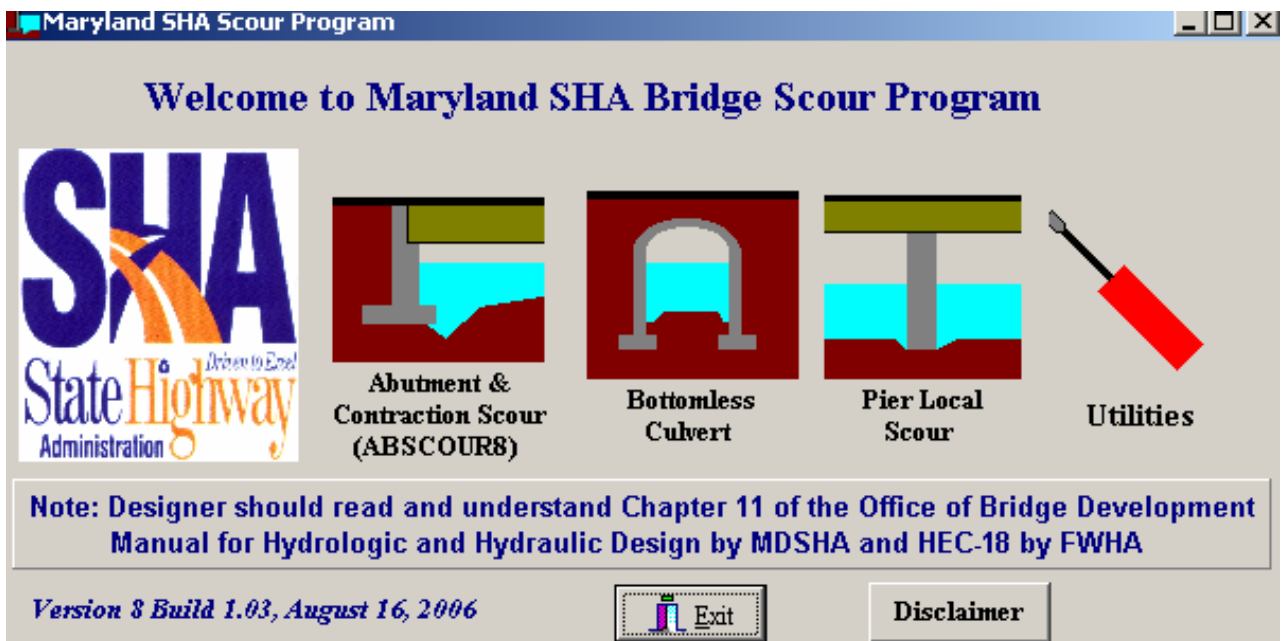


# OFFICE OF BRIDGE DEVELOPMENT BRIDGE SCOUR PROGRAM

## CHAPTER 11 APPENDIX A PART 1: DERIVATION OF METHODOLOGY

# ABSCOUR USERS MANUAL



The User's Manual is currently being up-dated to reflect the results of recent calibration studies of the ABSCOUR program

**SEPTEMBER 2007**

Preface

ABSCOUR 8, Build 1.03 dated August 16, 2006 is the current version of this program and all previous versions should be discarded. This program is being updated on a regular basis, and the user is advised to check the web site below for the most up-to-date version:

<http://www.gishydro.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 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.

### **Major Changes in ABSCOUR:**

- **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.
  - Iterated the contraction scour elevation calculation, until the scoured elevations are within the current soil layers at the over-bank and the channel.
  - Program calculates the live-bed and clear-water scours 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, fixed one bug that still default the bottomless culvert to the clear-water scour.
  - When the water does not reach abutment, the output is N/A for the abutment scour. However, the scour result drawing still show 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  $K_f$  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  $1.0 \leq (4.5 - z) \leq 4.0$ .
  - For  $K_v$  computation use the unit width discharge of the approach section ( $q_1$ ) and bridge section ( $q_2$ ) and not the special average unit discharge  $q_{1avg}$  for  $k_v$  and  $q_{2avg}$  for  $k_v$  as in previous version. This has a major impact to  $K_v$  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  $Q_1 - Q_{overtoppint} = \text{HECRAS discharge}$ . The input file is backward compatible. If user leave 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  $5y_0 > 0.75W$ , 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. Then followed by a output line labeled as "Control abutment scour depth". These two additional output line only happen 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 scout depth.
- When  $V_{\text{overbank}} > V_{\text{channel}}$  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:  $(K_h \text{ pier})$  may become negative based on Equation in HEC-18 Figure 6.5. This revision limit the  $(K_h \text{ pier})$  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  $K_v$ , when  $q^2$  average become zero or negative due to uneven overtopping flow, set  $K_v=1$ .
- **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  $D_{50} \leq 0.001$  feet based on the information from South Carolina.
  - Delete multiple columns option in pier scour unit

