scour and Erosion
ILDOT – Illinois Department of Transportation
NBIS – National Bridge Inspection Standards
NBSD – National Bridge Scour Database
NCHRP – National Cooperative Highway Research Program
NJDEP – New Jersey Department of Environmental Protection
NJDOT – New Jersey Department of Transportation
NJIT – New Jersey Institute of Technology
NWS – National Weather Service
PennDOT – Pennsylvania Department of Transportation
POA – Plan of Action
RQD – Rock Quality Designation
SCDOT – South Carolina Department of Transportation
SDI – Slake Durability Index
SEM – Scour Evaluation Model
SHA – State Highway Administration
SI&A – Structure Inventory and Appraisal
SRICOS – Scour Rate in Cohesive Soils
SRICOS-EFA – Scour Rate in Cohesive Soil – Erosion Function Apparatus
TXDOT – Texas Department of Transportation
US – United States
USDA – United States Department of Agriculture
USDOT – United States Department of Transportation
USGS – United States Geologic Survey
USSCS – United States Soil Conservation Service
WMA – Water Management Areas

APPENDICIES

Appendix A: Selected Scour Analysis Methods from HEC-18

Introduction

Foundation stability for bridges is determined using assessed or calculated scour conditions. Calculations are one of several available tools in making scour evaluations. This appendix summarizes scour equations from the 5th edition of HEC-18 (Arneson et al., 2012) that may be appropriate when applying the Scour Evaluation Model (SEM) to New Jersey bridges. The user should also consult with HEC-18, the source document.

This appendix presents scour analysis methods related to the following erosion classes:

G1 – Extremely Coarse Granular
G2 – Coarse Granular
G3 – Fine to Medium Granular
R1 – Weak Rock

This appendix should be used in combination with report section, "Description of Erosion Classes" in chapter "GEOTECHNICAL EVALUATION OF BRIDGE SCOUR" on page 32 and the SEM flow charts presented in chapter, "NEW JERSEY SCOUR EVALUATION MODEL (SEM)" on page 61, to determine when and how to apply the equations presented herein. Note that the examples presented in this appendix address the more common scour analyses for the State bridges. The practitioner is referred to HEC-18 for other scour situations, e.g. complex piers.

G1 - Extremely Coarse Granular Soil

This class includes coarse granular soil with a dominance of cobble- and boulder-sized particles. These geologic materials are highly erosion resistant and develop significant natural armoring as the finer particles are winnowed out during high flow events. A complete description of this material is given in **Table 4**.

Three scour equations in the 5th edition of HEC-18 are available for coarse granular soil. These are applicable to abutments, piers, and channel contraction, respectively. These will now be described.

<u>Abutments in Erosion Class G1</u>

For abutments in coarse granular soil, the NCHRP 24-20 method for total scour (Ettema et al, 2011) is available. However, only the clear-water version is considered applicable to G1 sediments given their extreme coarseness and the typically low contraction ratios for New Jersey bridges. The NCHRP 24-20 method stipulates clear-water as long as the length of embankment is less than 75 percent of the floodplain width. The relations for computing scour depth, y_s, for clear-water are designated as Eq. 8.3, 8.4, and 8.6 in HEC-18 and are provided below:

$$y_s = y_{max} - y_0 \qquad \text{(Eq. 8.4, HEC-18)}$$

$$y_{max} = \alpha_B y_c \qquad \text{(Eq. 8.3, HEC-18)}$$

$$y_c = \left[\frac{q_{2f}}{K_u D_{50}{}^{1/3}}\right]^{6/7} \qquad \text{(Eq. 8.6, HEC-18)}$$

Where:

- y_s = Abutment scour depth, ft
- y_{max} = Maximum flow depth resulting from abutment scour, ft
- y_0 = Flow depth prior to scour, ft
- α_B = Amplification factor for clear-water conditions (see HEC-18 Figs. 8.11 & 8.12 below)
- y_c = Flow depth including clear-water contraction scour, ft
- q_f = Unit discharge upstream, Q/w, ft^2/s
- q_{2f} = Unit discharge in the constricted opening, Q/w, ft^2/s
- K_u = 11.17 for English units (6.19 for SI)
- D_{50} = Particle size with 50 percent finer, ft

Note the NCHRP 24-20 relationships estimate total scour, so a separate calculation for contraction scour is not required.

Example Problem 1: A bridge is located on the edge of the Highlands province near the border of the Valley and Ridge. The site was analyzed to determine various geotechnical and hydrologic/hydraulic data.

Initial Parameters:

The bridge has one pier which has a square nose shape, a width of 7 ft, and a length of 28 ft. The total flow is 3025 cfs. A grain size analysis done by field measurement and visual inspection estimated the D_{50} to be 0.75 ft and D_{84} to be 1.2 ft. The specific gravity of the soil is assumed to be 2.65. The skew is measured to be 7.5 degrees. In addition, the following channel information was measured and computed:

Channel Upstream: Velocity = 6.0 fps; Depth = 6.5 ft; Width = 77 ft
Channel Under Bridge: Velocity = 7.5 fps; Depth = 5.4 ft; Width = 74.5 ft

Solution:

Now apply the NCHRP 24-20 relation to estimate clear-water abutment scour. The input variables are:

y_0 = 6.5 ft; Q = 3025 cfs; w (at bridge) = 74.5 ft: w (upstream) = 77 ft;

English units are used, so K_u = 11.17.

Note that the abutment is wingwall and that the embankment length is at least 75% of the width of the floodplain.

The unit discharge is calculated next. It is estimated by dividing the flow by the stream width at the point of interest.

$$q_{2f} = \frac{Q}{w} = \frac{3025}{74.5} = 40.6 \frac{ft^3/s}{ft} \quad \text{(unit discharge at bridge opening)}$$

$$q_f = \frac{Q}{w} = \frac{3025}{77} = 39.3 \frac{ft^3/s}{ft} \quad \text{(unit discharge upstream)}$$

The flow depth including clear-water contraction scour is then calculated (use eq. 8.6, HEC-18)

$$y_c = \left[\frac{q_{2f}}{K_u D_{50}{}^{1/3}}\right]^{6/7} = \left[\frac{40.6}{11.17 * 0.75^{1/3}}\right]^{6/7} = 3.28\,ft$$

To calculate y_{max}, α_B is needed.

$$\frac{q_{2f}}{q_f} = \frac{40.6}{39.3} = 1.03$$

Consult HEC-18 Figs. 8.9 thru 8.12. Since this bridge has wingwall abutments and clear-water conditions prevail, use Fig. 8.12. From Fig. 8.12, use design value (solid line) α_B = 2.5

$$y_{max} = \alpha_B y_c = 2.5 * 3.28 = 8.2 ft \quad \text{and} \quad y_s = y_{max} - y_0 = 8.2 - 6.5 = 1.7\,ft$$

Answer: The total abutment scour is therefore 1.7 ft.

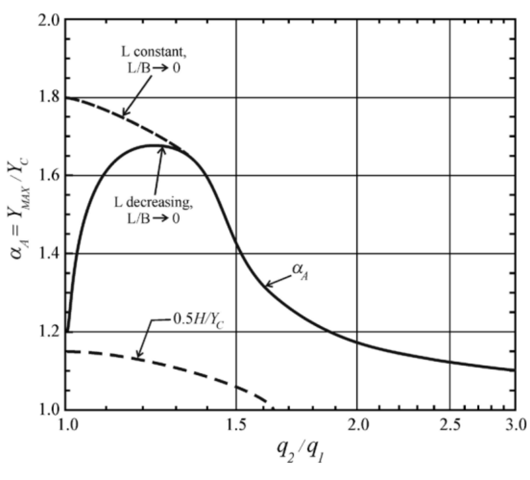


Figure 8.9 (from HEC-18 5th ed.) Scour amplification factor for spill-through abutments and live-bed conditions.

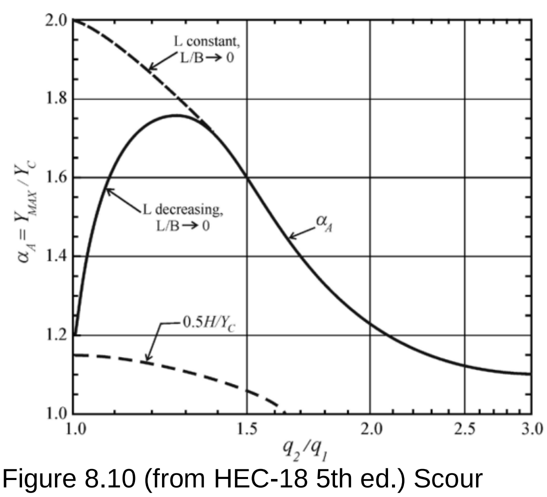


Figure 8.10 (from HEC-18 5th ed.) Scour amplification factor for wingwall abutments and live-bed conditions.

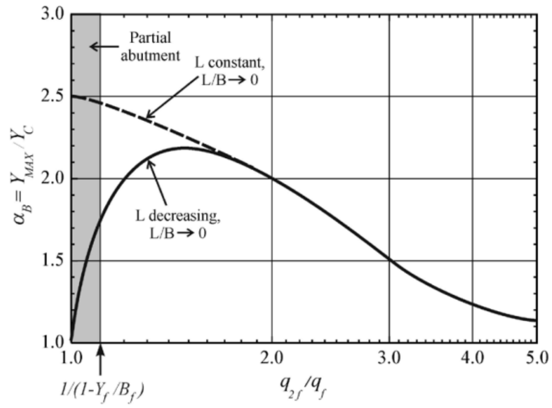


Figure 8.11 (from HEC-18 5th ed.) Scour amplification factor for spill-through abutments and clear-water conditions.

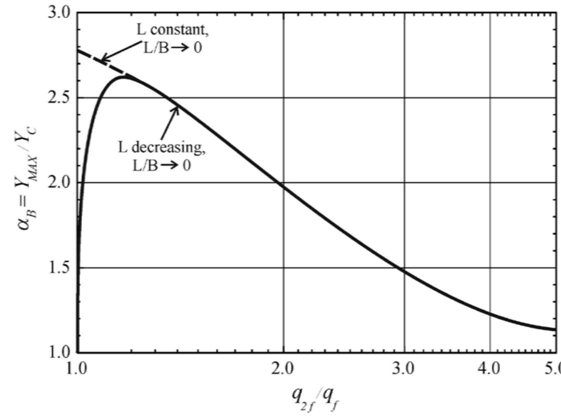


Figure 8.12 (from HEC-18 5th ed.) Scour amplification factor for wingwall abutments and clear-water conditions.

Piers in Erosion Class G1

Pier scour may be estimated using the coarse-particle equation developed by FHWA using USGS field data (FHWA 2012). The coarse-bed pier scour equation is for clear-water conditions only where the approach flow velocity is less than the critical velocity (V_c) for initiation of bed-material motion. The relation for computing scour depth, y_s, is designated as Eq. 7.34 in HEC-18 and is provided below:

$$y_s = 1.1K_1K_2a^{0.62}y_1^{0.38}tanh\left(\frac{H^2}{1.97\sigma^{1.5}}\right) \quad \text{(Eq. 7.34, HEC-18)}$$

Where:

y_s = Scour depth, ft
K_1 = Correction factor for pier nose shape (Figure 7.3 and Table 7.1, HEC-18)
K_2 = Correction factor for angle of attack of flow. Use either Eq. 7.4 or Table 7.2 below.

$$K_2 = \left(Cos\theta + \frac{L}{a}Sin\theta\right)^{0.65} \quad \text{(Eq. 7.4, HEC-18)}$$

θ = angle of attack of the flow, deg
a = Pier width, ft
y_1 = Flow depth directly upstream of the pier, ft
H = Densimetric particle Froude Number = $\frac{V_1}{\sqrt{g(S_g-1)D_{50}}}$

V_1 = Mean velocity of flow directly upstream of pier, ft/s
g = Acceleration due to gravity (32.2 ft/s^2)
D_{50}= Median bed material size, ft
S_g = Specific gravity of bed material
σ = Sediment gradation coefficient = D_{84}/D_{50}

Table 7.1 (HEC-18 5th ed.) Correction Factor, K_1, for Pier Nose Shape	
Shape of Pier Nose	K_1
Square nose	1.1
Round nose	1.0
Circular cylinder	1.0
Group of cylinders	1.0
Sharp nose	0.9

Table 7.2 (HEC-18 5th ed.) Correction Factor, K_2, for Angle of Attack, θ, of the Flow			
Angle	L/a = 4	L/a = 8	L/a = 12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.75	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0
Angle = skew angle of flow, L = Length of pier, if L/a larger than 12, use L/a=12			

Note that this equation is only applicable for clear-water flow conditions and for coarse-bed materials with D_{50} > 20 mm and σ ≥ 1.5. For bed materials composed principally of cobbles and boulders, clear water conditions can usually be assumed. However, if needed, it can also be checked using Eq. 6.1 in HEC-18 as shown below for contraction scour in G1 sediments and Example Problem 3.

Example Problem 2: Continuing analysis of the bridge in Example Problem 1 above, now apply the FHWA coarse particle relation, Eq. 7.34 in HEC-18.

Summarizing the needed input values from above:

Assume: $y_1 = y_0 = 6.5$ ft. Also: $D_{50} = 0.75$ ft; $D_{84} = 1.2$ ft; a = 7 ft; θ = 7.5 deg

D_{50} Check: 0.75ft * 12in/ft * 25.4mm/in = 228.6mm > 20mm

σ is calculated first:

$$\sigma = \frac{D_{84}}{D_{50}} = \frac{1.2}{0.75} = 1.6$$

And $V_1 = 6.0$ fps, so it follows that:

$$H = \frac{V_1}{\sqrt{g(S_g - 1)D_{50}}} = \frac{6.0}{\sqrt{32.2(2.65-1)0.75}} = 0.95$$

The hyperbolic tangent* portion of the equation will be calculated next:

$$tanh\left(\frac{H^2}{1.97\sigma^{1.5}}\right) = tanh\left(\frac{0.95^2}{1.97 * 1.6^{1.5}}\right) = tanh(0.2264) = 0.223$$

*If a calculator capable of performing hyperbolic tangents is unavailable, consult Table 7.4 of HEC-18 5th edition.

Now from HEC-18 Table 7.1 above for square piers, K_1 = 1.1

For K_2, L/a is 4 and angle is 7.5 degrees. Use eq. 7.4:

$$K_2 = \left(Cos\theta + \frac{L}{a}Sin\theta\right)^{0.65} = \left(\cos(7.5) + \frac{28}{7} * \sin(7.5)\right)^{0.65} = 1.31$$

Use K_2 = 1.25 (interpolate from table 7.2 or use eq. 7.4)

Finally, depth of local pier scour is calculated with equation 7.34 (HEC-18) as:

$$y_s = 1.1K_1K_2a^{0.62}{y_1}^{0.38}tanh\left(\frac{H^2}{1.97\sigma^{1.5}}\right) = 1.1 * 1.1 * 1.31 * 7^{0.62} * 6.5^{0.38} * 0.223 = 2.41\ ft$$

Thus, local pier scour is 2.41 ft.

Contraction in Erosion Class G1

To estimate total scour in the vicinity of a pier, the effect of contraction scour should also be added to the local scour computed above. For G1 sediments, clear-water conditions can normally be assumed given their extreme coarseness. The presence of clear-water conditions can be double-checked by computing the critical velocity based on median size particles (D_{50}), which is then compared with the design storm velocity. The procedure is as follows:

$$V_c = K_u y^{1/6} D^{1/3}$$ (Eq. 6.1, HEC-18)

Where:

- V_c = Critical velocity above which bed material of size D and smaller will be transported, ft/s
- y = Average depth of flow upstream of the bridge, ft
- D = Particle size for V_c (typically assumed to be D_{50}), ft
- K_u = 11.17 for English units (6.19 for SI units)

If V_c > V, then clear-water conditions prevail and Eqs. 6.4 and 6.5 in HEC-18 should be used to estimate contraction scour, y_s . These relationships are based on a development by Laursen (1963).

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3}\ W^2}\right]^{3/7}$$ (Eq. 6.4, HEC-18)

$$y_s = y_2 - y_0$$ (Eq. 6.5, HEC-18)

Where:

y_s	=	Average contraction scour depth, ft
y_2	=	Average equilibrium depth in the contracted section after contraction scour, ft
y_0	=	Average existing depth in the contracted section, ft
Q	=	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W, ft^3/s
D_m	=	Diameter of the smallest nontransportable particle in the bed material (1.25 D_{50}) in the contracted section, ft
D_{50}	=	Median diameter of bed material, ft
W	=	Bottom width of the contracted section less pier widths, ft
K_u	=	0.0077 for English units (0.025 for SI units)

Note that the computed contraction scour for erosion class G1 is often low or even zero, again, on account of the extreme coarseness. Also note that HEC-18 defines four general contraction scour cases and provides technical notes to help explain each one. Please refer to Pages 6.2 to 6.8, HEC-18, 5th Ed.

Example Problem 3: Continuing analysis of the bridge in Example Problems 1 and 2 above, now estimate the contraction scour in the vicinity of the pier. First compute the critical velocity to double-check for clear-water conditions. Summarizing the input values from above:

y = 6.5 ft; D = D_{50} = 0.75 ft; K_u = 11.17; V = 6.0 ft/s

Critical velocity is then calculated using Eq. 6.1, HEC-18:

$$V_c = 11.17 * 6.5^{1/6} * 0.75^{1/3} = 13.8\ ft/s$$

V_c > V (13.8 > 6.0), indicating clear-water scour will occur.

