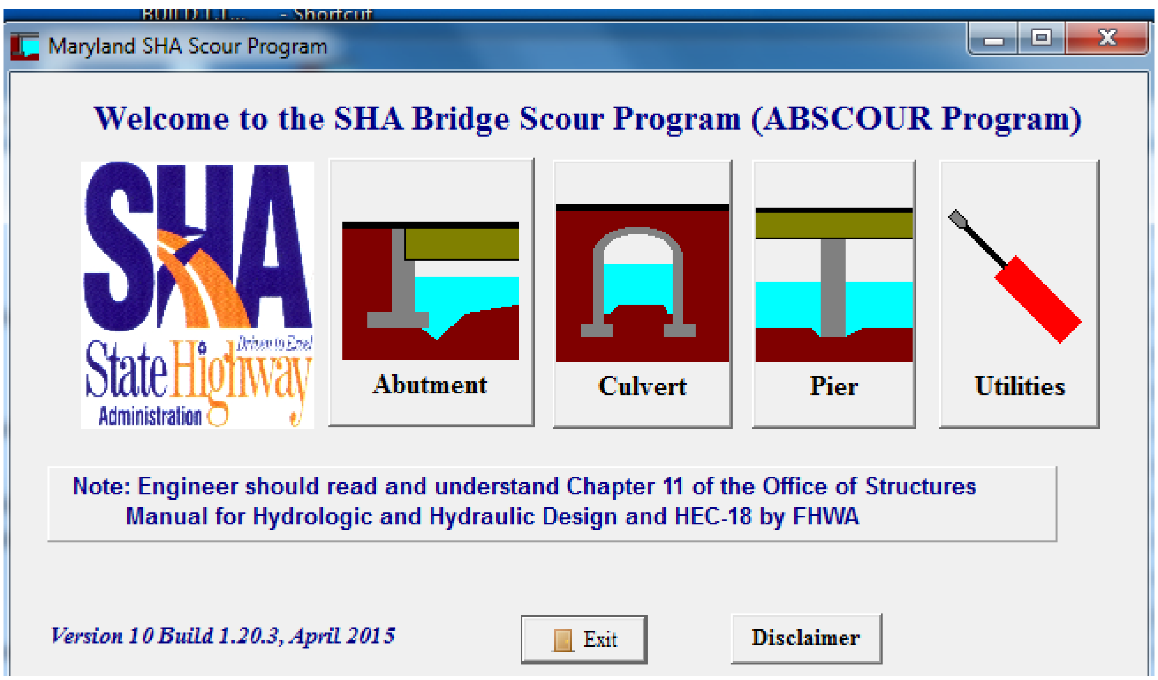
OFFICE OF STRUCTURES
STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

# CHAPTER 11 APPENDIX A

# ABSCOUR 10
# USERS MANUAL

## PART 1: DERIVATION OF METHODOLOGY




MAY 2015

# Preface

ABSCOUR 10 is the current version of the bridge scour analysis program. The user is advised to check the web site below for any revisions to the program:

http://www.gishydro.eng.umd.edu

The material presented in this ABSCOUR Users Manual has been carefully researched and evaluated. It is being continually updated and improved to incorporate the results of new research and technology. However, no warranty expressed or implied is made on the contents of this program or the user's manual. The distribution of this information does not constitute responsibility by the Maryland State Highway Administration or any contributors for omissions, errors or possible misinterpretations that may result from the use or interpretation of the materials contained herein.

**Significant Changes to ABSCOUR 10**

1. Incorporate the guidance in the FHWA HEC-18 Manual, Evaluating Scour at Bridges, 5$^{th}$ edition, April 2012 (See Appendix A, Part lll)
2. Update the help file system to incorporate revisions based on OOS policies and experience.
3. Revise the critical velocity for the Piedmont Zone (SHA modified Neill's critical velocity curves) based on USGS field study of ABSCOUR using abutment scour measurements of bridges in South Carolina)
4. Revise the recommended calibration/safety factors for ABSCOUR also based on the USGS study noted above
5. Revise the computation for pressure flow based on the vertical blockage of the flow by the structure superstructure (FHWA Research)
6. Current layered soil algorithm for contraction scour has been extended to the abutment scour.
7. Revise pier local scour to remove effect of soil particle size as per the guidance in HEC-18 5$^{th}$ edition.
8. Implement pier scour option 4 that automatically solves for the worst case pier scour condition, considering both uncontracted and contracted channel bed conditions. Flow depth, flow velocity and soil properties will be automatically revised based on the appropriate pier scour options and conditions.
9. Add a utility unit for abutment scour to consider the effect on scour if the channel moves into the abutment. The input data can be directly imported from the appropriate ABSCOUR run.
10. Change ABSCOUR default file extension to "asc". The old extension will remain visible on the file list. This will enable user to import files from older ABSCOUR runs.
11. See also the History of Changes included in the back of this Appendix

Questions regarding the use of the ABSCOUR Program should be directed to the Office of Structures, Structures Hydrology and Hydraulics Division

**Maryland SHA Office of Structures**
# BRIDGE SCOUR PROGRAM (ABSCOUR 10)
**APPENDIX A - USERS MANUAL, PART 1**

## CAPABILITIES AND LIMITATIONS

ABSCOUR is a computer program developed by the Office of Structures for estimating and evaluating scour at bridges and bottomless arch culverts. The program serves as an analytical tool to assist the user in identifying and utilizing the appropriate bridge geometry, hydraulic factors and soils/rock characteristics to estimate scour at structure foundations. The program is not an expert system. The accuracy of the answers obtained (scour depths) depends on the accuracy of the input information, the selection of the most appropriate analytical methods available in the program and the user's judgment. However, careful attention to the guidance in the manual should result in reasonable estimates of scour. Design considerations for scour should include other factors than estimated scour depths as discussed in this Appendix and in Chapter 11.

The Office of Structures has evaluated the latest version (fifth Edition, April 2012) of the FHWA Manual HEC-18, Evaluating Scour at Bridges. Recommendations for using the methodologies for evaluating scour in HEC-18 are set forth in the introduction to Chapter 11..

Verification and calibration efforts of the ABSCOUR 10 methodologies have been an on-going effort over the last 13 years. These efforts include:

- Several cooperative studies with FHWA utilizing the J. Sterling Jones Hydraulic Laboratory in McLean, Virginia,
- Two cooperative studies with the US Geological Survey using a database of measurements of clear water abutment scour collected at South Carolina Bridges.
- Continuing evaluation of the method within the Office of Structures on a bridge by bridge basis over the last 13 years to determine ways and means of improving the accuracy of the results and to facilitate its use by others. The Office of Structures provides periodic workshops on the use of the program.

PROGRAM CAPABILITIES

1 Estimate contraction scour under a bridge for left overbank, channel and right overbank using Laursen's live bed scour equation, and/or the option of either Laursen's clear water scour equations or a modified Neill's competent velocity equations for clear water scour (as calibrated using the USGS database in South Carolina,
2 Estimate contraction and abutment scour for multiple layers of channel bed materials
3 Estimate scour for complex and simple piers using a method based on the FHWA HEC-18 equations,
4 Print input and output information for the scour report,
5 Plot the scour cross-section for the scour report,

6 Estimate scour for open channel and pressure flow conditions,
7 Estimate scour in cohesive soils and rock,
8 Estimate scour in bottomless arch culverts,
9 Estimate minimum $D_{50}$ rock riprap sizes for design, based on the FHWA HEC 23 equations for abutments and piers,
10 Permit easy changes to hydraulic and soil parameter inputs in order to conduct sensitivity analyses of the estimated scour depths.
11 Allow user the option to select various scour parameters rather than use the standard values incorporated in the ABSCOUR program.

USER ASSISTANCE

1 Help screens and text files in the ABSCOUR Program to define, illustrate and explain each input parameter, using the F-1 key or the Help File,
2 Background on the concepts used to develop the ABSCOUR methodology,
3 Over-ride features to allow the user to modify the program logic,
4 Simple and fast procedures to conduct sensitivity analyses of input parameters,
5 Inclusion of the Example Problems in the April 2012 Fifth Edition of HEC-18 which can be used to compare the various methods available for estimating scour.
6 Engineers in the Office of Structures are available to provide user assistance upon request.

OUTPUT FILES

1. A detailed report summarizing the factors considered in the scour computations.
2. Plots of the Approach Section, Bridge Section and Scour Cross-Section under the bridge to a user defined scale for a plotter or to a dxf file for use in Microstation. This includes a scour cross-section for combinations of abutments and piers, and a comparison of the ABSCOUR cross-section with the corresponding HEC-RAS cross-section.

LIMITATIONS

1 The accuracy of the scour computations is dependent upon the experience and judgment of the user in the selection of input data and appropriate analytical methods. The methods selected for analysis need to be consistent with the field conditions as reflected in the input data and with appropriate hydraulic and sediment transport concepts.
2 Ideally, a 3-D model would be helpful to determine hydraulic flow conditions and to estimate scour, whereas the hydraulic data used to provide the input data is typically a 1-D model. ABSCOUR contains subroutines that permit the user to modify the hydraulic data (which are based on conveyance) to consider a more conservative flow (worst case) distribution under the bridge for purposes of estimating scour. The user needs to verify that the hydraulic model (typically HEC-RAS) provides for a reasonable flow distribution upstream, through and downstream of the bridge.
3 Calibration studies have been conducted, in cooperation with the US Geological Survey, for estimating clear water scour for fine-grained sands and for cohesive materials typical of the Piedmont. More accurate methods are available through use

of the EFA (Erosion Function Apparatus) to measure the critical velocity of Shelby tube samples through a laboratory procedure. Limited calibration studies have been made, to the best of our knowledge, for coarse-grained bed materials.

4 Available methods for estimating scour in rock (Erodibility Index Method) have had limited verification and need to be applied with judgment.

5 There are many variables that will have an effect on scour at a bridge. ABSCOUR will address a limited number of these conditions. The user is provided with flexibility through overrides and other mechanisms to expand the range of conditions which can be analyzed by ABSCOUR. The user is encouraged to make a critical review of the estimated scour depths to verify that the numbers look reasonable. If the ABSCOUR analysis does not appear to be reasonable, and there are no detectable errors in the input data or the computations, the user is encouraged to get in touch with the Office of Structures for guidance. Improper use of over-rides is a common source of errors in using ABSCOUR.