Questions regarding the use of the ABSCOUR Program should be directed to the Office of Bridge Development, Structure Hydrology and Hydraulics Unit

# **OBD BRIDGE SCOUR PROGRAM (ABSCOUR)**

## **APPENDIX A - USERS MANUAL, PART 1**

### **CAPABILITIES AND LIMITATIONS**

ABSCOUR is a computer program developed by the Office of Bridge Development 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 scour depths as discussed in this Appendix and in Chapter 11.

Verification and calibration efforts of the ABSCOUR methodology are on-going via testing at the FHWA J. Sterling Jones Hydraulic Laboratory in McLean, Virginia and through comparisons of the USGS data base of abutment scour collected at South Carolina Bridges.

#### **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 Neill's competent velocity equations for clear water scour,
- 2 Estimate abutment scour,
- 3 Estimate pier scour using 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.

#### **USER ASSISTANCE**

- 1 Users Manual
- 2 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.
- 3 Background on the concepts used to develop the ABSCOUR methodology,
- 4 Over-ride features to allow the user to modify the program logic,
- 5 Simple and fast procedures to conduct sensitivity analyses of input parameters.
- 6 The Structure Hydraulics and Hydrology Unit in the Office of Bridge

Development is available to provide user assistance, upon request.

#### OUTPUT FILES

- 7 A detailed report summarizing the factors considered in the scour computations.
- 8 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 should be used to determine hydraulic flow conditions and to estimate scour, whereas the hydraulic data used to provide the input data (HEC-RAS) is typically a 1-D model. ABSCOUR contains subroutines that permit the user to modify the HEC-RAS 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 (HEC-RAS, WSPRO) provides for a reasonable flow distribution upstream, through and downstream of the bridge.
- 3 Available methods for estimating clear water scour, particularly for very fine-grained sands and cohesive materials, should be assumed to provide for rough estimates of competent or critical velocities, and need to be applied with judgment. More accurate methods are available through use of the EFA (Erosion Function Apparatus) to actually calculate the critical velocity of Shelby tube samples through a laboratory procedure.
- 4 Available methods for estimating scour in rock 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. Nonetheless, the user is encouraged to make a critical review of the estimated scour depths to verify that the numbers look reasonable. If the analysis is not 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 Bridge Development.

It is the SHA's experience that the ABSCOUR Program, when applied with appropriate consideration of the site conditions and scour parameters, gives reasonable results for bridges over the small and medium-sized channels typical of Maryland streams. We have had limited experience in applying ABSCOUR to crossings with wide flood plains, particularly for site conditions consisting of swamps and wetlands on wide flood plains where the one-dimensional assumption about flow may not be valid.

# 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 abutment scour is based on Laursen's contraction scour equation as presented in the FHWA Publication HEC No. 18, Fourth 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 contraction and abutment scour equations developed for live bed scour have been modified for the computation of clear water scour. The User has the options of selecting Laursen's clear water scour equation or Neill's competent velocity procedure.