Now the average equilibrium depth in the contracted section, y_2, is calculated using Eq. 6.4, HEC-18:

Q = 6.5 ft^3/s; D_m = 1.25 D_{50} = (1.25)(0.75) = 0.94 ft; W = 74.5 – 7 = 67.5 ft; K_u = 0.0077;

$$y_2 = \left[\frac{0.0077 * 3025^2}{0.94^{2/3}\ 67.5^2}\right]^{3/7} = 3.29\ ft$$

Finally, compute the contraction scour depth using Eq. 6.5, HEC-18. Note that y_0 = 5.4 ft from the given channel information above:

$$y_s = y_2 - y_0 = 3.29 - 5.4 = -2.11\ ft$$

Value is negative, so there is no contraction scour. <u>Thus, total pier scour is 2.41 ft due to local scour only.</u>

G2 - Coarse Granular Soil

This classification includes gravels, sandy gravels, clayey gravels, and silty gravels with an average minimum D_{50} of 40 mm and a uniformity coefficient of 4 or greater. Included are soils with Unified Classifications of GW, GC, and GM. These soils exhibit moderate erosion resistance due to their coarse particle size and well graded distribution, as well as a tendency to develop some natural armoring. Such geologic materials may be encountered throughout the Piedmont, Highlands, and Ridge & Valley provinces.

Abutments in Erosion Class G2

Coarse granular soils can exhibit either live-bed or clear-water scour. The bridge must first be examined to determine which of these two phenomena is occurring. The procedure for distinguishing between live-bed and clear-water conditions is detailed in Example Problem 3 within the "Abutments in Erosion Class G1" section (see above).

If clear-water conditions exist, then the NCHRP 24-20 method may be used to estimate scour depth for abutments. This procedure was previously shown in Example Problem 1 within the "Abutments in Erosion Class G1" section (see above). If live-bed scour is occurring, the procedure shown in Example Problem 4 within the "Abutments in Erosion Class G3" section is recommended (see below).

Piers in Erosion Class G2

Once it has been determined whether the bridge is undergoing live-bed or clear-water scour, an estimation of scour depth can be made for the pier. If the bridge is undergoing clear-water scour, HEC-18 Eq. 7.34 is recommended to calculate predicted scour. This procedure was previously demonstrated in Example Problem 2 within the "Piers in Erosion Class G1" section (see above). If live-bed scour is occurring, HEC-18 eq. 7.1 may be used as shown in Example Problem 5 within the "Piers in Erosion Class G3" section (see below).

Contraction Scour in Erosion Class G2

To estimate total scour in the vicinity of a pier, the effect of contraction scour should be added to the local scour. If the bridge is undergoing clear-water scour, then HEC-18 Eqs. 6.4 and 6.5 are recommended. This procedure was previously demonstrated in Example Problem 3 within the "Contraction in Erosion Class G1" section (see above). If live-bed scour is occurring, HEC-18 Eqs. 6.2 and 6.3 may be used as shown in Example Problem 6 within the "Contraction in Erosion Class G3" section (see below).

G3 – Fine to Medium Granular Soil

This classification includes cohesionless granular soils such as sand, silt and gravel, and mixtures of these soils that do not meet the requirements of ‘Coarse Granular Soil’ as described in class G2. Included are soils with Unified Classifications of SW, SP, SM, GW, GP, GM, GC, ML, and MH. This kind of soil dominates streambeds throughout the

Coastal Plain province. It may also be encountered within the larger valleys of the other provinces, where stream gradients are mild.

Note that if the bridge is located within the Coastal Plain or Non-glaciated Piedmont provinces, scour depth in erosion class G3 may also be estimated using envelope curves. Please refer to Module 3 of the SEM for further guidance.

<u>Abutments in Erosion Class G3</u>

For abutments in granular soil, the NCHRP 24-20 method for total scour (Ettema et al, 2011) is available. Both clear-water and live-bed equations are provided in this method. Thus, it is first necessary to determine whether live-bed or clear-water conditions are present. This requires a calculation of the critical velocity based on median size particles (D_{50}), which is then compared with the design storm velocity. The procedure is as follows:

$$V_c = K_u y^{1/6} D^{1/3} \qquad \text{(Eq. 6.1, HEC-18)}$$

Where:

V_c = Critical velocity above which bed material of size D and smaller will be transported, ft/s
y = Average depth of flow upstream of the bridge, ft
D = Particle size for V_c (typically assumed to be D_{50}), ft
K_u = 11.17 for English units (6.19 for SI units)

If $V_c < V$, then live-bed conditions prevail. Note that the NCHRP 24-20 method further stipulates that for live-bed, the length of embankment must be at least 75 percent of the floodplain width. For ratios of embankment length to flood plain of less than 0.75, clear-water conditions typically prevail.

The relationships for analyzing live-bed conditions are described by HEC-18 Eqs. 8.3 through 8.5, and these will now be presented (Note that the procedure for clear-water scour was previously illustrated in Example Problem 1 above in the “Abutments in Erosion Class G1” section). Scour depth, y_s, for live-bed is computed as follows:

$$y_s = y_{max} - y_0 \qquad \text{(Eq. 8.4, HEC-18)}$$

$$y_{max} = \alpha_A y_c \qquad \text{(Eq. 8.3, HEC-18)}$$

$$y_c = y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7} \qquad \text{(Eq. 8.5, HEC-18)}$$

Where:

y_{max} = Maximum flow depth resulting from abutment scour, ft
y_0 = Flow depth prior to scour, ft

y_1 = Upstream flow depth, ft
α_A = Amplification factor for live-bed conditions (see HEC-18 Figure 8.9 and 8.10)
y_c = Flow depth including live-bed contraction scour, ft
q_1 = Upstream unit discharge, Q/w, ft^2/s
q_{2c} = Unit discharge in the constricted opening, Q/w, ft^2/s

Example Problem 4: A bridge is located in the glaciated part of the Piedmont province. The site was analyzed, and various geotechnical and hydrologic/hydraulic data were determined. These are summarized as follows. The bridge has one pier with a circular shape and a width of 5 ft. The flow velocity for the design storm was determined to be 12.8 fps under the bridge and 7.1 fps approaching the bridge. The depth of flow approaching the bridge is 4.3 ft and under the bridge is 4.8 ft. Channel widths are 50 ft under the bridge and 91 ft upstream of the bridge. The flow is 2,750 cfs. A grain size analysis determined that the D_{50} was 0.09 ft. The specific gravity of the soil is assumed to be 2.65. The skew is measured to be 11 deg and the channel slope is 0.01.

Summarizing the input variables: $y = y_0 = 4.3$ ft; D = 0.09 ft; $K_u = 11.17$; Q = 2750 ft^3/s; W = 50 (bridge opening); W = 91 (upstream).

Before applying the NCHRP 24-20 formulas, check for live-bed or clear-water scour.

$$V_c = K_u y^{1/6} D^{1/3} = 11.17 * 4.3^{1/6} * 0.09^{1/3} = 6.38\ fps$$

$V_c < V$ (6.38 < 7.1), indicating live-bed scour is occurring.

Now the unit discharges are calculated:

$$q_{2c} = \frac{Q}{w} = \frac{2750}{50} = 55\,\frac{ft^3/s}{ft} \qquad \text{(unit discharge at bridge opening)}$$

$$q_1 = \frac{Q}{w} = \frac{2750}{91} = 30.22\,\frac{ft^3/s}{ft} \qquad \text{(unit discharge upstream)}$$

The flow depth including live-bed scour is then calculated:

$$y_c = y_1\left(\frac{q_{2c}}{q_1}\right)^{6/7} = 4.3 * \left(\frac{55}{30.22}\right)^{\frac{6}{7}} = 7.18 \text{ ft}$$

Contraction ratio is, $\frac{q_{2c}}{q_1} = \frac{55}{30.22} = 1.8$

α_A is found in HEC-18 Figure 8.10 (see above) for wingwall abutments as: $\alpha_A = 1.35$

y_{max} is next calculated as follows:

$$y_{max} = \alpha_A y_c = 1.35 * 7.18 = 9.7\ ft$$

Finally, depth of scour is then computed as:

$$y_s = y_{max} - y_0 = 9.7 - 4.3 = 5.4\ ft$$

<u>The total abutment scour is therefore 5.4 ft.</u>

Piers in Erosion Class G3

For piers founded in granular soil, the "HEC-18 Equation" is available. It is derived from the Colorado State University (CSU) equation, which has demonstrated generally good correlation with field scour observations throughout the U.S. The relation appears as Eq. 7.1 in HEC-18 and is shown below:

$$\frac{y_s}{y_1} = 2.0K_1K_2K_3\left[\frac{a}{y_1}\right]^{0.65} {Fr_1}^{0.43}$$ (Eq. 7.1, HEC-18)

Where:

y_s = Scour depth, ft
y_1 = Flow depth directly upstream of the pier, ft
K_1 = Correction factor for pier nose shape from Table 7.1 (below)
K_2 = Correction factor for angle of attack of flow from Table 7.2 (below) or Eq. 7.4:

$$K_2 = \left(Cos\theta + \frac{L}{a}Sin\theta\right)^{0.65}$$ (Eq. 7.4, HEC-18)

θ = angle of attack of the flow, deg

K_3 = Correction factor for bed condition (from Table 7.3 below)
a = Pier width, ft
Fr_1 = Froude Number directly upstream of the pier

$$Fr_1 = \frac{V_1}{(gy_1)^{1/2}}$$

V_1 = Mean velocity of flow directly upstream of the pier, ft/s
g = Acceleration due to gravity (32.2 ft/s^2)

Table 7.1 (HEC-18 5th ed.) Correction Factor, K_1, for Pier Nose Shape	
Shape of Pier Nose	K_1
Square nose	1.1
Round nose	1.0
Circular cylinder	1.0
Group of cylinders	1.0
Sharp nose	0.9

Table 7.2 (HEC-18 5th ed.) Correction Factor, K_2, for Angle of Attack, θ, of the Flow			
Angle	L/a = 4	L/a = 8	L/a = 12
0	1.0	1.0	1.0
15	1.5	2.0	2.5
30	2.0	2.75	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5.0
Angle = skew angle of flow, L = Length of pier, if L/a larger than 12, use L/a=12			

Table 7.3 (HEC-18 5th ed.) Increase in Equilibrium Pier Scour Depths, K_3, for Various Bed Conditions.		
Bed Condition	Dune Height ft	K_3
Clear-Water Scour	N/A	1.1
Plane bed and Antidune flow	N/A	1.1
Small Dunes	10>H≥2	1.1
Medium Dunes	30>H≥10	1.2 to 1.1
Large Dunes	H≥30	1.3

***Example Problem 5*:** Continuing the analysis of the bridge in Example Problem 4 above, assume that pier scour must also be estimated. Since it has already been established that the bridge is experiencing live-bed scour, the HEC-18 Equation will be used. The relevant data are repeated for convenience:

y_1 = 4.3 ft; a = 5 ft, cylindrical pier; θ = 11 deg;
V_1 = 7.1 fps (use upstream velocity) No dunes

K factors will be calculated first,

From Table 7.1 (above), K_1 for cylindrical piers is 1.0.

The pier is a circle (cylindrical), so the pier width, a, and length, L, are the same.

$$K_2 = \left(Cos\theta + \frac{L}{a} Sin\theta\right)^{0.65} = \left(\cos(11) + \frac{1}{1}\sin(11)\right)^{0.65} = 1.11$$

From Table 7.3 (above) for Antidune flow, use K_3 = 1.1

$$Fr_1 = \frac{V_1}{(gy_1)^{\frac{1}{2}}} = \frac{7.1}{(32.2 * 4.3)^{\frac{1}{2}}} = 0.603$$

Therefore, the scour to depth ratio is:

$$\frac{y_s}{y_1} = 2.0 K_1 K_2 K_3 \left[\frac{a}{y_1}\right]^{0.65} {Fr_1}^{0.43} = 2.0 * 1.0 * 1.11 * 1.1 * \left[\frac{5}{4.3}\right]^{0.65} * 0.603^{0.43} = 2.167$$

It follows that the depth of live-bed pier scour is:

$$y_s = 2.167 * y_1 = 2.167 * 4.3 = 9.3\ ft$$

Thus, local pier scour is 9.3 ft.

Contraction Scour in Erosion Class G3

To estimate total scour in the vicinity of a pier, the effect of contraction scour should also be added to the local scour computed above. For granular soil, either live-bed or clear-water conditions may occur, so the critical velocity must be checked and compared to the storm velocity. This procedure was previously shown “Abutments in Erosion Class G3” and Example Problem 4 (see above).

If clear-water conditions are occurring, then Eqs. 6.4 and 6.5 in HEC-18 should be used to estimate contraction scour, y_s . This procedure was previously described in "Contraction in Erosion Class G1" and Example Problem 3 (see above). If live-bed conditions prevail, then the equations developed by Laursen (1960) are recommended

$$\frac{y_2}{y_1} = \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} \qquad \text{(Eq. 6.2, HEC-18)}$$

$$y_s = y_2 - y_0 \qquad \text{(Eq. 6.3, HEC-18)}$$

Where:

y_s = Average contraction scour depth, ft
y_1 = Average depth in the upstream main channel, ft
y_2 = Average depth in the contracted section, ft
y_0 = Existing depth in the contracted section before scour, ft
Q_1 = Flow in the upstream channel transporting sediment, ft^3/s
Q_2 = Flow in the contracted channel, ft^3/s
W_1 = Bottom width of the upstream main channel that is transporting bed material, ft
W_2 = Bottom width of main channel in contracted section less pier width(s), ft
k_1 = Exponent determined below

V_*/ω	k_1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

V_* = $(\tau_o/\rho)^{1/2} = (g\, y_1\, S_1)^{1/2}$ Shear velocity in upstream section, ft/s
ω = Fall velocity of bed material based on the D_{50} (see Fig. 6.8). For fall velocity in English units (ft/s), multiply ω in m/s by 3.28.
g = Acceleration of gravity (32.2 ft/s^2)
S_1 = Slope of energy grade line of main channel, ft/ft
τ_o = Shear stress on the bed, lb/ft^2
ρ = Density of Water (1.94 $slugs/ft^3$)

Note that HEC-18 defines four general contraction scour cases and provides technical notes to help explain each one. Please refer to Pages 6.2 to 6.8, HEC-18, 5th Ed.

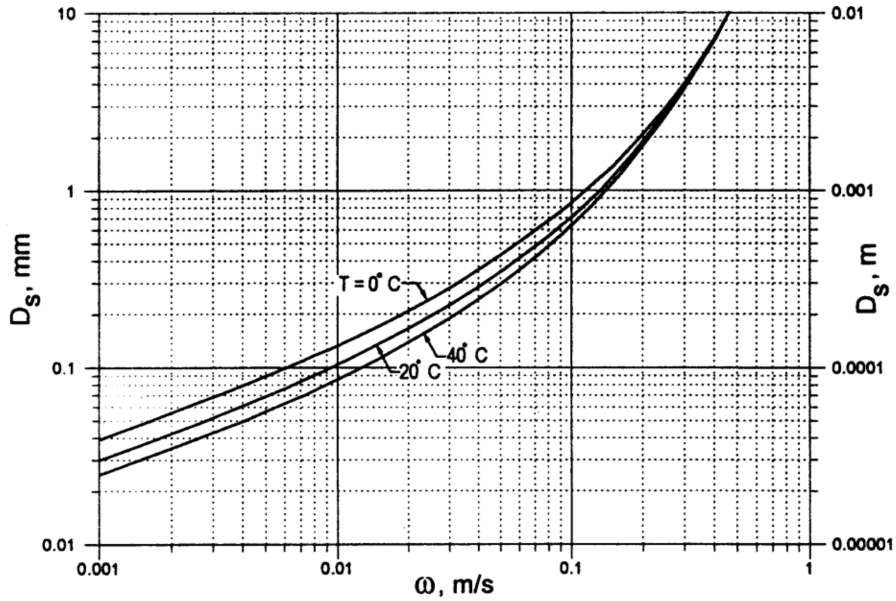


Figure 6.8 (from HEC-18 5th ed.) Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Example Problem 6: Continuing analysis of the bridge in Example Problems *4 and 5* above, now estimate the contraction scour in the vicinity of the pier. The relevant data are repeated for convenience:

$y_0 = y_1 = 4.3$ ft; $Q_1 = Q_2 = 2750$ cfs; $W_1 = 91$ ft; $W_2 = 50 - 5 = 45$ ft; $S_1 = 0.01$

$D_{50} = 0.09$ ft = 27.4 mm

To determine exponent, k_1, first calculate V^*

$V^* = (g\, y_1\, S_1)^{1/2} = (32.2*4.3*0.01)^{1/2} = 1.18$ ft/s

From Fig. 6.8, estimate fall velocity: ω = 0.5 m/s * 3.28 = 1.6 ft/s

Ratio $V^*/\omega = 1.18/1.6 = 0.74$, so from the HEC-18 table, $k_1 = 0.64$

Next compute y_2:

$y_2 = 4.3\left(\frac{2750}{2750}\right)^{6/7}\left(\frac{91}{45}\right)^{0.64} = 6.75\, ft$ (average depth in the contracted section)

$y_s = 6.75 - 4.8 = 1.95\, ft$ (average contraction scour depth)

In summary, total pier scour is the sum of local and contraction scours:

<u>Thus, total pier scour = 9.3 ft + 1.95 ft = 11.25 ft</u>

R1 - Weak Rock

This class includes all bedrock types not meeting the requirements of ‘Sound Bedrock’ as described in classification of in **Table 4**. Weak rock typically exhibits a higher fracture frequency, more weathering, lower strength, or a combination of these. Nevertheless, the amount of erosion observed at bridges founded on weak rock is normally minor.

In New Jersey, most situations involving bridges on R1 beds will occur in the Piedmont province. Here the predominant bedrock is the Passaic Formation, formerly known as the Brunswick Formation. It consists mostly of alternating beds of red-brown mudstone, shale, and sandstone. Although the rock is moderately sound at many locations and may classify as Sound Rock R0, it can also be weaker and/or weathered near the surface, in which case it would classify as R1. The latter condition is more common in the southern, non-glaciated section of the Piedmont.

