Scour Evaluation Guide

Revised August 2020

Chapter 1 TXDOT SCOUR EVALUATION PROGRAM

TxDOT Scour Policy is described in Chapter 5, Section 6 of the Geotechnical Manual. This guide presents a more detailed discussion of TxDOT's Scour Program and is intended to serve as a stand-alone resource for TxDOT staff and consultants performing and documenting scour evaluations.

Scour Evaluations and Scour Summary Sheets

All new span bridges must be designed to resist damage resulting from the Scour Design Flood. Scour vulnerability must also be evaluated for all existing bridges. As such, scour evaluations (and documentation thereof) are required for all span bridges over waterways. A scour summary sheet is also required for all span bridges over waterways (Form 2605). Form 2605 does not serve as documentation of a scour evaluation.

Scour evaluations are required for bridge-class culverts, but scour evaluations for culverts are based solely on inspection observations. The scour summary sheet for bridge-class culverts (Form 2606) serves as the scour summary sheet and the documentation of a scour evaluation. Form 2606 must be updated anytime a routine inspection identifies a change in conditions.

Scour summary sheets and documentation of scour evaluations must be uploaded to AssetWise by bridge inspection staff.

Bridge Scour Plans of Action

The scour summary sheet includes a recommended coding for National Bridge Inventory Item 113, "Scour Critical Bridges". Structures most vulnerable to scour (Item 113 $\leq$ 3) are designated scour critical. Bridge scour plans of action must be implemented for all scour critical bridges and bridge-class culverts.

If a bridge or culvert is scour critical, the district or area office must prepare a bridge scour plan of action. Plans of action for off-system bridges must be coordinated with local owners. Bridge scour plans of action must be prepared using the appropriate form listed in Table 1-1. The completed form must be signed and sealed by a professional engineer. Implementation efforts such as flood monitoring, debris removal, or countermeasure installation must be documented on Form 2607, "Plan of Action Follow-Up" after they are executed. District bridge inspection staff are responsible for uploading the bridge scour plan of action and Form 2607 to AssetWise. Form 2607 does not need to be signed and sealed by a professional engineer.

Table 1-1 – Bridge Scour Plan of Action Forms

NBI Item 113 Coding	Form Number
3	2604
2	2624
1	2609

Scour Evaluation Methods

Scour evaluation methods fall into one of three categories:

Screening | identification of low-risk structures which are not vulnerable to damage from scour

Assessment | detailed scour evaluation based on current & previous bridge inspection records

Analysis | detailed analytical scour evaluation based on hydrologic and hydraulic analyses

Screening criteria should always be checked before proceeding with a more rigorous scour evaluation. A detailed scour evaluation is required for any span bridge not designated low-risk during screening. For new span bridges, the detailed scour evaluation must be based on analysis as part of the bridge design phase. For most existing span bridges, the detailed scour evaluation may be based on assessment or analysis. However, detailed scour evaluations based on analysis are required for the following structures, regardless of age:

- span bridges on interstate highways or principal arterials;
- span bridges on evacuation routes;
- span bridges that provide access to local emergency services such as hospitals; and
- span bridges that are defined as critical in a local emergency plan (*i.e.*, bridges that enable immediate emergency response to disasters).

Scour Documentation

All required scour documentation must be uploaded to AssetWise by district bridge inspection staff. Documentation of a scour evaluations and the corresponding scour summary sheets must each be signed and sealed by a professional engineer. For scour critical bridges, a bridge scour plan of action is also required, and must also be signed and sealed by a professional engineer.

<u>Item 113 will not be coded “8” for any structure lacking documentation of a scour evaluation.</u> The following documents may serve as documentation of a scour evaluation:

- Scour Evaluation based on Screening
  - Scour Vulnerability Screening (Form 538)
  - TxDOT Secondary Screening Report*
- Scour Evaluation based on Assessment
  - Scour Vulnerability Assessment Form (Form 537)
  - TxDOT Secondary Scour Evaluation Report*
  - Risk Screening for Unknown Foundations
- Scour Evaluation based on Analysis
  - Detailed Report for Scour Evaluations based on Analysis
  - Bridge Hydraulic Data Sheet with Scour Calculations
  - TxDOT Simplified Scour Method Summary*
  - TxDOT Concise Analysis Report*
  - Bridge Layout Showing Calculated Scour Depths*

Methods marked with an asterisk (*) are no longer permitted for new scour evaluations, but remain valid for scour evaluations conducted prior to June 1, 2020. In general, scour evaluations remain valid for as long as the conditions assumed for the evaluation remain accurate.

Chapter 2 MAXIMUM ALLOWABLE SCOUR DEPTH

The maximum allowable scour depth (y_a) refers to the amount of scour that can occur before a bridge foundation becomes unstable. Instability may be caused by a reduction in bearing capacity, lateral support, rotational stiffness, and/or other factors.

Maximum Allowable Scour Depth for Foundations in Soil

For foundations founded in soil or soft rock, use the formulation in Figure 2-1 to determine the maximum allowable scour depth (y_a). The formulation illustrated in Figure 2-1 considers the maximum allowable scour depth for bearing (y_{ab}) and the maximum allowable scour depth for unbraced length (y_{al}). The maximum allowable scour depth is the minimum of y_{ab} and y_{al}.

Maximum Allowable Scour Depth for Foundations in Hard Rock

If a deep foundation is tipped in a hard founding layer (*e.g.*, hard rock), it may derive enough strength from point bearing to support the entire design load. If the allowable point bearing capacity is greater than the design load, then skin friction is not required for stability. This condition can be verified if resistance or strength measurements (*e.g.*, Texas Cone Penetration blow counts, laboratory strength measurements, etc.) are available for the bearing stratum.

The total allowable point bearing capacity may be calculated by multiplying the cross-sectional area of the pile or shaft by the unit value for allowable point bearing. Refer to Chapter 5, Section 2 of the TxDOT Geotechnical Manual for more information about obtaining the unit value for allowable point bearing. Note: if a softer layer exists within 2 pile or shaft diameters of the tip elevation, allowable point bearing must be based on the allowable point bearing of the softer layer.

If skin friction is not required for bearing capacity, use the formulation in Figure 2-2 to determine the maximum allowable scour depth (y_a). In these cases, there is no need to consider the maximum allowable scour depth for bearing (y_{ab}). However, the foundation must maintain a minimum embedment one pile or shaft diameter. This "rock socket" criterion ensures rotational stability. The maximum allowable scour depth is the minimum of y_{ar} and y_{al}.

Backcalculation by Structural Analysis

The formulations for maximum allowable scour depth shown in Figures 2-1 and 2-2 are appropriate for scour coding. However, if major foundation exposure is observed (*i.e.*, Item 113 = 2), the remaining capacity must be back-calculated using advanced methods. This requires a structural analysis based on subsurface, foundation, and channel properties. Please contact the Geotechnical Branch for assistance with back-calculation by structural analysis.

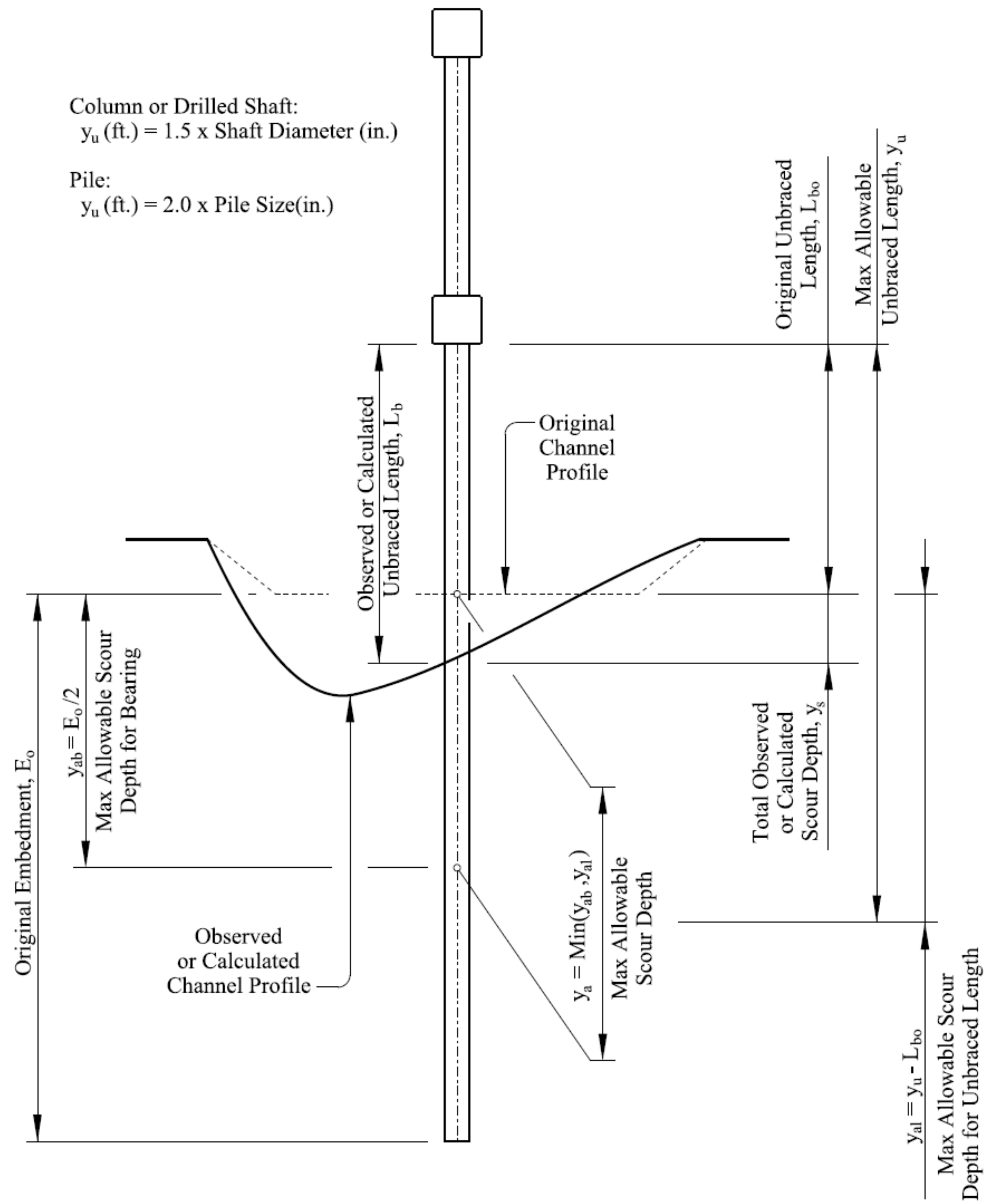

Figure 2-1 –Maximum Allowable Scour Depth for Foundations Tipped in Soil or Soft Rock