## 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:

$$y_2/y_1 = (W_1/W_2)^{k_2} \quad (1-1)$$

where:

$y_1$  = flow depth in the approach section

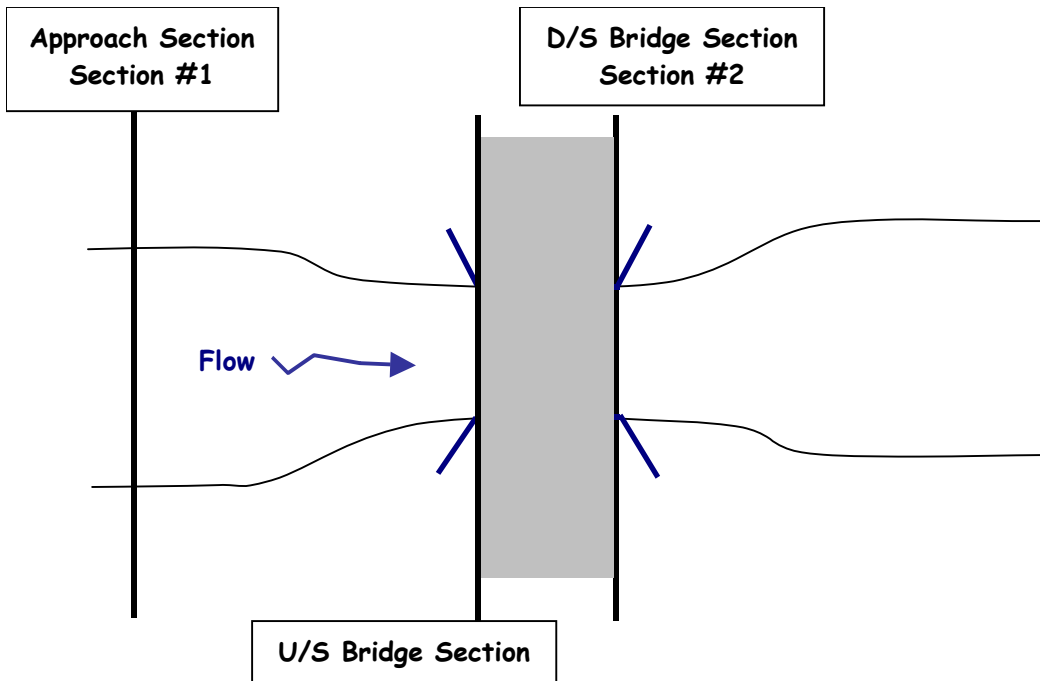
$y_2$  = total flow depth in the contracted section ( $y_2 = y_1 + y_s$ , where  $y_s$  is the scour depth)

$W_1$  = 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:

$$y_2/y_1 = (q_2/q_1)^{k_2} \quad (1-2)$$

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

If the bridge is subject to pressure flow, Equation 1-2 needs to be modified to account for the additional contraction scour caused by the pressure flow:

$$y_2/y_1 = (q_2/q_1)^{k_2} * k_p \quad (1-2a)$$

where:

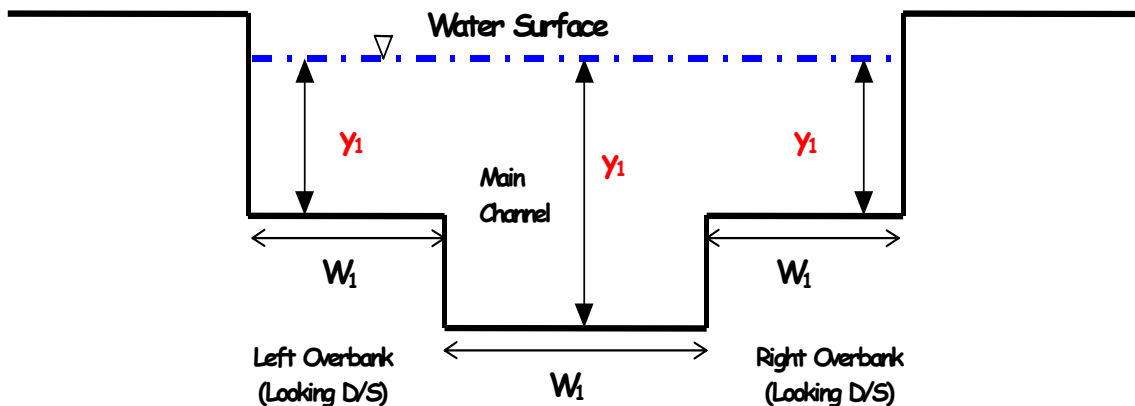
$k_p$  is the pressure flow coefficient ( See Eq.1-25, Section III.D of Part 1.  
All other values are the same as in Equation 1-2.