Abutments in Erosion Class R1

None of the HEC-18 relations have shown adequate correlation for scour evaluation of abutments in R1 class beds, so the following empirical depth method is recommended. Determine and compare the elevations of the top of rock with the elevations of the foundation footings. If the footing bottom on average is at least 1 foot below the rock surface, the geotechnical risk is considered low. Consult Module 2 of the Scour Evaluation Model.

Piers in Erosion Class R1

The pier scour equation for erodible rock by Annandale (2006) in the 5th edition of HEC-18 may be appropriate for R1 rocks that occur in New Jersey. The relationship correlates scour depth with a parameter known as the erodibility index, K, which depends on a number of rock mass properties including intact strength, as well as joint spacing, condition, and orientation. The method further assumes that the predominant scour mechanism will be quarrying and plucking rather than abrasion. The procedure appears as equations 7.37 to 7.40 in HEC-18.

In practice, erodibility index K is reported to range rather widely from 0.1 (very poor rock) to 10,000 (very good rock). However, some of the input properties required to compute the index are difficult to measure directly from drill cores and thus are usually “guessed.” Since most cases of scour in R1 beds in the State will occur in the Passaic mudstones and shales located in the Piedmont, the following values of K are provided:

K for R1 rock of Passaic Formation: Probable Range = 15 to 40+
Typical Average = 25

Once the value of K has been estimated, scour depth y_s is computed using HEC-18 equations 7.38, 7.39, and 7.40. **It is noted that these equations are computed using the S.I. system.**

$P_c = (K)^{0.75}$ (Eq. 7.38, HEC-18)

$P_a = 7.853 * \rho(\frac{\tau}{\rho})^{3/2}$ (Eq. 7.39, HEC-18)

*for P_a in KW/m^2, divide answer by 1000

$\tau = \gamma * y * S_f$ (Eq. 4.3, HEC-18)

$\frac{P}{P_a} = 8.42 * e^{-0.712*(\frac{y_s}{b})}$ (Eq. 7.40, HEC-18)

Where:

K	=	Erodibility Index, a measure of the tendency of rock to exhibit quarrying and plucking
P_c	=	Critical stream power, W/m^2
P_a	=	Stream power of approaching water, W/m^2
P	=	Stream power at pier, W/m^2
y_s	=	Depth of scour hole, m
b	=	Pier width perpendicular to flow direction, m
$\frac{y_s}{b}$	=	A ratio of the estimated scour depth to the pier width. As this value increases, the stream power, P, will decrease until P = P_c , at which point pier scour ceases.
S_f	=	Slope of the energy grade line, m/m
y	=	Design Flow Depth, m
γ	=	Unit weight of water (9800 N/m^3)
τ	=	Approach Shear Stress – a measure of the scour-inducing force per unit area in the vicinity of the pier, N/m^2.
ρ	=	Density of Water – 1000 kg/m^3.

Example Problem 7: A bridge located in the Piedmont province is founded in Passaic mudstone. There is one pier in the middle of the bridge with a width of 4 ft. The rock is considered to be of average strength. Slope of riverbed is found to be 0.008 ft/ft. The flow for the design storm is 3,200 ft^3/s, the velocity upstream is 5.5 ft/s, and the depth is 13.0 ft.

To find the estimated maximum scour, the recommended procedure is to set P_c equal to P. Scour will begin when the power, P, is greater than the critical power, P_c. The actual power will decrease until it equals the critical power, at which point scour will stop. This is because the ratio of depth of scour to pier width increases as scour increases. When this ratio increases, the P/P_a ratio decreases. It is assumed that quarrying and plucking is not occurring in the approach section of the river, so the approach power, P_a does not decrease.

First, convert to metric:

Depth, y = 13 ft * .3048 = 3.96 m

Pier width, b = 4 ft * 0.3048 = 1.22 m

The first step is to choose the K value:
For average mudstone within the Piedmont province, use K = 15. So compute P_c as,

$$P_c = (K)^{0.75} = (25)^{0.75} = 11.18 = \frac{kW}{m^2}$$

The shear stress must be calculated in order to determine the approach power, P_a:

$$\tau = \gamma * Y * S_f = 9800 * 3.96 * 0.008 = 310.46\, N/m^2$$

$$P_a = 7.853 * \rho(\frac{\tau}{\rho})^{3/2} = 7.853 * 1000 * \frac{\left(\frac{310.46}{1000}\right)^{\frac{3}{2}}}{1000} = 1.358 \frac{kW}{m^2}$$

*for P_a in KW/m^2, P_a was divided by 1,000

$$\frac{P}{P_a} = 8.42 * e^{-0.712*(\frac{y_s}{b})}$$

In order to solve for the expected maximum scour depth, it is convenient to create a table such like the one shown below. A spreadsheet program can be used as follows:

The first column is simply a series of estimations.
The second column is the result of Eq. 7.40 from HEC-18.
The third column is the product of P/P_a and P_a (Eq. 7.39, HEC-18).
The fourth column determines if maximum scour occurs at that particular scour to pier width ratio.
The final column is the depth of expected scour, which is calculated by multiplying column one by the pier width.

y_s/b	P/P_a	P (kW/m^2)	P > P_c	y_s (m)
0.03	8.242	11.197	yes	0.037
0.05	8.126	11.034	no	0.061
0.1	7.841	10.649	no	0.122
0.2	7.302	9.916	no	0.244
0.3	6.800	9.235	no	0.366
0.4	6.333	8.600	no	0.488

2.718282	1.358	1.22	11.18
e	P_a	b	P_c

Finally, the estimated scour is found to be about 0.05 m, or 0.05/0.3048 = 0.2 ft

Appendix B: Supplementary Materials

Appendix B1: USGS Envelope Curves Investigated

Envelope Curves Developed in South Carolina

In the past decade, the South Carolina Department of Transportation (SCDOT), in conjunction with the U.S. Geological Survey (USGS), has pioneered the development and application of envelope curves in the determination of scour depths associated with bridge stream crossings.

Scour (be it clear-water or live-bed) typically has three separate components: abutment-scour, contraction-scour and pier-scour. Over the past 15 years, the SCDOT and USGS have published the following documents which are addressed in this study.

1. “Trends of Abutment-Scour Prediction Equations Applied to 144 Field Sites in South Carolina,” (Benedict et al, 2006).
2. “Development and Evaluation of Live-Bed Pier and Contraction Scour Envelope Curves in the Coastal Plain and Piedmont Provinces of South Carolina,” Report #2009-5099, (Benedict and Caldwell, 2009).
3. “Development and Evaluation of Clear-Bed Pier and Contraction Scour Envelope Curves in the Coastal Plain and Piedmont Provinces of South Carolina,” Report #2005-5289, (Benedict and Caldwell, 2006).
4. “A Pier-Scour Database: 2,453 Field and Laboratory Measurements of Pier Scour” (Benedict and Caldwell, 2014).
5. “The upper bound of pier scour in laboratory and field data” (Benedict and Caldwell, 2016a).
6. “The upper bound of abutment scour in laboratory and field data” (Benedict and Caldwell, 2016b).
7. “The South Carolina Bridge-Scour Envelope Curves” (Benedict et al, 2016).

Excerpts from these studies pertinent to this investigation are provided below. Note that all data and envelope curves presented in this appendix are for non-tidal bridges.

Abutment-Scour Prediction Equations (Clear Water)

In the late 1990’s, field measurements of abutment-scour depth were made at 144 bridges (65 Piedmont, 79 Coastal). A total of 209 measured scour depths were taken at the respective bridges. Observed clear-water abutment-scour depths ranged from 0 to 23.6 feet. The measured data represent the maximum clear-water abutment-scour depth that occurred at each bridge since construction. In general, observations of abutment-scour were located in close proximity to the abutment toe and outside of the main channel.

The measured abutment-scour depths in this study represent the total scour, including effects from contraction and pier scour. However, pier scour effects are likely negligible at many sites because of the small pier widths (1 to 2.3 ft) associated with 85 percent of the bridge sites studied. The median grain sizes (in millimeters) of bed material were 0.073 mm in the Piedmont area and 0.180 mm in the Coastal Plain.

Of the numerous variables that are believed to influence the development of abutment scour (i.e., flow velocity, flow depth, sediment size, sediment gradation, embankment length, abutment shape, embankment skew, and channel geometry), the embankment length blocking flow was the only one found to be a strong indicator of scour potential. The data showed that as embankment length increased, the upper range of abutment-scour depth also increased.

Envelope curves of observed abutment-scour depth and abutment length were developed with the field data to assess the upper range of observed scour depth for a given embankment length. Figure 1 in the study relates the observed clear-water abutment-scour depth and the 100 year flow embankment length in the Piedmont area, and Figure 2 represents the same variables in the Coastal Plain. These plots were utilized to assess predicted scour depths in New Jersey. Note that the plot for the Piedmont province in was also found applicable for New Jersey's Non-Glaciated Highlands province.

The equation utilized in Figure B1.1 for the Piedmont is as follows:

$$Y_s = -0.000009\,L^2 + 0.0276L \quad \text{for } L \leq 950 \text{ ft.}$$

Where: L = 100-year-flow embankment length blocking flow (ft)

Y_s= Estimate of abutment scour depth along envelope curve, (ft)

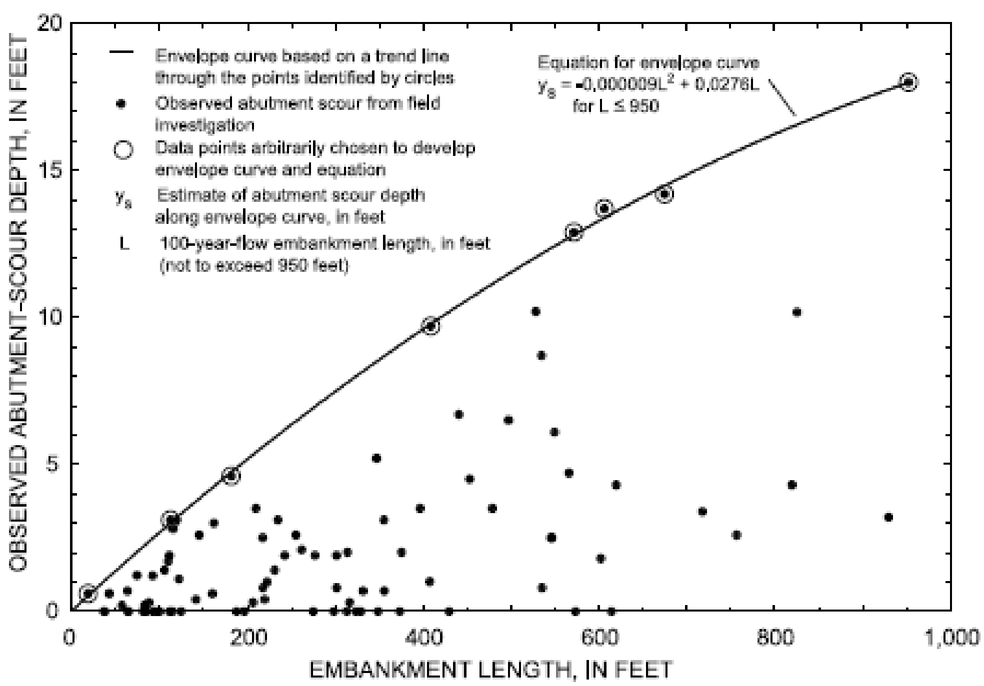


Figure B1.1 – Relation of Observed Clear-Water Abutment-Scour Depth and the 100-Year-Flow Embankment Length in the Piedmont of South Carolina (from Benedict and Caldwell, 2006, Figure 3; originally from Benedict, 2003)

The equation utilized in Figure B1.2 for the Coastal Plain is as follows:

$$Y_s = 0.0338L \qquad \text{when } L \leq 426 \text{ ft}$$

$$Y_s = 14.4 + 0.00131\,(L - 426) \qquad \text{when } L > 426 \text{ ft}$$

Where Y_s and L are defined as above.

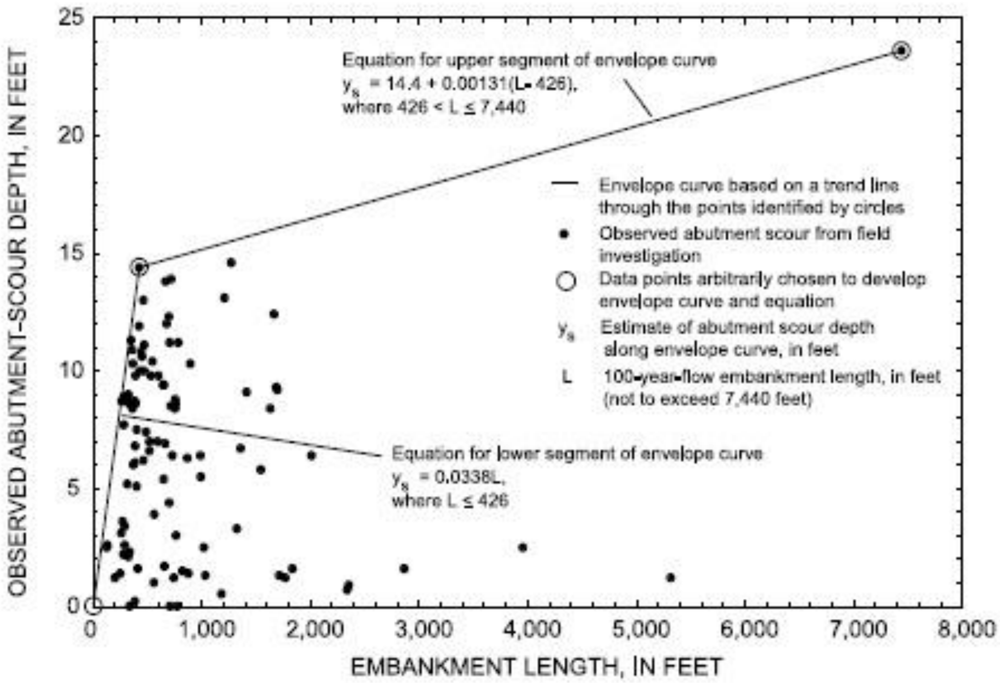


Figure B1.2 – Relation of Observed Clear-Water Abutment-Scour Depth and the 100-Year-Flow Embankment Length for the Coastal Plain of South Carolina (Figure 4 in Benedict and Caldwell, 2006; originally from Benedict, 2003)

The paper also indicates median embankment lengths of 276 feet and 557 feet, respectively, in the Piedmont and Coastal Plains of South Carolina, which agrees well with conditions in New Jersey.

<u>Evaluation of Live-Bed Pier and Contraction-Scour Envelope curves in South Carolina (Coastal Plain and Piedmont Provinces)</u>

151 measurements of live-bed pier-scour depth ranging from 1.7 to 16.9 feet, and 89 measurements of live-bed contraction-scour depth ranging from 0 to 16.1 feet were taken at 78 bridges in the Piedmont and Coastal Plain Physiographic Provinces of South Carolina. Of all variables believed to be associated with scour depth, the strongest explanatory variable was pier width (b), and an envelope curve for assessing the upper band of live-bed pier scour was developed using pier width as the primary explanatory variable.

Researchers agree that pier-scour depth is strongly related to pier width. According to Richardson and Davis (2001), “Pier width has a direct influence on depth of local scour. As pier width increases, there is an increase in scour depth.” Melville and Coleman

(2000) reported "…the depth of scour at a pier is strongly dependent on the width of the pier." After analyzing 224 field measurements of pier scour from the National Bridge Scour Database (NBSD), Mueller (1996) concluded, "…pier width shows the strongest correlation with pier scour." (p.43).

Relations in live-bed contraction-scour data also were investigated, and several envelope curves were developed using the geometric-contraction ratio as the primary explanatory variable.

Analysis of stream flow records and information related to the age of the respective bridges (p.14) "supports the assumption that the scour data collected in this investigation represent scour resulting from large floods. Therefore, the data likely will provide a good indicator for anticipated ranges of scour related to flows near the 100-year flow magnitude at bridges in South Carolina."

For the 151 measurements of pier scour in this study, the median stream bed grain size (D_{50}) ranged from 0.24 to 1.7 millimeters (mm), and the pier widths range from 0.8 to 9 feet.

Author's Note:

The grain sizes in this study are similar to those in the Coastal and Piedmont areas of New Jersey, as well as the ranges employed by researchers using laboratory flumes to develop scour depth prediction models utilized in the HEC-18 Manual. In addition, the range of pier widths is similar to that found on the critical bridge scour list in New Jersey.

An envelope curve relating pier scour depth (Y_s) versus pier width (b) generated in the study from South Carolina data is given in Figure B1.3 and is utilized to calculate pier scour depths in New Jersey. The equation used is as follows:

$$Y_s = 1.1b + 3.34$$

Where: Y_s = pier scour depth (ft)
b = pier width (ft); $b \leq 6$ ft

The use of the equation is limited to a pier width of 6 feet or less. The equation is applicable to piers with moderate skews (15 degrees or less) and spacings of 5 pier widths or greater.