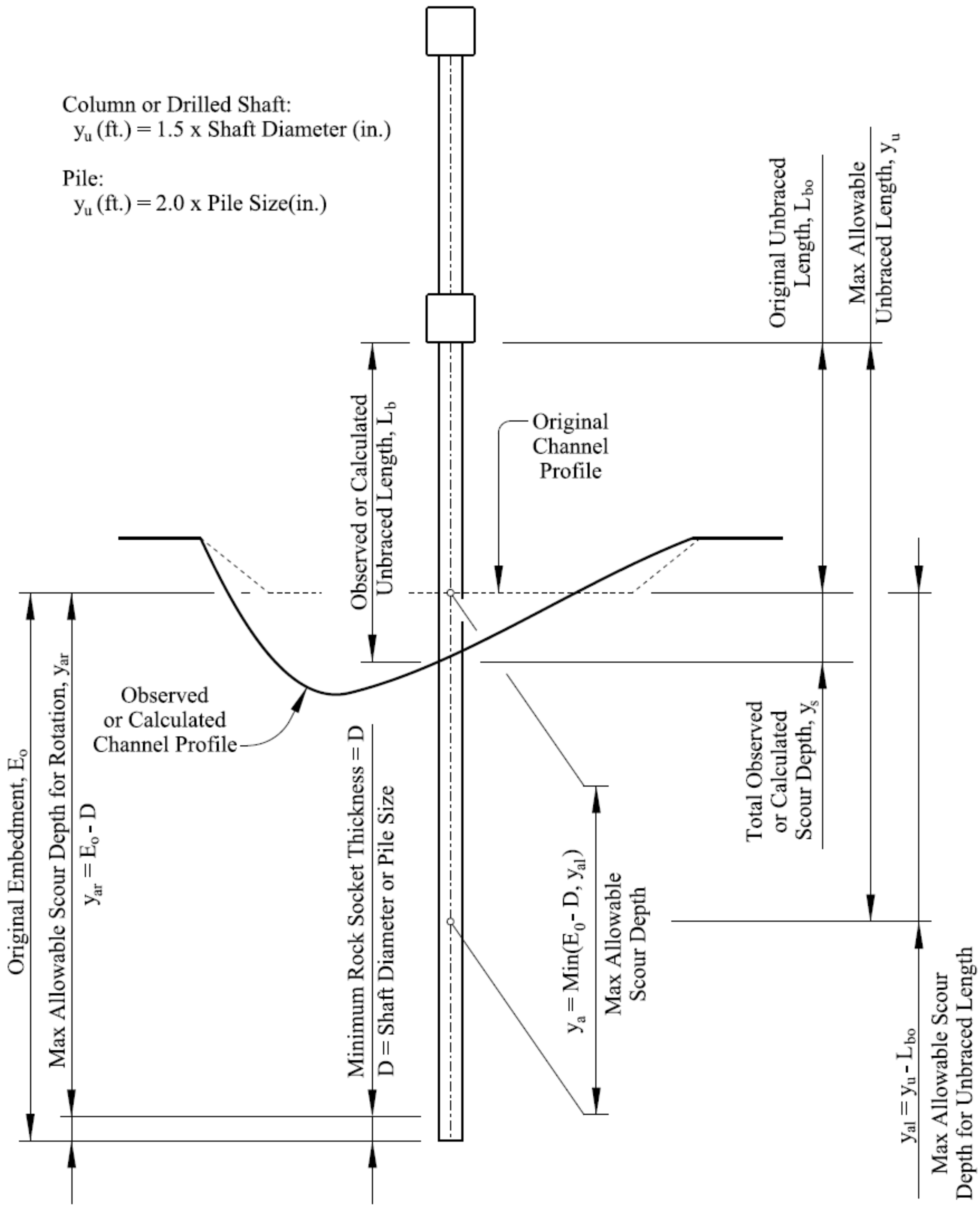

Figure 2-2 – Maximum Allowable Scour Depth for Foundations Tipped in Hard Rock

Chapter 3 MATERIAL CHARACTERIZATION

At a minimum, all scour evaluations and screenings require a rudimentary characterization of the channel material. Table 3-1 categorizes the scour vulnerability of common channel materials.

Sand is especially vulnerable to scour, even over the course of a single flood event. Mildly erodible materials may erode gradually over a long period of time, but those layers are not expected to experience significant erosion during a single flood event. Shales and stiff clays should be monitored for long-term degradations, especially where they are exposed to repeated wetting and drying cycles (*e.g.*, Sulphur River basin in northeast Texas).

Table 3-1 – Channel Materials and Scour Vulnerability

Material	Sub-Category	TCP Values	Scour Vulnerability
Rock	Hard (granite, limestone, shale)	< 4 in./100 blows	Non-Erodible
	Soft (shale)	< 12 in./100 blows	Mildly Erodible
Clay	Hard (redbed, shaley clays, very stiff clays)	< 12 in./100 blows	Mildly Erodible
	Soft to Medium	> 12 in./100 blows	Erodible
Sand	All	All	Very Erodible

Certain scour evaluation methods require additional input parameters to characterize the channel material. These parameters are geotechnical index properties that can be obtained from split-spoon samples. This usually requires drilling equipment and may be beyond the scope of Tex-100-E. The required inputs for each scour evaluation method are summarized below:

► **Scour Vulnerability Screening**
- Subsurface Profile
- Texas Cone Penetrometer Blow Count (Tex-132-E)
- Rock Quality Designation (RQD) (Optional)

► **Scour Vulnerability Assessment**
- Subsurface Profile
- Texas Cone Penetrometer Blow Count (Tex-132-E)

► **Detailed Scour Evaluation based on Analysis**
- Subsurface Profile, with the following information for each layer:
  - Particle Size Analysis (Tex-110-E)
    - Median Grain Size (D_{50}) & Percent Clay (percent passing No. 200 sieve)
    - Common grain dimensions are summarized in Table 3-2
  - Liquid Limit (Tex-104-E) [only for clayey soils]
  - Plastic Limit (Tex-105-E) [only for clayey soils]
  - Plasticity Index (Tex-106-E) [only for clayey soils]
  - USCS Soil Classification (Tex-142-E) [only for clayey soils]

Table 3-2 – Grain Dimensions of Cohesionless Materials

Soil Type	Grain Dimensions	
	ft.	mm
Boulders	> 0.840	> 256
Large Cobbles	0.840 – 0.420	256 – 128
Small Cobbles	0.420 – 0.210	128 – 64.0
Very Coarse Gravel	0.210 – 0.105	64.0 – 32.0
Coarse Gravel	0.105 – 0.0525	32.0 – 16.0
Medium Gravel	0.0525 – 0.0262	16.0 – 8.00
Fine Gravel	0.0262 – 0.0131	8.00 – 4.00
Very Fine Gravel	0.0131 – 0.00656	4.00 – 2.00
Very Coarse Sand	0.00656 – 0.00328	2.00 – 1.00
Coarse Sand	0.00328 – 0.00164	1.00 – 0.500
Medium Sand	0.00164 – 0.000820	0.500 – 0.250
Fine Sand	0.000820 – 0.000410	0.250 – 0.125

Chapter 4 SCOUR CODING

National Bridge Inventory (NBI) bridge inspection Item 113 describes a structure's vulnerability to scour damage. TxDOT also tracks Bridge Scour Plans of Action with Item 113.1 and Unknown Foundations with Item 113.2.

NBI Item 113 | Scour Critical Bridges

TxDOT Item 113.1 | Scour Plans of Action

TxDOT Item 113.2 | Unknown Foundations

Coding Guidance

The TxDOT Coding Guide includes detailed coding instructions for all three scour items. The same guidance is also provided in Appendix A of this document for ease of reference. An additional resource, Table 4-1, is provided here to help explain the basis of Item 113 codings for span bridges.

Table 4-1 – Basis of Item 113 Codings for Span Bridges

	Calculated Scour	Observed Scour
Minimal Foundation Exposure	8	
Moderate Foundation Exposure	5	4
Major Foundation Exposure	3	2

Documentation Requirements

All required scour documentation must be uploaded to AssetWise by district bridge inspection staff before scour coding values are updated. Scour documentation requirements are addressed in Chapter 1 and in Chapter 8, Section 5 of the Bridge Inspection Manual:

- Documentation of scour evaluation
- Inspection Records with Plot of Measured Channel Profile
- Signed and Sealed Scour Summary Sheet
- Signed and Sealed Bridge Scour Plan of Action (only for scour critical structures)

Item 113 must be updated for any structure with a change in scour vulnerability within 90 days of the inspection or scour evaluation date. It is the District's responsibility to upload scour documentation to AssetWise and request scour coding updates from Bridge Division. For new structures, District bridge inspection staff should upload scour documentation to AssetWise and request a coding update for Item 113 as soon as the structure is added to AssetWise.

Chapter 5 UNKNOWN FOUNDATIONS

Scour vulnerability is a function of hydraulic conditions, subsurface materials, and structural foundation properties. It is difficult to determine foundation properties unless construction plans are available in the bridge record. An "unknown foundation" is any foundation with unknown composition, gross dimensions, or embedment.

Coding

Item 113.2, Unknown Foundations, should be coded "U" for any span bridge or bottomless culvert with one or more unknown foundations.

Scour Evaluations

Scour evaluations for unknown foundations must be performed by TxDOT personnel (district, area, or division).

Unknown foundations complicate the determination of maximum allowable scour depth (y_a). This is most problematic for deep foundations, but could also affect shallow foundations if the footing thickness (t_f) or embedment is unknown. Three scour evaluation procedures are currently permitted for structures with unknown foundations:

- Unknown Foundation Risk Assessment
- Scour Vulnerability Screening (SVS)
- Scour Vulnerability Assessment (SVA)

► Bridge Scour Risk Screening for Unknown Foundations

The risk screening for unknown foundations assigns a structure to one of three risk categories: high, medium, or low. No assumptions about the unknown foundations are required. This method uses condition ratings from the NBI database to estimate the annual probability of failure (P_a) due to bridge scour. P_a is compared with the minimum performance level (MPL), which is assigned based on NBI Item 26 (Functional Classification). Risk categories are assigned as follows:

- P_a / MPL < 1 Risk Category = Low
- P_a / MPL = 1 – 2.5 Risk Category = Medium
- P_a / MPL > 2.5 Risk Category = High

If the risk category is Low, the risk screening serves as documentation of a scour evaluation and NBI Item 113 (Scour Critical Bridges) should be coded "5". If the risk category is Medium or High, the risk screening is not a sufficient scour evaluation. Either the Scour Vulnerability Screening (SVS) or the Scour Vulnerability Assessment (SVA) will be required. In either case, information about unknown foundations will need to be assumed or inferred.