## 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)*

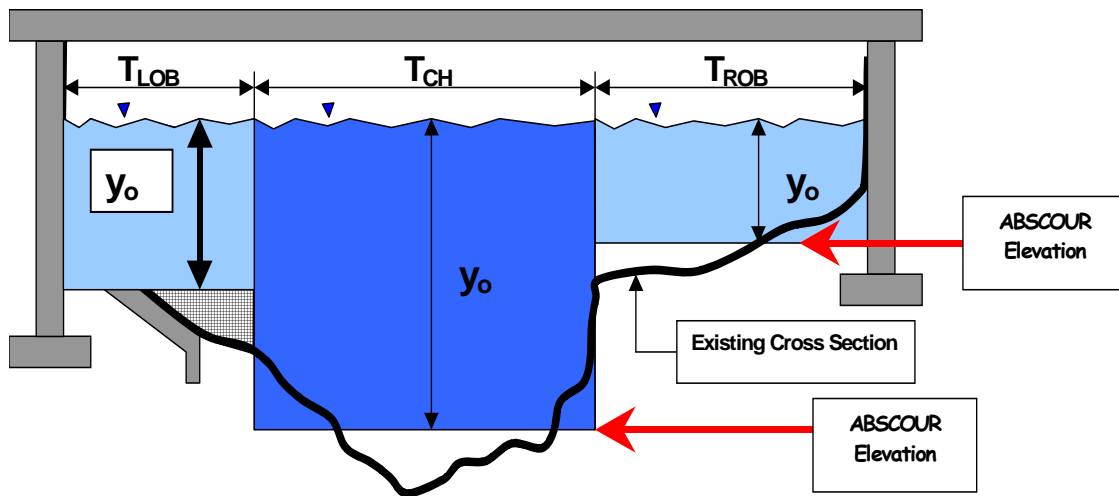
The ABCSCOUR estimating procedure is based on the consideration that the cross-section at the approach section remains constant in the reach between the approach section and the upstream bridge section. Select the upstream model cross-section with this consideration in mind. Guidance on modeling complex 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  $A = \text{area} = T \cdot y$ ) and  $q = V \cdot y$  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 ABCSCOUR 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.

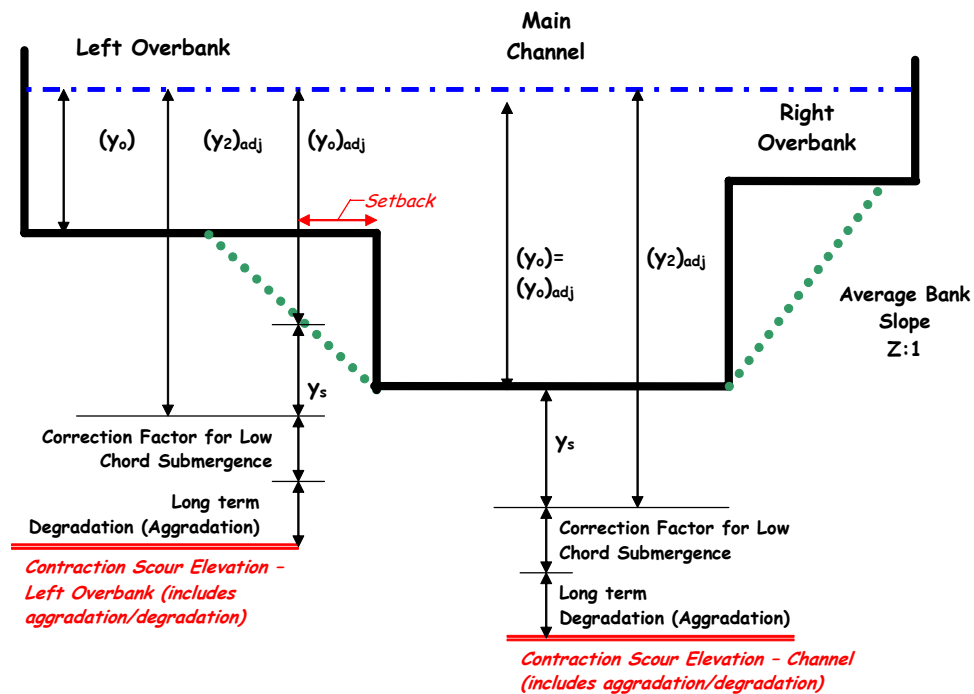


Figure 1-4

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

Please recall from Equation 1-2 (or Equation 1-2a 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 ( $y_2$ ) under the bridge and that  $(q_2) = V * y_o$ .