For pier widths greater than 6 feet (and up to 14 feet), the paper utilizes the equation below which was developed from NBSD based on 92 measurements of live-bed pier scour collected at 16 bridges in 9 different States (Alaska, Arkansas, Colorado, Georgia, Indiana, Louisiana, Ohio, Minnesota, and Missouri) with grain sizes similar to those of the South Carolina field data having a range from 0.12 to 1.82mm with a median size of 0.54 mm. The pier widths range from 2.5 ft to 18.1 ft with a median width of 9.3 ft. The equation is as follows, and is also found in Figure B1.3:

$$Y_s = 1.5b + 4.1; \; b \leq 14 \text{ ft}$$

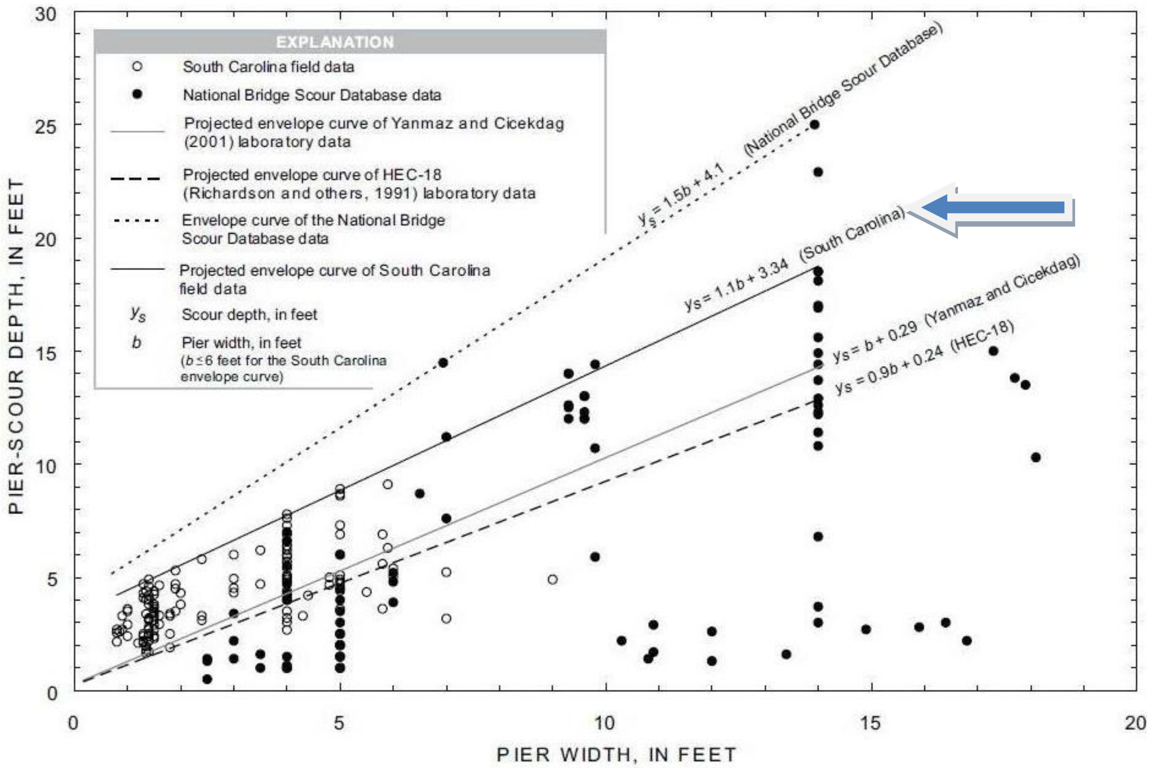


Figure B1.3 – Relation of Live-Bed Pier-Scour Depth and Pier Width for Selected Data from the National Bridge Scour Database and Selected Sites in South Carolina. Envelope Curves for Selected Laboratory and Field Data also are Shown (Fig. 40, Benedict & Caldwell, 2009)

Regarding live-bed contraction scour envelope curves in South Carolina, the authors indicate (Figure B1.4) that scour processes (i.e. clear-water and live-bed) are similar and that the maximum contraction scour depths are similar, as well. Live-bed scour typically occurs in the main channel where velocities are high and loose sediments are available for transport. Clear-bed scour typically occurs on the flood plain where velocities are low and soils are stable.

For the contraction scour studies, the D_{50} grain size ranged from 0.18 mm to 1.7mm, with a median value of 0.59 mm.

The best representation of contraction scour depth found in this study, which is applicable for both the Piedmont and Coastal Plain, is as follows:

$$Y_s = 24.7\ m^2 + 1.3\ m$$

Where: Y_s = contraction scour depth (ft)

m = contraction ratio = 1 – b/B

Where: B = approach top width of water course (ft)

b = bridge opening top width (ft)

The above equation is applicable for $m \leq 0.82$

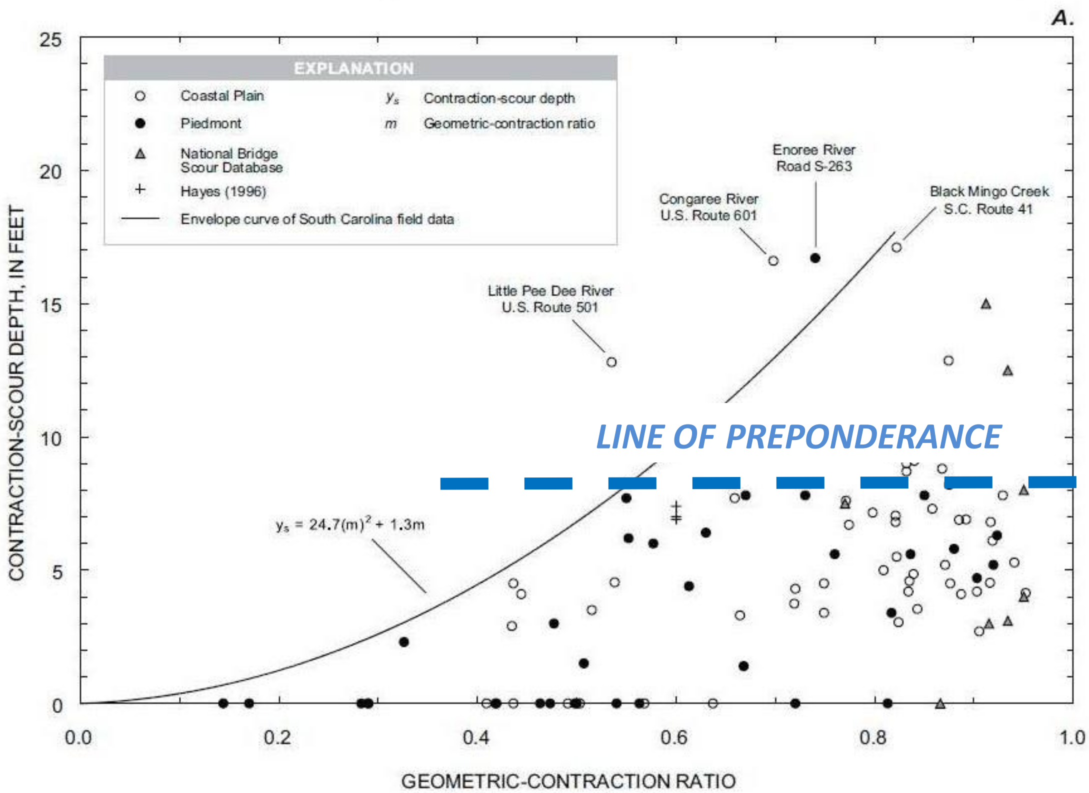


Figure B1.4 – Relation of the geometric-contraction ratio and measured live-bed contraction-scour depth with envelope curves for the most likely estimate of measured scour depth at selected sites in South Carolina and selected data from the National Bridge Scour Database and Hayes (1996) (modified from Figure 71A in Benedict and Caldwell, 2009).

Additional data extracted from the South Carolina studies related to live bed contraction scour as a function of contraction ratio (m) provides relationships for contraction ratios equal or less than 0.6 and greater than 0.6 (see Figure B1.5). The equations are as follows:

$Y_s = 0.3 + 11.75(m)$ when $m \leq 0.6$
$Y_s = 1 + 22.9(m)$ when $m > 0.6$

Where: Y_s = contraction scour depth (ft)
m = contraction ratio

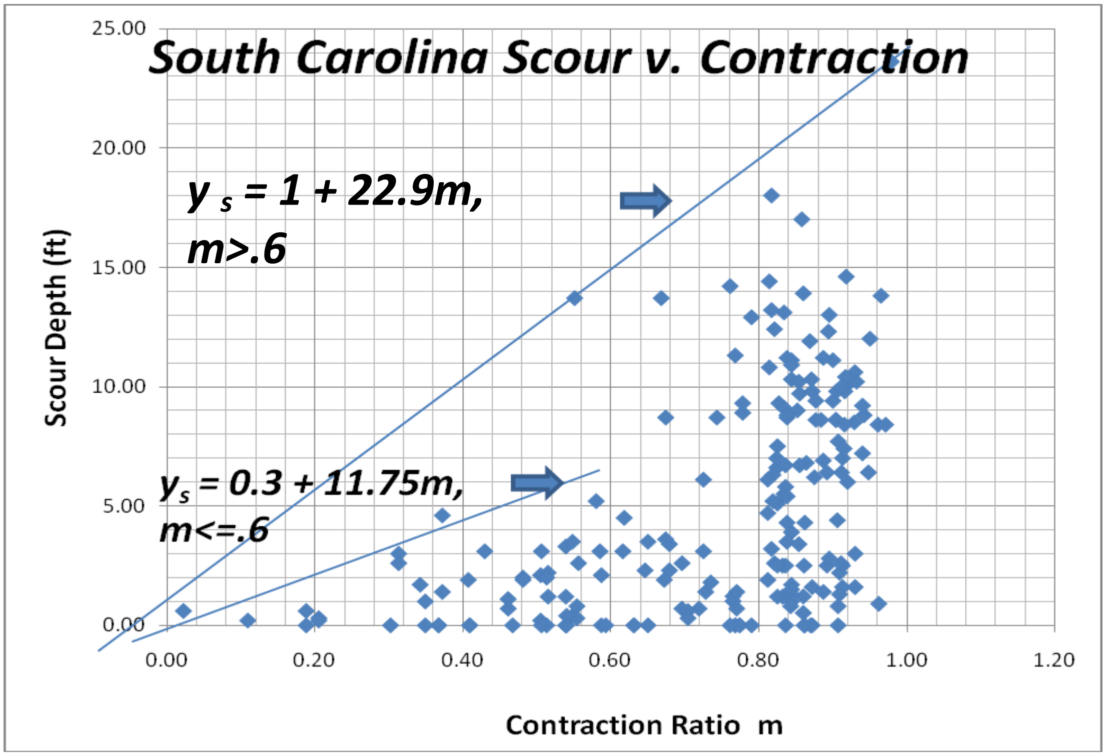


Figure B1.5 – South Carolina Scour versus Contraction Ratio (data from Benedict and Caldwell, 2009)

Evaluation of Clear-Water-Pier and Contraction Scour Envelope Curves in South Carolina (Coastal Plain and Piedmont Province)

In order to assess clear-water pier scour, 87 measurements of scour were conducted at 53 bridges in the Piedmont Provinces of South Carolina. The median grain size was 0.105 mm with a range between 0.062mm and 0.990mm. The maximum observed pier scour depth was 8 feet. In addition, 92 measurements of clear-water pier scour were conducted at 63 bridges in the Coastal Plain Province. At these bridges, the median grain size (in mm) was 0.162 mm with a range between 0.062mm and 0.556 mm. The maximum observed pier scour depth was 1.8 feet.

Regarding clear-water contraction scour, a total of 75 measurements were taken at 52 bridges in the Piedmont area, and 64 measurements at 53 bridges in the Coastal Plain area. The measured contraction scour depths in the Piedmont area ranged from 0 to 4.5 feet, whereas the contraction scour depths in the Coastal Plain area ranged from 0 to 3.9 feet.

Envelope curves for pier-scour and contraction-scour were again developed utilizing pier width (b) and geometric contraction ratio (m) as the primary explanatory variables. These curves are shown in Figures B1.6 and B1.7, respectively. The envelope equations developed were as follows:

Clear-water Pier Scour

$Y_s = 1.5b + 0.5$

Where: Y_s = pier scour depth (ft)

b = pier width (in feet); $b \leq 6$ ft

Clear-water Contraction Scour

$Y_s = -6m^2 + 10m + 0.6$

Where: Y_s = contraction scour depth (in ft)

m = contraction ratio (as previously defined)

The above equation is applicable for $m \leq 0.95$

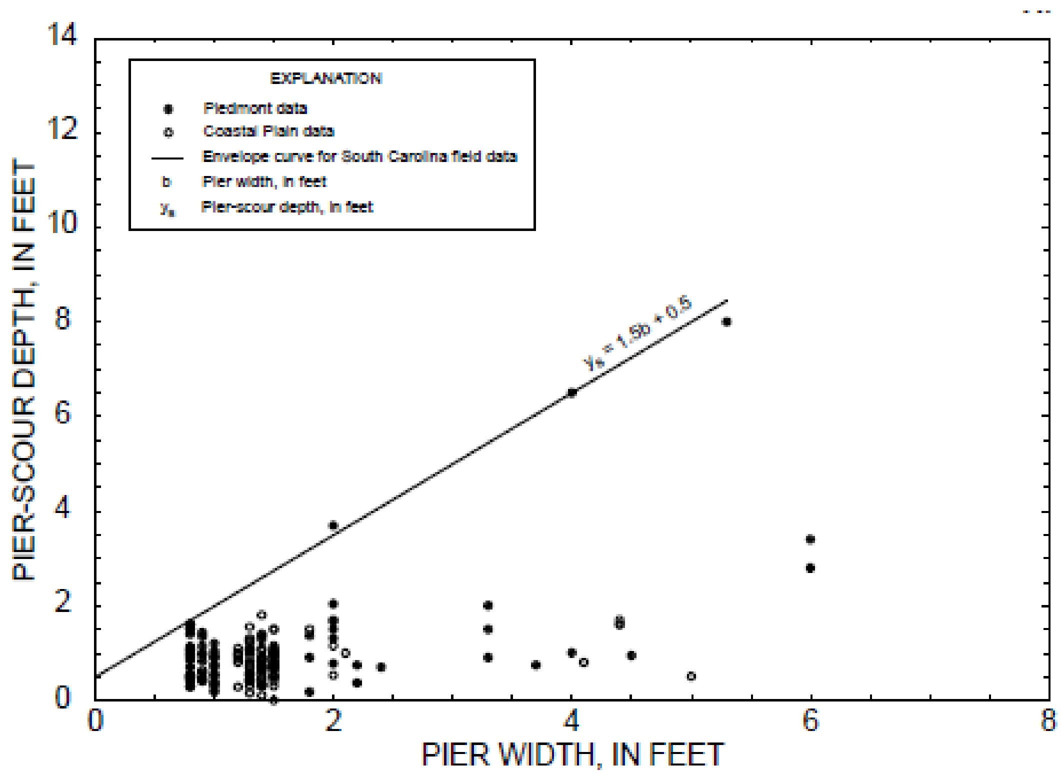


Figure B1.6 – Relation of pier width to (A) measured scour depth for selected sites in the Coastal Plain and Piedmont Physiographic Provinces of South Carolina (Figure 49A in Benedict and Caldwell, 2006).

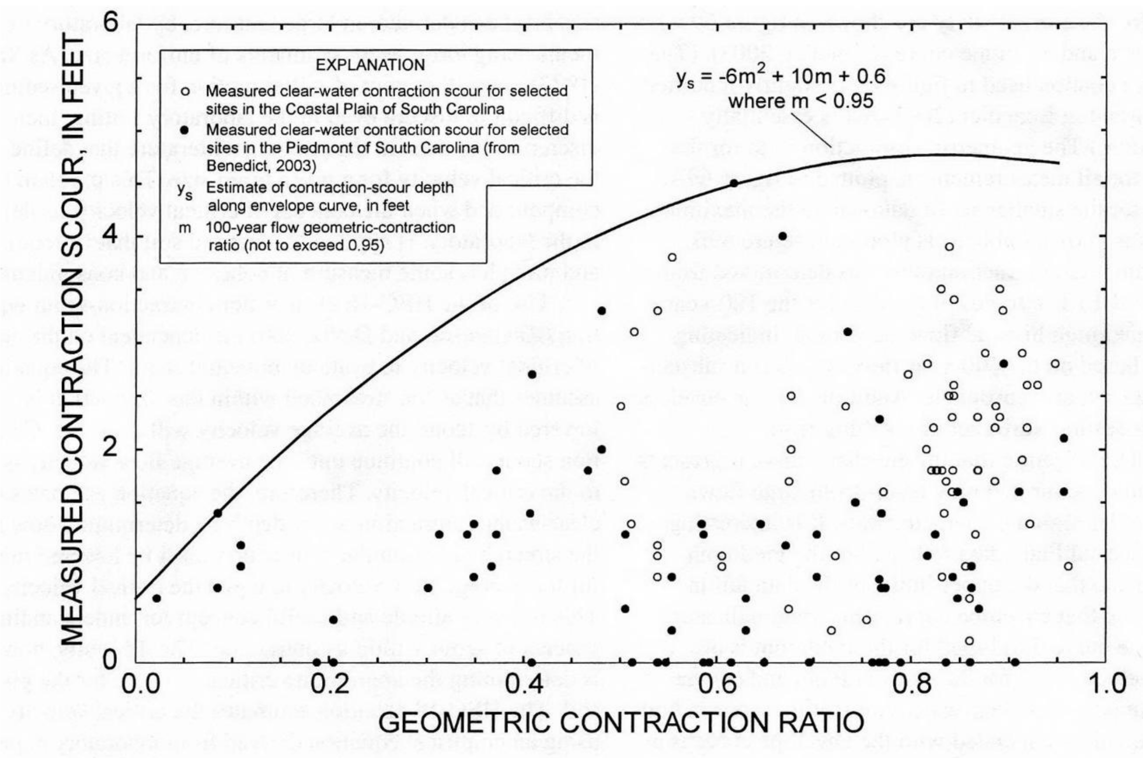


Figure B1.7 – Relation of measured clear-water contraction-scour depths to the geometric contraction ratio at selected sites in the Coastal Plain and Piedmont Physiographic Provinces of South Carolina for (A) the 100-year flow. (Figure 69 in Benedict and Caldwell, 2006).