The Bridge Scour Risk Screening for Unknown Foundations is programmed into an Excel spreadsheet which is available from the Bridge Division's Geotechnical Branch. The spreadsheet should be printed, signed and sealed, and uploaded to AssetWise to serve as documentation of a scour evaluation.

The risk screening for unknown foundations is not permissible for the following high-priority structures:

- span bridges on the interstate system or principal arterials;
- span bridges on evacuation routes;
- span bridges that provide access to local emergency services such as hospitals; and
- span bridges that are defined as critical in a local emergency plan (*i.e.*, bridges that enable immediate emergency response to disasters).

► **Scour Vulnerability Screening (SVS)**
Information about unknown foundations may need to be assumed or inferred. The SVS is permissible for a structure with unknown foundations if it meets the criteria for Bridges Founded in Non-Erodible Strata (see Chapter 6).

► **Scour Vulnerability Assessment (SVA)**
Information about unknown foundations may need to be assumed or inferred. The SVA is permissible for any structure with unknown foundations. All such assumptions must be listed on the scour summary sheet (Form 2605). When needed, a summary of assumptions and justifications may be attached to Form 2605.

Assumptions

Deep foundations should not be assumed to exist unless those elements are partially exposed or otherwise verifiable. If deep foundations are verified, assume an as-built embedment of 10 ft. If deep foundations cannot be verified, assume the foundation is a spread footing with 1-ft. embedment and 2-ft. thickness. More liberal assumptions may also be inferred after probing, obtaining test hole data, and/or identifying common practices from similar structures built in the same region and time period.

Documentation

Span bridges over waterways with unknown foundations have the same scour documentation and coding requirements as other span bridges over waterways. The following items must be completed, signed and sealed by a professional engineer, and uploaded to AssetWise by District bridge inspection staff:

- Scour Summary Sheet (Form 2605)
- Documentation of Scour Evaluation
- Bridge Scour Plan of Action (only required for scour critical structures)

A risk screening memo from the Geotechnical Branch serves as documentation of a scour evaluation, but it does not constitute a scour summary sheet or a bridge scour plan of action. Previous risk assessments for unknown foundations performed by the Geotechnical Branch remain valid if both of the following conditions apply:

- the risk assessment is properly documented in AssetWise
- conditions assumed for the risk assessment remain accurate

Chapter 6 SCOUR VULNERABILITY SCREENING

The Scour Vulnerability Screening (SVS) identifies span bridges with a low risk of scour damage. These bridges do not require detailed scour evaluations. Two categories of span bridges are considered low-risk: Bridges Not Over Waterways, and Bridges Founded in Non-Erodible Strata.

Bridges Not Over Waterways

If a bridge does not cross a waterway, it has a very low risk of incurring damage due to scour. Verify that a bridge does not cross a waterway by reviewing photographic inspection records, bridge layouts, and hydraulic data sheets. If high water is shown above the channel bed for the Scour Design Flood frequency, then the bridge does cross a waterway.

For structures in the category of Bridges Not Over Waterways:

- A detailed scour evaluation is not required.
- No scour documentation is required.
- NBI Items 71 (Waterway Adequacy) and 113 should both be coded "N".

Bridges Founded in Non-Erodible Strata

A detailed scour evaluation is not required if the foundation would remain stable after all materials above a non-erodible stratum were removed by scour. The maximum possible scour depth (y_{mp}) is the hypothetical scour depth that would remove all erodible materials above the non-erodible stratum. Structures may be assigned to this category if the following conditions apply:

- The stratum in question is determined to be non-erodible by one of the following methods:
    - Classification by Table 3-1. To be considered non-erodible, a stratum must also be free of open joints or other discontinuities in the rock mass.
    - Rock Quality Designation (RQD) is ≥ 75%.
- The maximum possible scour depth (y_{mp}) would cause minimal or moderate foundation exposure, as defined in the TxDOT Coding Guide. In other words, the Bridges Founded in Non-Erodible Strata category does not apply if the bridge could become scour critical.

Concrete-lined channels may also be categorized as Bridges Founded in Non-Erodible Strata, but only if all of the following conditions apply:

- The entire channel is lined by concrete; this includes any foundations that would be susceptible to scour from the Scour Design Flood
- The concrete channel is non-erodible (no failed joints, spalling, or major cracks)

For structures in the category of Bridges Founded in Non-Erodible Strata:

- The Scour Vulnerability Screening (SVS) form (Form 538) will serve as the documentation of a scour evaluation. It must be completed, signed and sealed by a professional engineer, and uploaded to AssetWise by district bridge inspection staff.
- A Scour Summary Sheet (Form 2605) must be completed, signed and sealed by a professional engineer, and uploaded to AssetWise by district bridge inspection staff.

Chapter 7 SCOUR VULNERABILITY ASSESSMENT

The Scour Vulnerability Assessment (SVA) is a detailed scour evaluation based on assessment. The SVA does not require detailed hydrologic or hydraulic analyses. The purpose of the SVA is to rate bridge's vulnerability to scour based on past and present observations. This rating includes two components: (i) Scour Vulnerability Class, and (ii) recommended coding for NBI Item 113.

(i) Scour Vulnerability Class

A bridge will be assigned to one of two scour vulnerability classes: Normal or Enhanced. Bridges with a troublesome scour history and/or multiple risk factors for future scour will be assigned the Enhanced scour vulnerability rating. All remaining bridges will be assigned the Normal scour vulnerability rating. Note that bridges with low scour vulnerability should be identified as such using the Scour Vulnerability Screening (SVS).

(ii) Recommended Coding for NBI Item 113

The SVA includes coding guidance for NBI Item 113. This guidance is consistent with the terms and definitions presented in the TxDOT Coding Guide. The SVA coding guidance is based on scour vulnerability class and current scour conditions. This guidance assumes bridges assigned to the Enhanced scour vulnerability class will experience more future scour than bridges assigned to the Normal scour vulnerability class.

SVA Method

Scour vulnerability class should be based on conditions at whichever abutment or bent is most vulnerable to scour. If it is not obvious which abutment or bent is most vulnerable to scour, determine the scour vulnerability class for multiple locations. If any abutment or bent is assigned to the Enhanced scour vulnerability class, then the entire bridge will be assigned to the Enhanced scour vulnerability class.

The scour vulnerability class is assessed based on four risk factors:

- Channel Material
- Channel Condition
- Scour History
- Channel Migration History

Each risk factor is scored based on criteria listed on the next page. Larger scores always indicate greater scour vulnerability. Negative scores indicate scour resistance. The total score for an abutment or bent is the sum of its four risk factor scores. The scour vulnerability class is assessed as follows:

- Total Score < 3 → Scour Vulnerability Class = **Normal**
- Total Score ≥ 3 → Scour Vulnerability Class = **Enhanced**

Record the score for each risk factor and the total score on the Form 537. Use the space provided on Form 537 to provide a brief description for each risk factor.

SVA Risk Factors

► **Channel Material**

Use Table 7-1 in conjunction with Table 3-1 to determine the Channel Material score. The subsurface profile will rarely comprise a single, homogeneous layer of material. The actual subsurface profile will likely be interbedded and may contain heterogeneous materials. Therefore, some judgment is required when determining the score for channel material.

Above all else, this score should convey the contribution of channel material to scour vulnerability. For example, sand is highly erodible; however, a thin layer of sand can only contribute to a small amount of scour. A competent layer of hard rock may be non-erodible, but it will only impact scour vulnerability if it is located near the surface. Thick material layers near the surface will generally have the greatest impact on scour vulnerability, especially for shallow or unknown foundations.

If channel materials are unknown, assume the channel material is sand.

Table 7-1 – SVA Scoring Criteria for Channel Material

Channel Material	Score
Competent, Hard Rock	-3
Soft Rock or Hard Clay	-1
Fractured or Weathered Rock	1
Soft to Medium Clay	2
Sand	3

► **Channel Condition**

The score for channel condition is based on the coding of NBI Item 61 (Channel and Channel Protection), which is available in AssetWise. Item 61 accounts for the condition of the stream bed, banks, and embankments. It also accounts for vegetation, previous protection or remediation efforts, and any existing issues with debris accumulation.

Table 7-2 – SVA Scoring Criteria for Channel Condition

NBI Item 61 Coding	Score
8 – 9	-1
6 – 7	1
5	3
≤ 4	5

► Scour History

The Scour History appraisal should be based on a review of the bridge's current and previous measured channel profiles. Each routine inspection report should include a plot of the measured channel cross-section at the end of the report. Routine inspection reports are available in "pdf" format in AssetWise – these documents are identified with "RTInsp_YYYY-MM" at the end of the filename.

Record the maximum historic scour depth (y_{sh}) at whichever abutment or bent has experienced the most severe foundation exposure, past or present. For example, if y_{sh} at one bent caused minimal foundation exposure, but y_{sh} at another bent caused moderate foundation exposure, the latter case would govern. Use Figure 7-1 to determine the category of foundation exposure. This will require consideration of the maximum allowable scour depth (y_a), which is addressed in Chapter 2. If the critical abutment or bent is supported by an unknown foundation, use assumed foundation dimensions to determine y_a (refer to Chapter 5). Scour depth is always measured from the as-built channel profile.

Table 7-3 – SVA Scoring Criteria for Scour History

Foundation Exposure from y_{sh}	Score
Minimal	-2
Moderate	1
Major	4

► Channel Migration History

Over time, streams and rivers can migrate laterally to new locations – this is called channel migration. Channel migration can have a negative impact on bridges because it shifts the deepest part of the channel away from mid-span, toward bents and abutments. Even if the elevation of the channel flowline remains constant, lateral migration of the channel itself can increase the exposure of adjacent foundations.

The Channel Migration History appraisal should be based on a review of the bridge's current and previous measured channel profiles. The score for Channel Migration History is based on what general category of channel migration has been observed.