It is the SHA’s experience that the ABSCOUR Program, when applied with appropriate consideration of the site conditions and scour parameters, will give reasonable results for bridges over typical Maryland streams.

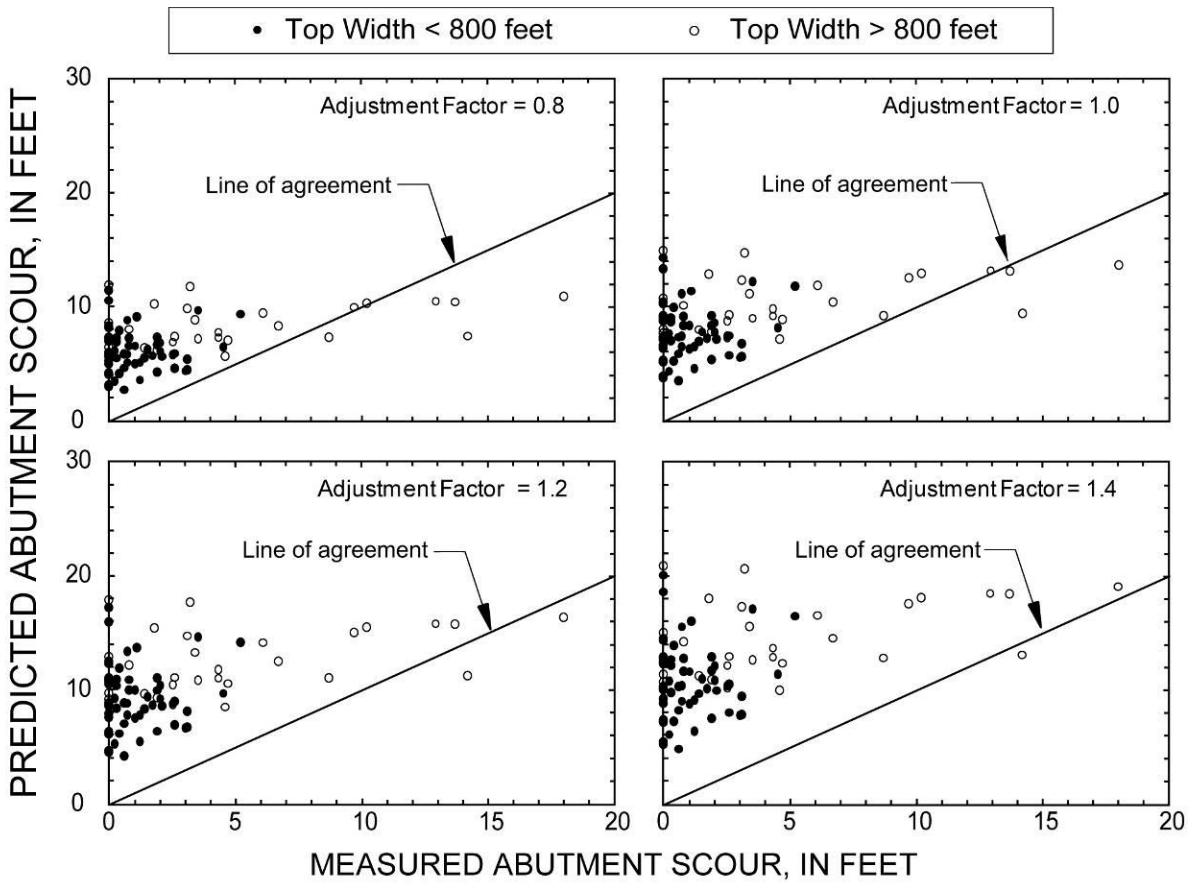
We have had the opportunity to apply ABSCOUR to many of the larger river crossing in Maryland with reasonable success. The scour evaluation equations for pier scour and contraction scour are essentially the same as those used in HEC-18. The concept of combining abutment scour and contraction scour as first utilized in ABSCOUR more than 10 years ago is now approved by the FHWA and is incorporated in HEC-18.

We were unable to get the ABSCOUR program to provide reasonable answers for bridge abutments in the wide swamps and wetlands in the non-tidal coastal zone in South Carolina. The preliminary studies indicate that the calculated ABSCOUR Kv values may be too low for such sites. We have developed an alternative approach for evaluating clear water abutment scour on streams which have characteristics similar to those of the Coastal (Non-tidal) Zone of South Carolina.

## Calibration Study Results

**The information presented in the following plots reflects the results of the USGS clear water calibration studies for ABSCOUR in the Piedmont Zone of South Carolina.** The characteristics of this zone are considered typical for many Maryland upland streams. The South Carolina bridges were divided into two categories depending on the width of the flood plain at the bridge for the 100-year flood: 1. Smaller streams with flood plain widths of under 800 feet (black dots) and 2. Larger streams with flood plain widths greater than 800 feet (white dots). For the smaller streams, using an adjustment factor (safety factor) of 0.8 still results in an over-prediction of abutment scour for all of the bridges in this category. For the larger streams an adjustment factor of 1.0 results in an over-prediction of all but two bridges. There were certain unique features at these two bridges which could not be modeled by the ABSCOUR program. (In both cases, deep abutment scour occurred at one abutment and zero scour at the other abutment, indicating a flow distribution condition not evident in the hydraulic analysis). This information has been used in developing guidance for selection of the calibration factor (safety factor) in ABSCOUR.

Please note that the study did not address live-bed scour.



## PIEDMONT PHYSIOGRAPHIC REGION

## CHARACTERISTICS OF THE SOUTH CAROLINA STREAMS USED IN THE CALIBRATION STUDIES

**TABLE 1 Range of Selected Stream Characteristics for Measurements of Clear-Water Abutment Scour Collected at 129 Bridges in the Piedmont and Coastal Plain of South Carolina**

| | | | Properties for Full Cross Section Upstream of Bridge | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Range value** | **Drainage area (miles$^2$)** | **Channel slope (ft/ft)** | **[a]Average cross section velocity (ft/s)** | **[a]Average cross section depth (ft)** | **[a] Cross section top width (ft)** | **[a, b] Unit width flow at bridge (cfs/ft)** | **Median grain size (mm)** | **Observed abutment-scour depth (ft)** | **Observed contraction-scour depth (ft)** |
| Piedmont (90 abutment and 66 contraction scour measurements) | | | | | | | | | |
| Minimum | 11 | 0.00037 | 0.49 | 3.4 | 213 | 6.7 | < 0.062 | 0.0 | 0.0 |
| Median | 82 | 0.0012 | 1.80 | 7.3 | 711 | 29.7 | 0.091 | 1.0 | 0.8 |
| Maximum | 677 | 0.0024 | 4.38 | 15.8 | 2663 | 72.9 | 1.19 | 18.0 | 4.5 |
| Coastal Plain (104 abutment and 42 contraction scour measurements) | | | | | | | | | |
| Minimum | 6 | 0.00007 | 0.25 | 2.1 | 463 | 3.8 | < 0.062 | 0.0 | 0.0 |
| Median | 54 | 0.0006 | 0.47 | 4.7 | 2154 | 17.7 | 0.19 | 8.4 | 2.0 |
| Maximum | 8,830 | 0.0024 | 0.94 | 16.3 | 28952 | 51.5 | 0.78 | 23.6 | 3.9 |

[a] Parameter was estimated with the 100-year flow. [b] Determined by ABSCOUR program.

## CALIBRATION OF ABSCOUR 9 FOR THE COASTAL REGION OF SOUTH CAROLINA

As indicated in the table above, the South Carolina Coastal Zone is characterized by wide swampy wetlands and there was no clearly defined main channel and flood plain at many of the bridge crossings. In general, it was difficult to model ABSCOUR for this type of crossing, and the correlation studies between measured and predicted scour depths were not adequate to recommend that ABSCOUR be used as a design method for this kind of condition.

Maryland has few watersheds that are similar to the upland (non-tidal) coastal region in South Carolina. An alternative approach is presented in Appendix A, Part 2, Attachment 5.

**USERS MANUAL**
**FOR THE SHA BRIDGE SCOUR PROGRAM (ABSCOUR)**

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## PART 1: DERIVATION OF THE ABSCOUR METHODOLOGY

### I. OVERVIEW

### A. LIVE BED SCOUR

The method presented in this guideline for estimating live-bed abutment scour is based on Laursen's contraction scour equation as presented in the FHWA Publication HEC No. 18, Fifth Edition. (1). This equation was originally derived by Straub (2) considering that the shear stresses (and thus the rates of sediment transport) in an uncontracted section and a contracted section are the same. It assumes a long contracted channel where the flow is considered to be uniform and the scour depth is constant across the channel section.

The contracting flow at the entrance corner of a channel constriction differs significantly from the conditions described above. The flow velocity across the channel is not uniform. The velocity near the edge of the constriction is faster than that in the midstream. Because of this higher velocity and its associated turbulence, the scour depth near the edge or corner of the constriction is usually deeper than in the center of the channel. The flow pattern at the upstream corner of an abutment will be similar to the flow at the entrance corner of a contracted channel, when the bridge approach roads obstruct overbank flow or the abutment constricts the channel. Local abutment scour can be expected to be deeper than the contraction scour in the center of the channel. Laursen's contraction scour equation is used as the basis for developing equations for estimating local abutment scour. Velocity variations caused by the flow contraction and spiral flow at the toe of the abutment are considered in developing the equations.

### B. CLEAR WATER SCOUR

The User has the options of selecting Laursen's clear water scour equation or a modified (by Maryland SHA) version of Neill's competent velocity procedure based on the calibration studies of ABSCOUR conducted by the USGS.

### C. SELECTION OF TYPE OF SCOUR TO BE EXPECTED

The ABSCOUR program will make a selection as to whether the type of scour to be expected at the structure will be live-bed or clear-water, based on the input provided by the user. However, our experience has been that this input information is often incomplete or incorrect, leading to erroneous program computations. The recommendation of the Office of Structures is that a geomorphologist should make this determination based on his field review of the stream and watershed characteristics, and include this information in the geomorphology report.

## II. CONTRACTION SCOUR

### A. LAURSEN'S LIVE BED CONTRACTION SCOUR EQUATION

Laursen's equation for estimating scour in a contracted section in a simple rectangular channel can be expressed in the following form:

$$\mathbf{y_2/y_1 = (W_2/W_1)^{k2}} \qquad \textbf{(1-1)}$$

Where:

$y_1$ = flow depth in the approach section

$y_2$ = total flow depth in the contracted section ($y_2 = y_1 + y_s$, where $y_s$. is the scour depth)

$W_1$ = channel width of the approach section

$W_2$ = channel width of the contracted section

$k_2$ = experimental constant related to sediment transport (originally identified as $\theta$ by Laursen).