<u>Comparison of Observed and Predicted Abutment Scour at Selected Bridges in Maine by Lombard and Hodgkins Scientific Investigations Report 2008-5099 U.S. Dept. of the Interior, U.S. Geological Survey</u>

Maximum abutment-scour depths were observed at 100 abutments at 50 bridge sites with a median age of 66 years. The study looked at abutments located at or near channel banks (as opposed to abutments located in the flood plains) to get maximum scour. Abutment Scour in the field ranged from 0 to 6.8 feet, with an average observed scour of less than 1.0 foot.

A study conducted by the USGS to evaluate bridge pier scour in Maine found that HEC-18 pier-scour equations worked reasonably well for bridges in Maine, over-predicting scour by 0.7 to 18.3 feet, and rarely under-predicting scour (Hodgkins and Lombard, 2002).

In this study, ninety percent of the bridges had abutments that protruded into the channel. As such, live-bed conditions were investigated. All bridges with abutment scour holes greater than 1.0 foot in depth and with fine materials (sand or silt) in the scour hole were checked. Several years of pier and abutment-scour observations in Maine have shown that scour holes typically do not infill substantially.

The estimated recurrence interval of the peak flow seen by the respective bridges (in years) generally ranged from 70 to over 100 years indicating that the bridges studied had seen major storm events reflected in the scour holes measured.

The median grain size was 4.17mm, with a range between 0.025 mm and 7.49 mm.

In the 50 bridges examined in this study, no correlation was found between maximum observed abutment scour and maximum predicted abutment scour from the Froehlich/Hire, Sturm, Maryland, and Melville methods employed. Furthermore, none of the individual variables used in this study to create envelope equations, such as the length of active flow blocked by the embankment (L), showed any correlation with maximum observed abutment scour depth.

However, utilization of raw data from Tables 1 through 4 from the same reference provides the following equation utilizing an envelope curve to correlate total scour with contraction ratio. This curve is presented in Figure B1.8, and the corresponding equation is:

$Y_s = 0.7 + 7.67m$

Where: Y_s = scour depth (ft)

m = contraction ratio (as previously defined)

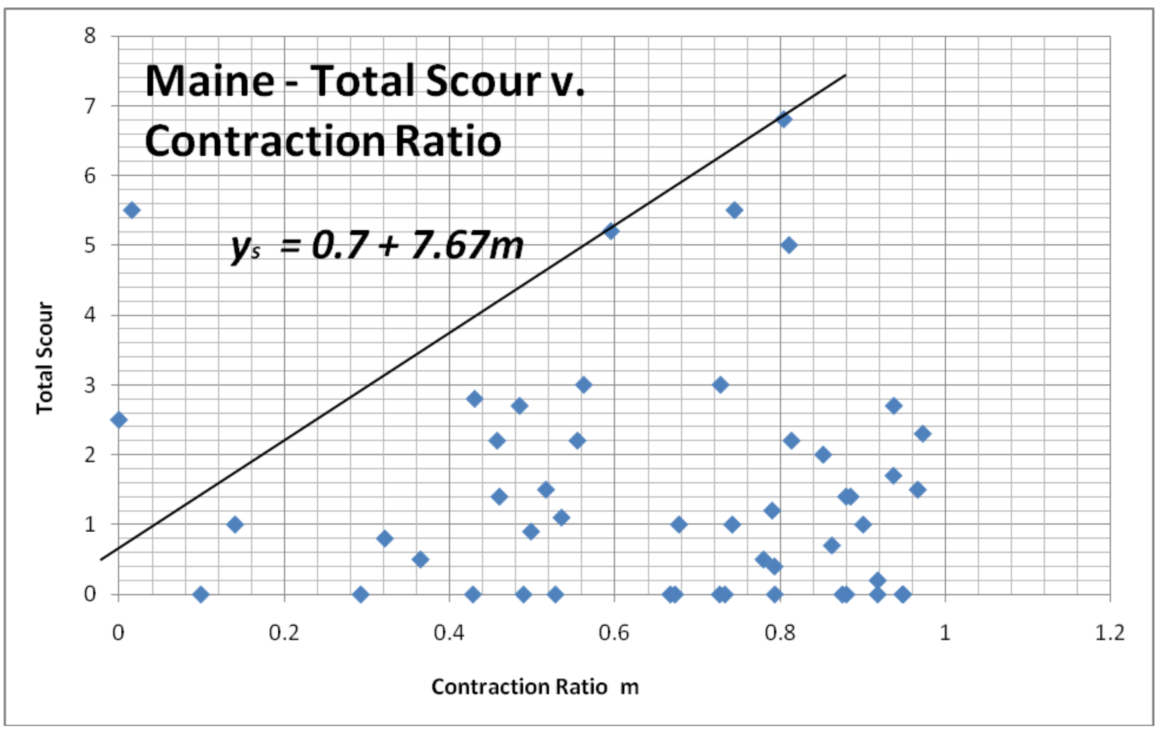


Figure B1.8 – Total Scour versus Contraction Ratio for Maine (data from Lombard and Hodgkins, 2008).

Use of USGS National Databases for Developing Envelope Curves for Pier and Abutment Scour

The USGS maintains databases from submissions for various states where USGS studies were conducted on either pier or abutment scour. The pier scour database lists 506 studies whereas the abutment scour database is somewhat limited in its data.

Utilizing the above data, envelope curves were developed to correlate envelope equations with scour depths as a function of pier width (b) and embankment length (L) blocking flow. The curves for piers are presented in Figure B1.9 and the corresponding equations are:

Pier Scour
for pier widths $\leq$ 6 ft: $Y_S = 1.5 + 1.56b$
for pier widths $>$ 6 ft and $\leq$ 14 ft: $Y_S = 3.7 + 1.52b$

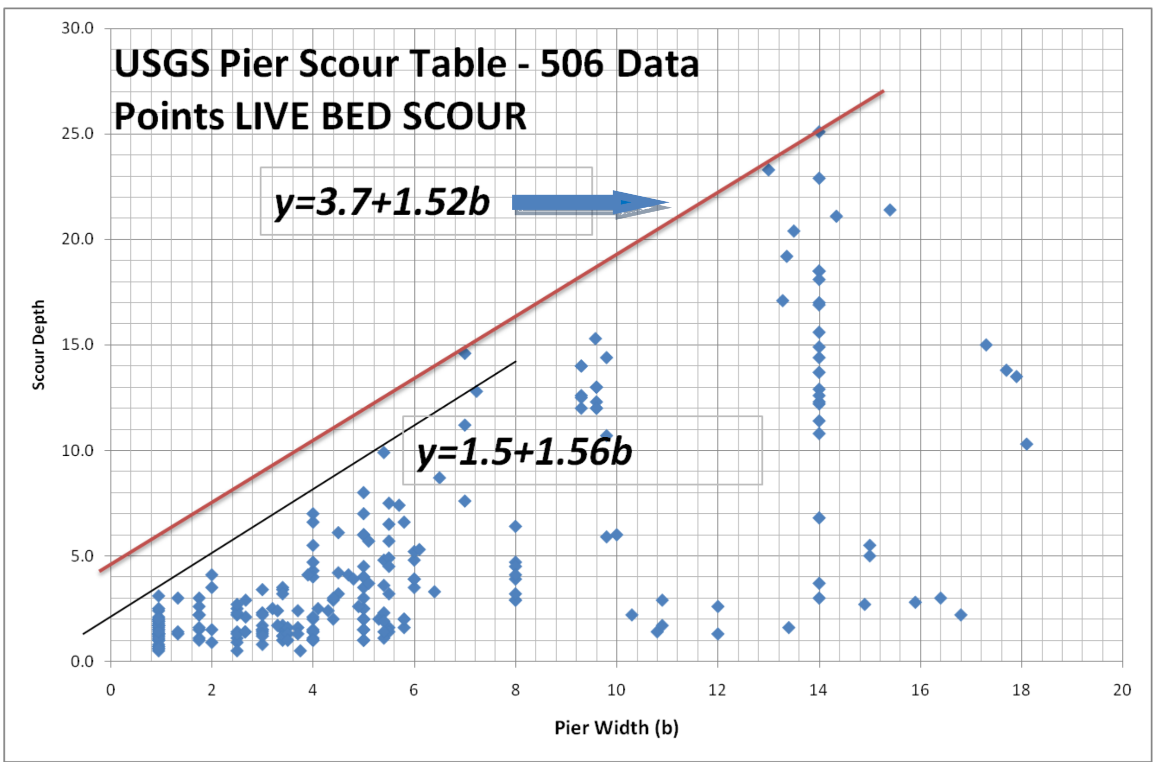


Figure B1.9 – Live-Bed Scour Depth versus Pier Width for USGS 506 Data (not for use with tidal bridges)

The curve for abutments is presented in Figure B1.10 and the corresponding equation is:

Abutment Scour
$Y_S = 3.385 - .00795L + .00003675L^2$
Where: L = embankment length (ft)

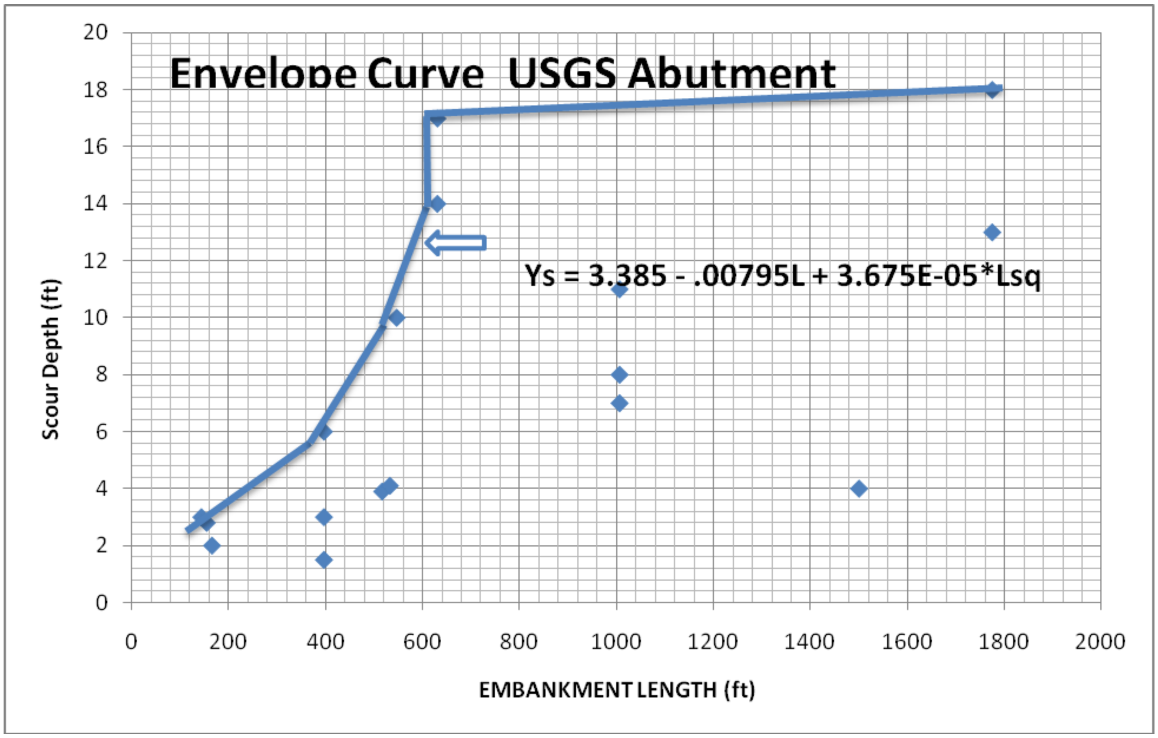


Figure B1.10 – Envelope Curve and Equation Developed from USGS Data (not for use with tidal bridges)

Author's Note:

It is noteworthy that the above mentioned envelope equations represent data from a broad array of states, and that the observed scour depths cover a large range of values (i.e. up to 18 feet for abutment-scour, and up to 25 feet for pier-scour). Note, also, that the observed scour depths exhibit a wider range in comparison with previously referenced studies (e.g. a maximum of 6.8 feet for Maine live-bed abutment scour and 8 feet for clear-water pier scour observations in South Carolina). Finally, note that the equation given for the envelope curve only applies for bridges with embankment lengths of up to 600 ft. This does not limit applicability within New Jersey because State bridges remain within this range.

In 2016, two new papers (Benedict and Caldwell, 2016a, 2016b) and a Scientific Investigations Report (Benedict et al, 2016) were published that are pertinent to this NJDOT study. Included was a plot of upper bound patterns of abutment scour, which combined South Carolina data with abutment scour data (both clear water and live-bed watercourses) from other sources to create a larger data set. In total, 446 laboratory and 331 field measurements of abutment scour from South Carolina and other states were utilized in his analysis.

The publications also combined South Carolina pier scour data with both clear water and live bed watercourse data from other sources to evaluate an upper-bound relationship for pier scour. The analysis included 569 laboratory and 1,858 field measurements of pier scour compiled from 23 states to form the 2014 USGS Pier Scour Database. An envelope curve was developed for the potential maximum pier scour depth encompassing this larger data set. The curve equation is provided below:

Pier Scour:
$Y_s = 2.1 (b)^{0.9}$ where Y_s= scour depth (ft.)
b = pier width (ft.)
applicable where $b \leq 30$ feet.

Conclusion and Recommendation:

Based on review of all previously cited envelope curve studies from 2003 through 2016, it is concluded that envelope curves can be an effective tool for screening scour risk in the Coastal Plain and Non-Glaciated Piedmont/Highlands Provinces of New Jersey. The envelope curves that are recommended to estimate abutment and pier scour within the State are presented in Figure B1.11 and B1.12, respectively. Use of these curves should be combined with the other SEM scour evaluative tools, as well as sound engineering judgment.

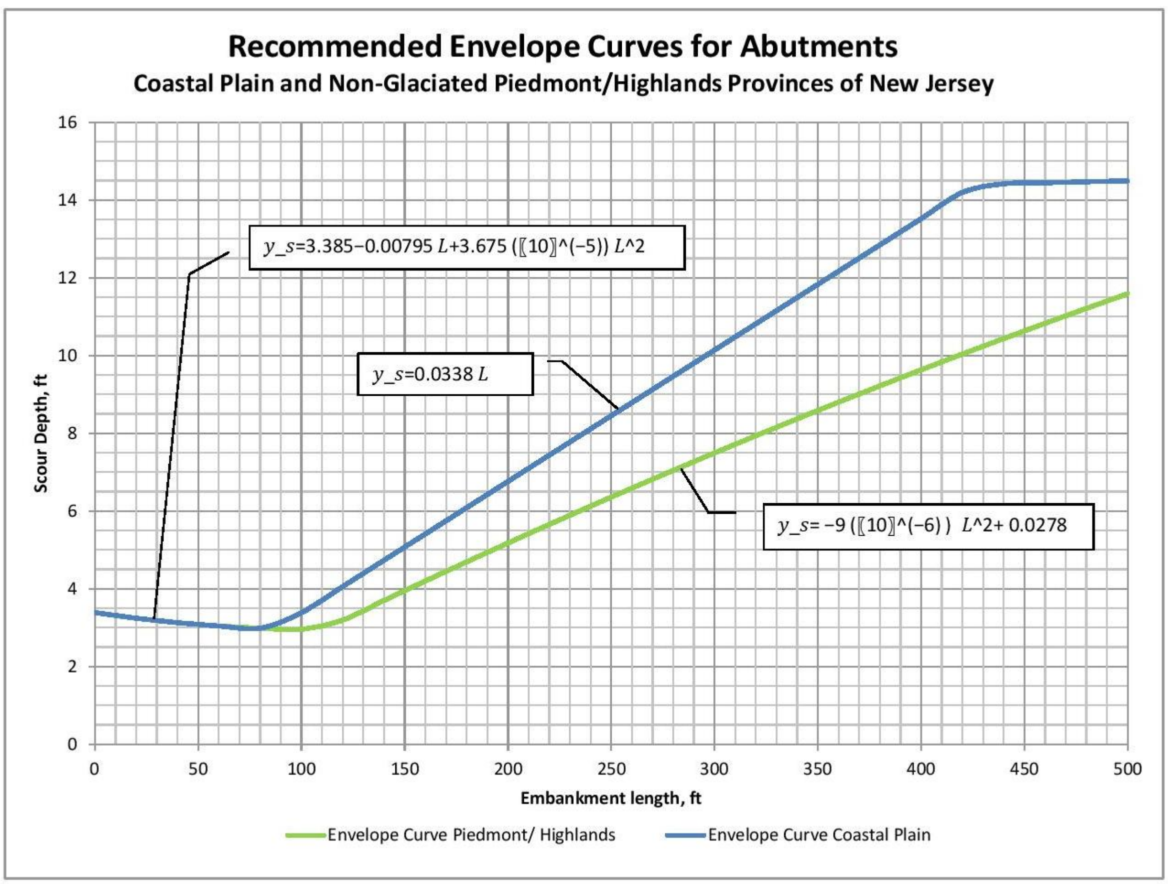


Figure B1.11 – Recommended Envelope Curves for Abutments, Coastal Plain and Non-Glaciated Piedmont/Highlands Provinces of New Jersey