Table 7-4 – SVA Scoring Criteria for Channel Migration History

Foundation Exposure from y_{max}	Score
No History of Channel Migration	0
Channel migration has occurred, but the shift has not impacted adjacent bents or abutments.	1
Channel migration has occurred, and the shift has impacted adjacent bents or abutments.	2

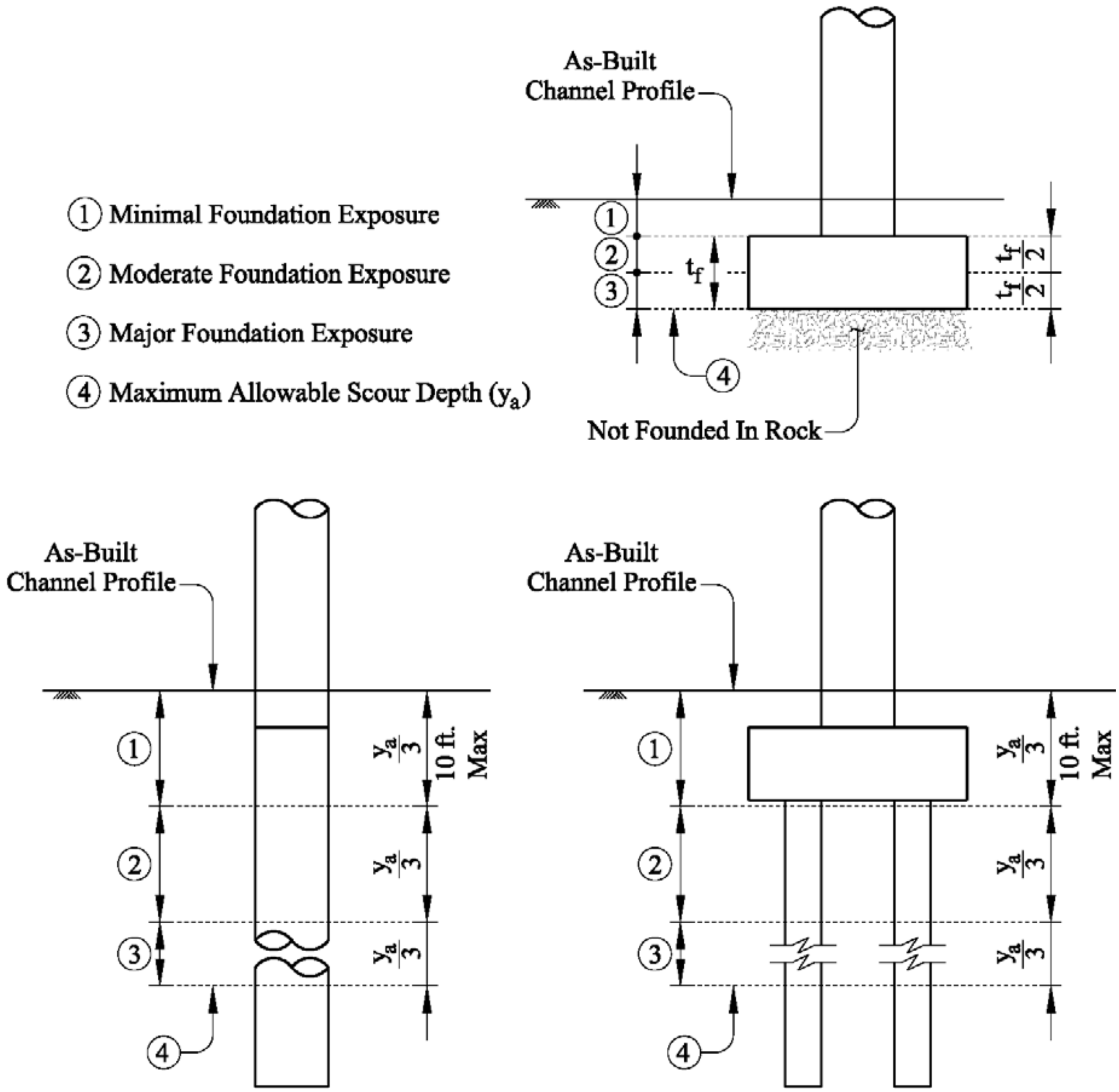

Figure 7-1 – Foundation Exposure Categories

SVA Coding Table for NBI Item 113

After determining the Scour Vulnerability Class, use the scour coding table in Table 7-5 to determine the appropriate coding for NBI Item 113. Table 7-5 uses the definitions from Figure 7-1 to define foundation exposure categories. Record the recommended scour coding on Form 537.

Table 7-5 – SVA Scour Coding Table

Current Scour Condition Refer to Figure 7-1 for Definitions of Foundation Exposure Categories	**Recommended NBI Item 113 Coding** Scour Vulnerability Class	
	Normal	Enhanced
Countermeasures Installed & Functioning	7	7
Minimal Foundation Exposure	8	5
Moderate Foundation Exposure	4	3
Major Foundation Exposure	2	2
Bridge Closed	1	1
Bridge Failed	0	0

Future Actions

Future actions may be required if the bridge is vulnerable to current or anticipated scour. If the bridge's vulnerability is based on currently observed scour, scour remediation may be required. This could include repairs, or the installation of scour countermeasures. If the bridge is considered vulnerable based on anticipated scour, then a more rigorous scour evaluation may be needed. Table 7-6 provides default recommendations and timelines for each scour coding. These recommendations may be modified when warranted by site-specific conditions.

Table 7-6 – Default Future Action Recommendations for SVA

Recommended Scour Coding	Future Action	Timeline for Completion
8	No additional action required.	-
7	No additional action required.	-
5	Detailed Scour Evaluation based on Analysis	4 years
4	Scour Remediation	3 years
3	Detailed Scour Evaluation based on Analysis	2 years
2	Scour Remediation	< 1 year

Upon completion of the SVA method, Form 537 must be completed, signed and sealed by a professional engineer, and uploaded to AssetWise by district bridge inspection staff. Future actions do not need to be described in detail on Form 537; detailed recommendations should be provided on the scour summary sheet and/or bridge scour plan of action.

Chapter 8 DETAILED SCOUR EVALUATIONS BASED ON ANALYSES

Overview

Detailed scour evaluations based on analyses result in calculated scour depths for the Scour Design Flood and the Scour Design Check Flood. New foundations must be designed to withstand the effects of calculated scour depths. Calculated scour depths should be used to determine the most prudent measures to protect new and existing foundations.

A detailed scour evaluation based on analyses must include each of the following:

- Site-Specific Hydrology Study
- Determination of Channel Cross-Sections
- Hydraulic Modeling
- Channel Material Sampling and Testing
- Scour Depth Calculations
- Detailed Report with Professional Engineer's Seal and Signature

Scour Design Flood

Determine peak discharges, average velocities, and water surface elevations for the return periods listed in Table 6-1. Use the Scour Design Flood return period for scour analyses, but also consider effects of the Scour Design Check Flood. <u>If the Scour Design Flood causes overtopping, also check the Incipient Overtopping Flood.</u>

The Design Flood return period for most TxDOT facilities is based on structure type and functional classification. Design Flood return periods for different types of facilities are given in Table 4-2 of the TxDOT Hydraulic Design Manual.

Table 6-1 – Scour Design and Scour Design Check Flood Return Periods

Design Flood	Scour Design Flood	Scour Design Check Flood
< 10-year	2, 5, 10, and 25-year	50-year
10-year	25-year	50-year
25-year	50-year	100-year
50-year	100-year	200-year
100-year	200-year	500-year

Site-Specific Hydrology Study

Conduct hydrologic studies in accordance with the most recent version of the TxDOT Hydraulic Design Manual.

Determination of Channel Cross-Sections

Channel cross sections are required for hydraulic modeling. Surveyed cross sections are recommended near the bridge (typically 200 ft. upstream and downstream). Within the surveyed reach, cross sections should be measured at all abrupt changes in channel geometry, channel slope, terrain, or vegetation. Additionally, surveys shall provide cross sections at the following four locations:

- Just upstream of the contraction zone upstream of the bridge crossing (assume 1:1 contraction ratio)
- Immediately upstream of the bridge crossing
- Immediately downstream of the bridge crossing
- Just downstream of the expansion zone downstream of the bridge crossing (assume 2:1 expansion ratio)

At a minimum, each surveyed cross section must include the following seven points:

- Left Natural Ground
- Top of Left Bank
- Toe of Left Slope
- Channel Flow Line
- Toe of Right Slope
- Top of Right Bank
- Right Natural Ground

Beyond the surveyed reach, cross-sections for the remaining extents of the hydraulic model (typically 5,000 ft. upstream and downstream) may be determined using Light Detection and Ranging (LiDAR) data.

Hydraulic Modeling

Use one-dimensional or two-dimensional bridge hydraulic analyses to determine hydraulic parameters for scour analyses. These analyses are tedious to perform manually and are usually conducted using hydraulic modeling software. Two-dimensional analyses are preferred for highly braided streams, flow around abrupt bends, or very wide and flat floodplains. Conduct hydraulic analyses in accordance with the most recent version of the TxDOT Hydraulic Design Manual.

Channel Material Sampling and Testing

Refer to Chapter 3 for sampling and testing requirements.

Scour Depth Calculations

Scour depths may be calculated manually, or using the FHWA Hydraulic Toolbox.

Note for HEC-RAS Users: Do not use the automated scour calculations in HEC-RAS; the HEC-RAS scour equations are out of date. HEC-RAS results may be imported to the Hydraulic Toolbox, but validation is recommended.

The Engineer is responsible for identifying any non-erodible layers in the channel profile. Refer to Chapter 6 for more information about identifying non-erodible strata. The top of a non-erodible layer marks the maximum possible scour depth (y_{mp}). Scour depth equations implicitly assume that an unlimited depth of material is available to be scoured – the Engineer must reconcile the calculated scour depth with the actual subsurface profile. Do not report calculated scour depths that extend into non-erodible strata. Calculate the total scour as follows:

At Abutment Toewall
Total Scour = Contraction Scour

Under Bridge, Away from Abutments and Piers
Total Scour = Contraction Scour

At Pier, Column, Pile, Drilled Shaft, or Similar Obstruction
Total Scour = Contraction Scour + Pier Scour

Do not use the abutment scour equations listed in Chapter 8 of Hydraulic Engineering Circular No. 18, "Evaluating Scour at Bridges" (HEC-18); these formulations have been found to be consistently over-conservative. However, abutment scour is a readily observable phenomenon. Therefore, all abutments should be protected against potential scour. A flexible revetment (*e.g.*, stone protection riprap) is recommended for all abutments, whenever possible.