These dimensions are illustrated in Figure 1-1

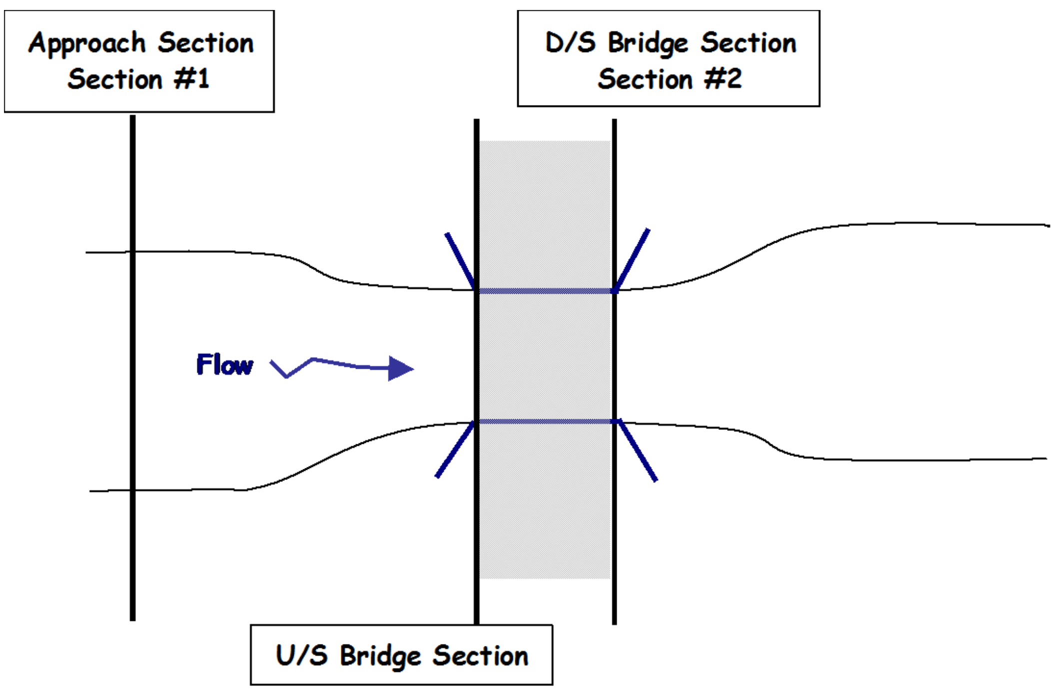



**Figure 1-1**
**Plan View of Approach and Bridge Sections**

Please note that this equation is a simplified form of Equation 1-1 in HEC-18 for a contraction of a constant flow in a rectangular channel with a uniform bed-material. The ratio of $q_2/q_1$ may be substituted for $W_1/W_2$, and Equation 1-1 may be rewritten as:

$$y_2/y_1 = (q_2/q_1)^{k2} \quad (1\text{-}2)$$

where:
$q_1$ = unit discharge in the approach section
$q_2$ = unit discharge in the contracted (bridge) section
$y_1$ = total flow depth in the approach section
$y_2$ = total flow depth in the contracted (bridge) section
$k_2$ = experimental constant related to sediment transport

Equation 1-2 is a comparative equation, equating the rates of sediment transport at the uncontracted and contracted sections. The equation applies to the live-bed condition to the extent that the shear stresses in the two sections are considered equal. The application of this equation can be extended to clear water scour for the special case where the shear stresses in the two sections are both equal to the critical shear stress. The contracted section, Section 2, is best represented for most cases as the downstream end of the bridge where the flow is contracted and uniform. The upstream uncontracted section, Section 1, should be selected at a point upstream where the flow is uniform and not influenced by the bridge contraction. The directions in the HEC-RAS program regarding ineffective flow areas can be used as a guide in selecting the approach section.

## B. MODIFICATION FOR PRESSURE FLOW

The Office of Structures has adopted the FHWA Manual HEC-18, Evaluating Scour at Bridges, 5th Edition, April 2012, as a companion guide to the ABSCOUR 10 User's Manual. Engineers conducting scour evaluations are expected to obtain and use HEC-18 as directed by the guidance set forth in Chapter 11. The HEC-18 method for pressure scour is now the method used by the Office of Structures in making scour evaluations. **The user needs to read and understand how the pressure scour factor is determined in order to evaluate contraction and abutment scour.** The user is referred to the help files in ABSCOUR 10 and to the FHWA HEC-18 Manual Section 6.10.1, Estimating Pressure Scour Flow for guidance and direction on estimating pressure scour. Please refer to the explanation of Pressure Flow in Section III D below which is excerpted from HEC-18.

## C. DEVELOPMENT OF THE ABUTMENT SCOUR EQUATIONS

The following guidance is offered in developing the abutment scour equations and in explaining the information needed for application of the abutment scour (ABSCOUR) method to compute contraction and abutment scour.

### *C.1 Upstream Approach Section, Section 1*

Section 1 is the upstream approach section. Convert the actual cross-sections from the water surface profile model program to ABSCOUR model cross-sections for the subareas of the left overbank, main channel and right overbank. Represent each subarea as a rectangle having a width and average depth. Obtain the top width (T) and flow area (A) of each subarea from the output tables of the water surface profile model. Compute the hydraulic depth of flow for each subarea as y = A/T. The computation of hydraulic depth and top width from the HEC-RAS model is acceptable for Section 1, but is not appropriate for Section 2, as explained below.  Figure 1-2 shows an example of an approach section.

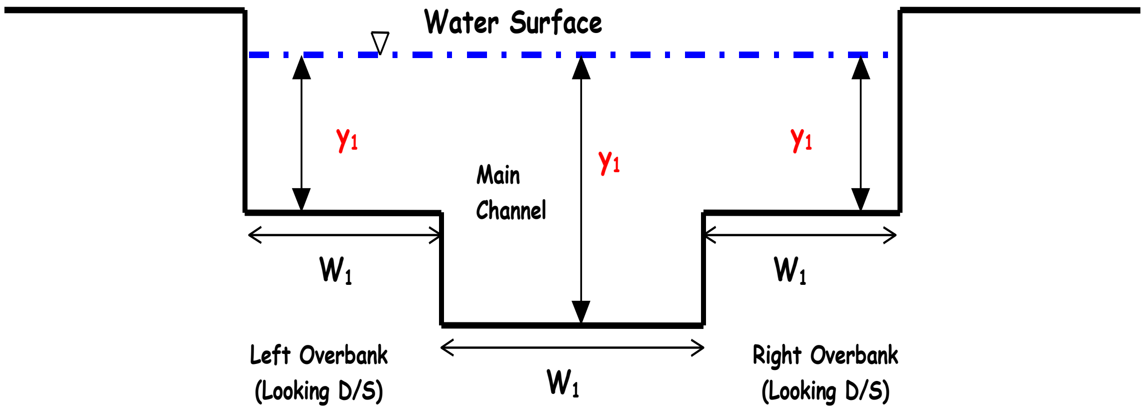



**Figure 1-2: Definition sketch for the Approach Section (Looking Downstream)**

*(Please note that W and T may be used interchangeably in figures and equations to designate a channel or floodplain width)*

The ABSCOUR estimating procedure is based on the consideration that the cross-section at the approach section remains constant in the reach between the approach section and the upstream bridge section. Select the upstream model cross-section with this consideration in mind. Guidance on modeling complex approach flow conditions is presented in Attachment 2 of this Users Manual. For bridges located on bends, the distribution of contraction scour needs to be assessed with regard to the effect of bendway scour (7).

Verify that values used for y (depth), V (velocity), T (width), q (discharge per foot of width) and Q (discharge) are consistent to assure that Q = VA (where A = area = T*y) and q = V*y for each cross-section subarea.

*C.2 Bridge (Contracted) Section*

All measurements relative to bridge widths, abutment setbacks, etc, should be made perpendicular to the flow in the channel and on the flood plains. This consideration is most important for bridges skewed at an angle to the channel.

As indicated in Figure 1-3, the actual cross-section under the bridge needs to be converted into the ABSCOUR Cross-section.  A detailed step-by-step procedure is used to do this as explained in Part 2, Step Four of this manual.

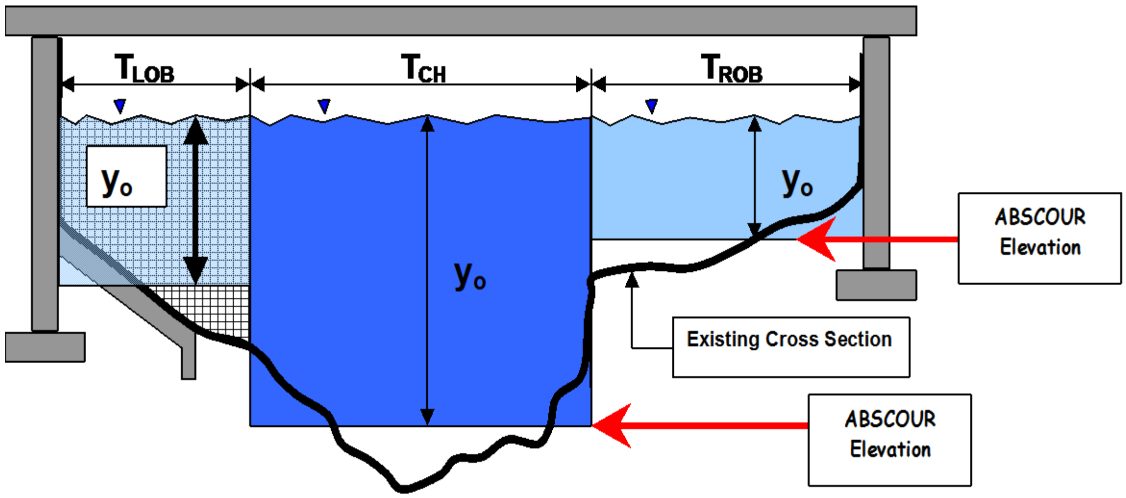



**Figure 1-3**

**Definition Sketch for Bridge Section (Looking Downstream)**

*(Please note that W and T may be used interchangeably in figures and equations to designate a channel or floodplain width)*

A basic limitation of the HEC-RAS program is that it distributes flow under the bridge by conveyance calculations. This approach does not take into account the three dimensional flow patterns observed in the field at bridge contractions. For scour calculations, it is important to account for the high local flow velocities and turbulence near the abutments caused by the contracting flow in the overbank areas upstream of the bridge. Findings from recent field surveys and laboratory studies of compound channels indicate that, for bridges with abutments near the channel banks, the overbank flow converges into the channel with rapid acceleration and high turbulence.