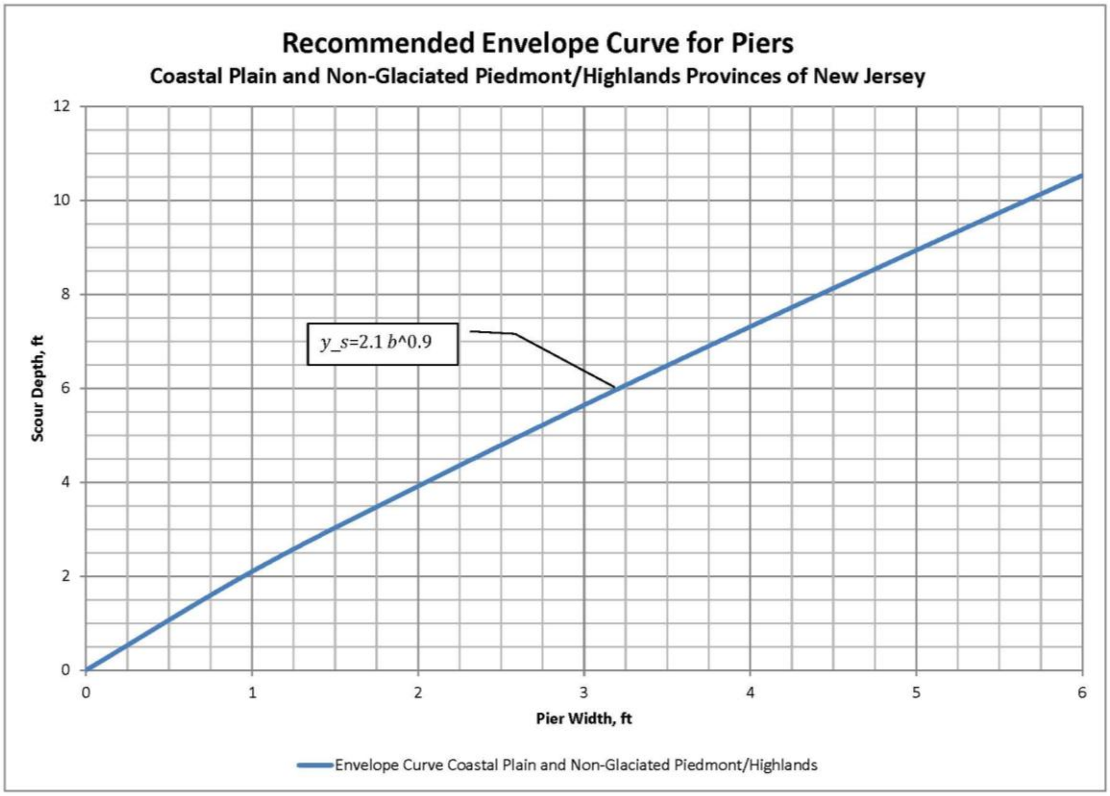


Figure B1.12 – Recommended Envelope Curves for Piers, Coastal Plain and Non-Glaciated Piedmont/Highlands Provinces of New Jersey

Appendix B2: Summaries of Envelope Curve Analyses and Supporting Data for the Coastal Plain & Piedmont Provinces

Table B2.1 – Estimated Abutment Scour – Stage II

	Left Abutment Estimated Scour				Right Abutment Estimated Scour			
	50 yr	100 yr	200 yr*	500 yr	50 yr	100 yr	200 yr*	500 yr
118152	12.7	13.8	14.8	18.8	8.1	9.3	10.8	16.6
118153	11.3	13.8	14.1	15.5	5.2	7.2	7.4	8.4
119151	13.9	15.4	**18.5**	~~12.7~~	16.2	18.4	18.7	19.7
119156	22.8	26.2	**31.4**	~~24.6~~	12.8	18	**21.6**	~~14.8~~
324153	4.1	4.9	5.3	6.9	4.8	5.7	6.2	8.3
324156	9	9.9	**11.9**	~~28.4~~	9	10	**12**	~~27.8~~
408160	17.4	~~17.1~~	**20.9**	~~14.1~~	18.4	20.3	20.5	21.2
826150	6.6	7.7	8.4	11.2	4	4.4	5.2	8.4
1122150	6	8	8.8	12	9	10.5	11	13
1304156	5	7.5	8.2	11	5.5	7	7.4	9
1308154	12.9	17.1	19	26.4	10	13.9	15.6	22.2
1703152	6.7	~~5.81~~	**8**	~~17.86~~	8.36	10.26	12.85	18.36
201151	4.6	6.2	7.5	12.9	7	8.5	9.4	13.2
719151	21	22	23	27	3	5	6.2	11
722158	14	14	14	14	14	14	14	14
1218158	11.99	15.81	16.15	17.54	7.59	9.97	8.18	11.03
1418154	8	12	12.4	14	15	16	16.8	20
1601157	6.5	7.5	7.9	9.7	18	19	19.4	21.2
1601160	17.3	18.7	19.4	22.2	18.3	19.7	20.6	24.2
1612154	10.5	19.5	**23.4**	~~17.5~~	1	6	6.2	7
1809153	13.9	14	14.1	14.6	10	~~3~~	12	~~2.7~~
1810153	~~47.1~~	~~35.2~~	**	~~22.7~~	~~36.1~~	~~31~~	**	~~19~~
1810165	13.2	16.9	16.9	16.9	17.6	20.8	21	21.7
2003162	4.8	6.3	6.5	7.2	4.8	6.3	6.5	7.2

*Estimated **Not calculated due to inconsistent data

BOLD & Larger Font = Interpolation

Strikethrough = Questionable Data

Table B2.2 – Embankment Length for Various Storm Events

	Left Abutment Embankment Length (ft)				Right Abutment Embankment Length (ft)			
	50 yr	100 yr	200 yr*	500 yr	50 yr	100 yr	200 yr*	500 yr
118152	39	40	49	83	3	5	18	68
118153	103	103	103	103	59	94	99	117
119151	21	24	27	41	46	48	48	48
119156	152	152	152	152	14	14	14	14
324153	34	37	40	50	41	46	54	85
324156	185	195	196	200	166	176	177	182
408160	126	126	126	126	45	62	70	102
826150	75	78	81	94	3	45	51	74
1122150	39	39	39	39	37	37	37	37
1304156	50	53	53	53	49	55	58	71
1308154	184	199	203	221	55	60	61	67
1703152	12	12	12	12	12	12	12	12
201151	3	4	5	9	11	12	24	71
719151	26	26	26	28	10	12	13	16
722158	345	345	345	345	464	464	464	464
1218158	30	30	30	30	10	10	10	10
1418154	71	71	71	71	83	83	83	83
1601157	7	8	9	13	4	4	4	4
1601160	24	27	29	37	32	34	36	44
1612154	77	85	91	114	3	3	8	28
1809153	18	18	18	19	25	27	28	30
1810153	~~362~~	~~66~~	**	~~34~~	~~27~~	~~26~~	**	~~30~~
1810165	26	39	42	54	89	89	98	134
2003162	5	5	5	5	5	5	5	5

*Estimated
**Not calculated due to inconsistent data
Strikethrough = Questionable Data

Table B2.3 – Summary of Envelope Curve Analysis of Abutments

Bridge Number	Obstructed Abutment Length (length of abutment projected normal to flow (ft))		Depth of Total Scour (ft)		Bottom of Footing Elevation (ft)		Elevation of Depth of Total Scour (200 yr) (ft)		Abutment Scour Based on Abutment Length (ft)						Height of Scour Above Abutment Footing Based on Envelope Curves (ft)			
									COASTAL		PIEDMONT		USGS DATA COAST- PIED					
									Ys=14.4+ .00131(L-426) L>426' Ys=.0338L L<426'		Ys=-9E-06Lsq + .0278L L<950'		Ys=3.385- .00795L+ 3.675E-05 *Lsq.		COASTAL		PIEDMONT	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Bridge #	W/N	E/S	W/N	E/S	W/N	E/S	W/N	E/S	W/N	E/S	W/N	E/S	W/N	E/S	W/N	E/S	W/N	E/S
118152	49	18	14.8	10.8	45.1	45.1	35.2	38.2	1.66	0.61			3.08	3.25	1.82	0.65		
118153	103	99	14.1	7.4	41.5	41.5	32	38.8	3.48	3.35			2.96	2.96	1.12	1.35		
119151	27	48	18.5	18.7	30.5	30.5	21	19.6	0.91	1.62			3.20	3.09	5.80	4.71		
119156	152	14	31.4	21.6	-5.7	-5.7	-15.1	-2.4	5.14	0.47			3.03	3.28	16.86	21.62		
324153	40	54	5.3	6.2	74	74	74.7	73.4	1.35	1.83			3.13	3.06	2.87	2.54		
324156	196	177	11.9	12	-15.4	-15.4	4.7	4.6	6.62	5.98			3.24	3.13	25.38	26.02		
408160	126	70	20.9	20.5	-17	-17	-10.2	-10	4.26	2.37			2.97	3.01	23.44	24.49		
826150	81	51	8.4	5.2	118	118	114.5	117.4	2.74	1.72			2.98	3.08	1.92	1.52		
1122150	39	37	8.8	11	-2.5	-2.5	-8.1	-4.3	1.32	1.25			3.13	3.14	0.07	6.06		
1304156	53	58	8.2	7.4	85	85	83	85.2	1.79	1.96			3.07	3.05	3.13	4.55		
1308154	203	61	19	15.6	38.4	38.4	26.3	34	6.86	2.06			3.29	3.04	0.04	8.16		
1703152	12	12	8	12.85	59.98	59.98	57	52.15	0.41	0.41			3.29	3.29	1.73	1.73		
201151	5	24	7.5	9.4	2	2	-1.7	-3.3			0.14	0.66	3.35	3.22			0.45	0.88
719151	26	13	23	6.2	262	262	246.7	264.8			0.71	0.36	3.20	3.29			4.50	5.71
722158	345	464	14	14	144	144	143.4	142.5			8.45	10.87	5.02	7.61			4.95	1.63
1218158	30	10	16.15	8.18	20.1	20.1	9.95	17.92			0.82	0.28	3.18	3.31			2.82	2.69
1418154	71	83	12.4	16.8	169.7	169.7	161.4	156.8			1.91	2.23	3.01	2.98			1.09	0.92
1601157	9	4	7.9	19.4	16.5	16.5	14.9	4.1			0.25	0.11	3.32	3.35			2.98	3.65
1601160	29	36	19.4	20.6	2	2	-8.4	-9.6			0.79	0.98	3.19	3.15			5.81	5.85
1612154	91	8	23.4	6.2	107.5	107.5	89.2	106.3			2.44	0.22	2.97	3.32			2.13	1.68
1809153	18	28	14.1	12	269.5	269.5	258.8	262			0.49	0.77	3.25	3.19			0.15	1.31
1810153					53	53	57	56.7			0	0					-4	-3.7
1810165	42	98	16.9	21	42.5	42.5	29.9	27.92			1.14	2.62	3.12	2.96			1.18	3.46
2003162	5	5	6.5	6.5	57.79	57.79	56.05	60.62			0.14	0.14	3.35	3.35			1.41	5.98

Table B2.4 – Summary of Envelope Curve Analysis for Piers

Bridge #	Coastal/ Piedmont	Pier Width	Elevation of Scour	Stage II Scour Depth	Elev. of Bottom of Pier	USGS 505 1.5+1.56B B<6' 3.7+1.52B B>6' & <14'	USGS 505 & Stage II Difference	South Carolina 1.5B+4.1 B>6 1.1*B+3.34 B<6	South Carolina & Stage II Difference	Difference Between Scour And Bottom Of Pier Elev. (Stage II)	Height Of Scour Above Footing Based On Envelope Curves*
119156	C	2.5	-7.14	24.84	-5.7	5.4	19.44	6.09	18.75	1.44	17.31
722158	P	4	138.8	12.5	143.5	7.74	4.76	7.74	4.76	4.7	0.06
1418154	P	3.5	144.4	13	146	6.96	6.04	7.19	5.81	1.6	4.21

*Based on most conservative curve estimate.

Table B2.5 – Summary of Q_{100} Analysis for Selected Bridges

Table 7.3 Back-up Bridge Name (Number)	Gage #	2011 data Q_{100} (cfs)	Peak Flow of Record	Date of Record	% 100 yr Flow Seen	Gage on/off	Q_{100} @ Bridge (cfs)	Drainage Area (sq. mi.) Bridge	Drainage Area (sq. mi.) Gage	Gage Transfer Coefficient
Rt 206 over Great Swamp Branch (118152)	1411000	1289	1370	2011-08-28	106.3	off	309	8.06	57.0	0.73
Rt 206 over Albertson's Brook(118153)	1411456	689	627	2011-08-28	89.9	off	1146	19.3	9.77	0.73
Rt 322 Over Big Ditch (119156)	1411000	1289	1370	2011-08-28	106.3	off	132	2.5	57.0	0.73
Rt 206 over Muskingum Creek (324153)	1467081	88.6	74	1999-9-16	83.5	off	64	2.07	3.22	0.73
Rt 206 over Jade Run (324156)	1465850	2204	2550	2011-08-28	115.7	off	633	11.2	64.9	0.71
Mill Road over SB Pennsauken Creek (408160)	1467081	1769	1560	2004-07-13	88.2	on	1768	8.98	8.99	0.66
US 130 over Doctors Creek (1122150)	1464500	6251	5940	2011-08-28	95.0	off	2930	25.9	81.5	0.66
NJ Route 34 over Big Brook (1308154)	1407290	1746	1350	2011-08-28	77.3	on	2089	8.41	6.41	0.66
US Rt 1 & 9 over Wolf Creek (201151)	1378615	437	750	1999-09-16	80.0	on	1037	2.03	1.75	0.68
Rt 23 over Peckman's Brook (719151)	1389534	2970	2770	1999-09-16	93.3	on	3862	6.46	4.39	0.68
Rt 46 WB over Passaic River (722158)	1389500	21660	20800	2011-08-30	96.0	on	21457	751	763	0.59
Rt27 over SB of Rahway River (1218158)	1395000	3024	7250	2011-08-28	239.7	on	204	0.79	41.7	0.68
Rt 280 EB over Passaic River (1418154)	1379500	3523	3380	1973-08-02	95.9	on	4161	131	98.8	0.59
Rt 3 over Third River (1601157)	1392210	2500	2300	1977-11-08	92.0	on	2514	12	11.9	0.68
US Rt 3 over Upper Pond Spillway (1601160)	1392170	3110	2670	1999-09-16	85.9	on	4359	12.7	7.73	0.68
RT 208 Ramp A over Goffle Brook (1612154)	1390810	2130	3010	1999-09-16	141.3	off	1391	4.85	9.08	0.68
US Rt 206 over Back Brook (1810153)	1401650	4660	8200	1999-09-16	176.0	off	4289	4.58	5.29	0.58
Rt 206 over BR of Royces Brook (1810165)	1402600	1510	2850	1999-09-16	188.7	off	2160	1.83	0.99	0.58
Rt 22 WB over Rahway River (2003162)	1394500	7532	8620	2011-08-28	114.4	on	7553	25	24.9	0.68

* Q_{100} calculated using StreamStats

Table B2.5 – Summary of Q_{100} Analysis for Selected Bridges (continued)

Table 9.1 Back-up Bridge Name (Number)	Gage #	2011 data Q_{100} (cfs)	Peak Flow of Record	Date of Record	% 100 yr Flow Seen	Gage on/off	Q_{100} @ Bridge (cfs)	Drainage Area (sq. mi.) Bridge	Drainage Area (sq. mi.) Gage	Gage Transfer Coefficient
Route 10 over Malapardis Brook (1402150)	1381500	3096	3780	2011-08-28	122.1	on	1089	4.99	29.4	0.59
Route 15 over Beaver Run (1922150)	1443280	429	589	2011-08-28	137.3	on	646	25.6	12.8	0.59
Rt 23 NB over Pequannock River (1605175)	1382500	4381	4360	1984-04-05	99.5	on	2152	19.1	63.7	0.59
Route 31 over Pequest River (2111155)	1445500	2358	2370	2011-09-08	100.5	on	2461	114	106	0.59
Rt 33 over Manalapan Brook (1304156)	1405400	4160	6650	2011-08-28	159.9	on	1319	7.85	40.7	0.70
US Rt 40 over BR of Salem Creek (1703152)	1482500	7374	8760	2011-08-28	118.8	on	2317	2.77	14.6	0.70
Rt 46 EB over BR Mine Brook (1407153)	1396152	664*	1360	2011-08-28	204.8	on	596	1.06	2.01	0.59
Route 46 over Musconetcong River (2108162)	1456000	2260	2170	1955-08-19	96.0	on	2389	75.7	68.9	0.59
Route 206 over Crusers Brook (1810155)	1401650	4660	8200	1999-09-16	176.0	off	4371	4.8	5.36	0.58
Route 206 over Branch Big Flat Brook (1912158)	1439800	3090*	4490	1955-08-19	145.3	on	3100	4.02	22.8	0.59
Route 206 over Big Flat Brook (1912160)	1440000	7778	10200	2011-08-28	131.1	on	4339	23.8	64	0.59
Rt 322 Over Hospitality Brook (119151)	1411000	1289	1370	2011-08-09	106.3	off	1241	54.2	57.1	0.73
US Rt 322 over Scotland Run (826150)	1411456	689	627	2011-08-28	89.9	off	363	3.98	9.77	0.73

* Q_{100} calculated using StreamStats

Appendix B3: Field Inspection Form for Bridge Scour Investigation

The following standard field inspection form was developed for NJDOT to record the observations of the stream channel and bridge structure related to scour. The form prompts the user to carefully evaluate the characteristics of the stream bed that can affect scour risk. Note that photography is a critical part of the Field Scour Investigation to document the existing condition of the bridge, especially the substructure and stream channel. A narrative describing procedures for conducting a field inspection is presented in **Appendix B4**.