If multiple material layers are encountered in the channel bed, scour analyses should be performed layer-by-layer. This procedure can be used for any material type or calculation method. The layer-by-layer procedure proceeds as follows:

- Divide the subsurface into multiple layers. Use at least one layer for each material.
- Starting with the top layer, calculate the total scour.
- If the calculated scour is larger than the layer thickness, assume the layer has eroded completely; do not extend the calculated scour to underlying layers. Update the hydraulic variables to account for the eroded channel profile.
- Calculate the total scour for the next layer using the updated hydraulic variables.
- Continue this process until the calculated scour is less than the layer thickness, or until the calculated scour reaches a non-erodible layer.

The following methods are permissible for calculating scour depths:

► Traditional HEC-18 Method | Recommended for Sandy Soils
Contraction and pier scour depths for sandy soils may be calculated using Equations 6.1, 6.2, 6.4, and 7.1 from HEC-18. This method is overly conservative for clay channels. Do not use D_{50} values less than 0.000656 ft. (0.20 mm). If the sand has more than 12% fines (material passing the No. 200 sieve), reduce the calculated pier scour by 50%.

► **FDOT Pier Scour Method | Recommended for Sandy Soils with Complex Piers**
The FDOT Pier Scour Method is a modified version of HEC-18 Equation 7.1. This method is documented in Section 7.3 of HEC-18. The FDOT Pier Scour Method is overly conservative for clay channels. Do not use D_{50} values less than 0.000656 ft. (0.20 mm). If the sand has more than 12% fines (material passing the No. 200 sieve), reduce the calculated pier scour by 50%.

When the FDOT Pier Scour Method is used for pier scour, contraction scour should be calculated with the traditional HEC-18 method (*i.e.*, HEC-18 Equations 6.1, 6.2, and 6.4).

► **Scour Rate in Cohesive Soils (SRICOS) Method | Recommended for Clay and Soft Rock**
This method accounts for the slower erosion rate of cohesive soils and intact rock. Instructions for using the SRICOS method are provided in Appendix B.

► **Annandale's Erodibility Index Method | Recommended for Fractured/Jointed Rock**
This methodology for calculating pier scour may be used for weathered rock or hard clay with a secondary structure of open joints or cracks. These materials tend to be eroded by quarrying and plucking, rather than by a gradual, grain-by-grain removal. Annandale's Erodibility Index Method is documented in Sections 4.7.2 and 7.13.1 in HEC-18

Detailed Report

Documentation of a scour evaluation based on analysis must be signed and sealed by a professional engineer and should include the following information:

- Hydrologic Method(s) and Details
  - drainage area, time of concentration, curve number, etc.
- Channel Cross-Section and Manning's Roughness Values
  - data source(s): survey, LiDAR, topographic maps, aerial maps, etc.
  - description of any extension or extrapolation between cross sections
- Hydraulic Method(s) and Assumptions
  - program and version; boundary conditions, modeling approach, etc.
  - summary of peak flow data for scour design flood & scour design check flood
- Soil Conditions Near the Bridge
  - layering, depth to bedrock, D_{50}, USCS classification, etc.
- Scour Calculations
  - description of method(s); include reference(s) and summary of calculations
  - assumptions (*e.g.*, reduction factors, erosion parameters, etc.)
  - summary of contraction, pier, and total scour depths

Generally speaking, the documentation for a detailed scour evaluation must include enough information to reproduce and justify its results.

Chapter 9 TRIGGER ELEVATIONS & CONDITIONS

All span bridges and bridge-class culverts require a scour coding for NBI Item 113 in AssetWise. In most cases, the scour coding will continue to be valid even if a certain amount of additional scour occurs. However, it is possible to identify a threshold elevation or condition, beyond which the structure will be significantly more vulnerable to scour. For example, beyond a certain threshold scour depth, the coding for Item 113 may need to be lowered. Coding thresholds can be determined using coding guidance for Item 113 from the TxDOT Coding Guide. The threshold scour depth could also describe a condition that requires certain scour remediation efforts.

The observation of a "trigger" should serve as an alert that the observed scour is nearing – but has not yet reached – a threshold condition. Therefore, the trigger must represent a condition that would be observed well before the threshold condition could occur. Observation of a trigger elevation or condition does not necessarily require a coding change, but it would automatically warrant a critical assessment of the scour condition. Such an assessment may result in a coding change, installation of countermeasures, load posting, or – in extreme cases – closure of the bridge.

The trigger elevation for a span bridge should generally be set higher than the threshold elevation it represents. If possible, the trigger elevation should also be identified in reference to a permanent physical feature so that it can be readily identified by inspectors. Always specify which abutment(s) and/or bent(s) a trigger elevation applies to. Table 9-1 provides generic trigger elevations for interior bents based on the current scour coding. (The trigger elevation for a spill-through abutment can usually be specified near the bottom of the abutment toewall.) Table 9-1 should be considered in conjunction with Section 113 in the TxDOT Coding Guide. Trigger elevations must be determined for site-specific conditions on a case-by-case basis.

Table 9-1 – Generic Trigger Elevations for Interior Bents

Current Item 113 Coding	Generic Trigger Elevations (Applies to Deep Foundations and Spread Footings)
8	Half-way between current channel profile and threshold for moderate foundation exposure.
7	
6	
5	
4	Half-way between current channel profile and threshold for major foundation exposure.
3	
2	Half-way between current channel profile and maximum allowable scour depth.

The trigger condition for a culvert should describe a specific amount of exposure or undermining for a specific element. (Scour coding thresholds for culverts are defined in the same way – refer to Section 113 in the TxDOT Coding Guide.) Exposure and undermining both refer to erosion, regardless of whether it occurs by scour, piping, or another mechanism. Exposure is measured vertically, measured downward from the as-built ground surface along the face of a toewall. Undermining is measured horizontally, parallel to the culvert barrel(s).

Chapter 10 STONE PROTECTION RIPRAP AT BRIDGES

Stone protection riprap is preferred over concrete riprap. Stone protection riprap is flexible, meaning that it can adjust to distortions and local movements. Concrete riprap is rigid – instead of adapting to problem areas, it tends to provoke and mask them. If undetected, erosion under concrete riprap can eventually undermine the pavement or approach slab.

Designers who elect to use stone protection riprap are required to determine the appropriate nominal stone size and gradation, thickness, and extents for the specific application and field conditions at the bridge. Refer to Hydraulic Engineering Circular No. 23, Vol. 2, "Bridge Scour and Stream Stability Countermeasures," (HEC-23 Vol. 2) for design guidance.

Stone protection is designed and specified in terms of gradation. Table 1 in Item 432 of the TxDOT Standard Specifications specifies gradation on the basis of weight, but weights are often converted to size for ease of visualization and measurement Estimated gradations based on size can be read from Table 2 if the bulk specific gravity (G_s) = 2.50, or calculated if G_s > 2.50:

$$D_{50} = 12\left(\frac{W_{50}}{0.85\gamma_w G_s}\right)$$

Where: W_{50} = 50% Size from Item 432, Table 1 (lb.)

γ_w = 62.4 pcf

G_s = bulk specific gravity (Tex-403-A) (-)

The required thickness of stone protection depends on the riprap application, nominal stone size, and the conditions where it is being placed. Minimum recommended stone riprap thicknesses from HEC-23 are summarized in Table 10-1.

Table 10-1 – Minimum Recommended Thickness for Stone Protection Riprap (HEC-23)

Application	Minimum Thickness
Abutment Protection	Greater of 1.5D_{50} or D_{100}
Pier Protection	3D_{50}
Other	Greater of 2.0D_{50} or D_{100}

Alternatively, for applications other than pier protection, riprap thickness may be specified as 1.5 times the nominal stone size. HEC-23 recommends increasing riprap thickness by 50% if the riprap will be placed under water.

Specify stone protection size (XX) and thickness (YY) in the plans as follows:

Riprap (Stone Protection) XX in.
Thickness = YY in.

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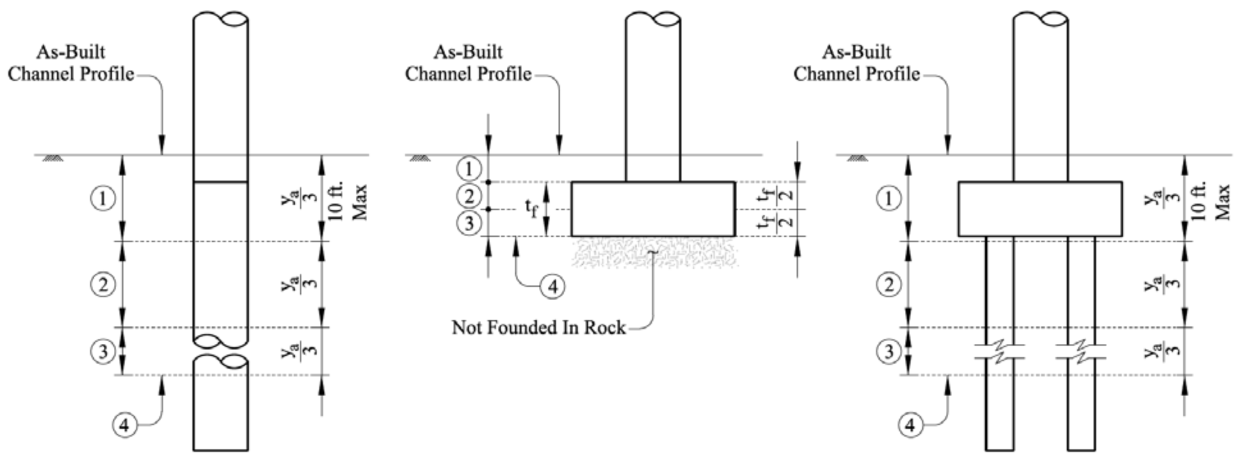
Appendix A ITEM 113 FROM TXDOT CODING GUIDE

Item 113 – Scour Critical Bridges

Use a single-digit code as indicated below to identify the current status of the bridge regarding its vulnerability to scour. A scour critical span bridge is one with major foundation exposure related to observed or calculated scour (*i.e.*, Item 113 = 0, 1, 2, or 3). A scour critical bridge-class culvert is one with major exposure and/or undermining caused by erosion/piping/scour.

If major foundation exposure is observed (*i.e.*, Item 113 = 0, 1, or 2), then Item 60, "Substructure" must receive the same coding as Item 113; major foundation exposure governs the overall condition of the entire substructure.

"Calculated scour depth" is a prediction – it is the result of a scour evaluation based on analysis. "Observed scour depth" refers to current conditions recorded during a physical inspection. "Maximum allowable scour depth" is a structural property of the foundation which indicates how much scour can occur before the foundation becomes unstable. Refer to the TxDOT Scour Evaluation Guide for more information about calculated, observed, and maximum allowable scour depths. FHWA guidance for evaluating scour at bridges is available in Technical Advisory 5140.23 and Hydraulic Engineering Circular No. 18.