Converging flows under bridges with abutments near the channel banks tend to mix and distribute uniformly, with higher local velocities observed at abutments. On the other hand, if the abutment is set well back from the channel bank near the edge of the flood plain, the overbank flow and the main channel flow tend to remain separated from each other and do not mix as the flow passes under the bridge. This concept is applied in the ABSCOUR model for purposes of computing velocities of flow.

*C.3. Computation of Velocity for Contraction Scour Computations*

This section explains how the velocity of flow is computed for the various conditions that occur at Section 2, the Bridge Section Figure 1-4 illustrates the various scour parameters addressed in this section.

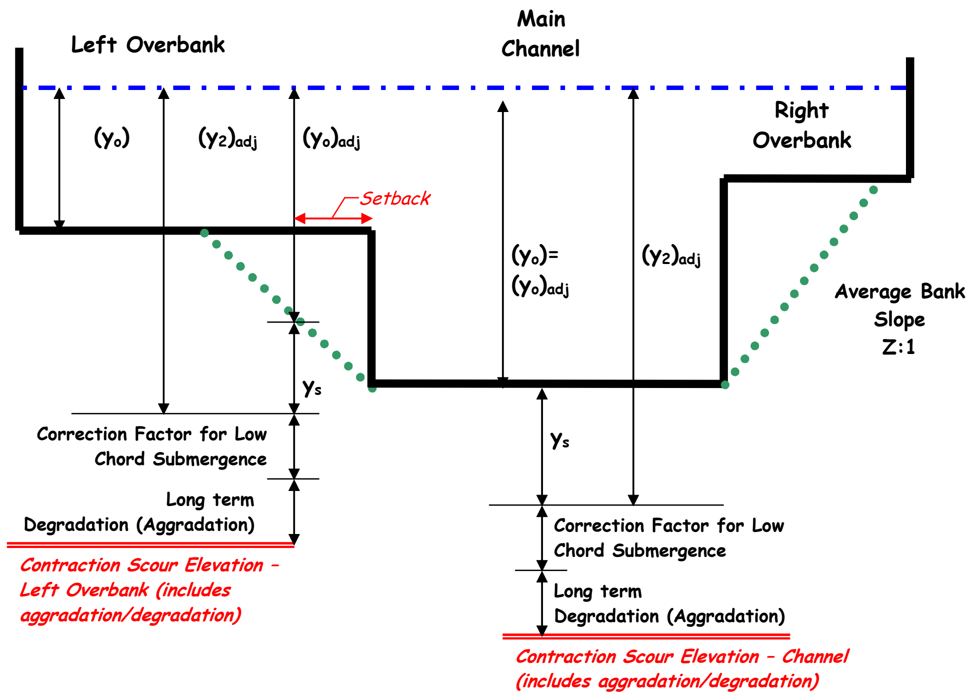



**Figure 1-4**

**Definition Sketch for Contraction Scour Computations at Section 2, Bridge Section**

Please recall from Equation 1-2 (or Equation1-2a for pressure flow) as depicted below, that the unit discharge ($q_2$) must be determined in order to compute the live bed total flow depth ($\mathbf{y_2}$) under the bridge and that ($q_2$) = V*$y_o$ .

$$\mathbf{y_2/y_1 = (q_2/q_1)^{k2}} \qquad \textbf{(1-2)}$$

If pressure flow is present, its effect is considered, as described in Part II B, contraction scour above. The flow separation zone, t, is computed and added to the contraction scour to obtain the total contraction scour

$$\mathbf{y_2/y_1 = (q_2/q_1)^{k2} + t} \qquad \textbf{(1-2a)}$$

Referring to Figure 1-4 above, once the total flow depth $y_2$ is calculated, the contraction scour depth can be computed as the total scour depth ($\mathbf{y_2}$) minus the original flow depth ($\mathbf{y_o}$) or:

$$\mathbf{y_s = y_2 - y_o} \qquad \textbf{(1-2b)}$$

The final contraction scour depth is computed as:

$$\textbf{Final } \mathbf{y_s = y_s * FS} \qquad \textbf{(1-2c)}$$

where FS = Factor of safety.

The discussion below describes the various methods for computing the velocity of flow under the bridge for various site conditions so that the contraction scour can be determined.

- **Method A Short Setback:** When an abutment is set back a distance from the channel bank no greater than five times the depth of flow in the channel, it is defined as a "short setback." For short setbacks, uniform mixing of flow is assumed so that the velocity of flow is the same throughout the waterway area at the downstream end of the bridge (Section 2). The average velocity of flow ($V_{ave}$) under the bridge is computed as:

  $$\mathbf{V_{ave} = Q / A} \qquad \textbf{(1-3)}$$

  where:
  Q = total flow under the bridge, and
  A = sum of the channel and flood plain flow areas under the bridge as measured from bridges plans.

  The unit discharge per foot (q) is computed as:

  $$\mathbf{q_2 = V_{ave} * y_o} \qquad \textbf{(1-4)}$$

  where:
  $y_o$ = hydraulic depth of flow on the flood plain or in the channel = A/T, where T is the top width of the subarea.

  Note that the value of $y_o$ will be different for the left overbank, channel and right overbank areas (Refer to Figure 1-3). It is computed as waterway area (A) of the subarea divided by the top width (T) of the subarea. The downstream water surface elevation input by the user serves as the datum for measuring the hydraulic depth and for all other vertical measurements at Section 2.

  The flow depth of scour, $y_{2,}$ is defined as the distance from the water surface to the scoured channel bed elevation and the actual scour depth ($y_s$) is defined as $y_s = y_2 - y_o$ (Refer to Figure 1-4). In the immediate area of the channel banks, there is a transition in the flow depth $y_o$ between the channel and the flood plain. The User selects the bank slope 'Z' (1 vertical to Z horizontal) in the vicinity of the bridge in order to approximate the actual ground elevation more closely in the bank area. The flow depth in the bank area is designated as $(y_o)_{adj}$, and is computed by ABSCOUR using Equation 1-5:

  $$\mathbf{(y_o)_{adj} = y_o + (setback)/Z} \qquad \textbf{(1-5)}$$

  where

  $(y_o)_{adj}$ = adjusted Section 2 overbank flow depth before scour.
  $y_{o..}$ = downstream section average channel flow depth before scour
  setback = the distance from the edge of channel to the face of the abutment for vertical and wing wall types or toe of the slope for a spill-through slope
  Z = bank full slope where Z is the horizontal dimension and 1 is the vertical dimension.

- **Method B Intermediate Setback:** This method for computing velocity applies where the Abutment Setback is greater than 5 times hydraulic depth of the channel, but less than 75% of the flood plain width. For this method, the program makes an interpolation to compute the velocity of flow on the overbank between Method A (Equation 1-3), the short setback, and Method C, the long setback (Equation1-7). The average velocity at the overbank area is adjusted by the following equations:

  **$V_{mix}$ = Q/A (short setback) at a setback distance of 5 $y_o$ (1-6a)**

  **$V_o$ = Q / $A_o$ (long setback) at a setback of 0.75 $W_o$ (1-6c)**

  **$(V_a)_o$ = $V_{mix}$- ( $V_{mix}$-$V_o$) *(Setback-5*$y_o$) /(0.75*$W_o$-5*$y_o$) (1-6d)**

  where:

  $y_o$ = flow depth in channel
  $W_o$ = width of overbank flood plain under bridge
  $V_{mix}$ = the velocity of the totally mixed flow condition., i.e., average total flow under bridge for the short setback case where setback = 5*$y_o$
  $V_o$ = the overbank flow velocity assuming a separate flow condition (i.e. long setback condition)
  $(V_a)_o$ = the average overbank velocity for this medium setback case

  This method provides for a smooth transition between the short and long setback cases. For narrow flood plains, there is a special case where 0.75Wo is less than 5yo; accordingly, the program will select Method A, short setback for the analysis. This special case is discussed in Attachment 1.

- **Method C Long Setback:** This method for computing velocity applies where the setback distance of the abutment from the channel bank is greater than seventy five percent of the flood plain width. For this case, the assumption is made that the flow on the flood plain at the approach section remains on the flood plain as it flows under the bridge. Similarly, the flow in the main channel at the approach section remains in the channel under the bridge. Accordingly, the following relationship will hold true for flows on either the right or left flood plain subsections for the approach section (1) and the bridge section (2):

  **$Q_1$ = $Q_2$**
  **$q_1$ $W_1$ = $q_2$ $W_2$**
  **$q_2$ = $q_1$ *$W_1$ /$W_2$ (1-7)**

  The discharge, $Q_1$, in any cross-section subarea of Section 1 (channel, overbank area) is obtained from the HEC-RAS program, and the unit discharge, $q_1$, is computed as $Q_1$ /$W_1$. $W_1$ and $W_2$ are obtained from the HEC-RAS program or from bridge plans. The flow velocity under the bridge for any subarea is computed as:

$$\mathbf{V_2 = q_2 / y_{o2}} \quad \textbf{(1-8)}$$

where $y_{o2}$ is the flow depth under the bridge

- **Modeling Flow Conditions for Different Setbacks of the Left and Right Abutments:** It is likely that situations will occur where one abutment will meet the criteria for analysis by Method A, Short Setback, and the other abutment for analysis by Method C Long Setback or Method B, Intermediate Setback. For such cases, computations for the left and right abutments are treated separately. As an example, assume that the left flood plain is set back from the channel a distance of more than 75 % of the width of the flood plain, (Method C analysis) and the right abutment is set back from the channel a distance less than five channel flow depths (Method A analysis). The ABSCOUR program will compute scour for the left abutment using unit discharges computed only for the left overbank ($V = Q_{overbank}/A_{overbank}$). The ABSCOUR program will compute scour for the right abutment using unit discharges computed for mixed flow where:

$$\mathbf{V_{mix} = (Q_{channel} + Q_{right\ overbank})/(A_{channel} + A_{right\ overbank}).} \quad \textbf{(1-9)}$$

There are actually 16 different combinations of channel characteristics and of the abutment setbacks considered in the ABSCOUR calculations. Numerical examples are presented in Attachment 1, Section III of this manual.