$$y_2/y_1 = (q_2/q_1)^{k_2} \quad (1-2)$$

$$y_2/y_1 = (q_2/q_1)^{k_2} * k_p \quad (1-2a)$$

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 ( $y_2$ ) minus the original flow depth ( $y_o$ ) or:

$$y_s = y_2 - y_o \quad (1-2b)$$

The final contraction scour depth is computed as:

$$\text{Final } y_s = y_s * FS \quad (1-2c)$$

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:

$$V_{ave} = Q / A \quad (1-3)$$

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:

$$q_2 = V_{ave} * y_o \quad (1-4)$$

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:

$$(y_o)_{adj} = y_o + (\text{setback})/Z \quad (1-5)$$

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 (Equation 1-7). The average velocity at the overbank area is adjusted by the following equations:

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

$$V_o = Q/A_o \quad (\text{long setback}) \quad \text{at a setback of } 0.75 W_o \quad (1-6c)$$

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

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  $0.75W_o$  is less than  $5y_o$ ; 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):

$$\begin{aligned}
 Q_1 &= Q_2 \\
 q_1 W_1 &= q_2 W_2 \\
 q_2 &= q_1 * W_1 / W_2
 \end{aligned}
 \tag{1-7}$$

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:

$$V_2 = q_2 / y_{o2} \tag{1-8}$$

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 ( $V = Q_{\text{overbank}} / A_{\text{overbank}}$ ). The ABSCOUR program will compute scour for the right abutment using unit discharges computed for mixed flow where:

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

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  $k_{ef}$  and  $k_{ava}$  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.*

$$y_{2a} = (k_f * (k_v)^{k_2}) * (\text{total contraction flow depth}) \quad (1-10)$$

As described earlier, modifications to the total contraction scour to account for pressure flow are applied to the total contracted flow depth prior to making the computation of Equation 1-10. The unadjusted abutment scour depth ( $y_{es}$ ) is computed as:

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

where:

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

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

$$(y_{sa})_{adj} = K_t * K_e * FS * y_{sa} \quad (1-12)$$

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:

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

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.

### 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:

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

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:

$$\tau_1 = \gamma y_1 S_{ave} \quad (1-15)$$

where:

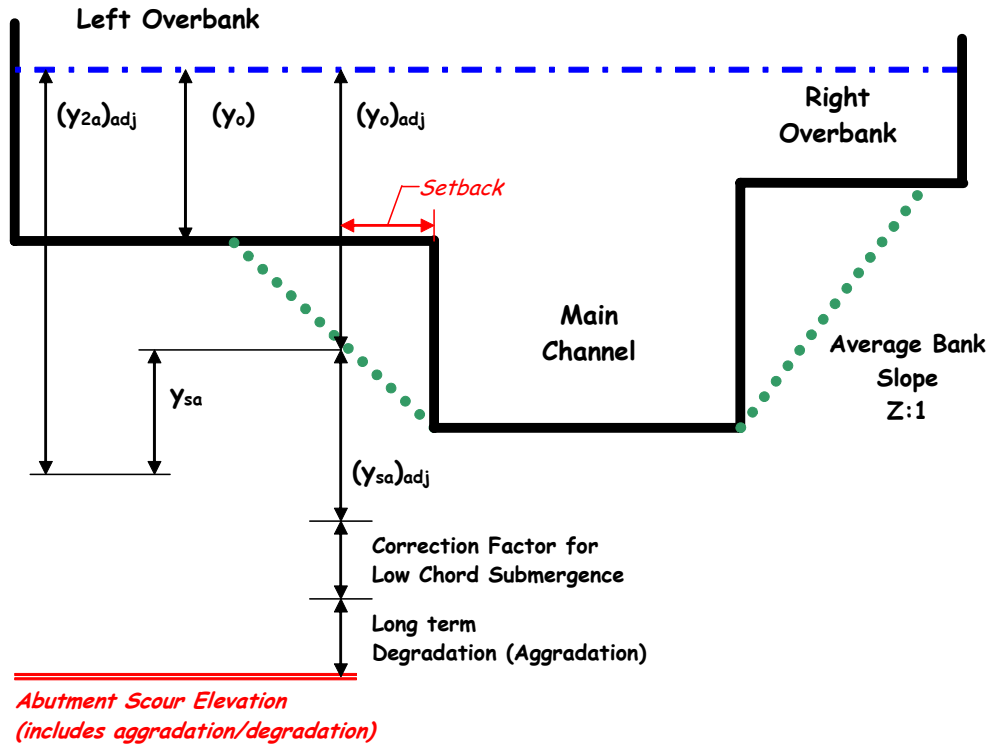
$\gamma$  = 62.4 lbs/ft<sup>3</sup>, in the English system