①Minimal Foundation Exposure ②Moderate Foundation Exposure ③Major Foundation Exposure ④Max Allowable Scour Depth (y_a)

Code	Descriptions for Span Bridges
N	Bridge is not over waterway.
U	Unknown foundation and lacking scour evaluation and/or documentation.
T	Over tidal waters and lacking scour evaluation and/or documentation.
9	All foundation components, including piles or shafts, are above flood waters.
8	The calculated scour depth (if applicable) would cause minimal foundation exposure. The observed scour depth has caused minimal foundation exposure.
7	Previously observed scour has been remediated: countermeasures have been installed and are performing well.
6	Lacking scour evaluation and/or documentation. Refer to the TxDOT Geotechnical Manual for scour evaluation and documentation requirements.
5	The calculated scour depth would cause moderate foundation exposure. The observed scour depth causes minimal foundation exposure.
4	The observed scour has caused moderate foundation exposure. The calculated scour would cause minimal or moderate foundation exposure. Action is required to address the observed scour.
3	The calculated scour depth would cause major foundation exposure. The observed scour has caused minimal or moderate foundation exposure. A Bridge Scour Plan of Action (Form 2604) is required.
2	Observed scour has caused major foundation exposure. Immediate action is required to remediate the observed scour. A Bridge Scour Plan of Action (Form 2624) is required.
1	Observed scour exceeds the max allowable scour depth. Failure is imminent and the bridge is closed to traffic. A Bridge Scour Plan of Action (Form 2609) is required.
0	Failure has occurred and the bridge is closed to traffic.

Code Descriptions for Bridge-Class Culverts

N Culvert does not span a waterway.

U [not applicable for culverts]

T [not applicable for culverts]

9 [not applicable for culverts]

8 Refer to the table and figures below.

7 Previously observed scour has been remediated: countermeasures have been installed and are performing well.

6 Lacking scour evaluation and/or documentation. Refer to the TxDOT Geotechnical Manual for scour evaluation and documentation requirements.

5 [not applicable for culverts]

4 Refer to the table and figures below.

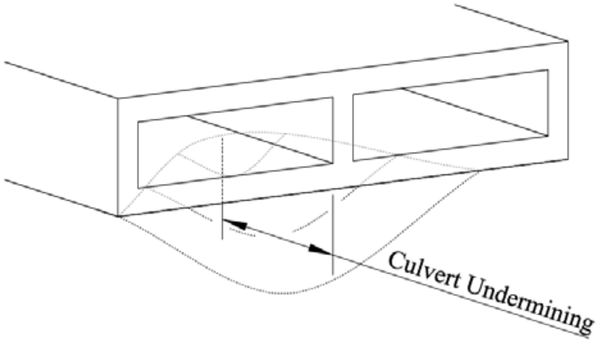
3 [not applicable for culverts]

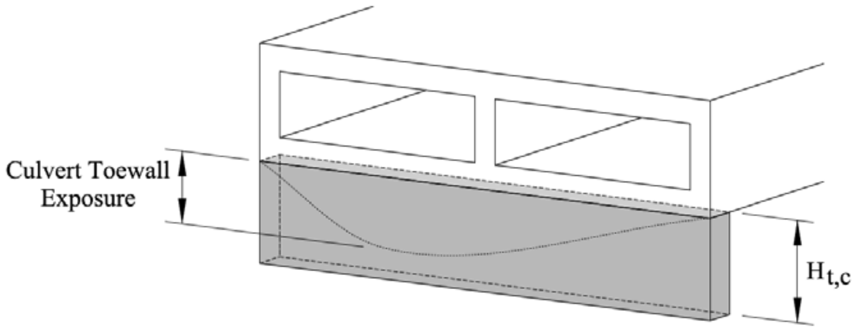
2 Refer to the table and figures below. A Bridge Scour Plan of Action (Form 2624) is required.

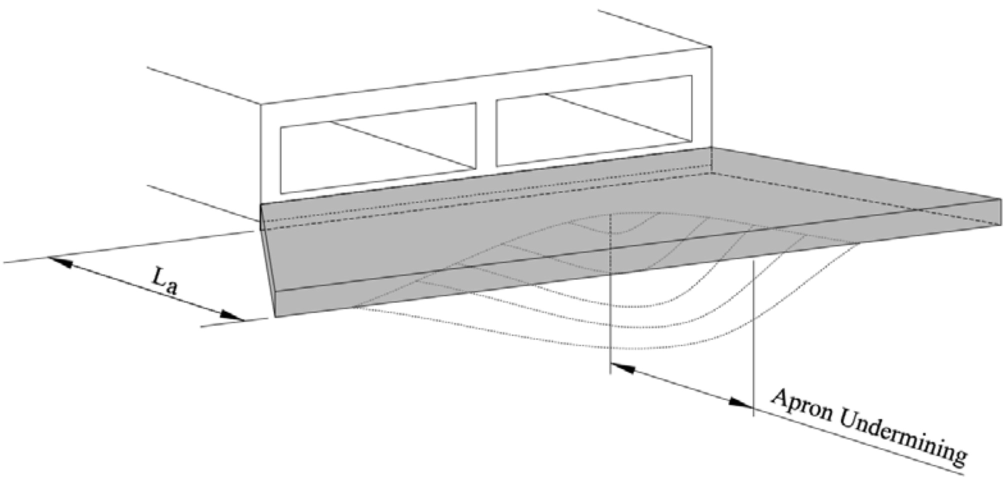
1 Failure is imminent and the bridge-class culvert is closed to traffic. A Bridge Scour Plan of Action (Form 2609) is required.

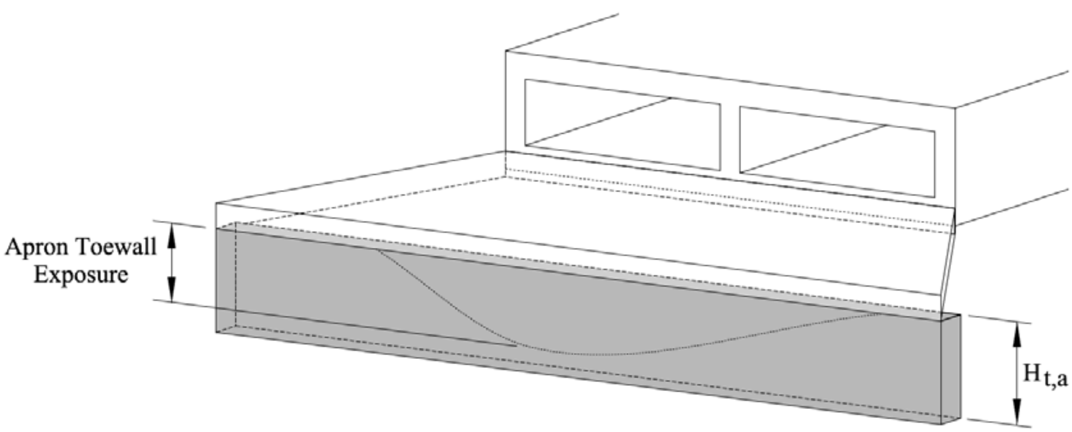
0 Failure has occurred and the bridge-class culvert is closed to traffic.

Item 113 Coding	Exposure and/or Undermining Category	*Choose the Most Critical Mechanism*			
		Culvert/Pipe Undermining	Culvert/Pipe Toewall Exposure	Apron Undermining	Apron Toewall Exposure
8	Minimal	< 1 ft.	$< {}^{1}/_{3}\,H_{t,c}$	$< {}^{1}/_{5}\,L_a$	$\leq H_{t,a}$
4	Moderate	1 – 3 ft.	$\leq H_{t,c}$	${}^{1}/_{5}\,L_a - {}^{3}/_{5}\,L_a$	$> H_{t,a}$
2	Major	> 3 ft.	$> H_{t,c}$	$> {}^{3}/_{5}\,L_a$	-


Culvert Undermining


Culvert Toewall
Exposure
Ht,c


La
Apron Undermining


Apron Toewall
Exposure
Ht,a

Appendix B SRICOS METHOD FOR CONTRACTION & PIER SCOUR

SRICOS Nomenclature and Units

α = pier skew (°)

a = pier width (m)

a′ = projected pier width for skewed bents (m)

A_1 = upstream (uncontracted) flow area (m^2)

B_1 = upstream (uncontracted) channel width (m)

B_2 = contracted channel width (m)

γ = unit weight of water = 9,810 N/m^3

g = acceleration due to gravity = 9.81 m/s^2

θ = abutment transition angle (°)

H_1 = average water depth in upstream section (m)

H_2 = representative water depth in contracted section before contraction scour (m)

$H_{2\Delta}$ = representative water depth in contracted section after contraction scour (m)

k_α = correction factor for pier skew angle effect on initial shear stress of pier scour (-)

k_θ = correction factor for transition angle effect on initial shear stress for contraction scour (-)

k_{Lc} = correction factor for contraction length effect on initial shear stress for contraction scour (-)

k_r = correction factor for contraction ratio effect on initial shear stress for contraction scour (-)

k_{sh} = correction factor for pier shape effect on initial shear stress of pier scour (-)

k_{sp} = correction factor for pier spacing effect on initial shear stress of pier scour (-)

k_w = correction factor for water depth effect on initial shear stress of pier scour (-)

K_W = correction factor for water depth effect on pier scour depth (-)

K_{SH} = correction factor for pier shape effect on pier scour depth (-)

K_{SP} = correction factor for pier spacing effect on pier scour depth (-)

L_c = length of contracted channel (m)

L_p = pier length (m)

n = Manning's roughness coefficient for channel bed (-)

n_b = number of interior bents (-)

ρ = density of water = 1,000 kg/m^3

P = wetted perimeter (m)

R_e = Reynolds number (-)

R_h = hydraulic radius = A_1 / P (m)

S = spacing between bents (m)

Δt = remaining life of structure = design life – age $\geq$ 15 (yr)

$t_{e(C)}$ = equivalent time for contraction scour (hr)

$t_{e(P)}$ = equivalent time for pier scour (hr)

τ_c = critical channel bed shear stress (Pa)

$\tau_{i(C)}$ = initial channel bed shear stress for contraction scour (Pa)

$\tau_{i(P)}$ = initial channel bed shear stress for pier scour (Pa)

ν = kinematic viscosity of water = 10^{-6} m^2/s = 0.000 001 m^2/s

V_1 = average velocity in upstream section (m/s)

V_2 = representative velocity in contracted section (m/s)

V_c = critical velocity (m/s)

$\dot{z}_{i(C)}$ = initial scour rate (corresponding to $\tau_{i(C)}$) for contraction scour (mm/hr)

$\dot{z}_{i(P)}$ = initial scour rate (corresponding to $\tau_{i(C)}$) for pier scour (mm/hr)

$Z_{max(C)}$ = maximum uniform contraction scour depth (m)

$Z_C(\Delta t)$ = uniform contraction scour depth expected during remaining life of structure (m)

$Z_{max(P)}$ = maximum pier scour depth (m)

$Z_P(\Delta t)$ = pier scour depth expected during remaining life of structure (m)

$Z_{tot}(\Delta t)$ = total scour depth expected during remaining life of structure (m)

Overview

The Scour Rate In COhesive Soil (SRICOS) method was developed at Texas A&M by Professor Briaud and his colleagues over the past several decades. This document provides a concise set of instructions for using the SRICOS equations to calculate scour for TxDOT projects.