*C.4 Contraction Scour Computations for Abutment with a Short Setback (Method A)*

When the abutment has no setback (is at the channel bank), the scour at the overbank will be equal to that for channel. When the setback is small, the scour at the overbank will be very close to the scour in the channel. However, due to the idealization of channel and overbank flow into the rectangular shapes for the ABSCOUR cross-section, the calculated overbank scour may be based on clear water scour (as determined from the Approach Section calculations) when it is actually subject to live bed scour conditions from the main channel. There is obviously a transition zone between the no setback case and the case where the abutment is set well back on the flood plain.

The limit of the transition zone is defined as five times the flow depth in the downstream channel. When there is no setback, the channel scour flow depth ($y_2$) is used for the contraction scour.

When the abutment setback on the flood plain exceeds the limit of the transition zone, separate flow is assumed between the channel and the flood plain, and contraction scour is computed directly using the procedure described for the medium setback or the long setback.
When the setback is within this transition zone of from zero to $5y_o$, the following scheme is used to compute contraction scour:

1. ABSCOUR separately calculates both clear water scour flow depth and live bed

scour flow depth for (1) the channel section and (2) the overbank section at a distance of 5 $y_o$.

2. The channel contraction scour flow depth ($y_2$) is the scour when the setback is equal to or less than zero - that is no setback case.

3. The overbank contraction scour flow depth ($y_2$) is the overbank scour when the setback is located on the flood plain beyond the channel banks a distance equal to 5 times the flow depth in the downstream channel (SB = $5y_o$)

There are four combination of overbank scour which may occur in the transition zone:

1. Clear water scour with no setback
2. Clear water scour with setback = $5y_o$
3. Live bed scour with no setback
4. Live bed scour with setback = $5y_o$

The computed overbank contraction scour will be interpolated between these four cases, depending on the setback distance and the scour type (live-bed or clear water at overbank and channel).

For example, when the channel is live bed and the overbank is clear water, then the overbank contraction scour for the actual setback (between 0 and 5 times channel flow depth) will be interpolated between case 3 ( live bed scour with no setback) and case 2 (clear water scour with setback = $5y_o$). The interpolation depends on the distance that the abutment is set back from the channel bank and the scour type at the overbank and channel sections.

A parabolic interpolation is used for the contraction scour flow depth calculation ($y_2$) since this method provides for a smooth transition that approximates the scour depths computed through the application of Laursen's contraction scour equations. The contraction scour flow depth is modified as necessary to take into account the effect of any pressure scour and to apply a safety factor to the design (See Attachment 1).

Next, the abutment scour flow depth ($y_{2a}$) is computed directly from the interpolated contraction scour value as indicated by Equation 1-10. A detailed discussion of Equations 1-10 through 1-12 and the derivation of $k_f$ and $k_v$
$_+$ are presented in Section III, Abutment Scour. *The abutment scour equations are introduced here primarily to present the complete process for computing scour for the short setback method.*

$$\mathbf{y_{2a} = ( k_f * (k_v)^{k2} ) * (total\ contraction\ flow\ depth)} \qquad \mathbf{(1\text{-}10)}$$

As described earlier, a modification to the contraction scour is made to account for the effect of pressure scour. This pressure scour factor is designated as "t' the maximum thickness of the flow separation zone and is added to the contraction scour to obtain the total contracted scour. The unadjusted abutment scour depth ($y_{sa}$) is computed as:

$$(y_{sa}) = y_{2a} - (y_o)_{adj} \qquad \textbf{(1-11)}$$

where:
$(y_o)_{adj}$ = flow depth before scour occurs.

The final or adjusted abutment scour depth $(y_{sa})_{adj}$ is computed as:

$$(y_{sa})_{adj} = k_t * k_e * FS * y_{sa} \qquad \textbf{(1-12)}$$

where:
$k_t$ = modification for abutment shape
$k_e$ = modification for embankment skew
FS = factor of safety
$y_{sa}$ = initial abutment scour estimate noted above ($y_{sa} = y_{2a} - (y_o)_{adj}$)

*C.5. Determination of $k_2$ or $\theta$:*

The value of $k_2$ ($\theta$) in Equation 1-2 varies from 0.637 to 0.857 depending on the critical shear stress of bed material to the boundary shear stress in the normal channel section. For clear-water flow it is 0.857 and for live-bed flows it is less depending on the ratio of shear stress to the critical shear stress of the bed material. Laursen (2) established the variation of $\theta$-value as a function of $\tau_c/\tau_1$ as shown in Figure 2.24 in ASCE Manual on Sedimentation (2). This curve may be approximated by the following equation:

$$k_2 \text{ or } \theta = 0.11(\tau_c/\tau_1 + 0.4)^{2.2} + 0.623 \qquad \textbf{(1-13)}$$

Where $\tau_c$ is the critical shear stress and $\tau_1$ is the boundary shear stress in the upstream or normal channel section. If $\tau_c$ is equal to or greater than $\tau_{1,}$ then clear water scour can be expected to take place at the bridge, and the value of $k_2$ ($\theta$) should be selected as 0.857. *Please note that current ABSCOUR recommendation is to evaluate the condition of live-bed vs. clear water scour as a part of the stream morphology report.*

*C.6 Critical Shear Stress and Boundary Shear Stress*

Critical shear stress, $\tau_c$, may be calculated by several methods. For non-cohesive materials and for fully developed clear-water scour, Laursen (1) used the following simple empirical equation developed for practical use:

$$\tau_c = 4D_{50} \qquad \textbf{(1-14)}$$

where:
$D_{50}$ is the median particle size (ft.) in the section (channel bed or overbank area) under consideration. On overbank areas, estimating the critical shear stress (lbs/ sq. ft.) may also involve consideration of the flood plain vegetation.

The boundary shear stress, $\tau_1$, in the approach channel or overbank subarea may be calculated as:

$$\tau_1 = \gamma \; y_1 S_{ave} \qquad \textbf{(1-15)}$$

where:

$\gamma$ = 62.4 lbs/ft$^3$, in the English system

$y_1$ = flow depth or hydraulic depth of the reach approximated by the depth at the approach section, and

$S_{ave}$ = the average energy slope between the approach section and the downstream section. (Refer to Part 2, Section C.1).

## III. ABUTMENT SCOUR

Figure 1-5 illustrates the various factors used in the evaluation of abutment scour.

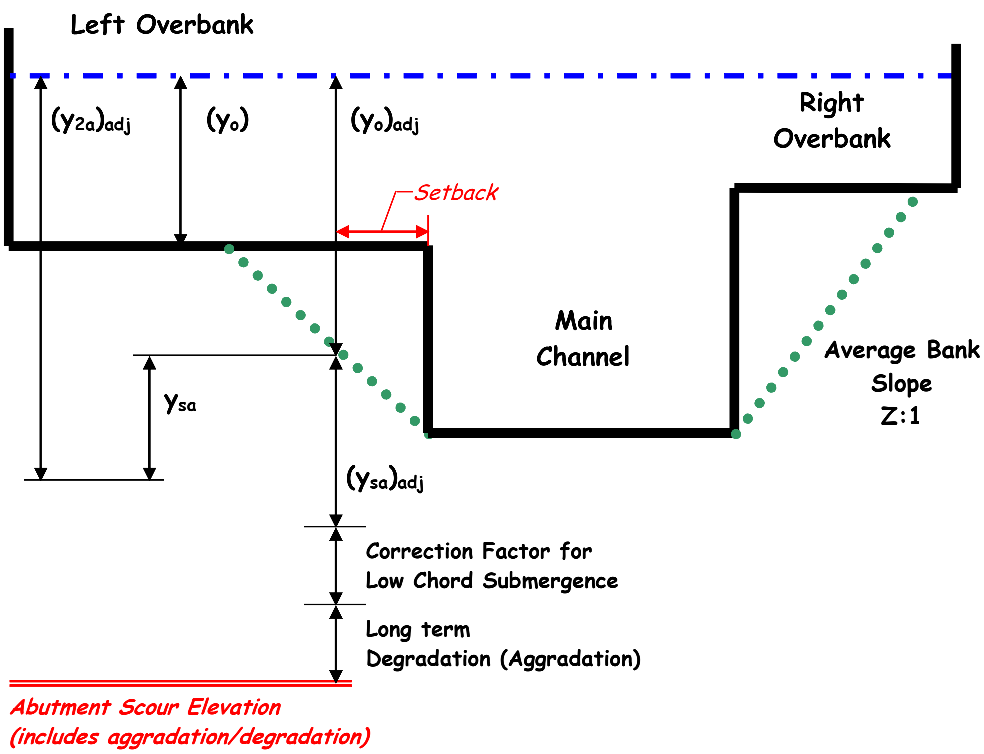



**Figure 1-5: Definition Sketch for Abutment Scour Computations at Section 2, Bridge Section (Looking Downstream)**

### A. ADJUSTMENT FACTOR FOR VELOCITY

The simple model depicted in Figure 1-1 and the accompanying analysis applies only to a long contraction where the flow velocity is considered uniform. For flow constricted by an abutment, the velocity across the section is not uniform, and the velocity at the face of the abutment is higher. To compute abutment scour, the contraction scour equations need to be modified to account for the higher velocity and resulting deeper scour which occurs at the abutment.

The two-dimensional potential flow pattern around a rectangular abutment was used for evaluating the velocity distribution across the contracted section. A study of the velocity distribution in this constricted section (3, 4) applying the principles of potential flow revealed that the ratio of the velocity at the toe of the abutment to the mean velocity of the flow in the contracted section of a simple rectangular channel can be approximated by the following equation:

$$\mathbf{k_v = 0.8(q_1/q_2)^{1.5} + 1} \quad \textbf{(1-16a)}$$

where:
$k_v$ = is a factor based on a comparison of the velocity at the abutment toe with the average velocity in the adjacent contracted section.
$q_1$ = average unit discharge in the approach section, and
$q_2$ = average unit discharge in the bridge section.

Equation 1-16a applies to a simple contraction, where the unit discharge of the approach section is less than that in the contraction, $q_1 < q_2$. The values of $k_v$ should be limited to the range of values between 1.0 and 1.8. If the computed value is less than 1.0, use a value of 1.0; if the computed value is greater than 1.8, use a value of 1.8.