FIELD INSPECTION FORM
FOR BRIDGE SCOUR INVESTIGATION Version 6.0 7-1-11

GENERAL DATA: **Date:**__________________________
Structure Number:______________________ **Time of Arrival:**________________
Time of Departure:_____________
Route Number/Stream Name:____

Township:____ **County:**______________________________

Physiographic Province:___________________________ **Reconn. Report Reviewed?** Yes_____ No_____

Field Team:_______________________________(Notes) ____________________________________
____

Bridge Type: Beam/Slab___ Girder/Stringer___ Arch___ Truss___ Other:___________________________
Support: Simple___ Continuous___
Comment:____

Visible Channel Slope: Flat_____ Mild_____ Moderate_____ Steep______

UPSTREAM CHANNEL:

Estimated Skew Angle: 0-15 deg____ 15-30 deg____ 30-45 deg_____ > 45 deg_____

Average Water Depth during Visit:_______ft.

Evidence of Overtopping? Yes___ No____ Comment:____

Evidence of Meandering? Yes___ No____ Comment:____

Evidence of Braiding? Yes___ No____ Comment:____

Evidence of Pressure Flow? Yes___ No____ Comment:____

Evidence of Debris? Yes___ No ___ Comment:____

Type: Brush_____ Whole Trees_____ Trash_____ Other____

Debris Source Potential: High___ Med____ Low_____ Comment:_________________________________

Debris Trapping Potential: High____ Med____ Low______ Comment:_____________________________
Approximate Vertical Bridge Clearance:____ft.

Contraction at Bridge? Yes___ No____ Comment:____

UPSTREAM CHANNEL (continued):

Bed Description:

Bed Exposed/Visible during Visit: Totally____ Mostly____ Partly______ Not______

General Textural Description:____
____

Predominant Erosion Class (refer to standard definitions)**:**

R0: Sound Rock_____ G2: Coarse Granular____ G3: Fine to Medium Granular_____
G1: Extr. Coarse Granular______ C2: Hard Cohesive____ C3: Soft Cohesive______
R1: Weak Rock_____

Est. % Boulders:_____ Est. % Gravel:_____
Est. % Cobbles:_____ Est. % Sand, Silt & Clay:_____

Additional Comments (e.g. composite class):____

Results of Rod Probing (if done)**:**

Textural Description: Hard_____ Firm_____ Medium_____ Soft_____

Depth of Penetration:_____in. Apparatus:_________________________ Hammer Weight:_____lbs.

Results of Shallow Sampling (if done): Method:___________________________ Depth _________ft.

Description____

Est. % Vegetative Cover:_______ Dominant Type**:** Tree_____ Shrub_____ Weed_____ Other______

Bank Condition:

N S E W: Est. % Vegetative Cover_______
Bank Material___________________________
Bank Erosion: None_____ Light_____ Medium_____ Heavy______

N S E W: Ext. % Vegetative Cover_______
Bank Material___________________________
Bank Erosion: None_____ Light_____ Medium_____ Heavy______

Tributary Drain Outlets? Yes ___ No ____ If yes, describe ___________________________________

Countermeasures Present? Yes___ No____ If yes, describe type and condition:____________________
____

Additional Channel Comments:____
____
____
____

UNDER THE BRIDGE:

Bed Description:

Bed Exposed/Visible during Visit: Totally____ Mostly____ Partly______ Not______

General Textural Description: ____

____

Predominant Erosion Class (refer to standard definitions)**:**

R0: Sound Rock_____ G2: Coarse Granular____ G3: Fine to Medium Granular_____
G1: Extr. Coarse Granular______ C2: Hard Cohesive____ C3: Soft Cohesive______
R1: Weak Rock_____

Est. % Boulders:_____ Est. % Gravel:_____
Est. % Cobbles:_____ Est. % Sand, Silt & Clay:_____

Additional comments (e.g. composite class):____

Results of Rod Probing (if done)**:**

Textural Description: Hard_____ Firm_____ Medium_____ Soft_____

Depth of penetration:_____in. Apparatus:_________________________ Hammer Weight:_____lbs.

Results of Shallow Sampling (if done): Method:___________________________ Depth _________ft.
Description____

Degradation/Aggradation Present? Yes___ No____ If yes, describe depth/height, texture, and extent:

____

Tributary Drain Outlets? Yes ___ No ____ If yes, describe ___________________________________

Countermeasures Present? Yes___ No____ If yes, describe type and condition: ___________________

____

Scour Condition of Abutments:

Location	Type	Foundation Type	Water Depth (ft.)	Scour Present?	Scour Depth (ft.)
N S E W					
N S E W					

N S W E Abutment Findings (detail observed scour or related damage to substructure)**:**_________________

____
____
____
____

N S W E Abutment Comments (detail observed scour or related damage to substructure):___________________

____
____
____
____

UNDER THE BRIDGE (continued):

Scour Condition of Piers:

	Type	Foundation Type	Water Depth (ft.)	Scour Present?	Scour Depth (ft.)
Pier 1					
Pier 2					
Pier 3					

Pier Findings (detail observed scour or related damage to substructure)**:______________________________**
____
____
____

DOWNSTREAM CHANNEL:

Bed Description:

Bed Exposed/Visible during Visit: Totally____ Mostly____ Partly______ Not______

General Textual Description: ____
____

Predominant Erosion Class (refer to standard definitions)**:**

R0: Sound Rock_____ G2: Coarse Granular____ G3: Fine to Medium Granular_____
G1: Extr. Coarse Granular______ C2: Hard Cohesive____ C3: Soft Cohesive______
R1: Weak Rock_____

Est. % Boulders:_____ Est. % Gravel:_____
Est. % Cobbles:_____ Est. % Sand, Silt & Clay:_____

Additional comments (e.g. composite class):____

Results of Rod Probing (if done)**:**

Textural Description: Hard_____ Firm_____ Medium_____ Soft_____

Depth of penetration:_____in. Apparatus:__________________________ Hammer Weight:_____lbs.

Est. % Vegetative Cover:_______ Dominant Type**:** Tree_____ Shrub_____ Weed_____ Other_____

Bank Condition:

N S E W:
% Vegetative Cover:________
Bank Material:_____________________________
Bank Erosion: None___ Light___ Med___ Heavy____

N S E W:
% Vegetative Cover:________
Bank Material:_____________________________
Bank Erosion: None___ Light___ Med___ Heavy____

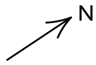
Countermeasures Present? Yes___ No____ Describe type and condition:___________________________

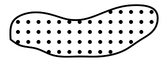
Watercourse Confluences within 0.5 miles (backwater effect)**?___________________________________**

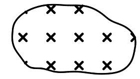
Additional Channel Comments:____

FIELD SKETCH:

Essential features (show dimensions where appropriate)**:**

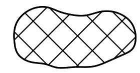
North Arrow 

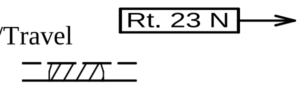
Channel Bars and Aggradation Zones 

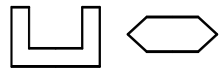
Debris 

Flow Direction 

Countermeasures 

Scour Holes & Erosion Zones 

Route/Travel Direction 

Abutments, Piers, & Wingwalls 

Exp. Footings/ Pile Caps

Continued on Additional Sheet(s) Yes ___ No ___ No. of Additional Sheets = ____

SOUNDINGS: (**Optional:** Useful for bridges where channel bottom is not visible)

Location of Section: Upstream Fascia___ Downstream Fascia___: Other ___ Describe ______________

Sounding Method: ____

Method to Measure Distance between Soundings: ____

Level Line Reference:_______________________________

Table of Soundings:

Sounding	**Location**	**Distance from last (ft).**	**Depth (ft.)**	**Notes**
1	N S E W Abutment			
2				
3				
4				
5				
6				
7				
8				
9				
10				

Stream Cross-Section Plot:

	Sounding Number									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Spacing between measurements (specify distances between each measurement) →									
Depth (specify scale) ↓										

Continued on Additional Sheet(s) Yes ___ No ___ No. of Additional Sheets = _______

Appendix B4: Procedures for Completing the "Field Inspection Form for Bridge Scour Investigation"

INTRODUCTION

This document provides guidelines for the field inspection of bridges to assess scour. Field inspections for scour are best conducted during low water conditions, typically during the summer and fall months or during a period of drought. This assures that a maximum percentage of the streambed and substructure features are visible.

Before inspecting a bridge, it is critical that the inspection team be certain that they are inspecting the correct bridge. In order to accomplish this, the bridge location should first be established both in terms of milepost and cross street by using the NJDOT straight line diagram for the route on which the bridge is located. Upon arrival, the team should verify the nameplate on the bridge indicating the structure number and milepost.

Photography is a critical part of the Field Scour Investigation to document the existing condition of the bridge, especially the substructure and stream channel. At a minimum, the following views should be recorded: (1) channel looking upstream; (2) upstream fascia; (3) substructures and channel under the bridge; (4) downstream fascia; and (5) channel looking downstream. In addition, all areas of exposed streambed, riprap, channel erosions, and scour zones should also be photographed.

EQUIPMENT REQUIRED:

- Safety gear including hard hat, gloves, boots, safety glasses, and reflective vest. A life preserver should be used whenever water is present.

- Surveyors range pole, or, alternatively a 1 in X 2 in X 8 ft wood stick marked in 1 ft increments. These are used to check for scour holes and erosion zones.

- Stainless Steel "T-bar" Push Probe. This is used to assess the density and texture of the stream bed, and it is advanced by pushing.
  (The T-bar probe is easily custom built by any metal fabricator using 0.5 inch diameter stainless steel rod. Weld a 12 inch long handle atop a 36 inch long shaft. Sharpen the bottom tip of the shaft to a blunt point.)

- 1-5/16 inch Hammer-driven Probe. This is also used to assess the density and texture of the stream bed, and it is advanced with a 4 lb hammer.
  (The hammer-driven probe is actually a small diameter drill rod equipped with a hardened drive head and a hardened tip. One source of this equipment is the Acker Drill Company of Scranton, PA. Order the following parts:
  Drive Head Assembly with Wash Tee and Handle, Part No. 22070-1
  Drill Rods, 1-5/16" O.D., 2 ft 6 in long, Part No. 21041-1 (suggest two rods)
  Probe, 1-5/16" O.D., Part No. 110060-9

Note: These parts can be ordered separately, although they are also included within the Acker Soil Sampling Kit (Part. No 41007-1). This full kit is versatile and can be used for many different hand-sampling situations.

- 4 lb Surveyors Hand Sledge (to drive the 1-5/16 in Probe)

GENERAL DATA

This first section of the field inspection form contains information about the bridge's general structure, identification, and location. It is critical that the correct structure number be entered as well as the route number and waterway name. The inspector should also record the date and time of inspection as well as the names of the field team members. It is strongly recommended that a geotechnical reconnaissance study be prepared and reviewed prior to the field inspection.

Visible Channel Slope: The inspector shall judge the slope of the channel by observation. A "flat" slope is characterized by a smooth water surface with little or no discernible current. A "mild" slope is also characterized by a smooth water surface, but there will be noticeable current and possible minor riffling. A "moderate" channel slope is characterized by substantial surface riffling, moderate to strong current, and some turbulence. A "steep" channel has a pitch or slope that is clearly apparent; current is strong and dominated by strong riffling, turbulence, and possible drops.

UPSTREAM CHANNEL

The reach of the upstream channel includes approximately two bridge lengths from the upstream fascia.

Estimated Skew Angle: The estimated skew angle is the angle measured between a line projected perpendicularly to the upstream fascia of the bridge and the centerline of the channel. Because skew may vary between low and high flow conditions, the inspector shall use the high flow condition to judge the channel direction.

Evidence of Overtopping: Examples of evidence of overtopping are debris piles, seed lines, or a high water mark (painted or natural) near or above bridge deck elevation. Comment field should be used to describe affirmative responses.

Evidence of Meandering: A meander in a river consists of two consecutive loops, one flowing clockwise and the other counter-clockwise. The channel generally exhibits a characteristic process of bank erosion and point bar deposition associated with systematically shifting meanders. Note that meanders are distinguishable from, and are not the same as, a curve in the upstream channel as it approaches the bridge. Channel curvature may be accounted for in the estimated skew angle shown above if it occurs within two bridge lengths of the bridge. Meanders generally require a relatively flat channel slope and terrain. Observed meanders should be included in the field sketch with notes about the impact on banks. Comment field should be used to describe affirmative responses.

Evidence of Braiding: A stream is considered braided when its flow is divided at normal stage by small mid-channel bars or small islands. Inspector shall note percentage and type of vegetation on individual bars. Comment field should be used to describe affirmative responses.

Evidence of Pressure Flow: Pressure flow conditions exist at a bridge when the water surface elevation at the upstream face is greater than the lowest chord of the bridge superstructure. The best indicator of pressure flow is the presence of debris between the beams or on the beam seats. Comment field should be used to describe affirmative responses.

Evidence of Debris: Debris includes materials such as logs, vegetation, or trash, transported by a stream that has become entangled or lodged upon a bridge element. Debris can increase the effective width of a bridge element, causing the flow to plunge downward against the bed, thus increasing pier scour. The form prompts for the most common debris types, but the inspector can elaborate in the comment field if necessary. Location and nature of debris should be noted on the field sketch.

Debris Source Potential: The inspector shall rate the upstream basin for the potential for producing debris. Bridge sites with predominantly shrubby or grassy vegetation and little or no observable debris would be assigned a low debris potential rating. If abundant debris is noted at the bridge site or nearby, the basin likely has a high potential for debris production. Banks with extensive tree growth that are clearly stable and show little or no evidence of erosion would generally have a low to moderate debris source potential. However, if the bank shows evidence of significant undercutting of trees, it would be rated with a high source potential. Note that for larger drainage basins, debris potential may be elevated because of the possibility of large debris coming from upstream.

Debris Trapping Potential: The inspector shall make a judgment with respect to the relative potential for debris to become trapped at the upstream bridge elements. Rating should consider the size of trees and shrubs relative to the width(s) and height of the bridge opening(s).

Contraction: If, at bank full conditions, the bridge appears to cause a narrowing of the channel cross-section, then contraction is present. Use the comment field to indicate the degree of contraction.

General Textural Description: The inspector should describe the soil conditions of the streambed, with emphasis on grain size distribution.

Predominant Erosion Class: A principal objective of the field inspection is to establish the *erosion class* of the stream bed materials. Seven distinct classes of soil and rock materials have been established for the New Jersey SEM, reflecting the wide range of erosion resistance encountered in bridge scour situations. The criteria for each are summarized in the table below, and more detailed descriptions are provided in report section, “Description of Erosion Classes” in chapter “GEOTECHNICAL EVALUATION OF BRIDGE SCOUR” on page 32.

Table B4.1 – Summary of Erosion Classes for Scour Evaluation

Erosion Class	Predominant Texture & Description
High Erosion Resistance	
R0. Sound Rock	Rock of this classification shall be generally sound, although some fracturing and weathering may be present. Includes granite, gneiss, basalt, diabase, dolomite, limestone, slate, siltstone, sandstone, and related rocks. Extracted rock cores shall exhibit an average RQD of 70%. Also includes mudstone and shale with the same RQD and recovery and a Slake Durability Index (SDI) of 90 or greater.
G1. Extremely Coarse Granular Soil	Includes coarse granular soil with significant cobble- and boulder-sized pieces. Must contain 50% or more particles classified as cobble-size or larger (>75 mm diam.).
R1. Weak Rock	Includes all bedrock types not meeting the requirements of ‘Sound Rock’ R0 above. Such rock typically exhibits higher fracture frequency, more intense weathering, lower strength, or a combination of these. Classification of weak rock can usually be made on the basis of recover ratio, RQD and degree of weathering (visual inspection). Optionally, measure the Slake Durability Index (SDI) of extracted cores or block samples, which will range from 80-90 for weak rock. Materials with an SDI of less than 80 should be treated as soil.
Moderate Erosion Resistance	
G2. Coarse Granular Soil	Includes well graded gravels, sandy gravels, clayey gravels, and silty gravels with an average minimum D_{50} of 40 mm and uniformity coefficient of 4 or more. Included are soils with Unified Classification of GW, GC, and GM.
C2. Hard Cohesive Soil	Includes hard, cohesive soils such as clay, silty clay, sandy clay, and boulder clay exhibiting an average minimum unconfined compressive strength of 1.5 ton/ft^2 or greater. Included are soils with Unified Classification of CL, CH, MH, SC, and GC.
Low Erosion Resistance	
G3. Fine to Medium Granular Soil	Includes cohesionless, granular soils such as sand, silt, and gravel, and mixtures of these soils that do not meet the requirements of ‘Coarse Granular Soil’ G2 above. Included are soils with Unified Classifications of SW, SP, SM, GW, GP, GM, GC, ML, and MH.
C3. Soft Cohesive Soil	Includes soft, cohesive soils such as clay, silty clay, clayey silt, plastic silt, and organic silts and clays. Soils in this classification will exhibit an average unconfined compressive strength of less than 1.5 ton/ft^2 Included are soils with Unified Classifications of CL, CH, MH, OL, and OH.

Erosion class is determined by some combination of the following methods: (1) direct visual observation; (2) probing the stream bed; (3) shallow sampling of the streambed; and (4) review of reconnaissance information. Note that erosion class may not be uniform over the entire bridge site, so it is should be evaluated separately for the upstream, under the bridge, and downstream sections. Thus, the field inspection form prompts the inspector to examine each channel section separately. On occasion, more than one erosion class will be observed within a given section. This constitutes a compound erosion class, and the inspector shall record and describe each class that is present.