$y_1$  = 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:

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

where:

$k_v$  = ratio of velocity at the abutment toe to the mean velocity in the contracted section.

$q_1$  = average unit discharge in the approach section, and

$q_2$  = average unit discharge in the bridge section.

Equation 1-16 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  $k_{ava}$  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.

#### Computation of $k_{ava}$ for 2-D flow models

If the ABSCOUR user selects a 2-D model instead of a 1-D model such as HEC-RAS for the hydraulic analysis,  $k_{ava}$  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 ( $F_{ace}$ ). Referring back to equation 1-16a,  $k_{ava}$  is defined as the ratio of velocity at the abutment face or toe to the mean velocity ( $V_{ave}$ ) in the adjacent contracted section. Both of these parameters are calculated by the 2-D model. The procedure to calculate  $k_{ava}$  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  $F_{ace}$
  - 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  $k_{ava}$  using Equation 1-16b:

$$k_v = V_{face}/V_{ave} \qquad \qquad \qquad \mathbf{1-16b}$$

## 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,  $k_{ef}$ .

For clear-water scour:

$$k_f = 0.13 + 5.85F \quad (1-20)$$

For live-bed scour:

$$k_f = 0.46 + 4.16F \quad (1-21)$$

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. 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.)*

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

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

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:

$$y_2/y_1 = k_f(k_v q_2/q_1)^{k_2} \quad (1-23)$$

where:

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

$y_2$  = total flow depth of scour in the contracted section ( $y_2 = y_o + y_s$ , 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 multiplying by the pressure coefficient,  $k_p$ :

$$y_2/y_1 = (k_f * (k_v * q_2/q_1)^{k_2}) * k_p \quad (1-24)$$

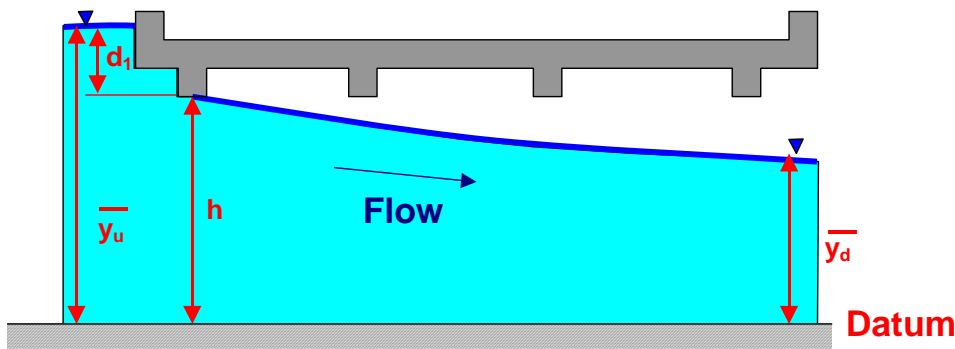
The pressure coefficient,  $k_p$ , has been determined experimentally (6). Preliminary conclusions suggest that  $k_p$  be applied within the following limits:

$$k_p = 0.66F_1^{-0.45} \quad (1-25)$$

where:

$F_1$  = Froude Number in the main channel at the approach section.