<u>Computation of $k_v$ for 2-D flow models</u>

If the ABSCOUR user selects a 2-D model instead of a 1-D model such as HEC-RAS for the hydraulic analysis, $k_v$ should be computed by a different procedure. The 2-D model can be used to measure directly the velocity of flow at the face or toe of the abutment ($V_{face}$). Referring back to equation 1-16a, $k_v$ is a factor based on the comparison of the flow at the abutment toe and the average flow in ($V_{ave}$) in the adjacent contracted section. Both of these parameters are calculated by the 2-D model. The procedure to calculate $k_v$ is described below:

1. Select the override option for 2-D flow on the Project Information Card
2. Step 1 above will open two cells on the Downstream Bridge Data Card:
    1. Enter the calculated/measured flow velocity at the abutment face/toe in the cell designated $V_{face}$
    2. Enter the calculated/measured average flow velocity in the adjacent contracted section in the cell designated $V_{ave}$
3. The ABSCOUR program will then calculate $k_v$ using Equation 1-16b:

$$k_v = V_{face}/V_{ave} \quad \textbf{1-16b}$$

**Please Note that Equations 17-19 have been deleted; they are not missing from the manual.**

## B. ADJUSTMENT FACTOR FOR SPIRAL FLOW AT ABUTMENT TOE

The above discussion with respect to the velocity coefficient reflects the limited analysis available using two-dimensional flow concepts. The flow at an abutment toe is in spiral motion, which is three-dimensional. Accordingly, a factor for adjusting two-dimensional flow to three-dimensional flow needs to be added to Equation 1-2. Available scour data for vertical-wall abutments were analyzed (5). The analyses resulted in the following two envelop equations for determining the value of the spiral flow adjustment factor, $k_f$.

For clear-water scour:

$$\mathbf{k_f = 0.13 + 5.85F} \qquad \textbf{(1-20)}$$

For live-bed scour:

$$\mathbf{k_f = 0.46 + 4.16F} \qquad \textbf{(1-21)}$$

where:

$k_f$ = experimental coefficient for spiral flow at the abutment toe. *(The values of $k_f$ should range from 1.4 to 4.0.* The ABSCOUR recommendations are as follows:

- If the computed value is less than 1.4, use a value of 1.4;
- if the computed value is greater than 4.0, use a value of 4.0.)
- An over-ride feature is provided for $K_f$; however, the user should exercise considerable caution in applying this over-ride only to sites where it may be warranted (such as a wetland area with very low flow velocities.)

F = Froude number of the flow in the approach channel or overbank subarea, depending on the location of the abutment.

$$\mathbf{F = V_1 / (gy_1)^{0.5}} \qquad \textbf{(1-22)}$$

where:

$V_1$ is the average velocity

$y_1$ is the average depth in the approach subarea

g is the gravitational constant.

## C. LOCAL ABUTMENT SCOUR EQUATION - VERTICAL WALL ABUTMENTS

The adjustment factors presented above are combined with Laursen's contraction scour equation to develop the equation for abutment scour for a vertical wall abutment:

$$\mathbf{y_2/y_1 = k_f(k_v q_2/q_1)^{k2}} \qquad \textbf{(1-23)}$$

where:

$y_1$ = total flow depth in the approach section,

$y_2$ = total flow depth of scour in the contracted section ($y_2$ = yo + $y_s$, where $y_o$ = the initial flow depth and $y_s$ = the scour depth )

$q_1$ = unit discharge in the approach section

$q_2$ = unit discharge in the contracted section

$k_2$ = experimental constant related to sediment transport (identified as $\theta$ by Laursen).

## D. ADJUSTMENT OF ABUTMENT SCOUR DEPTH FOR PRESSURE FLOW

For conditions of pressure flow, Equation 1-23 needs to be adjusted to account for the effect of pressure flow by adding the value of t, the thickness of the flow separation zone.:

$$y_2/y_1 = (k_f * (k_v * q_2/q_1)^{k2}) + t \qquad \textbf{(1-24)}$$

Where t is the thickness of the flow separation zone as described in Section II B, Contraction Scour, above. The following is an excerpt from HEC-18

### 6.10 PRESSURE FLOW SCOUR (VERTICAL CONTRACTION SCOUR)

#### 6.10.1 Estimating Pressure Flow Scour

Prediction of pressure flow scour underneath an inundated deck in an extreme flood event is important for safe bridge design and for evaluation of scour at existing bridges. A formula calibrated with experimental data and Computational Fluid Dynamics (CFD) simulation was developed by FHWA (2012c) to calculate pressure flow scour depth under various bridge inundation conditions. The maximum scour depth is evaluated by using contraction scour equations combined with a correlation of separation zone thickness under the inundated bridge. Data from Arneson (1998), TRB (1998b), Umbrell et al. (1998), and the Turner-Fairbank Highway Research Center (FHWA 2012c) were used to develop the scour equations.

Figure 6.18 illustrates the flow characteristics at a fully submerged bridge superstructure. Note that the bridge "superstructure" mentioned in this section refers to a continuous cross section of the structural and non-structural elements that span the waterway and that can produce significant blockage when it is partially or fully inundated. Discharge under the superstructure can be conservatively assumed to be all approach flow below the top of the superstructure at height $h_b$ + T, where $h_b$ is the vertical size of the bridge opening prior to scour and T is the height of the obstruction including girders, deck, and parapet. For floods that do not create overtopping, all discharge upstream goes into the bridge opening. The depth at the location of maximum scour is comprised of three components: $h_c$, the vertically contracted flow height from the streamline bounding the separation zone under the superstructure at the maximum scour depth, $y_s$, the scour depth, and t, the maximum thickness of the flow separation zone. The separation zone does not convey any net mass from the upstream opening of the bridge to the downstream exit.

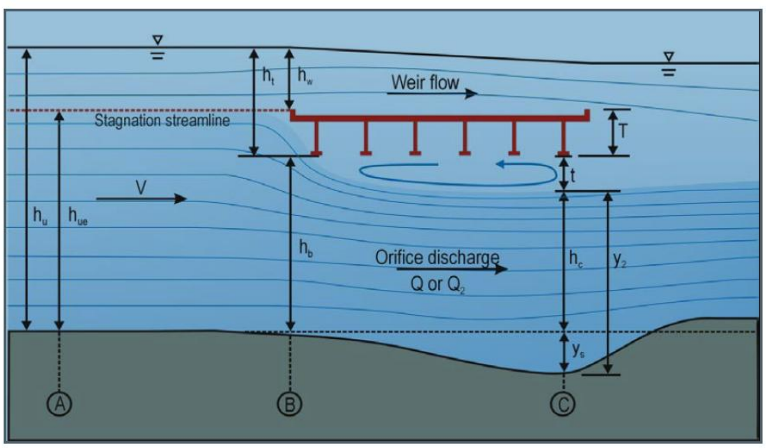



Figure 6.18. Vertical contraction and definition for geometric parameters.

The pressure scour depth $y_s$ is determined by using the horizontal contraction scour equations to calculate the height, $y_s + h_c$, required to convey flow through the bridge opening at the critical velocity. This height is equivalent to $y_2$ (the average depth in the contracted section) in the clear-water contraction scour Equation 6.4 and the live-bed contraction scour Equation 6.2. Combining this relation with the definitions of t and $h_b$:

$$y_s = y_2 + t - h_b \quad (6.14)$$

Note that $h_b$ in pressure flow scour is analogous to $y_0$ (existing depth in the contracted section before scour) in contraction scour. Comparing contraction scour Equations 6.3 and 6.5 with Equation 6.14, the scour depth of pressure flow can be significantly greater than that of non-pressure flow because depth available to convey flow through the opening under the bridge is reduced by the flow separation thickness, t.

## E. COMPUTATION OF ABUTMENT SCOUR DEPTH (ABSCOUR PROGRAM)

The ABSCOUR program computes abutment scour as:

$$\mathbf{y_{2a} = k_f*(k_v)^{k2} * y_2} \quad \textbf{(1-26)}$$

where:

$y_2$, the contraction scour flow depth, is defined by either Equation 1-23 (no pressure flow) or 1-24 (pressure flow) as appropriate.

For conditions of open channel flow or pressure flow at a bridge, using the depths determined from Equation 1-11, the unadjusted abutment scour depth is:

$$\mathbf{y_{sa} = y_{2a} - (y_o)_{adj}} \quad \textbf{(1-27)}$$

where:

$y_{sa}$ = unadjusted abutment scour depth,

$y_{2a}$ = depth of flow at the bridge abutment after scour has occurred

$(y_o)_{adj}$ = initial depth of flow at the bridge abutment, prior to the occurrence of scour. As noted earlier, the adjustment factor is applied to modify flow depths affected by the bank slope.

## F. OTHER ADJUSTMENTS TO THE ABUTMENT SCOUR DEPTH, $y_{sa}$

The final abutment scour depth, $(y_{sa})_{adj}$ is determined from the following adjustments:

$$\mathbf{(y_{sa})_{adj} = k_t * k_e *FS * y_{sa}} \quad \textbf{(1-28)}$$

where:

$k_t$ = modification for abutment shape

$k_e$ = modification for embankment skew

FS = factor of safety.

$y_{sa}$ = initial scour estimate from Equations 27 = $y_{2a} - (y_o)_{adj}$

**Please note that these adjustment factors (See FHWA Manual HEC-18) are applied to the initial abutment scour depth to arrive at a final abutment scour depth and elevation.**

The adjustment factors are described below:

*F.1 Adjustment Factor, kt, for Abutments with Wing wall and Spill-through Slopes*

The scour depth estimated from Equation 1-23 for vertical wall abutments is adjusted by the program for spill-through slopes and wing-wall abutments by multiplying by the adjustment factor $k_t$. The factor is computed on the basis of the ratio of the horizontal offset provided by the spill-through slope or wing wall to the total length of the abutment and approach embankment in the flood plain. This factor serves to account for the more streamlined flow condition provided by the wing wall or spill-through slope.