Results of Rod Probing: Rod Probing is very helpful in assessing the density and texture of the stream bed. It is best performed using either a stainless steel T-bar Probe or a Hammer-driven Probe. Both kinds of probes should be available to the field inspector, who will use one or both depending on the conditions. Generally, the T-bar probe is most useful when evaluating either very soft or very hard beds. If the T-bar probe can be pushed to full depth with moderate effort, then a “soft” bed consistency is indicated. Conversely, if it is not possible to advance the T-bar probe at all like when the stream bed is lined with packed cobbles and boulders, the streambed shall be designated “hard”. If the streambed is found to be neither “soft” nor “hard,” or if the results of the T-bar Probe are indeterminate, the Hammer-driven Probe is recommended for use. The Hammer-drive Probe test procedure is as follows: (1) position the probe tip on the stream bed surface; (2) steady the probe head with the rod handle with one hand, and then strike the head with the 4 lb surveyor’s sledge using the other hand with a moderate swing and force (as if one is driving a stake into the ground); (3) count 8 blows of the hammer while simultaneously noting the depth of penetration; and (4) finally, correlate the density/texture of the bed with the depth of penetration using the table below. Note that this semi-quantitative procedure is only meant as an aid to other observations and reconnaissance data, but it has proven quite helpful is assessing stream bed density and texture when applied consistently.

Correlation of Bed Density/Texture with Penetration of the Hammer-driven Probe

Penetration (inches)	Textural Description
< 2	Hard
3 to 6	Firm
7 to 12	Medium
> 12	Soft

Results of Shallow Sampling: Another method to assess the composition of the stream bed is to recover a sediment sample using hand-sampling tools such as an Iwan auger, a hand-driven split-barrel (spoon) sampler, or simply a shovel (“grab” sample). Recovered samples are typically field classified and may also be preserved for transport to a laboratory for further analysis. Caution should be exercised in interpreting the results of such sampling due to limited penetration depth into the streambed, usually only several inches to a few feet. A related problem is collection of a nonrepresentative sample, as may occur when only fine sediments are recovered while the oversize gravel, cobbles, and boulders are ignored.

Bank Condition: The condition of both stream banks should be described on the form in the sections provided. To distinguish one bank from the other, the inspector must circle N, S, E, or W on the form. If the bridge being inspected is part of a numbered roadway system, nominal direction shall be used, regardless of actual direction. The 'bank material' field is used to describe the uppermost layer of material that composes the bank (for example: soil, boulders, mud, till, riprap, etc.). 'Bank erosion' refers to the effect of fluvial action on the bank; it requires a judgment about the severity of ongoing erosion.

Countermeasures Present: If present, the type, condition, and location of all countermeasures should be described thoroughly. Examples of countermeasures include riprap, gabions, paved banks, and articulated concrete blocks.

UNDER THE BRIDGE CHANNEL

Note that instructions for completing the form fields in the first part of this section were previously described in the "Upstream Channel" section.

Degradation/Aggradation Present: The presence and extent of degradation or aggradation shall be documented by the inspector. "Degradation" refers to a long-term lowering of the channel over a relatively wide area, while "aggradation" is the progressive buildup of sediments in the channel. Degradation can sometimes be identified by the presence of a stain or other marking along piers or abutment walls that indicate a previous bed elevation. Aggradation can be identified by the presence of bars or other elevated portions of the streambed, possibly comprised of materials inconsistent with those in the rest of the channel. Long term degradation/aggradation can be assessed by examining as-built drawings, Stage II studies, and past bridge inspection reports, which usually contain fascia soundings. Examine and compare historic cross sections and longitudinal profiles to identify trends. This helps to establish the current amount of sediment cover over the foundations.

Abutments: The conditions of both abutments should be described on the form in the section provided. To distinguish one abutment from the other, the inspector must circle N, S, E, or W on the form for each bank in a manner similar to that used to distinguish between banks (see "Bank Condition"). The following information about each abutment should be noted in the appropriate field provided: type, foundation type, water depth, scour presence, and scour depth. Water Depth should be the average depth along the entire length of footing at time of inspection. If scour is present, the inspector shall record details of the observed scour and related damage to the substructure in the 'Abutment Findings' field and on the Field Sketch.

Scour Condition: Checking for scour is among the most critical tasks of the field inspection. Scour refers to observable erosion of the stream bed or bank surrounding a substructure element. Advanced scour can cause undermining of spread footings or exposure of piles shafts beneath caps. If advanced scour is left unchecked, the substructure may become damaged, which can lead to settlement and distortion of bridge superstructure, or in extreme cases, collapse of the superstructure.

While advanced scour can lead to serious consequences, the presence of scour does not necessarily mean that a bridge is at risk. In fact, essentially all bridges experience some amount of scour over their lifetime as the stream channel “adjusts” to the changes in flow velocity and direction caused by the substructures, as well as disturbance by construction activities. Thus, the task of the inspector is to not only to check for the presence of scour, but also to assess its severity.

Application of the New Jersey Scour Evaluation Model (SEM) requires a field determination as to whether or not the bridge has experienced “substantial scour.” A number of factors enter into this determination, including the depth and lateral extent of observed scour, depth of the footings or pile caps, bridge age, and erosion class of the stream bed. The following is a list of guidelines that the field inspector can use to assess scour. Another helpful publication for field inspection is “Stream Instability, Bridge Scour, and Countermeasures, A Field Guide for Bridge Inspectors” (FHWA 2009).

1. The following terminology is recommended for use in describing scour. The term “scour hole” is reserved for steep-sided erosion features that extend several feet or more beneath the stream bed. The term “erosion zone” is used for shallower erosion features, which have more gradual side slopes and extend a few feet or less below the stream bed.
2. The inspector shall note the depth and lateral extent of any observed erosion zones and scour holes. Depth is always measured with respect to the adjacent average stream bed, not the water surface.
3. Erosion zones and scour holes that are not in contact with the substructure are usually considered less serious, although they should still be noted during the inspection.
4. Among the most common bridge and channel conditions that exacerbate scour are: (1) significant contraction of the channel relative to the bridge opening; (2) a high skew angle between the upstream channel and the bridge structure; and (3) piers with excessive width (>6 feet). Inspectors should be especially vigilant for the presence of scour in such situations.
5. When an inspection shows that spread footings or pile caps are <u>not</u> exposed, then any scour present would usually not be considered as substantial scour.
6. When an inspection shows that spread footings are exposed, then a careful assessment shall be made as to exactly what parts of the foundation elements are showing (top surface, face) and whether or not there is undermining. Such observations should be recorded quantitatively, e.g. “Top of footing of the north abutment is exposed an average of 4 in. for a length of 15 ft. beginning at the upstream fascia.”
7. If the spread footings are found to be undermined to any degree, a designation of “substantial scour” is usually appropriate. Exceptions are possible, though, like if an

older bridge that has seen a 100+ year storm exhibits a small percentage of the foundation undermining (≤5%). In this case, a targeted repair may be more appropriate than to declare the entire bridge as having substantial scour (see Directed Maintenance and Repair option in Table 8).

8. If the top or face of a spread footing is exposed but there is no undermining, then the scour designation will depend on the degree of exposure and apparent stability of the channel. If the exposure is significant and the channel appears to be actively degrading, then a designation of substantial scour is appropriate. However, if the exposure is the result of long-term degradation that has apparently reached a state of equilibrium, then a designation of substantial scour may not be warranted. The latter condition is sometimes seen, for example, at older bridges with stream beds containing erosion resistant cobbles and boulders (class G1), where natural armoring has developed over time.
9. Installed countermeasures may influence the determination of whether substantial scour is present at a bridge. Often, existing countermeasures are an indicator that the bridge has experienced substantial historic scour. But if the countermeasures are in good condition and appear to be providing adequate protection from scour, then a SEM finding of "no" substantial scour is appropriate, in spite of the historic scour. However, if the existing countermeasures are failing, or if they do not appear to provide an adequate level of protection, then a finding of "yes" substantial scour should be used.
10. The same general principles given above for spread footings also apply to pile caps. However, there is a greater tolerance for exposure of pile caps, given that supporting capacity is derived at depth. Concerns should be raised when the current thalweg is at or below the bottom of the pile cap, or if permanent countermeasures protecting a cap is chronically failing, thus exposing multiple piles. Note that, in accordance with the SEM analysis procedures, a lateral stability assessment may be required for pile foundations affected by scour and should be factored into the designation of substantial scour.
11. Watch for scour holes that are re-filled with sediment following a major flooding event. Refilling is most commonly associated with live-bed scour in channels with fine bed materials. Probing can usually detect such holes by noting the decreased density of the refill sediments compared with the underlying native bed materials. Ground penetrating radar (GPR) is also effective for detecting infills, but because of its complexity and expense, it is not normally used for routine scour inspections.
12. Direct inspection of a stream bed with waders is the preferred method for detecting scour. For this reason, field inspections are best performed during the summer and early fall when water levels are the lowest. Poles and probes should be employed to check for scour (see previous equipment and method descriptions in this appendix).
13. When inspecting streams with deeper water, consider the use of soundings to profile the bed and detect scour. Soundings can be made using sonar techniques or simply with a measuring tape and weight. In many deep water situations, the only reliable method to detect scour is to dispatch a professional diver.

Piers: The conditions of all piers should be described on the form in the section provided. To distinguish one from the other, the inspector must circle N, S, E, or W on the form for the pier closest to each bank, in a manner similar to that used to distinguish between banks and abutments (see “Bank Condition”). The following information about each pier should be noted in the appropriate field provided: type, foundation type, water depth, scour presence, and scour depth. Water Depth should be the average depth along the entire length of footing at time of inspection. If scour is present, the inspector shall record details of the observed scour and related damage to the substructure in the ‘Pier Findings’ field and on the Field Sketch. Please refer back to the section on “Abutments” for guidelines that the field inspector can use to assess scour condition.

DOWNSTREAM CHANNEL

The reach of the downstream channel includes approximately one bridge length from the downstream fascia. All fields contained in this section were previously described either in the “Upstream Channel” or the “Under the Bridge Channel” sections. Please refer to those sections for instructions on completing the form.

FIELD SKETCH

The field sketch is a critical element of the inspection process. As such, it should be completed while the inspection team is still at the bridge site, after the remainder of the form has been completed. At a minimum, the following elements should be included in the sketch:

- A north arrow (optimally, the sketch should be aligned such that true north is in the direction of the top of the page).
- All major features of the bridge, including the location of all piers, columns, abutments, wingwalls, and other substructure elements.
- The location of both edges of the stream as it approaches, goes under, and departs the bridge site, including all curves, braids, bars, and meanders.
- A curved arrow indicating direction of stream flow.
- All major roadway features such as the location and travel direction of all lanes.
- The location and dimensions of all exposed and undermined footings or pile caps.
- The location of all erosion zones and scour holes, including depth and lateral dimensions.
- All countermeasures present upstream, underneath, and downstream of the bridge.
- The location of any debris noted to be present at or near the bridge.
- Rock outcrops or pockets of cobbles or boulders (very large boulders should be drawn individually)
- The location of any significant trees or other vegetation.

SOUNDINGS

At some streams, the channel bottom is not visible due to deeper water and/or turbid conditions. In such cases, soundings can be used to establish a cross-sectional profile of the bed and to detect scour. Note that all measurements shall be specified in feet.

Location of Soundings: Make sure to indicate the location of the sounding. The most common locations for soundings are the upstream and downstream fascias. Cross-sections underneath the bridge may also be useful.

Sounding Method: Describe the method of sounding utilized. The most common methods are sonar techniques or simply a measuring tape and weight.

Method to Measure Distance between Soundings: Accurate measurement of the distance between soundings is important in establishing an accurate cross-sectional profile. Measurement by tape measure is the most common.

Level Line Reference: A level line reference must be established to serve as a local datum. Commonly used reference lines include the bridge railing or the top edge of the bridge opening.

Table of Soundings: For each sounding taken, the following information should be recorded: a sounding identification number, the location of the sounding, the distance from last sounding, depth and any notes related to the sounding that the inspector deems relevant. Sounding identification numbers shall be assigned by the inspector and are usually integers, starting at 1. The location of each sounding should be specified as either at a particular abutment or as the relative direction and distance from another, previously recorded sounding. Depth of sounding is the most critical quantity and, as such, should be measured and recorded carefully.

Stream Cross-section Plot: A graph-table is provided to plot the stream cross-section for visualization purposes.

Appendix B5: Web Survey Email Transmittal and Web Survey Form

TO: State Bridge Engineers

SUBJECT: Research Survey of Scour Design Practices

The New Jersey Institute of Technology (NJIT) is conducting a survey of methods to compute bridge scour depth. The survey is part of a research study sponsored by the New Jersey Department of Transportation (NJDOT) aimed at improving scour design and evaluation practices. DOTs from across the U.S. and many countries are participating in this important survey.

Your agency's participation in this survey is respectfully requested. The survey involves answering 10 questions. If you are not the person in your organization with detailed knowledge of scour design and evaluation, kindly forward this survey to the most appropriate individual or group.

You can provide your survey responses by one of two methods:

(1) Direct Web Link (Preferred Method). Just click on:
http://telus-national.org/SurveyOfScourPractice/index.asp

(2) Mailed Hard Copy: Just print and fill out the attached pdf and mail it to the address provided.

As NJDOT and NJIT progress through this two-year project, we will share the survey results with all respondents. It is important that you include the name and contact of the person completing this survey for follow up purposes (see text box at end of survey).

We greatly appreciate your cooperation and time in providing this information. Please submit your responses not later than June 30, 2009 to ensure inclusion in the study. If you have any questions about the survey or would like more information about the study, please contact the NJIT Research Team at **scour@njit.edu** or phone John Schuring at 973-596-5849.

Sincerely,

Richard Dunne, P.E.
Chief of Bridges
New Jersey Department of Transportation

STATE OF NEW JERSEY
DEPARTMENT OF TRANSPORTATION

NJIT
New Jersey's Science & Technology University

The New Jersey Institute of Technology (NJIT) is conducting a survey of methods to compute bridge scour depth. The survey is part of a research study sponsored by the New Jersey Department of Transportation (NJDOT) aimed at improving scour design and evaluation practices.

Your agency's participation in this survey is respectfully requested. We greatly appreciate your cooperation and time in providing this information. As NJDOT and NJIT progress through this two-year project, we will share the survey results with all respondents. It is important that you include the name and contact of the person completing this survey for follow up purposes (see text box at end of survey).

If you have any questions about the survey or would like more information about the study, please contact the NJIT Research Team at scour@njit.edu or phone John Schuring at 973-596-5849.

Q1: We are interested in the performance of scour critical bridges in your State, either against peak or recurring smaller floods. Have you had any bridges that have failed due to scour? Please consider outright failures, as well as bridges that you may have replaced "preemptively" on account of erosion concerns.

____ Yes

____No

** If yes, please forward any available reports describing the cause of failure(s), as well as the physical and hydrologic data surrounding the failure(s) via e-file, fax, hard copy, or web link.*

Please write web link or title here:

Q2: In your experience, what are the most prevalent types of erosion that have caused failure and/or created potential danger of failure (may check more than one):

____Contraction

____Local

____Degradation (long term)

____Other(please specify)

_____Meandering

_____Overtopping

_____Debris (not aggradation)

Q3: All bridge agencies are required to monitor scour at existing structures. Have you generated any summaries that compare field measurements with predicted scour (either published or unpublished)?

____Yes

____No

** If yes, please forward the comparative summary(s) via e-file, fax, hard copy, or web link.*

Please write web link or title here:

Q4: Have you installed fixed instrumentation to measure scour at abutments or piers (either automated or semi-automated)?

____Yes

____No

** If yes, please forward any available reports describing the type and effectiveness of instrumentation via e-file, fax, hard copy, or web link.*

Please write web link or title here:

Q5: Have you made any field or laboratory measurements of erosion rates of soil or rock materials for the purposes of scour evaluation?

____Yes

____No

** If yes, please forward any available reports describing erosion rate measurements via e-file, fax, hard copy, or web link.*

Please write web link or title here:

Q6: In the light of your experience of different types of bridge scour, is there a need to modify current HEC-18 design procedures?

____Yes

____No

Q7: What scour procedures and equations do you use in the design of **new** bridges?

___ A. Standard FHWA Guidelines in HEC 18 and HEC 23.

___ B. A version of HEC 18 and HEC 23 modified by your agency.

___ C. An alternate scour design procedure.

** If you answered B. or C. above, please forward the scour design procedure via e-file, fax, hard copy, or web link.*

Please write web link or title here:

Q8: What scour procedures and equations do you use in the evaluation of **existing** bridges?

___ A. Standard FHWA Guidelines in HEC 18 and HEC 23.

___ B. A version of HEC 18 and HEC 23 modified by your agency.

___ C. An alternate scour design procedure.

** If you answered B. or C. above, please forward the scour design procedure via e-file, fax, hard copy, or web link.*

Please write web link or title here:

Q9: Do you consider the effects of natural armoring in your scour computations? (natural armoring occurs when a residual layer of coarse particles is exposed on the stream bed due to erosion)

____Yes

____No

Q10: Does your agency have a preference for particular kinds of scour countermeasures? (may check more than one)

____ Concrete Pavement

____ Riprap

____ Gabion/Gabion Mattress

____ Other (please specify)

____Articulated Concrete Blocks (interlocking or tied)

____ Foundation Strengthening

____ Debris Deflection/Removal

Are there any additional comments that you wish to share about scour practice?

CONTACT INFO FOR PERSON COMPLETING THIS SURVEY (very important):

Please forward your completed survey and any supporting documents for your responses to the NJIT Research Team at:

Email: scour@njit.edu

Mail: Prof. John Schuring
Dept. of Civil Engineering
New Jersey Institute of Technology
323 Martin Luther King Blvd.
Newark, NJ 07102

Phone: 973-596-5849

Fax: 973-596-5790

State of New Jersey
Department of Transportation

NJIT
New Jersey's Science & Technology University

Dept. of Civil Engineering
New Jersey Institute of Technology
Phone:973.596.5849 • Fax:973.596.5790
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