This procedure has been implemented in a Microsoft® Excel spreadsheet, which is available from the Bridge Division's Geotechnical Branch.

Metric Units

SRICOS equations were derived using metric units. This document maintains that convention so that interested readers can compare these equations to those in the literature. Users should convert variables to the specified metric units, then convert calculated scour depths to feet.

Erosion Rate Parameters

Channel bed material affects the rate of erosion. SRICOS uses the following channel bed parameters to determine erosion rate:

- Manning's roughness coefficient (n)
- initial channel bed shear stresses ($\tau_{i(C)}$ and $\tau_{i(P)}$)
- critical channel bed shear stress (τ_c)
- critical velocity (V_c)
- initial scour rates ($\dot{z}_{i(C)}$ and $\dot{z}_{i(P)}$)

Manning's roughness coefficient (n) should represent the roughness in the contracted channel. Many resources are available for estimating Manning's roughness coefficient. Roughness Characteristics of Natural Channels by Harry H. Barnes, Jr. is a great resource, and it is available for free online: https://pubs.usgs.gov/wsp/wsp_1849/pdf/wsp_1849-test-2.pdf.

Maximum channel bed shear stresses are calculated using basic channel geometry and hydraulics information. Equations are presented in the Maximum Channel Bed Shear Stress section.

The remaining parameters, τ_c, V_c, $\dot{z}_{i(C)}$, and $\dot{z}_{i(C)}$, can be obtained from a free spreadsheet database associated with NCHRP 915. Navigate to http://www.trb.org/Main/Blurbs/179128.aspx and click the "NCHRP Erosion" link to download the Excel workbook.

NCHRP Erosion contains measured erosion parameters from a plethora of tests on a variety of different materials. The "NCHRP-Erosion" tab includes a summary of all the test results. The user can sort and filter that list by sample type, soil classification, plasticity, or other geotechnical properties to identify test records for the desired material type. Within the NCHRP-Erosion worksheet, measured values of τ_c and V_c are reported in Columns P and Q, respectively.

Individual test results are tabulated in separate worksheets. A table of scour rate ($\dot{z}$) vs. shear stress (τ) is provided for each test. The user will need to calculate the initial bed shear stresses ($\tau_{i(C)}$ and $\tau_{i(P)}$) and infer the corresponding scour rates ($\dot{z}_{i(C)}$ and $\dot{z}_{i(P)}$).

Initial Channel Bed Shear Stress

Use Equation 1 to calculate the initial channel bed shear stress ($\tau_{i(C)}$) for contraction scour:

$$\tau_{i(P)} = k_r k_{Lc} k_\theta \gamma (n^2)(V_1{}^2)(R_h{}^{-1/3}) \qquad \text{[Eq. 1]}$$

Where:

$$k_r = 0.62 + 0.38\left(\frac{B_1}{B_2}\right)^{1.75} \qquad \text{[Eq. 2]}$$

$$k_{Lc} = \begin{cases} 0.77 + 1.36\left(\dfrac{L_c}{B_1 - B_2}\right) - 1.98\left(\dfrac{L_c}{B_1 - B_2}\right)^2 & ;\ \left(\dfrac{L_c}{B_1 - B_2}\right) < 0.35 \\ 1.0 & ;\ \left(\dfrac{L_c}{B_1 - B_2}\right) \geq 0.35 \end{cases} \qquad \text{[Eq. 3]}$$

$$k_\theta = 1 + \left(\frac{\theta}{90°}\right)^{1.5} \qquad \text{[Eq. 4]}$$

$$R_h = \frac{A_1}{P} \qquad \text{[Eq. 5]}$$

Use Equation 6 to calculate the initial channel bed shear stress ($\tau_{i(P)}$) for pier scour:

$$\tau_{i(P)} = k_w k_{sh} k_{sp} k_\alpha (0.094 \rho V_2{}^2)\left(\frac{1}{\log R_e} - 0.1\right) \qquad \text{[Eq. 6]}$$

Where:

$$k_w = 1 + 16(2.71828)^{\frac{-4H}{a}} \qquad \text{[Eq. 7]}$$

$$k_{sh} = 1.15 + 7(2.71828)^{\frac{-4L}{a}} \qquad \text{[Eq. 8]}$$

$$k_{sp} = 1 + 5(2.71828)^{\frac{-1.1(S)}{a}} \qquad \text{[Eq. 9]}$$

$$k_\alpha = 1 + 1.5\left(\frac{\alpha}{90°}\right)^{0.57} \qquad \text{[Eq. 10]}$$

$$R_e = \begin{cases} \dfrac{V_2 a'}{\upsilon} & Z_{max(C)} = 0 \\ \dfrac{V_c a'}{\upsilon} & Z_{max(C)} > 0 \end{cases} \qquad \text{[Eq. 11]}$$

$$A' = (L)sin(\alpha) + (a)cos(\alpha) \qquad \text{[Eq. 12]}$$

Maximum Contraction Scour

Use Equation 13 to calculate the maximum uniform contraction scour. Equation 13 uses the velocity in the contracted section (V_2). For contraction scour, V_2 should represent the average velocity in the contracted section. If only the upstream velocity (V_1) is known, Equation 14 may be used to approximate V_2. Refer to Figure 1 for a definition of the contraction ratio parameters.

$$Z_{\max(C)} = 1.41H_1\left(\frac{1.31(V_2)}{\sqrt{gH_1}} - \frac{\sqrt{\frac{\tau_c}{\rho}}}{gn(H_1)^{1/3}}\right) \geq 0 \quad \text{[Eq. 13]}$$

$$V_2 \approx V_1\left(\frac{B_1}{B_2}\right) \quad \text{[Eq. 14]}$$

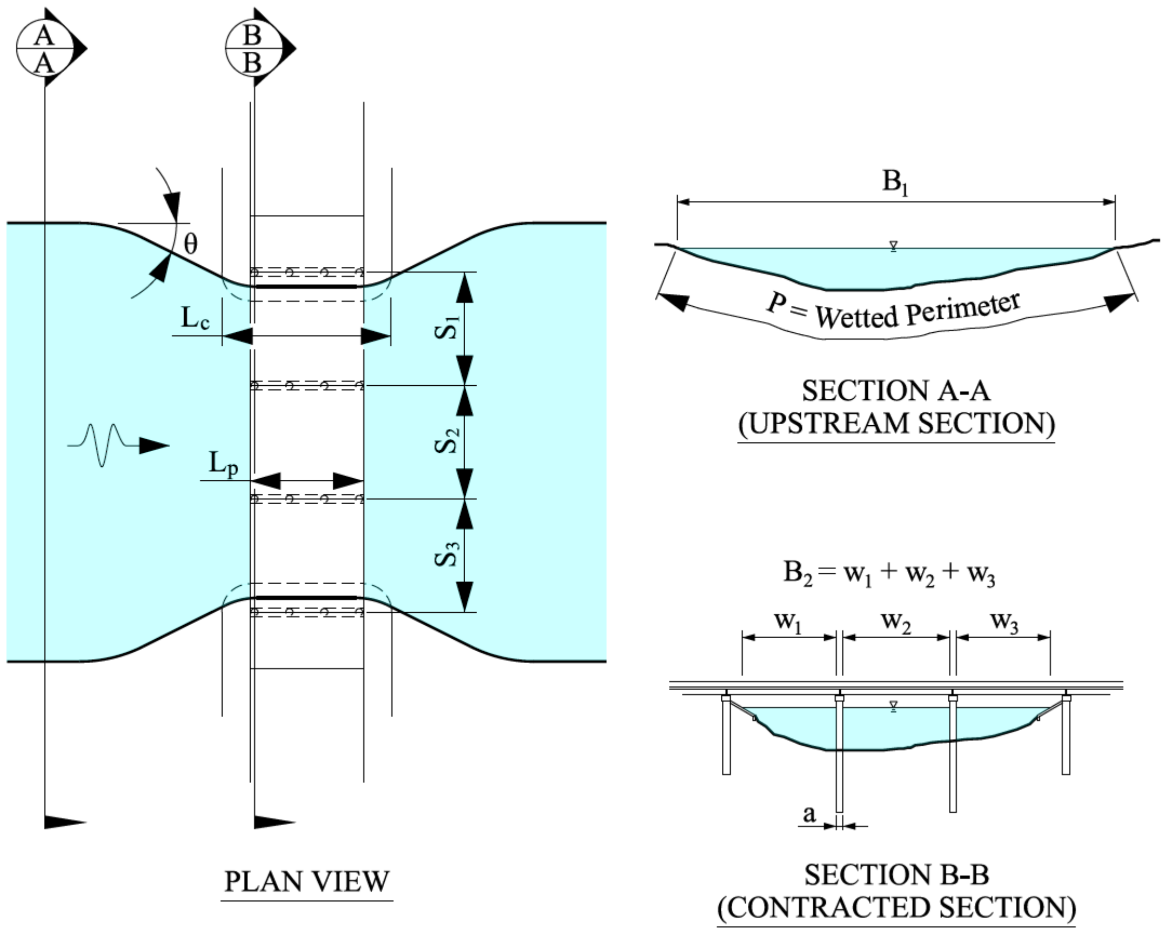


Figure 1 – Illustration of Contraction Scour Terms

Maximum Pier Scour

Equation 15 is the SRICOS equation for maximum pier scour.

$$Z_{\max(P)} = 0.18 K_{SH} K_{SP} K_W (R_e)^{0.635} \quad \text{[Eq. 15]}$$

Where:

$$K_{SH} = \begin{cases} 1.0 & round\ pier\ shape \\ 1.1 & square\ pier\ shape \end{cases} \quad \text{[Eq. 16]}$$

$$K_{SP} = \frac{B_1}{B_1 - (Number\ of\ Piers\ in\ Contracted\ Section)(a)} \quad \text{[Eq. 17]}$$