The abutment shape factors in HEC-18 Table 8.1 (0.55 for spill-through abutment and 0.82 for wing wall abutment) apply to short abutments. As the length of the abutment and approach road in the flood plain increase, the effect of a spill-through slope in reducing scour is decreased. For long approach road sections on the flood plain, this coefficient will approach a value of 1.0. Similarly, scour for vertical wall abutments with wing walls on short abutment sections is reduced to 82 percent of the scour of vertical wall abutments without wing walls. As the length of this abutment and approach road in the flood plain increase, the effect of the wing wall in reducing scour is also decreased. For long approach road sections in the flood plain, $k_t$ will approach a value of 1.0. Refer to Part II of this report for a definition sketch of the ABSCOUR Shape Factor as SF = $X_1/X_2$ (*Please note the terminology for shape factor, SF, should not be confused with the safety/calibration factor used elsewhere in the ABSCOUR methodology).*

For a spill-through slope abutment:

$$\mathbf{k_t = 0.55 + 0.05\,((1/SF) - 1)} \qquad \textbf{(1-29)}$$

For abutments with wing walls:

$$\mathbf{k_t = 0.82 + 0.02((1/SF) - 1)} \qquad \textbf{(1-30)}$$

If SF < 0.1, then kt = 1.0

Detailed information on the selection of the Shape Factor, SF, is provided in Part 2, Section E, Upstream Bridge Data.

*F.2 Adjustment Factor $k_e$ for Embankment Skew Angle*

For highways embankments skewed to flood plain flow, a correction factor, $k_e$, is computed to account for the effect of the embankment skew on abutment scour. The embankment skew angle, $\alpha$ , is the angle between the direction of flow and the centerline of the roadway (bridge) at the left or right abutment:

$$\mathbf{k_e = (\alpha/90)\text{^}0.13} \qquad \textbf{(1-31)}$$

This value will be usually different for each abutment. Note that the embankment skew may not be the same as the skew angle of the abutment. The effect of the abutment skew angle is taken into account by using the flow width that is normal to the flow.

*F.3 Adjustment Factor, FS, for Calibration/Factor of Safety*

In developing the ABSCOUR equations for estimating abutment scour, available information from laboratory studies collected by the consultant firm of GKY and Associates was used as a means of calibrating the model. These laboratory tests were conducted in simple rectangular straight channels (laboratory flumes) with uniform flow. A total of 126 data points were used to develop the envelop equation describing the average value of the coefficient for the spiral flow adjustment factor, $k_f$ . Use of the envelope curve provides for a limited factor of safety in the calculations.

In addition, the results of the calibration studies conducted by the USGS comparing measured vs. computed abutment scour depths have provided additional information regarding the accuracy of computed contraction scour and abutment scour depths.

However, each stream crossing represents a unique situation. For practical design of new structures, use of a safety factor may be prudent to take into account the effect of the complex flow patterns which can be expected to occur at bridges Recommendations regarding the selection of a safety factor are described in Attachment 3.

G. FINAL SCOUR ELEVATION

**Elev. of Bottom of Scour Hole = Water surface elevation - $(yo)_{adj}$ - $(y_{sa})_{adj}$ (1-32)**

Please note that Equation 1-32 takes into account all factors in Equations 1-5 through 1-28. The user must modify these values where aggradation/ degradation or channel movement is a consideration.

IV. CLEAR WATER SCOUR EQUATIONS

A. CONTRACTION SCOUR

Clear-water Contraction Scour

Laursen's contraction scour equation in the form of Equation 1-2 assumes the bed materials and the shear stresses in the approach and the contracted sections are the same. Where the bed material of the approach section is not the same as the contracted section, Equation 1-2 should not be used. Where the upstream section is covered with vegetation and no sediment is transported (clear water scour), or where there is a limited supply of bed load available, the Maryland clear water scour curves (based on Neill's concept) may be used in determining contraction scour. Recent findings of several stream morphology reports indicate that clear water scour may be the expected type of scour in many Maryland streams The bed material in the contracted section will be eroded until (1) the bed shear is reduced to its critical value, or (2) the flow depth increases until it reaches the depth where the mean velocity is reduced to the value of the critical velocity.

Section 2, the downstream side of the bridge, is used to define the parameters for estimating clear water contraction and abutment scour. Flow depth $y_2$ and flow velocity $V_2$ are determined for the appropriate portion of Section 2 under consideration. The basic concept used in the computations is that scour will continue until the bed material has the stability to resist the flow. At this depth, the flow velocity is reduced to the critical velocity of the bed material, and $V_2 = V_c$ . This basic relationship can be expressed as:

$$\mathbf{y_2 = (V_2 / V_c) \; (y_o)_{adj}}$$

$$\mathbf{ys = (y_2 - (yo)_{adj}) \, FS}$$

Where:

**$y_2$ = $y_c$ = flow** depth in contracted channel when bed shear is at the critical value.
**$(yo)_{adj}$ = initial flow depth before scour**
**$V_2$ = flow velocity before scour**
**Vc = critical velocity of bed material**
**FS = safety/ calibration factor**

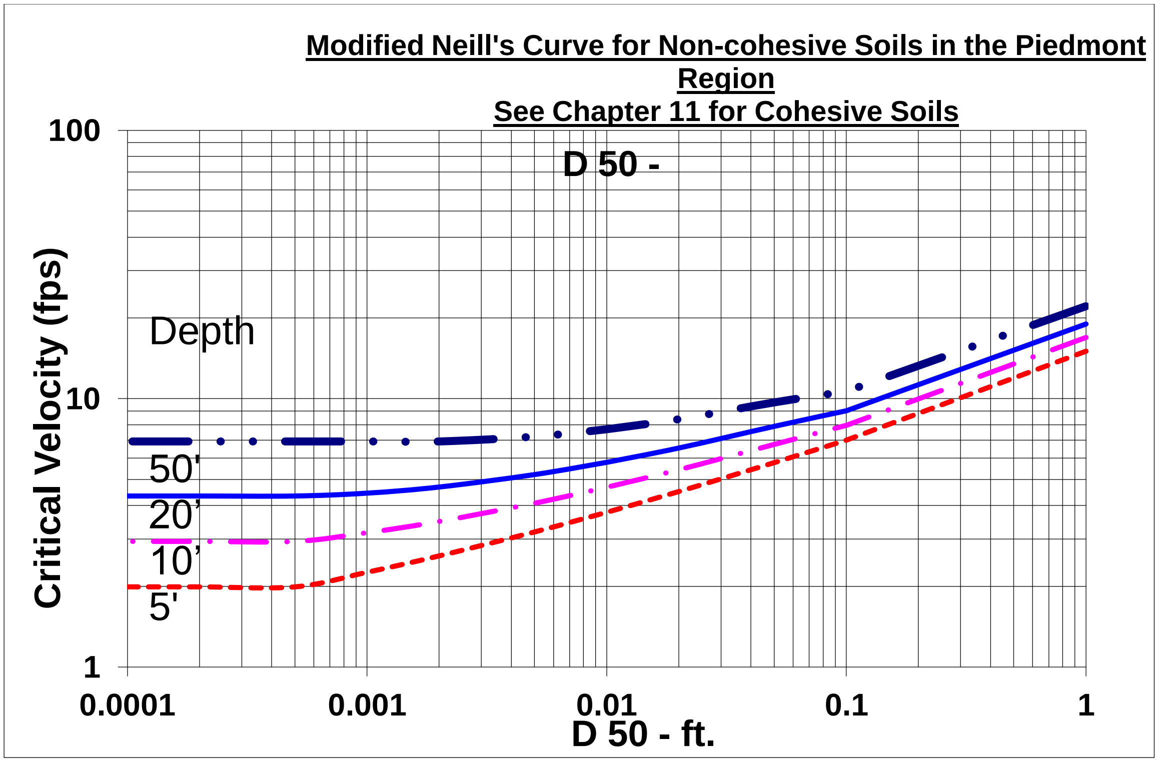
For conditions of clear-water scour, the following equations are used in the ABSCOUR program to solve for $y_2$. These equations were originally developed from Neill's competent velocity curves, Reference 11, and modified as a result of the findings of the USGS studies of abutment scour in South Carolina streams.

Modified Neill Critical Velocity Curves for the Piedmont Zone

| EQUATION | D50 RANGE(ft) | PIEDMONT ZONE |
|---|---|---|
| 1 | 0.1 ≤ D50 | Vc = 11.5 d^0.167 D50^0.33 |
| 2 | 0.01≤ D50< 0.1 | Vc = [ 11.5 d^(0.123/D50^0.2)] D50^0.35 |
| 3 | 0.0001≤ D50< 0.01 | Vc = [ 11.5 d^(0.123/D50^0.2)] D50^0.35 |

Note:

1. D50 = 50% particle size of channel/flood plain bed: d = flow depth
2. If D50< 0.0005 ft, Vc = constant at D50 = 0.0005 ft.
3. If computed Vc< 1.0 fps, then set Vc =1




The following relationship applies to the above equations:

$$\mathbf{y_2 = y_1 + y_s} \qquad \textbf{(1-37)}$$

where:
$y_1$ = flow depth before scour
$y_2$ = flow depth after scour
$y_s$ = contraction scour depth below stream bed.

If pressure flow conditions exist, the value of $y_2$ is increased as:

$$\mathbf{y_{2\,(modified)} = y_2 + t} \qquad \textbf{(1-38)}$$

Calculation of the value of t, the thickness of the flow separation zone, is explained in Section III D.

## B. ABUTMENT SCOUR

Once the total clear water contraction scour value ($y_2$ or $y_{2\,(modified)}$ is determined, clear water abutment scour ($y_{2a}$) can be calculated as:

$$y_{2a} = ( k_f (k_v)^{0.857}) y_2 \qquad \textbf{(1-39)}$$

where:

$y_2$ =(total) clear water contraction scour depth determined from Equations 1-37 to 1-38.

$k_f$ is dependent on the intensity of the spiral flow in the approach flow, and is calculated as explained in Part I, Section III B.

$k_v$ is related to the contraction ratio of the approach flow and is calculated as explained in Part I, Section III A.