The values of  $k_p$  should range from 1.0 to 1.15. If the computed value is less than 1.0, use a value of 1.0. Cases of severe submergence are defined where the depth of flow above the low chord is greater than 40% of the flow depth as measured from the channel bottom to the low chord ( $h/d_1 > 0.4$ ), See Figure 1-6. For this case, the value of  $k_p$  should be multiplied by a factor of 1.15. If the computed value of  $k_p$  exceeds 1.15, use a value of 1.15.



**Figure 1-6**  
**Definition Sketch for Pressure Scour**

These preliminary findings are still being verified. The ABSCOUR program uses a value of  $k_p$  of 1.1 for pressure scour when the upstream water surface is equal to or greater than 1.2 of the distance of the height of the low chord above the streambed. The  $k_p$  value varies linearly between 1.0 and 1.1 for submergences of the low chord between 1.0 and 1.2

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

The ABSCOUR program computes abutment scour as:

$$y_{2a} = k_f * (k_v)^{k_2} * (\text{contraction scour flow depth}) \quad (1-26)$$

where:

the contraction scour flow depth is defined by either Equation 1-2 (no pressure flow) or 1-2a (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:

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

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, $y_{es}$

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

$$(y_{sa})_{adj} = K_t * K_e * FS * y_{sa} \quad (1-28)$$

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 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, $K_t$ , 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  $SF = X_1/X_2$

For a spill-through slope abutment:

$$K_t = 0.55 + 0.05 ((1/SF) - 1) \quad (1-29)$$

For abutments with wing walls:

$$K_t = 0.82 + 0.02((1/SF) - 1) \quad (1-30)$$

If  $SF < 0.1$ , then  $K_t = 1.0$

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. Detailed information on the selection of the Shape Factor, SF, is provided in Part 2, Section E, Upstream Bridge Data, and in the FHWA publication HEC-18). 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:

$$K_e = (\alpha/90)^{0.13} \quad (1-31)$$

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 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,  $k_{ef}$ . Use of the envelope curve provides for a limited factor of safety in the calculations. However, natural rivers are not accurately represented by the simple flow conditions modeled in a laboratory flume. For practical design, use of a safety factor is recommended to take into

account the effect of the complex flow patterns which can be expected to occur at bridges. Selection of a safety factor is described in Attachment 3.

G. FINAL SCOUR ELEVATION

$$\text{Elev. of Bottom of Scour Hole} = \text{Water surface elevation} - (y_o)_{\text{adj}} - (y_{sa})_{\text{adj}} \quad (1-32)$$

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

IV. CLEAR WATER SCOUR EQUATIONS

A. 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), Neill's concept may be used in determining contraction scour. 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 shear stress is reduced to the value of the critical shear stress. Equation 1-2 for contraction scour, then, may be reduced to the following form:

$$y_2 = y_c \quad (1-33)$$

where:

$y_c$  = flow depth in contracted channel when bed shear is at the critical value.

Clear water scour occurs at a structure when the upstream channel bed is armored or the flood plain is covered with vegetation and no sediment is transported to the bridge. For such cases, the following clear water scour equations are used in the ABSCOUR program to solve for  $y_2$ . These equations are developed from Neill's competent velocity curves, Reference 11.

$$\begin{array}{l} \text{For } D_{50} \leq 0.001 \text{ ft.} \\ y_2 = [q / (2.84 D_{50}^{.15})]^{0.67} \end{array} \quad (1-34)$$

$$\begin{array}{l} \text{For } 0.1 > D_{50} > 0.001 \text{ ft.} \\ y_2 = [q / (11.5 D_{50}^{.35})]^x \end{array} \quad (1-35)$$

where:

$$x = 1 / [1 + (0.123 / D_{50}^{0.20})]$$

$$\begin{array}{l} \text{For } D_{50} \geq 0.1 \text{ ft.} \\ y_2 = [q / (11.5 D_{50}^{.33})]^{0.86} \end{array} \quad (1-36)$$

The following relationship applies to the above equations:

$$y_2 = y_1 + y_s \quad (1-37)$$

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:

$$y_2 \text{ (modified)} = k_p * y_2 \cdot \quad (1-38)$$

The value of  $k_p$  is explained in Section III D.

## B. ABUTMENT SCOUR

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

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

where:

$y_2$  = clear water contraction scour depth determined from Equations 1-34 to 1-36.

$k_f$  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.

## 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.

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