K_W depends on the calculated contraction scour, $Z_{\max(C)}$. If there is no contraction scour (*i.e.*, $Z_{\max(C)} = 0$), use Equation 18. If there is contraction scour (*i.e.*, $Z_{\max(C)} > 0$), use Equations 19 and 20. For pier scour, H_2, $H_{2\Delta}$, and V_2 should represent the pier location in the contracted section.

$$K_W = \begin{cases} 0.85\left(\frac{H_2}{a}\right)^{0.34} & \left(\frac{H_2}{a}\right) \le 1.6 \\ 1.0 & \left(\frac{H_2}{a}\right) > 1.6 \end{cases} \quad \text{[Eq. 18]}$$

$$H_{2\Delta} = H_2 + Z_{\max(C)} \quad \text{[Eq. 19]}$$

$$K_W = \begin{cases} 0.85\left(\frac{H_{2\Delta}}{a}\right)^{0.34} & \left(\frac{H_{2\Delta}}{a}\right) \le 1.6 \\ 1.0 & \left(\frac{H_{2\Delta}}{a}\right) > 1.6 \end{cases} \quad \text{[Eq. 20]}$$

Equivalent Time

The preceding equations for maximum pier and contraction scour assume a constant flow velocity over an indefinite period of time. The scour depths expected during a bridge's remaining life (Δt) are less than the maximum scour values. The design life for most new bridges is either 75 years or 100 years. In most cases, a bridge's remaining life is equal to its design life minus its age. However, Δt should never be taken less than 15 years.

Use Equations 21 and 22 to calculate the equivalent time for contraction scour ($t_{e(C)}$) and pier scour ($t_{e(P)}$), respectively. Note: these equations used mixed units.

$$t_{e(C)} = 644.32(\Delta t)^{0.4242}(V_2)^{1.648}(\dot{z}_i)^{-0.605} \quad \text{[Eq. 21]}$$

$$t_{e(P)} = 73(\Delta t)^{0.126}(V_2)^{1.706}(\dot{z}_i)^{-0.200} \quad \text{[Eq. 22]}$$

Where:

$t_{e(C)}$ = equivalent time for contraction scour (hr)

$t_{e(P)}$ = equivalent time for pier scour (hr)

Δt = remaining life of bridge in years = (design life) – (age) ≥ 15 years

V_2 = representative velocity in contracted section (m/s)

$\dot{z}_{i(C)}$ = initial scour rate of pier scour corresponding to $\tau_{i(C)}$ (mm/hr)

$\dot{z}_{i(P)}$ = initial scour rate of contraction scour corresponding to $\tau_{i(P)}$ (mm/hr)

Use Equations 23 and 24 to calculate the scour depths expected during the remaining life of the structure.

$$Z_C(\Delta t) = \frac{t_{e(C)}}{\frac{1}{\dot{z}_{i(C)}} + \frac{t_{e(C)}}{Z_{\max(C)}}} \quad \text{[Eq. 23]}$$

$$Z_P(\Delta t) = \frac{t_{e(P)}}{\frac{1}{\dot{z}_{i(P)}} + \frac{t_{e(P)}}{Z_{\max(P)}}} \quad \text{[Eq. 24]}$$

Total Calculated Scour Depth

Calculate total scour using Equation 25 and then convert the result from millimeters to feet.

$$Z_{tot}(\Delta t) = Z_C(\Delta t) + Z_P(\Delta t) \quad \text{[Eq. 25]}$$

Appendix C SCOUR SUMMARY SHEET FOR SPAN BRIDGES

Use these guidelines to complete Form 2605, "Scour Summary Sheet for Span Bridges".

Title Block
Enter the District, County, Permanent Structure Number (PSN), Highway, Crossing, and CSJ in the appropriate boxes.

Recommended Scour Codings
Enter the recommended codings for Items 113, 113.1, and 113.2. Refer to the TxDOT Coding Guide (or Appendix A) for coding instructions.

Engineer of Record for the Recommended Scour Codings
Enter the name and agency of the engineer who is responsible for the recommended scour codings. This is the engineer who must sign and seal the scour summary sheet.

Date of Recommendation
Enter the date of the coding recommendations.

SCOUR EVALUATION DETAILS

Date – Enter the date of the scour evaluation. This date should be shown on the documentation of the scour evaluation.
Engineer of Record for Scour Evaluation – Enter the name and agency of the engineer who is responsible for the scour evaluation. This individual's seal and signature must be shown on the scour evaluation documentation.
Scour Evaluation Method – Check the box next to the scour evaluation method that was used. If an evaluation method other than those listed was used, check the box next to "Other" and list the method in the space provided.

FOUNDATION DETAILS

Non-Erodible Stratum – Check this box if the foundations are protected by a non-erodible stratum. If this box is checked, describe the non-erodible stratum in the space provided. For example: *Very hard limestone at EL = 535 ft. with TCP < 2 inches per 50 blows.*
Unknown Foundations – Check this box if the bridge is supported by even one unknown foundation (*i.e.*, gross dimensions and embedment not known). If this box is checked, some foundation dimensions may have been assumed to estimate the max allowable scour depths. Use the space provided to document any assumptions that were made. Attach an additional sheet if more space is needed.

INSPECTION DETAILS

Date of Most Recent Inspection – Enter the date of the most recent bridge inspection.
Scour Countermeasures – Check this box if the bridge has a documented history of scour issues which have been corrected by the installation of countermeasures. If this box is checked, provide a brief description of the countermeasures in the space provided. Attach photos if countermeasures were installed recently and are not documented in the latest inspection report.

SCOUR DEPTHS

All reported scour depths should be measured from the same reference profile or elevation so that maximum allowable, calculated, observed, and/or max possible scour depths at any given bent can be compared "apples to apples".

Scour depths are measured from the as-built channel profile. – Check this box if scour depths are measured from the as-built channel profile. This is always recommended when the as-built channel profile is available (*i.e.*, shown on bridge layout).
Scour depths measured from ________. – Check this box if the as-built channel profile is not known, and indicate the elevation, physical point, or profile from which scour depths are measured.

The recommended scour coding will reflect conditions at whichever abutment or bent is most vulnerable. In some cases, multiple locations will qualify as "most vulnerable". Complete the Scour Depths table only for those abutment(s) and/or bent(s) which are most vulnerable. Enter "N/A" for any fields that are not applicable, and "–" for any values that are not available.

Abutment or Bent # – Identify the abutment or bent using the same nomenclature as the original plans and inspection records.
y_{ab} – Max allowable scour depth for bearing. If the foundation is embedded in rock, this field may be used for y_{ar} (max allowable scour depth for rotation).
y_{al} – Max allowable scour depth for unbraced length. Not applicable for shallow foundations.
Max Allowable Scour Depth – The lesser of y_{ab} and y_{al}
Max Possible Scour Depth – Scour depth that would be required to reach a non-erodible stratum. Only applicable if a non-erodible stratum is present.
Calculated Contraction Scour – One of the calculated scour depths from a detailed scour evaluation based on analysis.
Calculated Pier Scour – One of the calculated scour depths from a detailed scour evaluation based on analysis.
Total Calculated Scour Depth – Equal to sum of calculated contraction and pier scour.
Observed Scour Depth – Scour depth determined from channel profile measured during latest inspection.

TRIGGER ELEVATION & FUTURE ACTION

List a trigger elevation and any actions that should be considered if/when the trigger elevation is observed. Refer to Chapter 9 for more information about selecting a trigger elevation. The trigger elevation must be determined for site-specific conditions on a case-by-case basis.

Appendix D SCOUR SUMMARY SHEET FOR BRIDGE-CLASS CULVERTS

Use these guidelines to complete Form 2606, "Scour Summary Sheet for Bridge Class Culverts".

Title Block
Enter the District, County, Permanent Structure Number (PSN), Highway, Crossing, and CSJ in the appropriate boxes.

Engineer of Record for the Recommended Scour Codings
Enter the name and agency of the engineer who is responsible for the recommended scour codings. This is the engineer who must sign and seal the scour summary sheet.

Date of Recommendation
Enter the date of the coding recommendations.

Recommended Scour Codings
Enter the recommended codings for Items 113, 113.1, and 113.2. Refer to the TxDOT Coding Guide (or Appendix A) for coding instructions.

STRUCTURE DETAILS

Pipe – Check this box if the structure is a pipe culvert.
Box – Check this box if the structure is a box culvert.
Number of Barrels – Enter the number of boxes or pipes.

The following terms are illustrated under Item 113 in the TxDOT Coding Guide:

Culvert/Pipe Toewall Height ($H_{t,c}$) – Enter the height of the culvert toewall. If there is no toewall adjacent to the culvert, check the box for "N/A".
Length of Apron (L_a) – Enter the length of the apron, measured parallel to the barrel(s). If the culvert does not have an apron, check the box for "N/A".
Apron Toewall Height ($H_{t,a}$) – Enter the height of the apron toewall. If the culvert does not have an apron toewall, check the box for "N/A".

INSPECTION DETAILS

Date of Most Recent Inspection – Enter the date of the most recent inspection.

The following terms are illustrated under Item 113 in the TxDOT Coding Guide:

Culvert or Pipe Undermining – Enter the amount of undermining beneath the culvert (not the apron). This is a horizontal length, measured parallel to the barrel(s).
Culvert or Pipe Toewall Exposure – Enter the amount of culvert toewall exposure. This is a vertical length, measured downward from the top of the culvert toewall. If there is no toewall adjacent to the culvert, check the box for "N/A".
Apron Undermining – Enter the amount of undermining beneath the apron. This is a horizontal length, measured parallel to the barrel(s). If the culvert does not have an apron, check the box for "N/A".

Apron Toewall Exposure – Enter the amount of apron toewall exposure. This is a vertical length, measured downward from the top of the apron toewall. If the culvert does not have an apron toewall, check the box for “N/A”.

TRIGGER CONDITION & FUTURE ACTION

List a trigger condition and any actions that should be considered if/when the trigger elevation is observed. The trigger condition for a culvert is analogous to the trigger elevation for a span bridge. However, the trigger condition for a culvert should define a specific amount of exposure and/or undermining for a particular element (*e.g.*, apron toewall, apron, culvert toewall, pipe, or culvert). Refer to Chapter 9 for more information about selecting a trigger condition. The trigger condition must be determined for site-specific conditions on a case-by-case basis.