The final or adjusted abutment scour depth $(y_{sa})_{adj}$ for clear water scour is computed in the same manner as for live bed abutment scour, Equation 1-12:

$$(y_{sa})_{adj} = k_t * k_e * FS * y_{sa} \qquad \textbf{(1-12)}$$

where:
$k_t$ = modification for abutment shape
$k_e$ = modification for embankment skew
FS = factor of safety
$y_{sa}$ = initial abutment scour estimate noted above ($y_{sa} = y_{2a} - (y_o)_{adj}$)

Consolidated Clear-water Abutment Scour Equation

The following ABSCOUR clear-water abutment scour equation for clear water abutment scour was developed by Stephen Benedict, USGS, in his report (referenced above) on the ABSCOUR program, comparing predicted vs. measured abutment scour depths at South Carolina Bridges:

$$y_{sa} = k_t k_e \left( \left( (k_v)^{0.857} k_f k_p \, {}^{q_2}\!/\!_{V_c} \right) - (y_o) adj \right) FS$$

Where

*$y_{sa}$ is the scour depth at the abutment, in feet;*

*$k_t$ is a coefficient for abutment shape that ranges from 0.55 to 1.00;*

*$k_e$ is a coefficient for abutment skew;*

*$k_v$ is a coefficient to account for the increase in flow velocity at the abutment that ranges from 1.0 to 1.8*

*$q_2$ is the unit-width flow, in cubic feet per second per foot, under the bridge; please note that $q_2/V_c$ is equal to $y_2$*

*$k_f$ is a coefficient to account for turbulence at the abutment that ranges from 1.4 to 4.0;*

*$k_p$ is a pressure flow coefficient*

*$V_c$ is the critical velocity of the bed material for the computed scour depth*

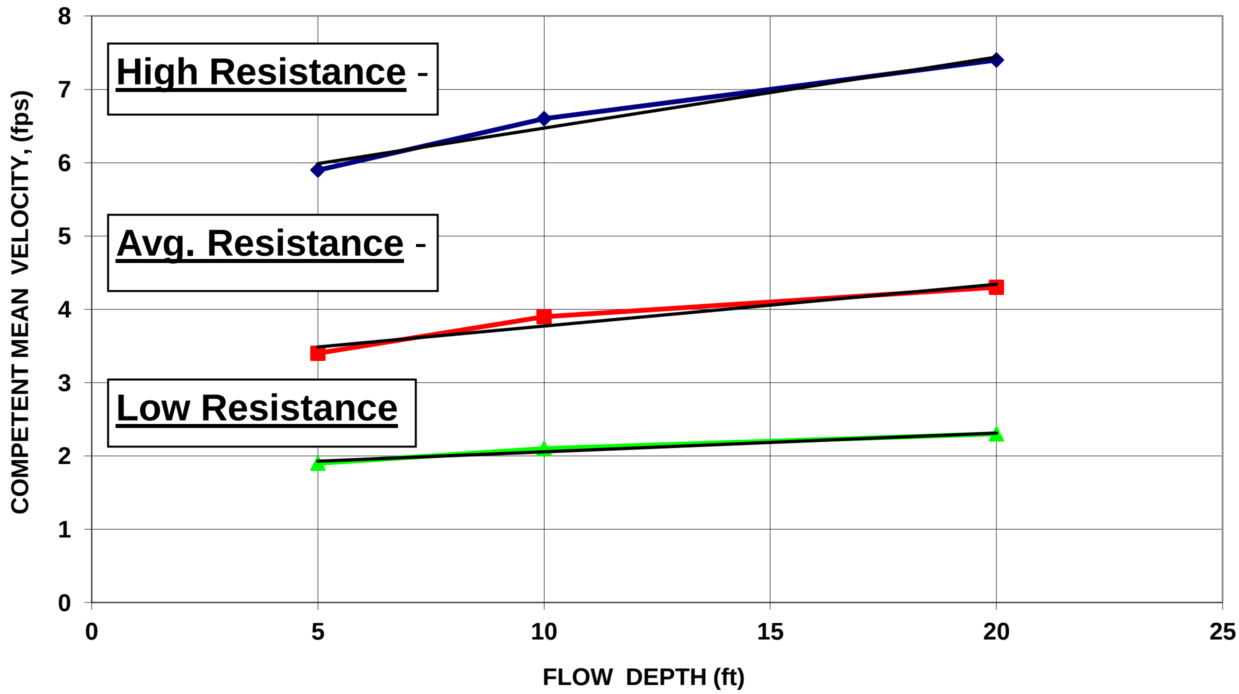
*$y_{o\,adj}$ is the initial flow depth before scour*

*FS is a calibration/safety factor*

CRITICAL VELOCITIES IN COHESIVE SOILS

There are as yet no definitive data available for determining critical velocities in cohesive soils. In an unpublished paper (Permissible Shear Stresses/Critical Velocities, 2005) Sterling Jones, Research Engineer, FHWA, has collected and commented on various methods available in the literature regarding this subject. The Office of Structures has conducted limited tests of critical velocities in cohesive soils using the EFA Apparatus in the SHA Soils Lab. On the basis of this existing information, the Office of Structures recommends the following:

1. For preliminary guidance on estimates of critical velocities in cohesive soils, use the figure below developed from information in Neill's "Guide to Bridge Hydraulics, Second Edition, June 2001" (Please note that three plots are presented for low, medium and high resistance to flow velocities. Each plot contains the values excerpted from Neill's tables which are connected by straight lines. There is also a curve drawn to fit the data for each plot which can be used in a spread sheet application of the method.
2. For more refined estimates of the critical velocity of cohesive soil layers at a bridge site, take Shelby Tube samples of the various soil layers and test them in an EFA Apparatus.




V. COMPUTATIONAL PROCEDURES

The computational procedures in the ABSCOUR program described above have been developed on the basis of straight channels with rectangular cross sections. Actual stream channels and flood plains are likely to vary significantly from these geometric shapes. The Engineer needs to apply judgment when using the ABSCOUR methodology to evaluate scour at an actual bridge crossing. The ABSCOUR User's Guide presented in Part 2 of this paper discusses ways to input data and interpret output data so as to achieve a reasonable estimate of contraction, pier and abutment scour for cases where the channel is not straight or where there is a complex flow distribution in the approach channel.

## VI. HISTORY OF OTHER CHANGES TOABSCOUR

- **August 18, 2006**
  - Change the lower bound of the kf (spiral flow coefficient) from 1.0 to 1.4 based on studies of clear water scour in the FHWA flume at the Turner Fairbanks Highway Research Laboratory.
  - Modify the recommended procedure in the medium setback case for evaluating the flow distribution under the bridge.
- **June 15, 2006**
  - Change downstream bridge soil D50 input cell to allow layered soil input.
  - Utilize an iterated contraction scour elevation calculation so as to determine the appropriate soil layer to contain the scour at the over-bank and the channel.
  - Calculate the live-bed and clear-water scour for the channel and over-banks. The contraction scour flow depth depends on the approach section scour type (live-bed or clear-water). If it is clear-water, then the clear-water scour flow depth is used. If it is the live-bed scour, then the smaller of the live-bed and clear-water scour flow depth will be used. This is to account for the armoring effect due to the coarse sediments. A warning will be issued when it is live-bed scour and bridge D50 of the control soil layer is less than 1/10 of the approach D50. This approach also applies to the interpolation scheme of the short setback case.
  - Apply the layered soil and live-bed scour flow depth changes to the bottomless culvert.
  - When the water does not reach abutment, the output is N/A for the abutment scour. However, the scour result drawing still shows the abutment scour. This problem is fixed by using the contraction scour elevation at the abutment in this case.
  - Change the help topics to reflect the changes above.
- **January 11, 2006**
  - Revise help context and interface of the program in response to suggestions received from participants at the recent ABSCOUR course
  - Revise suggested Safety Factor
- **August 1, 2005**
  - Revise abutment spiral flow adjustment factor Kf based on updated test data
  - Add override option for 2-D flow velocity at abutment face and add option for the cross-section orientation.

- Add actual approach and downstream bridge cross-section. Allow sections to be imported from existing HEC-RAS project file. On the cross-section drawing, superimpose the ABSCOUR cross-section with the actual cross-section for checking ABSCOUR input data. Add tools to calculate the flow geometry and the flow distribution based on the actual cross-section and the results can be used as the ABSCOUR input.
- Update help context.
-

- **September 30, 2004**
  - Revise short setback contraction scour parabolic interpolation equation exponent from 2.5 to 1.0<= (4.5-z) <=4.0.
  - For Kv computation use the unit width discharge of the approach section (q1) and bridge section (q2) and not the special average unit discharge q1avg for kv and q2avg for kv as in previous version. This has a major impact to Kv and the abutment scour depth.
  - Add HECRAS discharge under bridge and Override discharge under bridge. No more overtopping flow / flow adjustment. Revise the program input data structure so that the previous version input file will be read such that the Q1-Qovertoppint=HECRAS discharge. The input file is backward compatible. If user leaves override discharge blank, no override discharge will be shown in the output. If user do input override discharge, program will check the total of HECRAS discharge and total of override discharge, if the difference is no less than 1 cfs, then the program will issue an input error message. If the total discharge under the bridge is larger than the total discharge of the approach, program issue an error. Revise the help context to reflect this change. Output total discharge at the approach and under the bridge for estimate the overtopping discharge.
  - When 5y0>0.75W, the output of the method of computing flow velocity will be labeled as "short setback" although it is a special case.
  - If one of the final abutment scour is less 5 feet, then the program will output "Recommended minimum abutment scour depth" as 5 feet. This will be followed by an output line labeled as "Control abutment scour depth". These two additional output lines only occur when one of the abutment's final scour depth is less than 5 feet.
  - Change bank slope upstream of bridge fro "Z H: 1 V" to "Z=H/V" in both input and output.
  - Change the output line "Scour depth at abutment (y2a) adj" to "Abut. scour flow depth (y2a) adj" to make it clear that (y2a) adj is the flow depth not the scour depth.
  - When $V_{overbank}$>$V_{channel}$ program issues a warning.
- **May 5, 2003**
  - Flow velocity under the bridge
  - Change contraction scour interpolation from linear to parabolic
  - Apply safety factor to contraction scour
  - No interpolation for abutment scour, instead use the interpolated contraction scour and apply the necessary correction factors

  - Allow live bed scour for bottomless culvert
  - Include rock scour in the utility menu
- **March 13, 2003**
  - Change approach energy slope to average energy slope between approach section and bridge section
  - Add [F1] help for the average energy slope with illustration
- **February 20, 2003**
  - Pier scour: (Kh pier) may become negative based on Equation in HEC-18 Figure 6.5. This revision limits the (Kh pier) to 0 as minimum.
  - Pier scour: Revise grain roughness of the bed to D84 from D85 and only echo this input when pier local scour case 2 is selected.
  - ABSCOUR: In calculating Kv, when q2 average become zero or negative due to uneven overtopping flow, set Kv=1.

- **December 23, 2002**
  - boundary shear has been changed to match HEC-RAS. A new input item, energy slope at approach section, is required.
  - Clear water scour equation has been revised for D50<=0.001 feet based on the information from South Carolina.
  - Delete multiple columns option in pier scour unit

## VII. REFERENCES

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11. “Guide to Bridge Hydraulics”, Second Edition, Transportation Association of Canada, 2001.

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